Appendix B. Water Management

Draft Kansas River Reservoirs Flood and Sediment Study

October 2023

U.S. Army Corps of Engineers
Kansas City District

EXISTING CONDITIONS

Kansas River Reservoirs Flood and Sediment Study
HEC-ResSim Documentation
Model Data Review and Documentation

ATR Report: February 2022
USACE Kansas City District

Executive Summary

The following work is included as part of the Kansas River Reservoirs Flood and Sediment Study (KRRFSS). This ongoing study investigates water and related land resource issues and opportunities in the Kansas River Basin to recommend comprehensive, long-term, and sustainable water resource solutions and management based on a Shared Vision for the basin.

An existing HEC-ResSim model was updated to evaluate the impacts of the current operation of the lower seven flood control reservoirs on the Kansas River basin. The reservoir operation sets are based on the current Water Control Manuals for each reservoir. With and without navigation scenarios were run for the existing conditions. Existing data sets were extended to cover the period of January 1, 1920 to December 31, 2019. Reservoir routing parameters were verified and changed as necessary. Updated local flows were created using the extended data set for use in the updated model simulation.

Necessary output from the model includes a complete regulated set of flows at several key stream gage locations on the Kansas River and the pool elevations and releases for each reservoir. Model output is available for use by other disciplines within the study.

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1 Introduction

This document provides the methodology used to simulate regulated flow on the Kansas River from January 1920 through December 2019. Reservoir modeling was conducted using Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) version 3.5. Several data sets needed to be extended beyond their existing period of record. These included USGS gauging stations, inflow points, and local flow between gages. The flood control reservoirs included in this study are the lower seven reservoirs all on tributaries of the Kansas River: Kanopolis, Wilson, Waconda, Milford, Tuttle Creek, Perry, and Clinton.

All analysis is conducted as part of the Kansas River Reservoirs Flood and Sediment Study (KRRFSS). The existing conditions simulation will be used as a baseline for future without project simulations that evaluate changes as sediment accumulates over the next 100 years of the project study evaluation. Several alternatives will also be evaluated including changes to reservoir operations. The existing condition flows on the Kansas River will be used to evaluated flood risk reduction measures and will develop updated flow frequency relationships for unregulated and regulated basin conditions. Simulated reservoir pool elevations and outflows will be utilized for evaluation of recreation, water supply, and water quality needs within the basin.

2 Basin Description

The Kansas River is formed by the confluence of Smoky Hill and Republican Rivers near Junction City, Kansas. It flows approximately 148 miles generally eastward where it joins the Missouri River near Kansas City. There are seven U.S. Army Corps of Engineers (USACE) and eleven U.S Bureau of Reclamation (USBR) reservoirs which are authorized for flood control in the basin. The lower seven reservoirs are included in this study since they are the major contributors to Kansas River Basin flood storage.

These seven reservoirs include three which are in the Smoky Hill River Basin: Kanopolis Reservoir on the Smoky Hill River, Wilson Reservoir on the Saline River, and Waconda Reservoir on the Solomon River. The Smoky Hill River Basin reservoirs and the corresponding control point gages are shown in Figure 2-1. The rest of the seven reservoirs are on tributaries to the lower Kansas River and are Milford Reservoir on the Republican River, Tuttle Creek Reservoir on the Big Blue River, Perry Reservoir on the Delaware River, and Clinton Reservoir on the Wakarusa River. The Kansas River Basin reservoirs and the corresponding control point gages for flood control operations are shown in Figure 2-2.

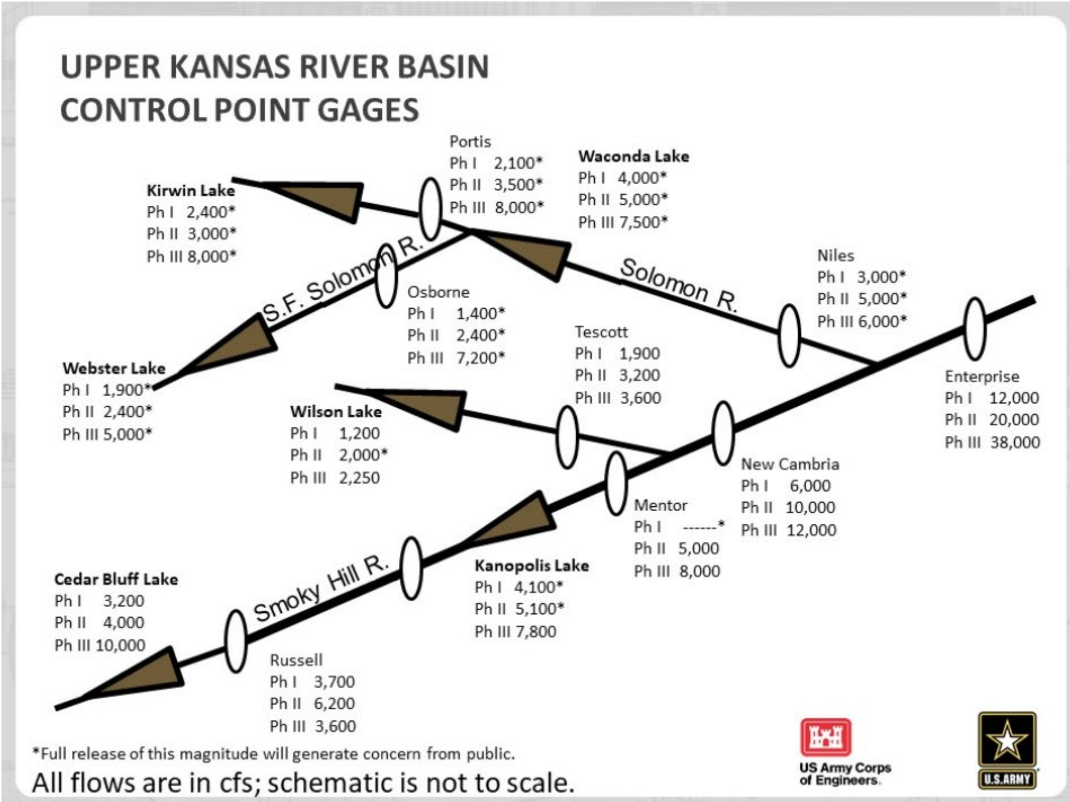


Figure 2-1 Schematic of the Smoky Hill River Basin reservoirs and control points.

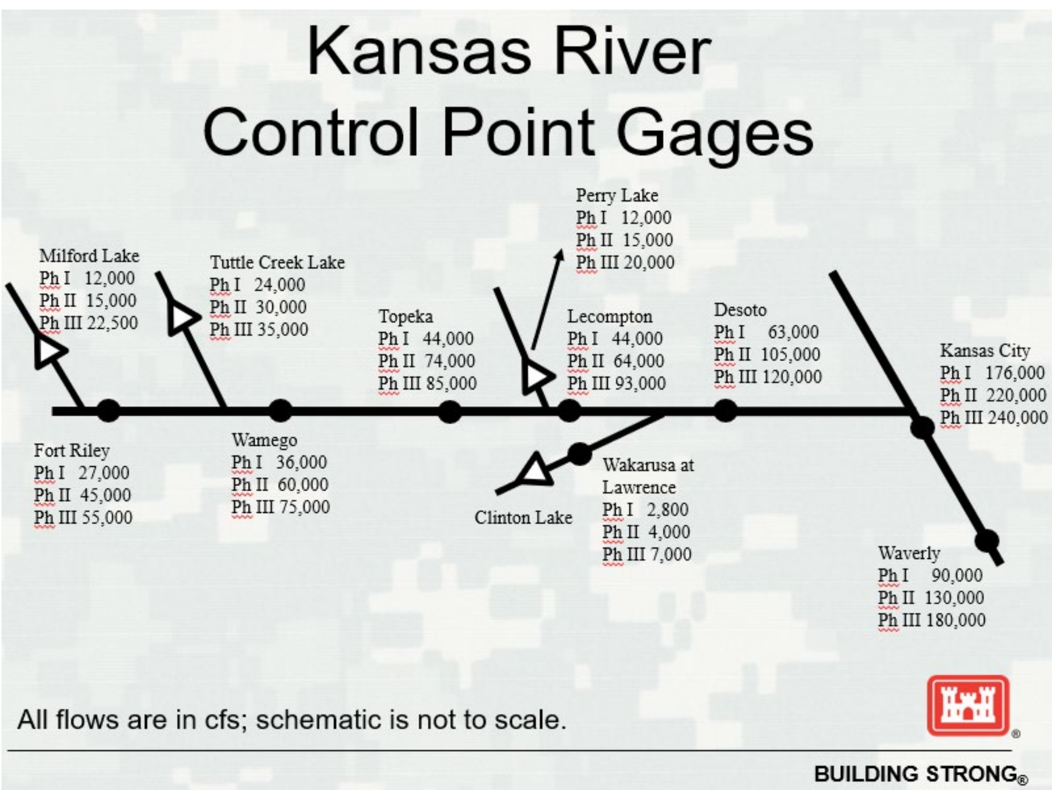
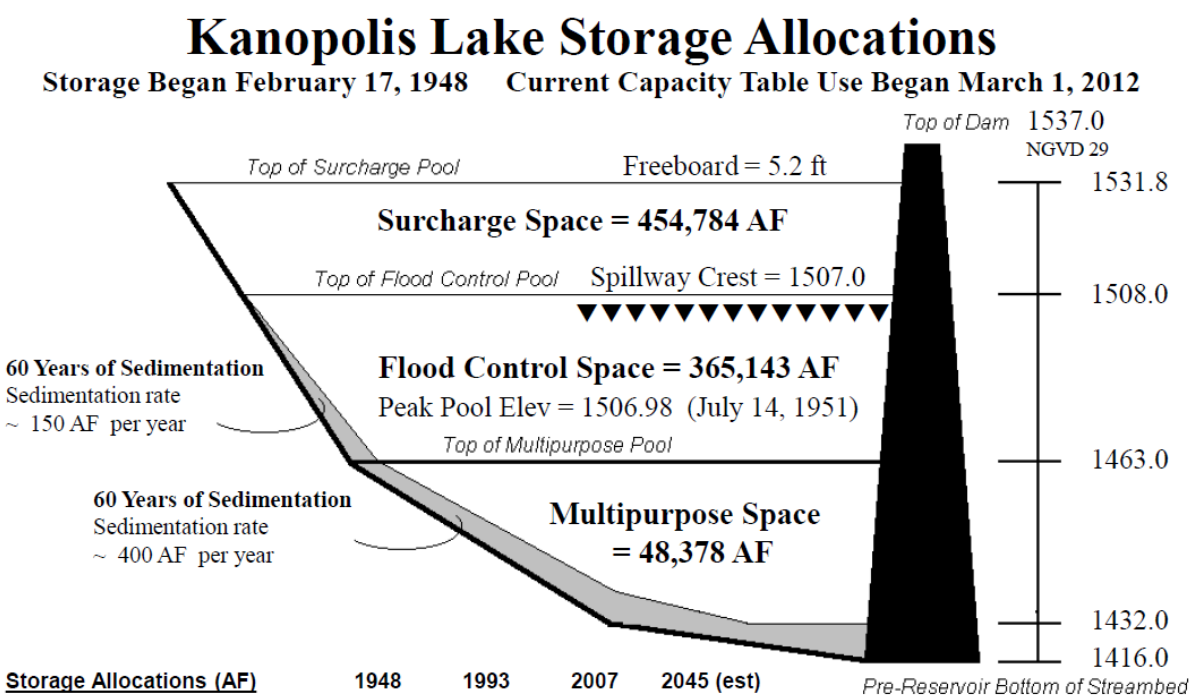


Figure 2-2 Schematic of the Kansas River Basin reservoirs and control points.

These seven reservoirs vary widely in storage and release capacity. Table 2-1 details pertinent information for each reservoir. Generally, the size of the flood storage and the discharge capacity is indicative of how much the reservoir impacts downstream flows. The larger reservoirs also tend to be authorized for more release capacity. Figure 2-3 through Figure 2-9 depict the current reservoir allocation zones and storage capacity of each zone to include the multipurpose or conservation pool.

Table 2-1 Pertinent data for the lower seven reservoirs in the Kansas River Basin

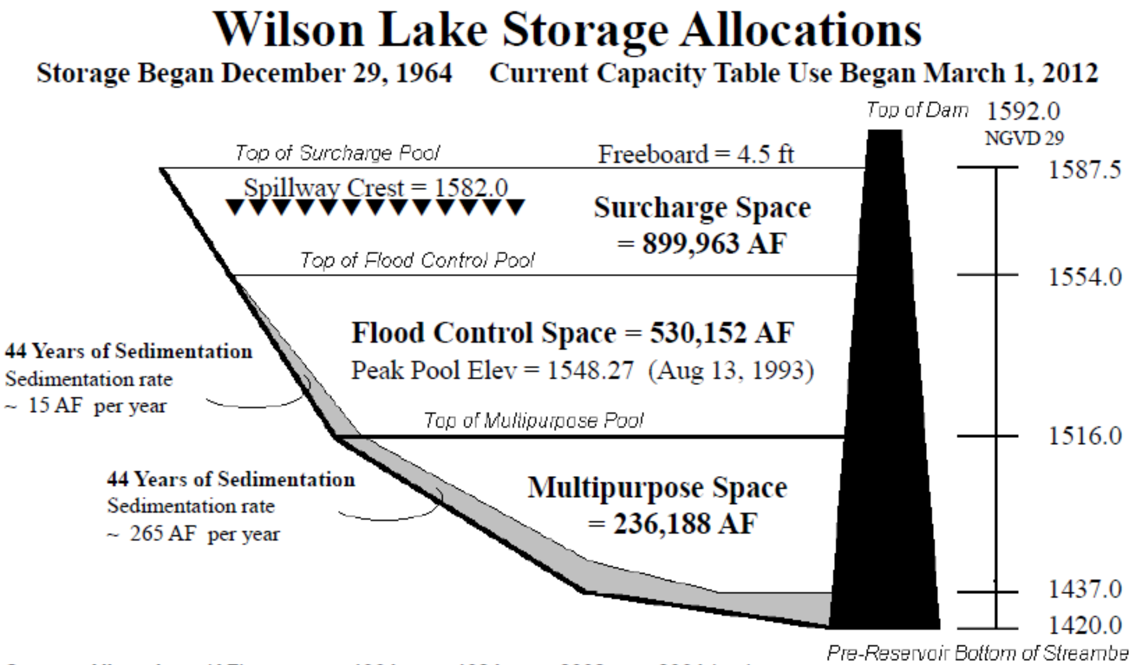
Reservoir	Owner	Date of Closure	Date Multi-purpose Filled	Flood Control Storage (ac-ft)	Outlet Discharge Capacity Top of Flood Pool (cfs)	Surcharge Storage (ac-ft)	Spillway Discharge Capacity Top of Surcharge Pool (cfs)
Kanopolis	USACE	26Jul1946	19July1948	365,143	6,400	484,912	172,000
Wilson	USACE	3Sep1963	12Mar1973	530,152	6,500	899,749	15,700
Waconda	USBR	18Oct1967	16May1973	722,986	5,200	166,572	278,000
Milford	USACE	24Aug1964	14Jul1967	757,874	23,100	1,475,913	560,000
Tuttle Creek	USACE	20Jul1959	29Apr1963	1,884,312	45,900	959,939	579,000
Perry	USACE	2Aug1966	3Jun1970	515,520	27,500	695,362	65,000
Clinton	USACE	23Aug1975	3Apr1980	292,496	7,570	286,875	44,200



Storage Allocations (AF)	1948	1993	2007	2045 (est)
Total Flood Control Pool	**373,891**	**368,114**	**365,143**	**362,254**
Projected Flood Control	373,891	368,114	362,254	362,254
FP Sediment Reserve	0	0	2,889	0
Total Multipurpose Pool (1463)	**73,200**	**50,273**	**48,378**	**26,833**
Water Supply	0	0	12,500	12,500
Multipurpose Uses	15,041	11,890	14,333	14,333
MP Sediment Reserve	58,159	38,383	21,545	0

MP pool elev raised from 1459.0 to 1463.0 in 1968. MP pool reallocated in 2002 to add water supply allocation, with the remaining portion for operating MP uses, mainly minimum releases. Sediment reserve also added to FP. The State of Kansas (KWO) contracted for all water supply space in 2002. All in service.

Figure 2-3 Kanopolis Reservoir Storage Allocations



Storage Allocations (AF)	1964	1984	2008	2064 (est)
Total Flood Control Pool	**530,710**	**530,204**	**530,152**	**510,000**
Exclusive Flood Control	510,000	510,000	510,000	510,000
FP Sediment Reserve	20,710	20,204	20,152	0
Total Multipurpose Pool	**247,835**	**242,528**	**236,188**	**225,000**
Multipurpose (all purposes)	225,000	225,000	225,000	225,000
MP Sediment Reserve	22,835	17,528	11,188	0

The tables resulting from the 2008 survey have been used for operations since Mar 2012. The State of Kansas (KWO) has requested a reallocation study of Wilson Lake to make water supply space available, but the study has been put on hold.

Figure 2-4 Wilson Reservoir Storage Allocations

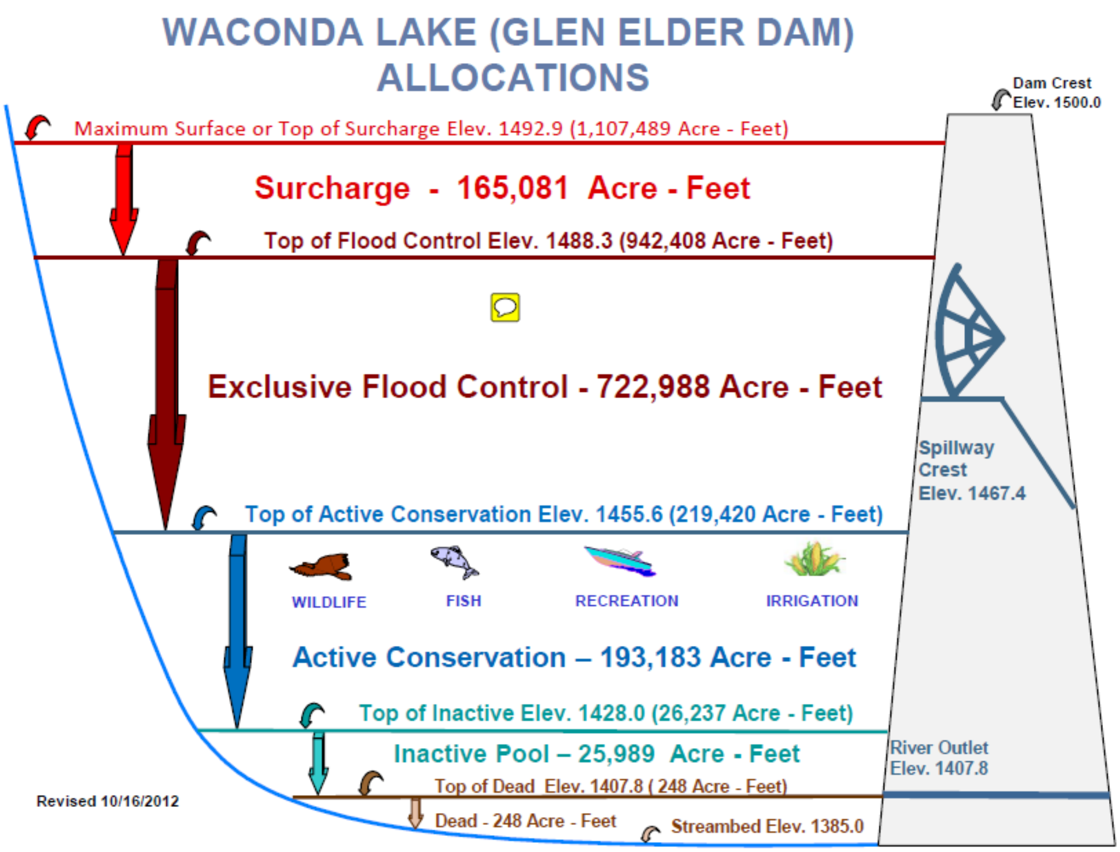
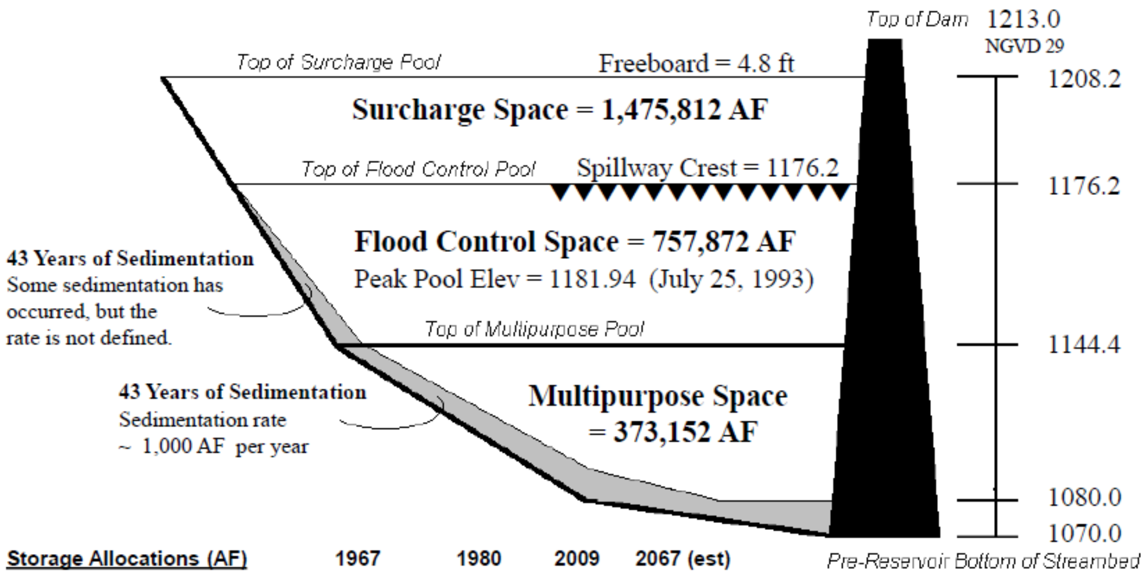


Figure 2-5 Waconda Reservoir Storage Allocations

Milford Lake Storage Allocations

Storage Began January 16, 1967   Current Capacity Table Use Began March 1, 2012



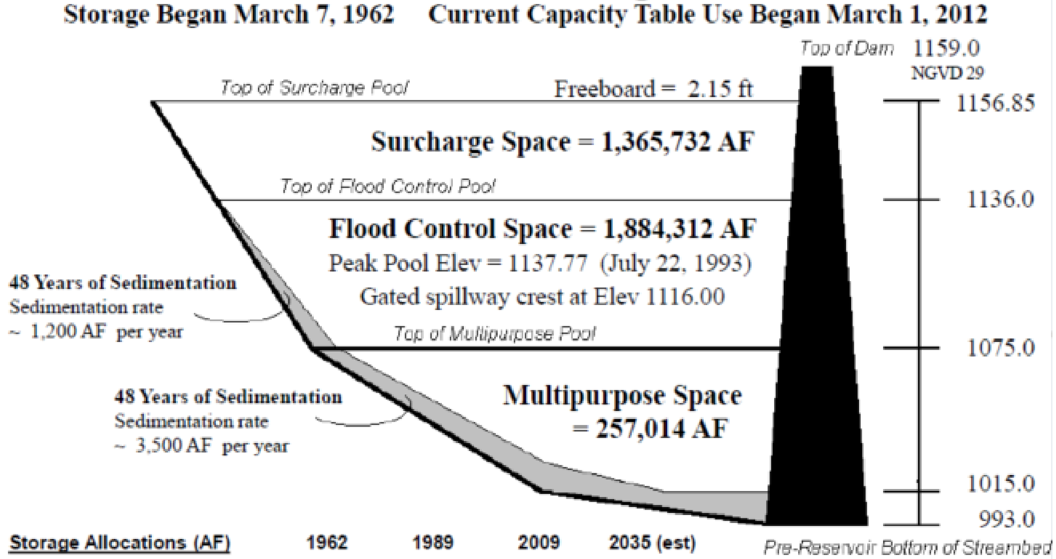
Storage Allocations (AF)	1967	1980	2009	2067 (est)
Total Flood Control Pool	**757,746**	**756,601**	**757,872**	**700,000**
Exclusive Flood Control	700,000	700,000	700,000	700,000
FP Sediment Reserve	57,746	56,601	57,872	0
Total Multipurpose Pool	**415,352**	**388,608**	**373,152**	**300,000**
In-Service Water Supply	0	101,650	101,650	300,000
Future Use Water Supply	300,000	198,350	198,350	0
MP Sediment Reserve	115,352	88,608	73,152	0

2009 tables now used for lake ops. State of Kansas (KWO) contracted for water supply allocation in 1974. The initial in-service increment of 101,650 AF is subcontracted to the Kansas River Water Assurance District and KP&L. Until called into service, the future use space is operated for other MP uses.

Figure 2-6 Milford Reservoir Storage Allocations

Tuttle Creek Lake Storage Allocations

Storage Began March 7, 1962   Current Capacity Table Use Began March 1, 2012



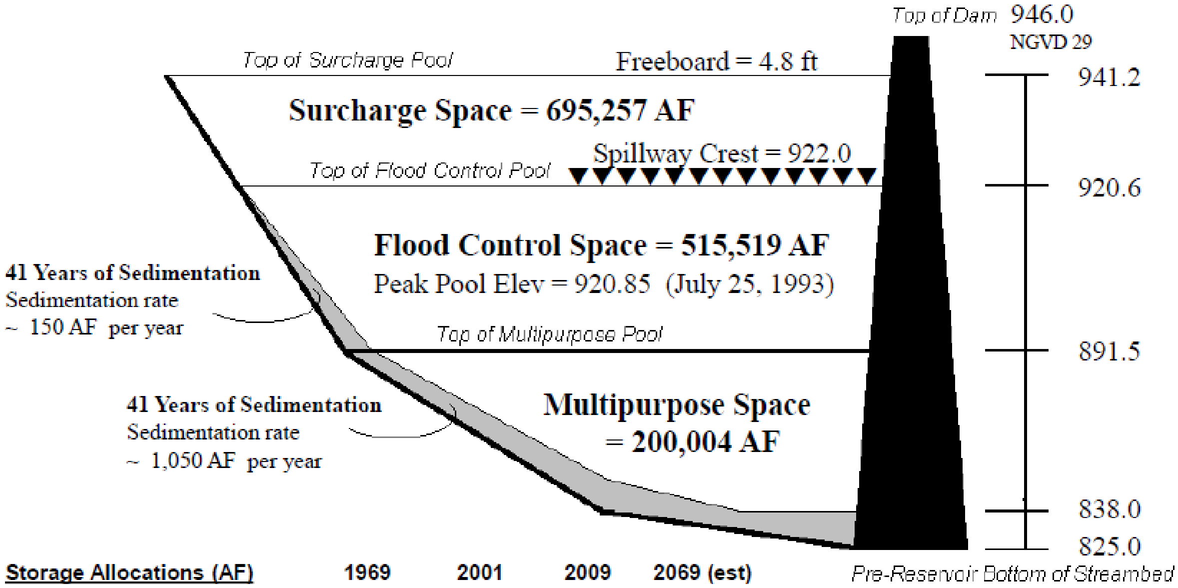
Storage Allocations (AF)	1962	1989	2009	2035 (est)
Total Flood Control Pool	**1,941,705**	**1,922,085**	**1,884,312**	**1,879,000**
Projected Flood Control	1,941,705	1,879,000	1,879,000	1,879,000
Nominal Sediment Reserve	0	43,085	5,312	0
Total Multipurpose Pool	**425,312**	**335,100**	**257,014**	**122,000**
Water Supply (all in-service)	0	50,000	50,000	50,000
WQ, Nav, Other Purposes	185,000	72,000	72,000	72,000
MP Sediment Reserve	240,312	213,100	135,014	0

The 1989 Reallocation added a water supply allocation and added space to the sediment reserve to extend its design life from 2012 to 2035. The State (KWO) contracted for the water supply, all of which is in service.

Figure 2-7 Tuttle Creek Reservoir Storage Allocations

Perry Lake Storage Allocations

Storage Began January 15, 1969 Current Capacity Table Use Began March 1, 2012



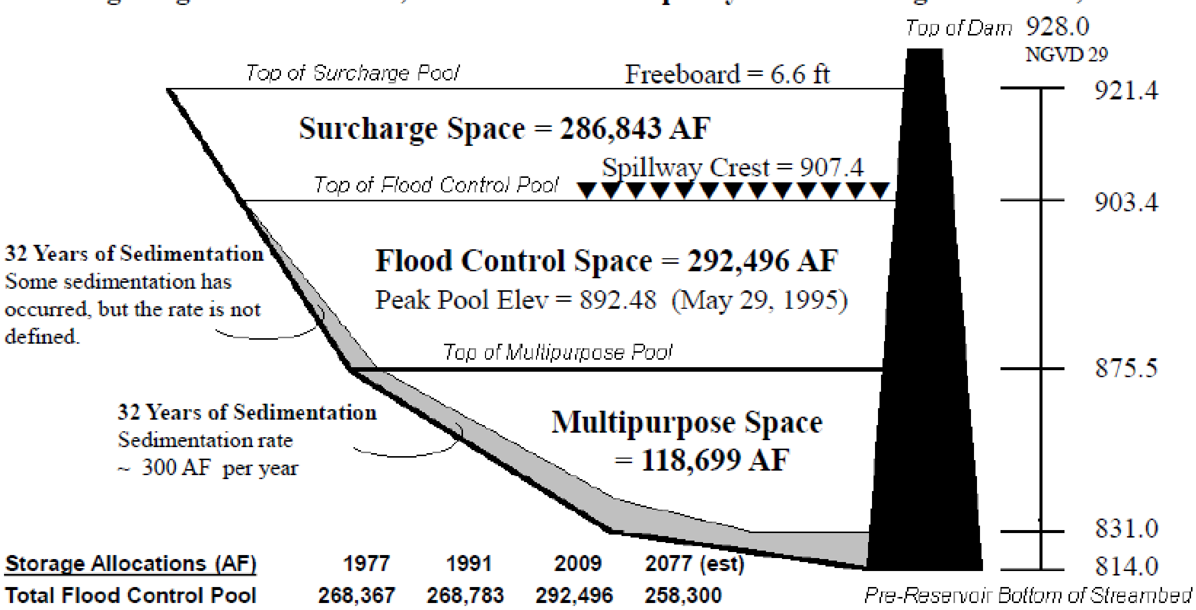
Storage Allocations (AF)	1969	2001	2009	2069 (est)
Total Flood Control Pool	**521,880**	**515,397**	**515,519**	**480,000**
Exclusive Flood Control	480,000	480,000	480,000	480,000
FP Sediment Reserve	41,880	35,397	35,519	0
Total Multipurpose Pool	**243,220**	**206,682**	**200,004**	**150,000**
In-Service Water Supply	0	25,000	25,000	150,000
Future Use Water Supply	150,000	125,000	125,000	0
MP Sediment Reserve	93,220	56,582	50,004	0

2009 tables now used for operations. The State of Kansas (KWO) contracted for the water supply allocation in 1977. The initial 25,000 AF increment is contracted to the Kansas River Water Assurance District. Valley Falls has a separate water withdrawal contract.

Figure 2-8 Perry Reservoir Storage Allocations

Clinton Lake Storage Allocations

Storage Began November 30, 1977 Current Capacity Table Use Began March 1, 2012



Storage Allocations (AF)	1977	1991	2009	2077 (est)
Total Flood Control Pool	**268,367**	**268,783**	**292,496**	**258,300**
Exclusive Flood Control	258,300	258,300	258,300	258,300
FP Sediment Reserve	10,067	10,483	34,196	0
Total Multipurpose Pool	**129,171**	**125,334**	**118,699**	**110,400**
In-Service Water Supply	53,520	53,520	53,520	89,200
Future Use Water Supply	35,680	35,680	35,680	0
Water Quality	21,200	21,200	21,200	21,200
MP Sediment Reserve	18,771	14,934	8,299	0

2012 tables based on 2009 lake survey. Water supply allocation contracted to the State of Kansas (KWO) in 1977, with an initial in-service increment of 53,500 AF; the available water is subcontracted to the cities of Lawrence, Baldwin City, and six Douglas County rural water districts.

Figure 2-9 Clinton Reservoir Storage Allocations

Reservoirs upstream of Kanopolis, Waconda, and Milford have not been included in this study; however, these reservoirs do impact the inflow records of the downstream reservoirs after their respective closure dates since observed inflows are relied upon in the performance of this study. These upstream reservoirs and their dam closure dates are show in Table 2-2.

Table 2-2 Reservoirs upstream of the study area.

Downstream Lake	Upstream Lake(s)	Closure Date	Initial Fill Date
Kanopolis	Cedar Bluff	Sep 10, 1950	Jun 21, 1951
Waconda	Webster	May 3, 1956	Jun 18, 1957
	Kirwin	Mar 7, 1955	Jul 2, 1957
Milford	Lovewell	May 29, 1957	May 20, 1958
	Harlan County	July 22, 1951	Nov 14, 1952
	Norton	Jan 8, 1964	Jun 21, 1967
	Harry Strunk	Aug 8, 1949	Apr 2, 1951
	Hugh Butler	Sep 5, 1961	May 22, 1961
	Swanson	May 4, 1953	May 15, 1957
	Bonny	Jul 6, 1950	Mar 29, 1954
	Enders	Oct 23, 1950	January 1952

3 Methodology

HEC-ResSim version 3.5 was used to simulate reservoir operations and route water through the basin. HEC-ResSim is a reservoir simulation model which incorporates user-defined rules and data sets to determine reservoir outflows, resulting pool elevations and flow at downstream locations. The model routes reservoir outflows using hydrologic routing methods defined by the user. A depiction of the model junctions and reaches in the basin is shown in Figure 3-1 below. Note that the model schematic shows some portions of the Republican River above Milford Reservoir as being included in this study; however, this model reach was not set up due to time constraints and the majority of the KRRFSS alternatives being focused on other portions of the basin. Active modeling along the Republican River begins at Clay Center which is the inflow gage to Milford Reservoir. In addition to the Kansas River Basin, the Missouri River is modeled from St. Joseph to Waverly to allow the Missouri River control point of Waverly, Missouri to be modeled properly.

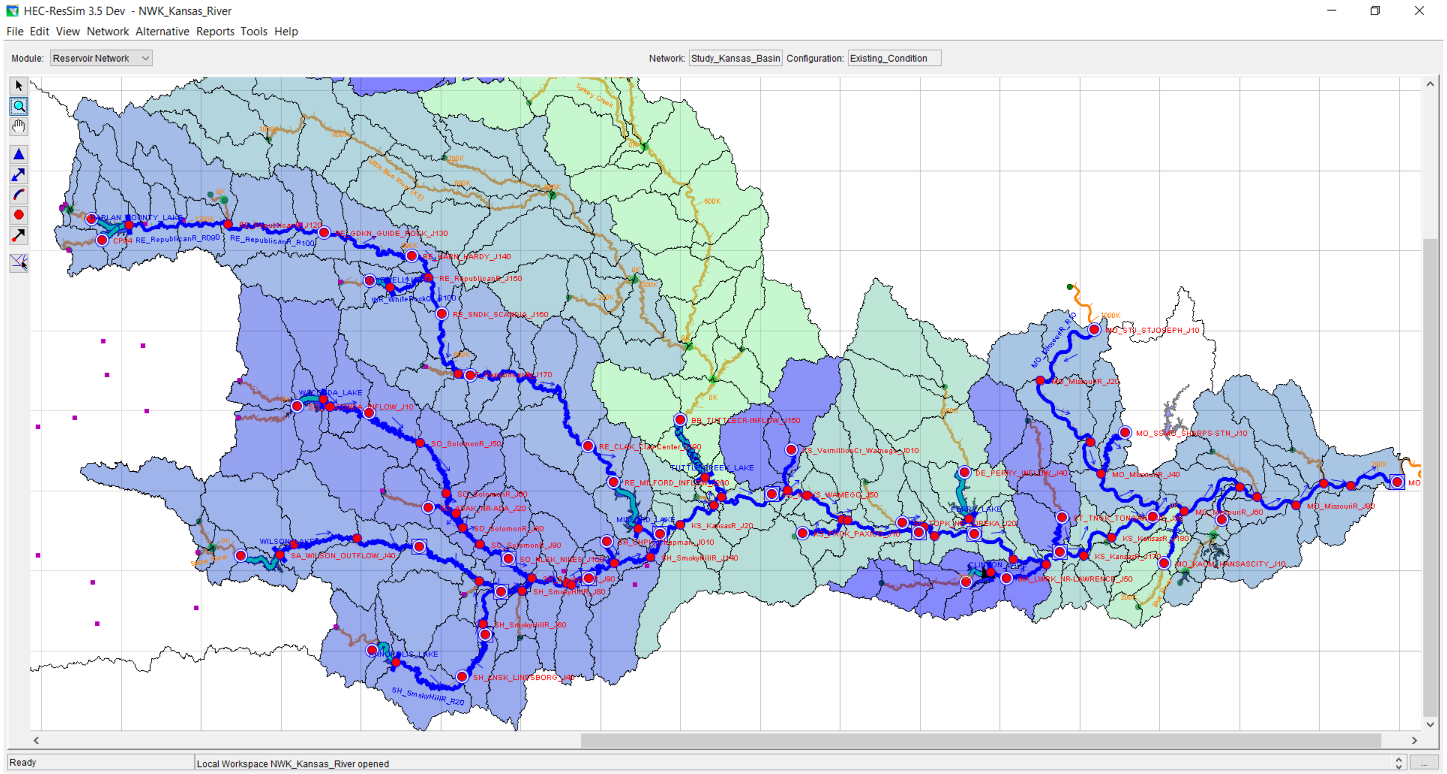


Figure 3-1 HEC-ResSim Kansas River network.

An existing Kansas River basin HEC-ResSim model was utilized to begin this study. The existing model was completed in April 2017 through support of the Modeling, Mapping, and Consequence (MMC) Production Center. This model was primarily developed to operate as part of the CWMS modeling package using inputs from HEC-HMS and feeding output data into HEC-RAS. It was setup to run in an hourly time step and primarily used for real-time forecasting. The KRRFSS model modified the existing reservoir network to be used for long-term daily modeling. Over the course of this project, hydrologic routing parameters, local flow junctions, and the reservoir operation rule set were re-evaluated and updated where necessary to better suit the purposes of the KRRFSS.

3.1 Reservoir Data Extension

To utilize the model, a complete period of analysis data set for a number of inputs is required. Data sets were collected from observed records (period of record data) and extended, filling in missing and historical data by a variety of methods. Observed records were obtained from the U.S. Geological Study (USGS), comprising official daily streamflow records, as well as record inflow, release, and elevation data from the Corps Water Management System (CWMS) database. The period of analysis for the model input data was December 1, 1919 through January 2, 2020 with the first month used as a model lookback period. The functional data output is from 1920 through 2019. The model utilizes a daily time step in simulations.

Inflow from the Kansas City District CWMS database was used for the period after all lakes were constructed through 2019. CWMS lake inflow is mean daily as averaged over the 24-hour period extending from 1200 hours UTC of the previous day to 1200 hours UTC of the current day. As the Model operates on a midnight to midnight (UTC) basis, the inflow data from the database is time shifted from the model timestep. To account for this effect, the data has been shifted backward 12 hours. No averaging between days was attempted because that would further diminish peak inflow magnitudes. This data was all simply shifted backwards 12 hours. All USGS data is provided as a daily average value at midnight UTC and no shift is necessary for this data. Once the inflow values are shifted back 12 hours the data from the CWMS database begin for each lake on the dates listed in Table 3-1.

Table 3-1 Beginning of calculated daily average inflows.

Lake	Initial Database Date
Kanopolis Lake	February 16, 1948
Wilson Lake	September 3, 1963
Waconda Lake	October 17, 1967
Milford Lake	August 23, 1964
Tuttle Creek Lake	July 20, 1959
Perry Lake	July 31, 1966
Clinton Lake	November 30, 1977

The CWMS database inflow is calculated by adding the following parameters: daily change in storage, reservoir releases, and evaporation. Precipitation on the pool of the lake accounts for some of the change in storage on rainy days. The data developed for the period prior to the CWMS data does not include the rain on pool component, but only includes runoff from the upstream basin as seen in the available gages at the time. This may result in a discrepancy inherent in the pre-dam data as rain on the reservoir water surface would provide some additional inflow that otherwise may have not reached the lake if infiltration occurred. This was assumed to be a small discrepancy.

For the timeframe that precedes the period of record database entries, the lake inflow was determined by evaluating the upstream gages, using standard hydrologic methods and statistical analysis. All gage data was obtained from the USGS website; daily, period-average flow records were obtained in all cases. A ratio of flow based on a direct comparison of the drainage basin area ratios was used only occasionally, due to the very large areas involved and the high variability in the amount of contribution. Hydrologic conditions in the basin tend to result in a much lower runoff contribution from the western drainage areas. The following sections describe the specific methods used for each lake.

3.1.1 Kanopolis Lake

Kanopolis Dam is located at river mile 183.7 of the Smoky Hill River and controls about 7,857 square miles of drainage area. The dam started impounding water on 17 Feb 1948; however, the downstream gages appear to be impacted by dam construction at the date of closure on 26 Jul 1946. The observed Corps of Engineers reservoir elevation, inflow, and outflow records extend from 17 Feb 1948 through the present. As the stored data is 1200 UTC of the day before to 1200 UTC of the current day, the values have been shifted backward 12 hours to make them representative of midnight-to-midnight flows. With the time shift, the observed inflow is used from 16 Feb 1948 through 31 Jan 2019. Table 3-2 provides a list of available gage information. The Ellsworth gage is upstream of the reservoir; the Langley gage is 0.8 miles downstream of the dam; the Lindsborg gage is about one day travel time downstream of the dam; and the Mentor gage is about two days travel time downstream of the dam.

Table 3-2 Pertinent Kanopolis Lake Gages

Gage	Drainage Area (mi^2)	Record
Smoky Hill River at Ellsworth	7,580	1Jan1900 to 31Oct 1905, 23Jul1918 to 04 July1925, Aug 1, 1928 to Present
Smoky Hill River at Langley	7,857	Oct 1, 1940 to Present

Smoky Hill River at Lindsborg	8,110	Partial years 1905 to 1923, 01Feb1930 to 29Sep1965, 31July2014 to Present
Smoky Hill River at Mentor	8,341	01Dec1923 to 01Nov1930, 22May1931 to 30Jun1932, 01Oct1947 to Present

Before the dam was constructed, inflow records are approximated using several different methods depending on the data available in the period of record beginning in 1920. Where possible the data was extended using linear and multi-linear regression as outlined in chapter 9 of EM 1110-2-1415, Hydrologic Frequency Analysis. The various approaches are outlined in Table 3-3. Comparing the simulated data to the portion of overlapping observed data for each computation method reveals the degree of correlation that was achieved. Pre-dam Langley and the Kanopolis computed inflow record were used as the observed data. HEC-DSS and Microsoft Excel were utilized to develop linear and multi-linear regressions between gages to approximate flow at the dam when no data was available. The equations were generally calculated in DSS and the plots in Excel. Occasionally, the coefficients were slightly different between the two methods. Each equation is explained in more detail in the following sections.

Table 3-3 Methods used to extend daily Kanopolis inflow records from 1920 to present

Date Range	Equation Used	Comment
23July1918 to 30Dec1918	KANS = 51.308+0.995*Ellsworth	Based on linear regression with Ellsworth data
31Dec1918 to 30July1919	KANS = -11.681+0.513*Ellsworth +0.507*Lindsborg	Based on multi-linear regression with Ellsworth and Lindsborg minus 1 day
31July1919 to 28Feb1920	KANS = 51.308+0.995*Ellsworth	Based on linear regression with Ellsworth data
29Feb1920 to 29Sep1920	KANS = -11.681+0.513*Ellsworth +0.507*Lindsborg	Based on multi-linear regression with Ellsworth and Lindsborg minus 1 day
30Sep1920 to 27Feb1921	KANS = 51.308+0.995*Ellsworth	Based on linear regression with Ellsworth data
28Feb1921 to 29Sep1921	KANS = -11.681+0.513*Ellsworth +0.507*Lindsborg	Based on multi-linear regression with Ellsworth and Lindsborg minus 1 day
30Sep1921 to 27Feb1922	KANS = 51.308+0.995*Ellsworth	Based on linear regression with Ellsworth data
28Feb1922 to 29Sep1922	KANS = -11.681+0.513*Ellsworth +0.507*Lindsborg	Based on multi-linear regression with Ellsworth and Lindsborg minus 1 day
30Sep1922 to 27Feb1923	KANS = 51.308+0.995*Ellsworth	Based on linear regression with Ellsworth data
28Feb1923 to 28Sep1923	KANS = -11.681+0.513*Ellsworth +0.507*Lindsborg	Based on multi-linear regression with Ellsworth and Lindsborg minus 1 day
29Sep1923 to 4July1925	KANS = 51.308+0.995*Ellsworth	Based on linear regression with Ellsworth data
5Jul1925 to 31July1928	KANS = Mentor/1.0616	Mentor reduced to account for gain in watershed between Kanopolis and Mentor.
01Aug1928 to 30Jan1930	KANS = 51.308+0.995*Ellsworth	Based on linear regression with Ellsworth data
31Jan1930 to 22Oct1940	KANS = -11.681+0.513*Ellsworth +0.507*Lindsborg	Based on multi-linear regression with Ellsworth and Lindsborg minus 1 day
23Oct1940 to 26Jul1946		Used the USGS daily Langley Flow

27Jul1946 to 15Feb1948	KANS = 51.308+0.995*Ellsworth	Based on linear regression with Ellsworth data
16Feb1948 to present		Kanopolis Inflow minus 12 hours

The regulation impacts of upstream Cedar Bluff Reservoir were not modeled as part of this analysis. Cedar Bluff controls 5,365 square miles and began storage on 13 Nov 1950. The majority of the Kanopolis inflow comes from regions downstream of Cedar Bluff as the eastern portion of the basin is much wetter than the west. Since this study is developing a period of record regulated data set, ideally the Kanopolis inflow would be a fully regulated data set. Since the extended inflow data set is a mixture of unregulated before 13 Nov 1950 and fully regulated after it, the extended inflows before Nov 1950 may tend to be higher than a fully regulated system as discussed in the following paragraphs.

Upstream reservoir holdouts have been calculated from 1950 through 2019 and routed to Kanopolis Reservoir. Holdouts are calculated by subtracting inflow from the outflow for a given day. Holdouts are positive when the reservoir is rising and negative when it is dropping. The upstream holdouts routed to Kanopolis were then used to calculate the unregulated Kanopolis inflow starting in 1950. To do this the routed holdouts are added to the daily inflow.

To understand the impact of regulation above Kanopolis the annual flow volume of holdouts, observed inflow and unregulated inflow were calculated and can be compared in Table 3-4. The percent difference between the inflow and the unregulated inflow is also shown. Some years there is very little difference or even increased flow because of the regulation. However, some years result in significantly reduced flows. The long-term average percent difference indicates a 10% reduction in annual flow volume by having Cedar Bluff Reservoir in place. If additional time and funding are available, it is recommended to further work on developing a fully regulated Kanopolis inflow. Some additional, event specific, plots are included in Section 2.1 of "Attachment 1 Supporting Plots" that show examples of observed and unregulated flows for Kanopolis during specific flood events.

Table 3-4 Annual flow volume for holdouts, inflows, and unregulated inflows at Kanopolis Reservoir.

Annual Flow Volume				
Year	Upstream Holdouts Routed to Kanopolis	Kanopolis Observed Inflow	Kanopolis Calculated Unregulated Inflow	Percent Difference
1948		127,375		
1949		317,878		
1950		453,658		
1951	145,531	1,063,580	1,209,170	14%
1952	-41,303	172,680	131,416	-24%
1953	10,004	62,318	72,339	16%
1954	-1,459	66,061	64,626	-2%
1955	63,116	104,906	168,038	60%
1956	25,510	41,686	67,207	61%
1957	52,830	574,080	626,939	9%
1958	-17,514	394,855	377,339	-4%
1959	32,161	222,831	255,021	14%
1960	34,829	408,325	443,186	9%
1961	32,193	441,606	473,822	7%
1962	-1,060	302,468	301,414	0%
1963	32,363	77,763	110,174	42%
1964	19,087	75,304	94,418	25%
1965	58,264	242,449	300,755	24%
1966	892	120,795	121,728	1%
1967	25,140	305,679	330,843	8%
1968	2,999	111,465	114,465	3%
1969	36,209	319,472	355,726	11%
1970	1,882	166,383	168,283	1%
1971	882	247,423	248,322	0%

1972	26,863	115,173	142,067	23%
1973	50,157	800,417	850,614	6%
1974	-280	301,982	301,779	0%
1975	19,775	200,830	220,630	10%
1976	-5,294	85,696	80,422	-6%
1977	-3,604	113,541	109,960	-3%
1978	-11,675	65,341	53,694	-18%
1979	6,346	159,488	165,854	4%
1980	2,365	88,407	90,817	3%
1981	4,553	124,911	129,491	4%
1982	13,290	97,988	111,303	14%
1983	3,581	31,728	35,352	11%
1984	6,949	71,407	78,422	10%
1985	3,610	118,147	121,791	3%
1986	2,285	82,603	84,914	3%
1987	23,632	455,448	479,125	5%
1988	2,503	33,209	35,729	8%
1989	1,841	61,463	63,317	3%
1990	3,574	115,773	119,344	3%
1991	2,289	52,969	55,289	4%
1992	1,232	173,677	174,928	1%
1993	66,674	946,238	1,012,932	7%
1994	15,063	107,312	122,395	14%
1995	38,154	285,210	323,381	13%
1996	81,193	244,090	325,306	33%
1997	33,559	125,032	158,607	27%
1998	47,420	298,475	345,991	16%
1999	26,988	220,664	247,718	12%
2000	29,411	134,367	163,827	22%
2001	32,680	270,601	303,367	12%
2002	7,456	56,490	63,987	13%
2003	12,072	65,936	78,066	18%
2004	11,822	58,811	70,665	20%
2005	6,063	28,332	34,469	22%
2006	2,987	19,537	22,524	15%
2007	21,125	362,529	383,736	6%
2008	15,012	295,219	310,289	5%
2009	13,996	87,299	101,363	16%
2010	29,032	104,138	133,243	28%
2011	11,856	55,642	67,580	21%
2012	6,785	21,464	28,282	32%
2013	3,535	62,287	65,871	6%
2014	21,618	84,760	106,465	26%
2015	8,237	42,522	50,798	19%
2016	12,044	134,140	146,229	9%
2017	10,248	161,041	171,332	6%
2018	29,060	291,326	320,443	10%
2019	66,775	699,607	765,934	9%

To extend the Kanopolis inflow record, the first preference was to use the Langley flow since it is at the dam site and did not need to be transformed. This data set was available from October 1940 to July 1946.

The second preference was to use the multi-linear regression between Ellsworth and Lindsborg minus one day. The regression equation was matched to the Langley pre-dam data. Shifting Lindsborg back one day resulted in a more fitting regression since the peak flows at Ellsworth and Lindsborg were closer to each other. This equation did a good job of balancing the peak flows with the low flow conditions. This multi-linear regression yielded an R^2 value of 0.8429 which is the best of any of the methods; however, it also had the least amount of overlapping observed data since it was only correlated with the pre-dam Langley data. All other observed Lindsborg flow was a regulated data set and was not used for correlation. Figure 3-2 shows the relationship.

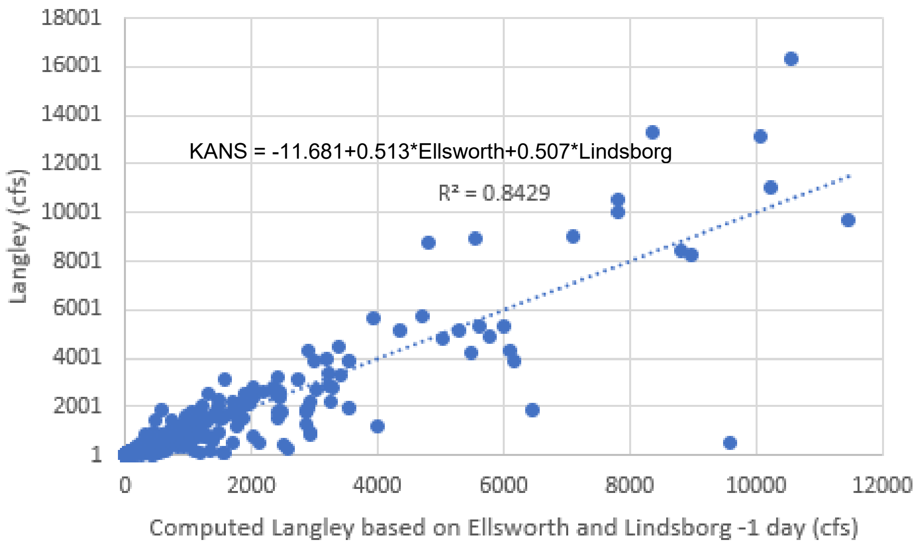


Figure 3-2 Relationship between the daily Langley flow and the computed daily flow from the multi-linear regression of Ellsworth and Lindsborg -1 day.

The third preference was to use a linear regression with Ellsworth. This regression was developed using the period of record Ellsworth data as it correlated to the period of record Kanopolis inflow combined with the pre-dam Langley flow since all these records are either unregulated or impacted equally by regulation. The R^2 of 0.8018 is slightly worse than the multi-linear regression, but still shows a reasonable correlation. Figure 3-3 shows the data correlation and resulting regression equation between observed data.

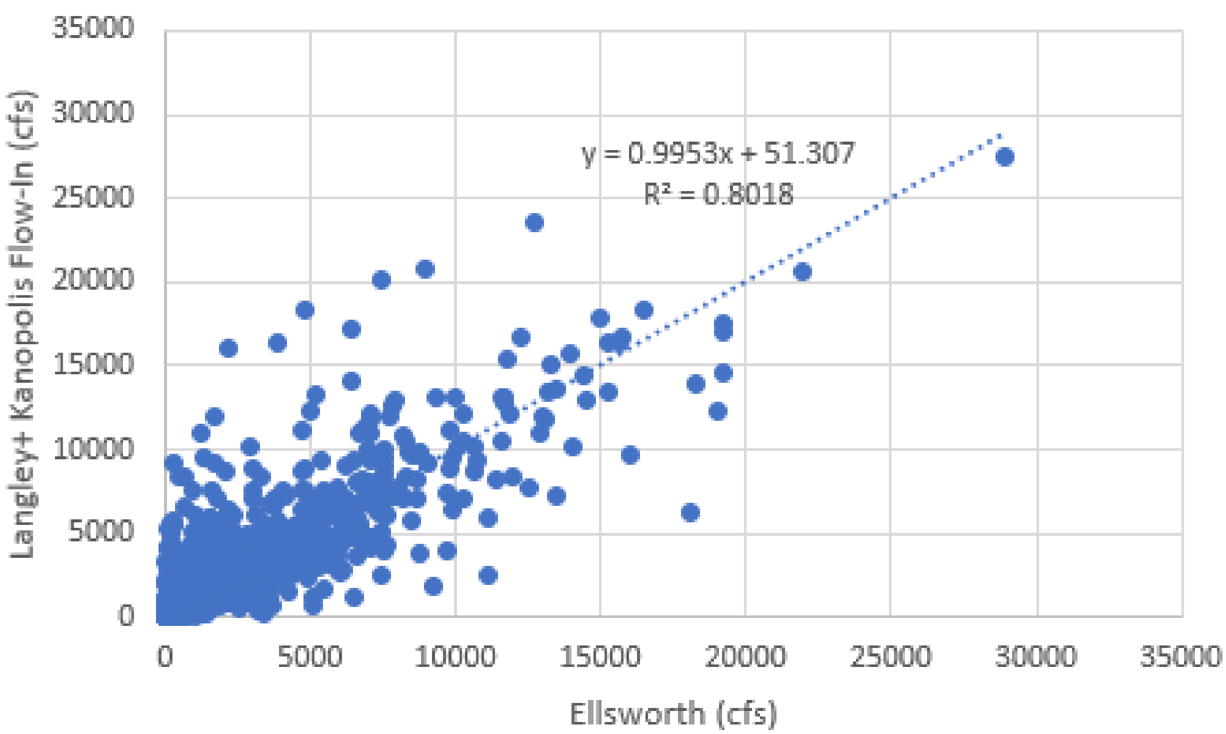


Figure 3-3 Relationship between pre-dam, daily Langley and Kanopolis Inflow observed data and observed Ellsworth data.

After these methods are used a small portion of data is missing from 1925 to 1928. Unregulated data exists at Mentor during this time. However, there is very little overlap of Mentor data with any other dataset during the unregulated period to be used in developing regression equations. Consequently, the Mentor data set was transformed based on the watershed area ratio. There is approximately 6% increase in watershed area between Kanopolis and Mentor.

To test the accuracy of this transformation, the relationship between regulated Langley and Mentor observed was plotted. The travel time from Kanopolis to Mentor is two to three days. To account for this, the R^2 of the Langley vs. Mentor data was tested for observed data, Mentor minus one day, Mentor minus two days, and Mentor minus three days. The best R^2 value was the Mentor minus two days with an R^2 of 0.6747. The Mentor data was shifted backward two days and then divided by 1.06 to develop the transform of Mentor to Kanopolis which is shown in Figure 3-4. The plot shows a skew for occasional higher flow at Mentor. This occurs when rainfall in the watershed area downstream of Langley and upstream of Mentor contribute to significantly higher flows at Mentor than at Langley.

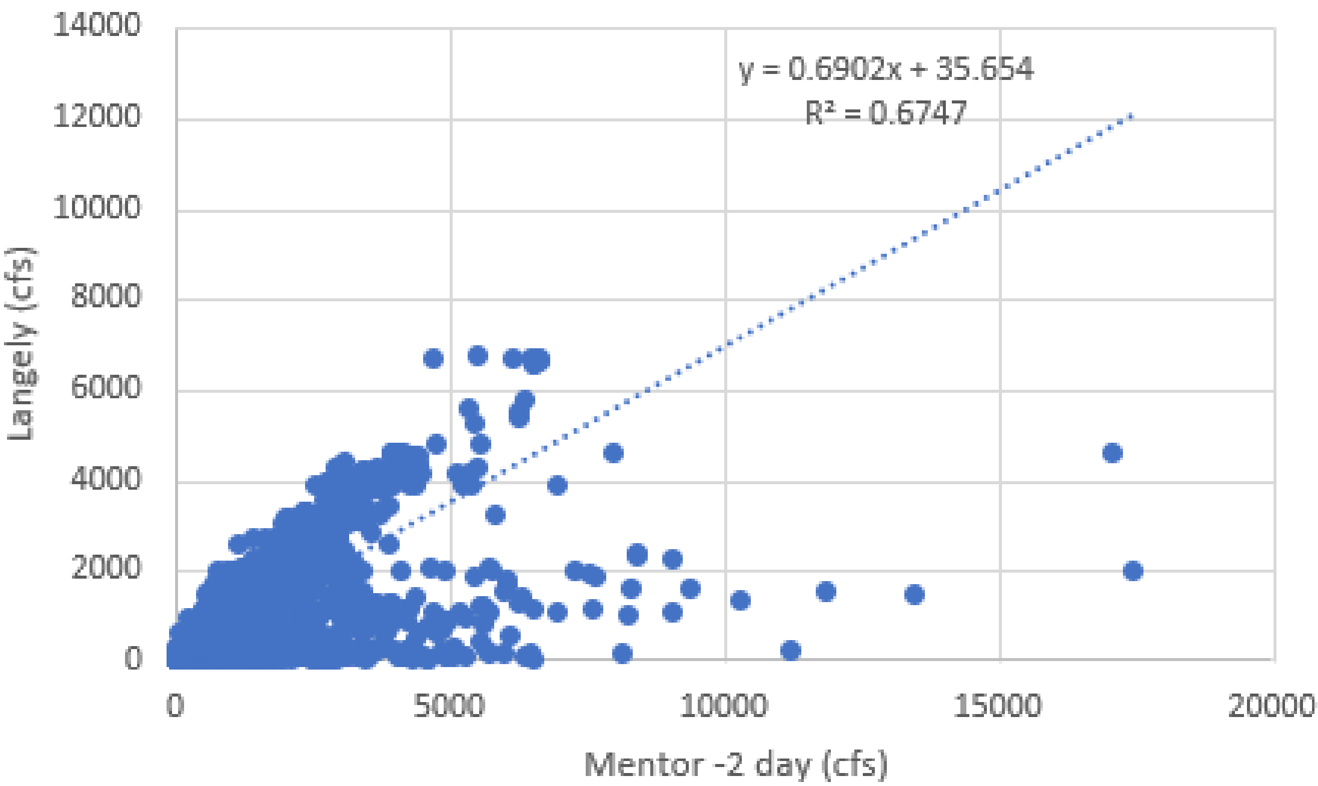


Figure 3-4 Relationship between regulated Langely and Mentor flow daily observed data.

A plot of the final extended Kanopolis inflow is provided in Figure 3-5.

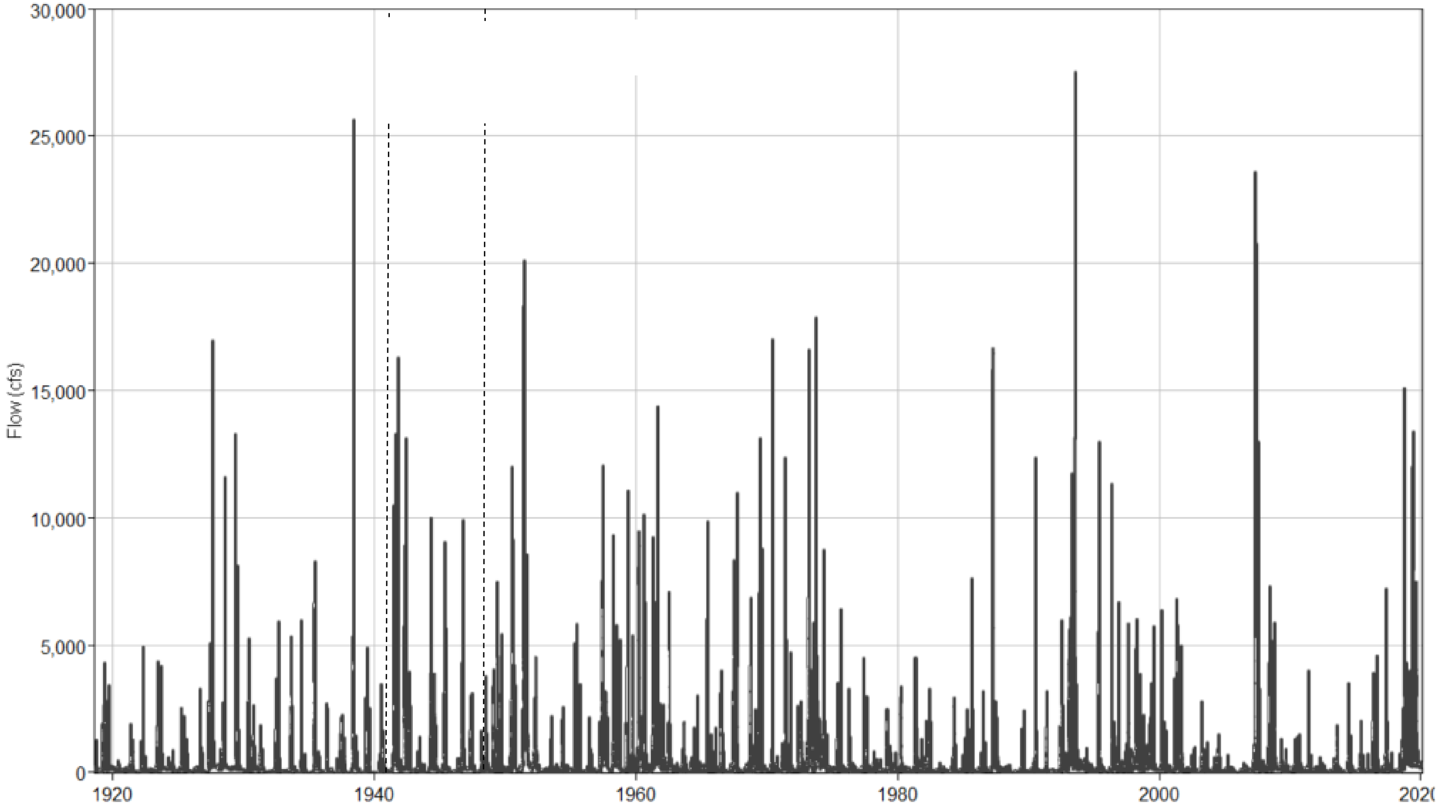


Figure 3-5 Kanopolis extended daily inflow record.

3.1.2 Wilson Dam

Wilson Dam is located at river mile 153.9 of the Saline River and controls about 1,917 square miles of drainage area. The date of closure is September 3, 1963 and the lake began impounding water in January 1964. The multipurpose pool was initially filled in March 1973. Table 3-5 shows the available gage information. The Wilson gage, which was within the pool near the dam site, provides a historic record through 1963 until the gage was inundated by the lake. The Russell gage is upstream of the lake and provides current lake inflow data. The Tescott gage is far below the dam and there is a gain of over 900 square miles between the dam and Tescott.

Table 3-5 Pertinent Saline River gages.

Gage	Drainage Area (mi^2)	Record
Saline River at Russell, KS	1,502	Oct 1, 1945 to Present
Saline River at Wilson, KS	1,900	May 11, 1929 to Sep 30, 1963
Saline River at Tescott, KS	2,820	Sept 1, 1919 to Present

The CWMS database records inflow data beginning on September 4, 1963 for Wilson Lake. As the stored data is 1200 UTC of the day before to 1200 UTC of the current day, the values have been shifted back 12 hours to make them representative of midnight-to-midnight flows. With the time shift, the observed inflow is used from 03 Sept 1963 through 31 Jan 2019.

For the period prior to May 1929, a regression equation based on the Tescott data was necessary. Observed unregulated (pre-dam) Tescott data was compared to the unregulated Wilson gage data. The best correlation was found by shifting Tescott back two days. This lined up the peak flow between the two gages. The regression equation intercept was set to zero to provide more reasonable flow results instead of the fully optimized R-Squared. The relationship is shown in Figure 3-6. The correlation is poor but considering the amount of watershed between the two gages, it is understandable. The equation used to estimate Wilson inflow from 01 Sept 1919 to 10 May 1929 based on time shifted Tescott flow is Wilson=0.4774*Tescott + 0.

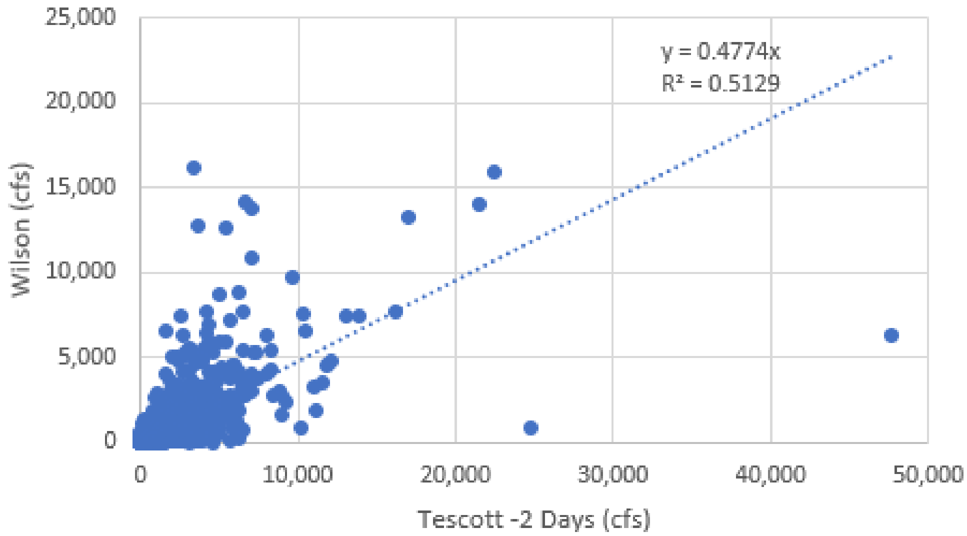


Figure 3-6 Relationship between daily Tescott flow shifted back two days and the Wilson observed flow.

The poor relationship between Wilson and Tescott is concerning but alleviated somewhat by the fact that 1919 through 1926 were dry years with the peak flow at Tescott not exceeding 3000 cfs. More flow was observed in 1927 and 1928 with peak flows of 5,480 and 6,150 cfs, respectively. A plot of the inflow from 1919 to 2019 is provided as Figure 3-7.

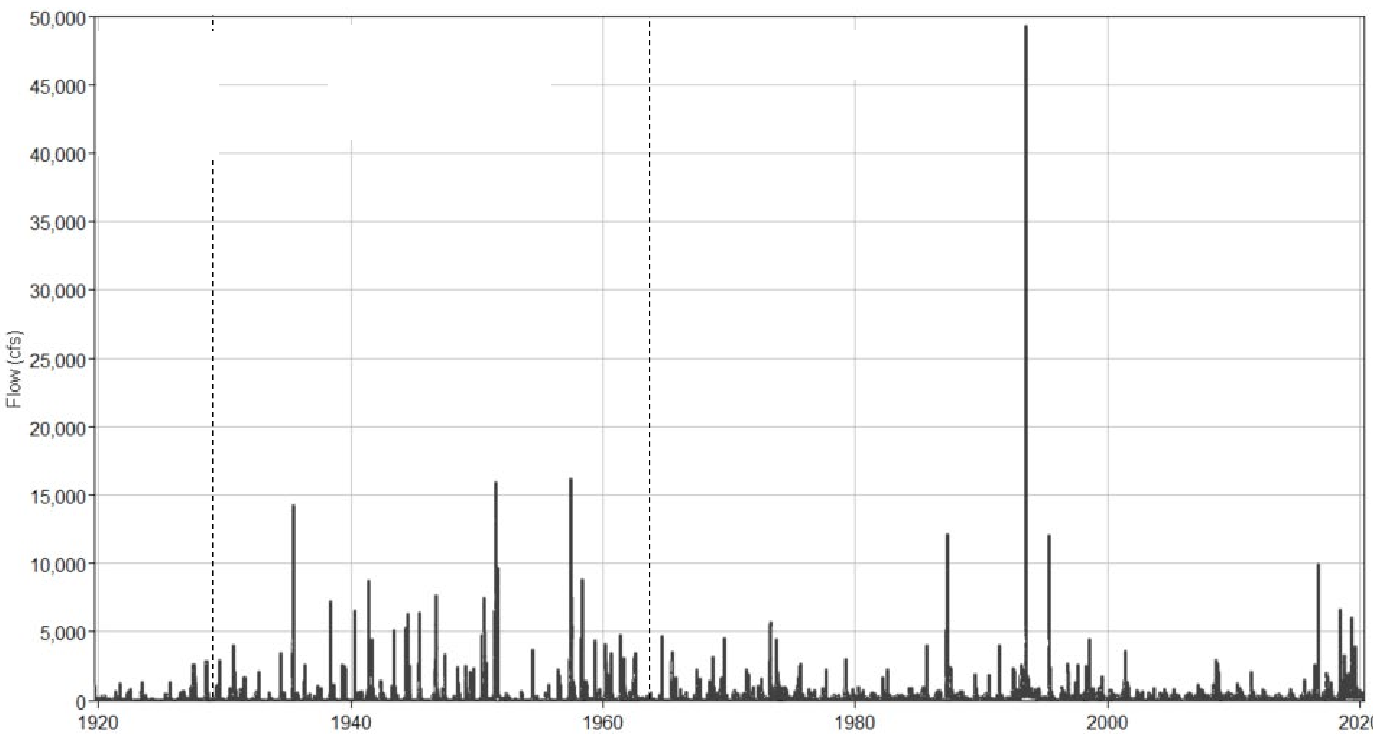


Figure 3-7 Wilson daily extended inflow record.

3.1.3 Waconda Lake

Glen Elder Dam impounds Waconda Lake and is located at river mile 172.4 of the Solomon River. Glen Elder controls about 2,559 square miles drainage area below the upstream dams of Kirwin and Webster Reservoirs. The total drainage area including Kirwin (1,367 square miles) and Webster (1,150 square miles) is 5,076 square miles. Kirwin Reservoir is on the North Fork Solomon River and was initially closed on 07 Mar 1955, achieving full conservation pool (multi-purpose pool) on 02 Jul 1957. Webster Reservoir is on the South Fork Solomon River and was initially closed on 03 May 1956, achieving full conservation pool (multipurpose pool) on 18 June 1957. The date of Glen Elder dam closure was 18 Oct 1967. The reservoir did not initially fill to the top of the conservation pool until 16 May 1973.

Table 3-6 provides the available gage information. The North Fork Solomon River at Portis, which is upstream of the reservoir, was installed on 17 Sep 1945. The South Fork Solomon River at Osborne, which is also upstream of the reservoir, was installed on 28 Mar 1946. The Glen Elder gage, which is just downstream of the dam, was installed on 01 Oct 1964. The Beloit gage supplies historic stream flow data downstream of the dam site at river mile 145.7 on the Solomon River, from 14 Apr 1929 to 30 Sep 1965. Referencing recent gate changes and gage data, the Glen Elder gage is 3 to 6 hours travel time from Glen Elder Dam and Beloit is 12 to 24 hours travel time downstream of the dam.

Table 3-6 Pertinent Waconda Lake Gages

Gage	Drainage Area (mi^2)	Record
North Fork Solomon River at Kirwin, KS	1,367	Aug 30, 1919 to Sept 29, 2002
North Fork Solomon River at Portis, KS	2,315	Sept 17, 1945 to present
South Fork Solomon River at Alton, KS	1,720	Aug 31, 1919 to Sept 29,1957
South Fork Solomon River at Osborne, KS	2,012	Mar 28, 1946 to present
Solomon River near Glen Elder, KS	5,340	Oct 1, 1964 to present
Solomon River at Beloit, KS	5,440	Apr 14, 1929 to Sep 30, 1965 and July 17, 2012 to present
Solomon River at Niles, KS	6,770	May 6, 1897 to present

Waconda lake inflow from 18 Oct 1967 to the end of the study period originate from the CWMS database. As the stored data is 1200 UTC of the day before to 1200 UTC of the current day, the values have been shifted back 12 hours to make them representative of midnight-to-midnight flows. With the time shift, the observed inflow is used from 17 Oct 1967.

The Beloit gage can be used to determine lake inflow values from 14 Apr 1929 until the gage was discontinued on 30 Sep 1965. The Glen Elder gage represents the period from 01 Oct 1964 until the beginning of the Waconda inflow record (18 Oct 1967) and has a one-year overlap with the Beloit gage. Prior to 14 Apr 1929, a combination of Kirwin, Alton, and Niles data are used to extend the inflow record back to 1920.

Because there is very little data at the dam site prior to the dam, regression equations were used to extend the Beloit data record back to 1920. Afterward, all the pre-dam Beloit data was adjusted to the dam location. Shifting data twice appeared to be the best method because that allowed regression equations to have a long period of observed unregulated Beloit data for comparison.

The Beloit gage was extended by developing a multi-linear regression equation in DSS. This relationship was based on the fully unregulated Beloit data prior to 02 May 1956, Kirwin shifted forward one day, Alton shifted forward one day, and Niles shifted backward two days. These parameters resulted in a reasonable simulation of the Beloit data with an R^2 factor of 0.8677 as shown in Figure 3-8. Kirwin and Alton were not in operation from

June 1925 to August 1928, so Niles was used to estimate Beloit during that time frame. It was found that the best linear relationship between Beloit and Niles came from shifting Niles back one day. This relationship is shown in Figure 3-9. The data and equations used to extend Beloit are shown in Table 3-7.

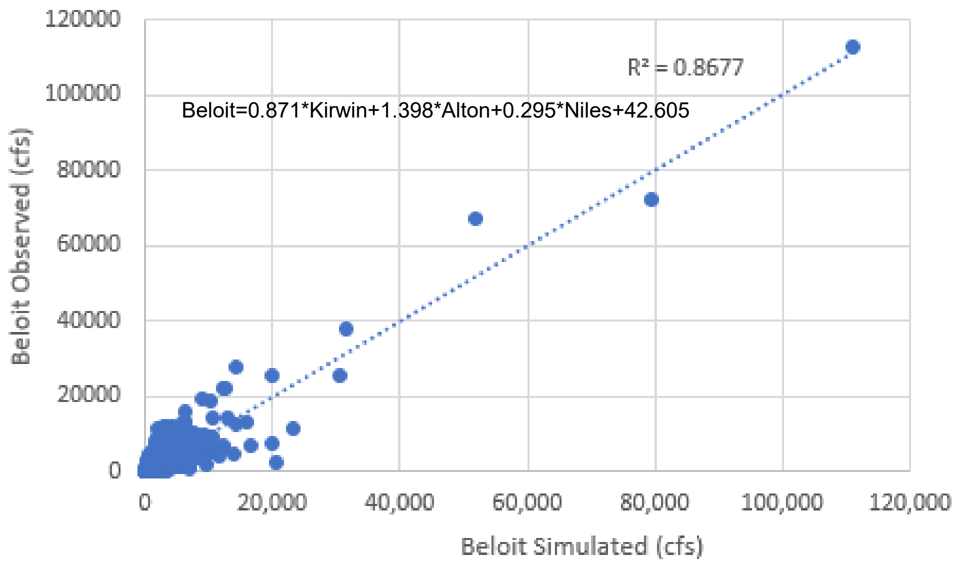


Figure 3-8 Beloit multi-linear regression relationship base on daily data.

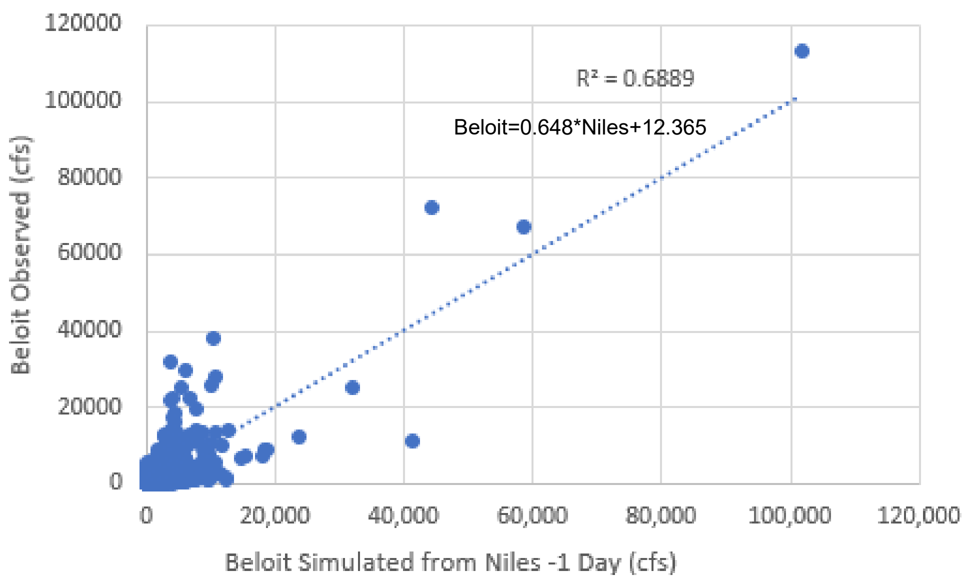


Figure 3-9 Beloit linear relationship with the daily Niles data set.

Table 3-7 Data used to extend daily Beloit flow.

Date Range	Equation Used	Comment
01Sept1919 to 01July1925	Beloit=0.871*Kirwin+1.398*Alton +0.295*Niles+42.605	Based on multi-linear regression with Kirwin plus 1 day, Alton plus 1 day, and Niles minus 2 days
02July1925 to 12Aug1928	Beloit=0.648*Niles+12.365	Based on linear regression with Niles minus 1 day
13Aug1928 to 13Apr1929	Beloit=0.871*Kirwin+1.398*Alton +0.295*Niles+42.605	Based on multi-linear regression with Kirwin plus 1 day, Alton plus 1 day, and Niles minus 2 days
14Apr1929 to 29Sep1965		Observed Beloit data

The Beloit gage is approximately 26 miles downstream of the dam and represented 364 more square miles of drainage basin. The ratio of the Beloit and Waconda Lake drainage basins is:

$$5076 \text{ mi}^2 / 5440 \text{ mi}^2 = 93.3\%$$

From 17 July 2012 to 31 Dec 2019 the Waconda outflow record overlaps with the Beloit gage data. While this is all a regulated data set, it provides insight into the relationship between the gages and how much discharge is provided by the uncontrolled drainage area below the dam. It was found that the best relationship comes from shifting Beloit back one day to help with travel time. The gages' relationship is provided in Figure 3-10. The regression equation indicates that about 80% of the Beloit flow comes from Waconda. The other 20% comes from below the dam which is more than the watershed area indicates; however, the basin is much wetter in the eastern portion of the basin. This relationship was compared to the annual flow volume at each gage from 2013 through 2019 and the Waconda outflow ranged from 66% to 86% of the Beloit flow with an average of 76%. This compares well to the regression equation.

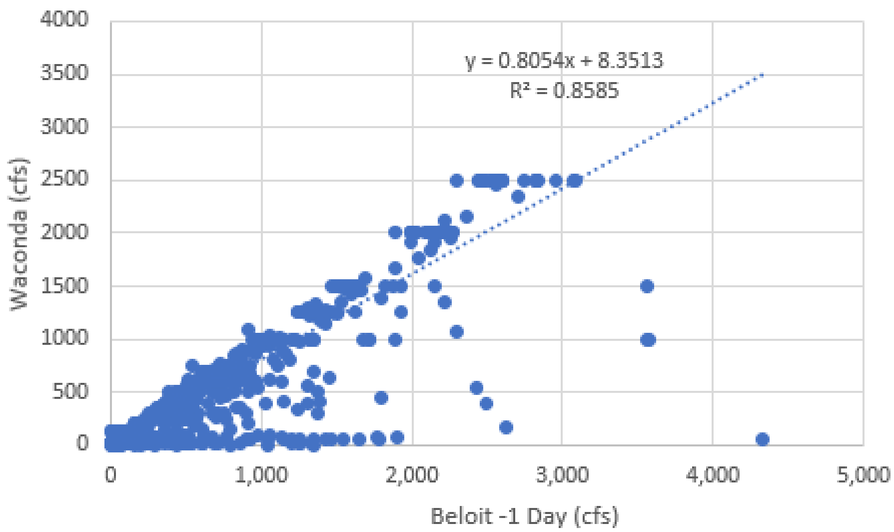


Figure 3-10 Relationship between Waconda outflow and regulated Beloit daily observed flow data.

The extended Beloit data was used to estimate the Waconda inflow from 1919 through 1964. Once the Glen Elder gage flow becomes available it is adjusted to estimate inflow. Even though Glen Elder is the below gage for Waconda, an additional 264 mi^2 of drainage area is picked up between the dam and the gage primarily coming from the left bank tributary, Limestone Creek. The Glen Elder data was adjusted using the relationship shown in Figure 3-11. The linear equation indicates that about 87% of the Glen Elder flow comes from Waconda outflow. This relationship was compared to the annual flow volumes from both sites from 1968 to 2019. The percent of Glen Elder's flow originating from Waconda ranges from 40% to 119% with an average of 90%. The average compares favorably with the regression equation. Actual Waconda inflows are used for the period beginning 17 Oct 1967. Table 3-8 details the data that is used to estimate the Waconda inflow record.

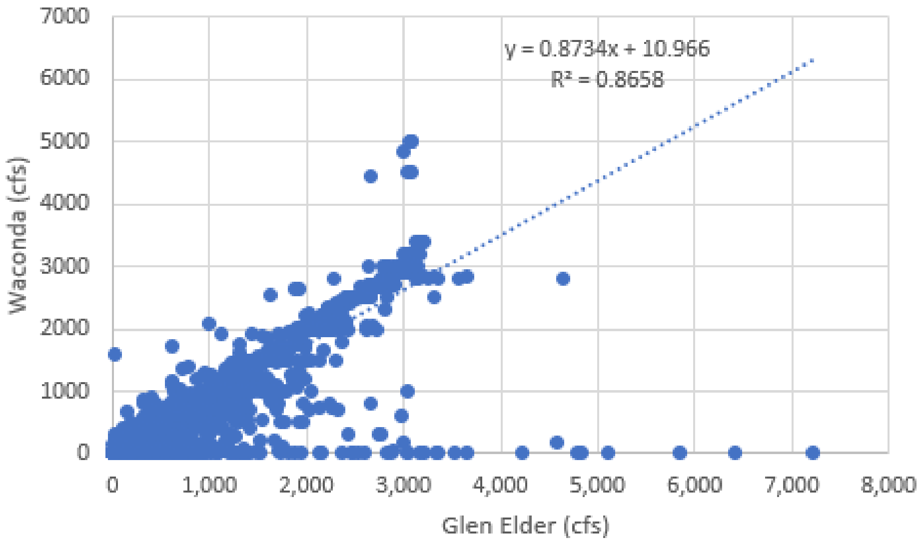


Figure 3-11 Relationship between Waconda outflow and the Glen Elder daily observed data..

Table 3-8 Data used to extend the daily Waconda inflow

Date Range	Equation Used	Comment
31Aug1919 to 30Sep1964	GLEL=0.8054*Beloit+8.4201	Based on linear regression with the extended Beloit data minus 1 day
01Oct1964 to 16Oct1967	GLEL=0.873*Glen Elder+10.965	Based on linear regression with Glen Elder data
17Oct1967 to 31Dec2019		Observed Waconda Inflow

After 03 May 1956, Beloit flow is influenced by the regulation of Webster and Kirwin Reservoirs. Glen Elder inflow is influenced by this regulation. Since this KRRFSS modeling effort is not investigating these reservoirs, it is assumed that their influence on the gage record is minimal. The Solomon River basin is wetter in the east than the western side of the basin; however, depending on the event, the impact of the upstream reservoirs can influence inflows. Since this study is developing a period of record regulated data set, ideally the Glen Elder inflow would be a fully regulated data set. Since the extended inflow data set is a mixture of unregulated before 07 Mar 1955 (closure of Kirwin), partially regulated until 03 May 1956 (closure of Webster), and fully regulated after it, the extended inflows before March 1955 may tend to be a little higher than a fully regulated system as discussed in the following paragraphs.

Upstream reservoir holdouts have been calculated from 1955 through 2019 and routed to Waconda Reservoir. Holdouts are calculated by subtracting inflow from the outflow for a given day. Holdouts are positive when the reservoir is rising and negative when it is dropping. The upstream holdouts routed to Waconda were then used to calculate the unregulated Waconda inflow starting in 1967. To do this the routed holdouts are added to the daily inflow.

To understand the impact of regulation above Glen Elder the annual flow volume of holdouts, observed inflow and unregulated inflow were calculated and can be compared in Table 3-9. The percent difference between the inflow and the unregulated inflow is also shown. Some years there is very little difference or even increased flow because of the regulation. However, some years result in significantly reduced flows. The long-term average percent difference indicates an 8% reduction in annual flow volume by having the upstream reservoirs in place. If additional time and funding are available, it is recommended to further work on developing a fully regulated Waconda inflow. Some additional, event specific, plots are included in Section 2.1 of "Attachment 1

Supporting Plots" that show examples of observed and unregulated flows for Waconda during specific flood events.

Table 3-9 Annual flow volume for holdouts, inflows, and unregulated inflows at Waconda Reservoir.

	Annual Flow Volume			
Year	Upstream Holdouts Routed to Waconda	Waconda Observed Inflow	Waconda Calculated Unregulated Inflow	Percent Difference
1955	8,696.70			
1956	6,873.60			
1957	154,844.90			
1958	42,009.50			
1959	8,488.40			
1960	28,304.50			
1961	25,231.10			
1962	30,207.70			
1963	17,946.70			
1964	-14,790.00			
1965	92,922.00			
1966	-32,450.10			
1967	8,132.40	26,310	30,487	16%
1968	33,596.50	98,281	131,969	34%
1969	40,725.20	160,080	200,946	26%
1970	-14,803.90	46,753	31,989	-32%
1971	-3,752.80	64,387	60,743	-6%
1972	6,663.60	55,210	61,981	12%
1973	32,405.40	443,089	475,668	7%
1974	4,552.10	199,774	204,428	2%
1975	69,722.00	170,507	240,370	41%
1976	-29,518.40	75,044	45,570	-39%
1977	-1,366.60	86,585	85,299	-1%
1978	22,121.00	83,311	105,557	27%
1979	33,914.90	202,853	236,901	17%
1980	-7,545.20	98,540	91,065	-8%
1981	17,484.60	76,761	94,360	23%
1982	21,467.40	270,585	292,160	8%
1983	-4,378.60	85,519	81,229	-5%
1984	16,999.60	145,061	162,151	12%
1985	23,810.90	92,253	116,200	26%
1986	9,744.90	104,967	114,813	9%
1987	51,386.50	516,814	568,346	10%
1988	-11,444.80	86,902	75,520	-13%
1989	3,654.60	160,792	164,574	2%
1990	329.3	101,218	101,628	0%
1991	1,501.50	43,642	45,252	4%
1992	23,870.40	170,422	194,373	14%
1993	222,041.90	1,463,164	1,684,900	15%
1994	-12,265.00	414,155	402,600	-3%
1995	38,038.60	532,588	570,734	7%
1996	33,777.00	316,115	349,935	11%
1997	9,512.90	182,059	191,697	5%
1998	22,536.50	277,551	300,152	8%
1999	43,830.40	229,342	273,267	19%
2000	-5,599.40	89,743	84,125	-6%
2001	19,129.90	167,907	187,125	11%
2002	-16,870.70	65,054	48,244	-26%
2003	-14,756.20	61,627	46,947	-24%
2004	-6,435.50	55,483	49,154	-11%
2005	17,359.60	66,801	84,322	26%
2006	9,524.80	28,743	38,462	34%

2007	20,467.70	74,912	95,422	27%
2008	137,266.10	410,707	548,240	33%
2009	48,200.40	219,702	267,751	22%
2010	19,683.50	492,165	512,090	4%
2011	44,033.90	437,322	481,465	10%
2012	-23,080.40	110,407	87,418	-21%
2013	-12,540.70	65,406	52,912	-19%
2014	11,768.10	68,907	80,825	17%
2015	10,221.20	106,349	116,669	10%
2016	111,730.00	194,910	306,806	57%
2017	57,680.80	200,553	258,297	29%
2018	44,555.60	306,253	350,914	15%
2019	30,584.60	785,815	819,898	4%

The extended Waconda Lake inflow hydrograph is provided as Figure 3-12.

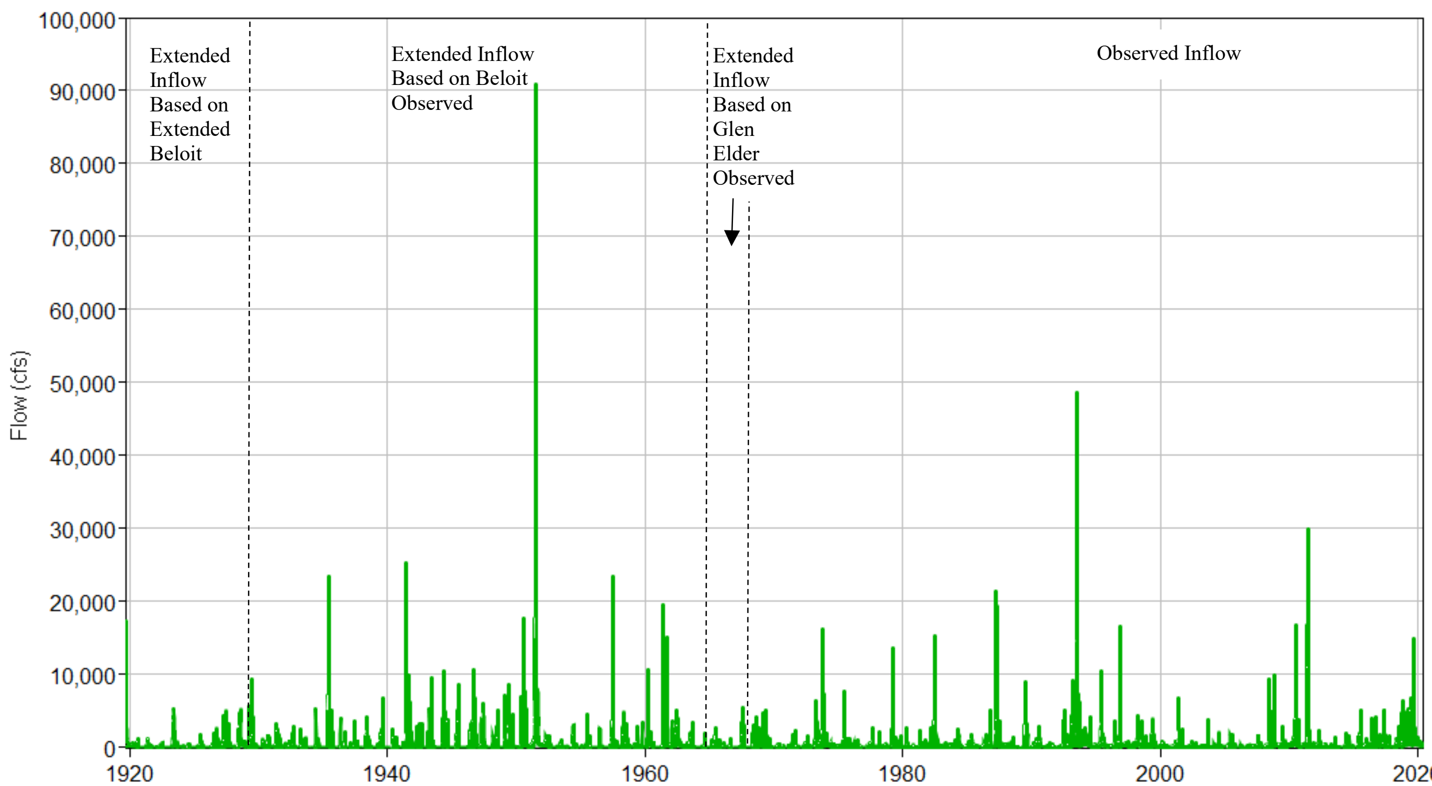


Figure 3-12 Waconda extended daily inflow record.

3.1.4 Milford Lake

Milford Dam, which is located at river mile 7.7 of the Republican River, controls about 24,880 square miles of drainage area. A large portion of this basin is considered non-contributing. The closure of the dam was on 24 Aug 1964 and the database inflow begins on the same date. The dam began storing water on 16 Jan 1967 and the multipurpose pool was initially filled on 14 Jul 1967. Table 3-10 shows the key gages related to Milford Dam.

Table 3-10 Gages associated with Milford Dam.

Gage	Drainage Area (mi^2)	Record
Republican River at Clay Center, KS	24,542	01Jun1917 to present
Republican River at Milford, KS	24,900	01Jan1900 to 31Oct1905

		01Oct1950 to 31Mar1964
Republican River at Milford Dam	24,900	24Aug1964 to present
Republican River at Junction City, KS	24,900	01Oct1963 to present

The observed Corps of Engineers reservoir stage, inflow, and outflow records are from 24 Aug 1964 through the present. As the stored data is 1200 UTC of the day before to 1200 UTC of the current day, the values have been shifted back 12 hours to make them representative of midnight-to-midnight flows. With the time shift, the observed inflow is used from 23 Aug 1964 through the end of the study period.

The regulation impacts of upstream Milford Reservoir were not modeled as part of this analysis. The total contributing watershed area into Milford is 17,388 square miles. The contributing watershed area below Harlan County and Lovewell and above Milford is 3,507 square miles. Although the south-eastern portion of the watershed tends to be much wetter than the western portion of the watershed, the large regulated area could be impactful on the Milford inflow depending on the location of rainfall. Since this study is developing a period of record regulated data set, ideally the Milford inflow would be a fully regulated data set. Since the extended inflow data set is a mixture of unregulated before 08 Aug 1949 (closure of the first upstream dam—Harry Strunk), partially regulated until 08 Jan 1964 (closure of the final upstream dam—Norton), and fully regulated after that, the extended inflows before this may tend to be higher than a fully regulated system as discussed in the following paragraphs.

Upstream reservoir holdouts have been calculated from 1950 through 2019 and routed to Milford Reservoir. Holdouts are calculated by subtracting inflow from the outflow for a given day. Holdouts are positive when the reservoir is rising and negative when it is dropping. The upstream holdouts routed to Milford were then used to calculate the unregulated Milford inflow starting in 1950. To do this the routed holdouts are added to the daily inflow.

To understand the impact of regulation above Milford the annual flow volume of holdouts, observed inflow and unregulated inflow were calculated and can be compared in Table 3-11. The percent difference between the inflow and the unregulated inflow is also shown. The Milford Reservoir unregulated inflow was consistently higher than the observed inflow. It ranged anywhere from 11% to 125% higher with an average of 51% higher than observed. The long-term average percent difference indicates a 51% reduction in annual flow volume by having the upstream reservoirs in place. If additional time and funding are available, it is recommended to further work on developing a fully regulated Milford inflow or at least expand the model to include Harlan County and Lovewell. Although the upstream reservoirs provide a significant flow volume reduction, the impacts may not create a large flow difference on the Kansas River below Milford. Milford will smooth any peak flows from the unregulated inflow data set. Some additional, event specific, plots are included in Section 2.1 of "Attachment 1 Supporting Plots" that show examples of observed and unregulated flows for Kanopolis during specific flood events.

Table 3-11 Annual flow volume for holdouts, inflows, and unregulated inflows at Milford Reservoir.

	Annual Flow Volume			
Year	Upstream Holdouts Routed to Milford	Milford Observed Inflow	Milford Calculated Unregulated Inflow	Percent Difference
1950	35,694			
1951	49,825			
1952	86,525			
1953	285,057			
1954	231,536			
1955	266,403			
1956	255,504			
1957	487,234			

1958	133,884			
1959	290,223			
1960	323,143			
1961	326,112			
1962	345,931			
1963	367,009			
1964	401,597			
1965	536,437	918,554	1,455,089	58%
1966	300,810	400,821	701,468	75%
1967	292,673	848,491	1,141,209	34%
1968	287,501	557,191	844,702	52%
1969	424,319	920,352	1,344,617	46%
1970	289,575	528,051	817,664	55%
1971	413,966	573,047	986,972	72%
1972	385,881	436,275	822,052	88%
1973	430,804	2,030,241	2,461,062	21%
1974	241,600	642,424	884,106	38%
1975	418,039	449,843	867,856	93%
1976	325,912	288,868	614,859	113%
1977	401,695	603,787	1,005,504	67%
1978	300,002	517,388	817,413	58%
1979	319,482	854,808	1,174,176	37%
1980	322,221	513,047	835,287	63%
1981	328,596	384,189	712,789	86%
1982	283,131	880,972	1,163,978	32%
1983	196,728	775,107	971,940	25%
1984	295,852	891,306	1,187,156	33%
1985	302,013	671,648	973,628	45%
1986	276,993	1,127,605	1,404,593	25%
1987	318,534	1,348,463	1,667,001	24%
1988	284,844	259,164	543,996	110%
1989	244,853	346,726	591,636	71%
1990	221,896	350,529	572,506	63%
1991	206,159	165,064	371,107	125%
1992	260,360	651,391	911,791	40%
1993	343,920	3,027,674	3,371,685	11%
1994	181,914	592,422	774,169	31%
1995	241,894	856,634	1,098,618	28%
1996	334,910	731,336	1,066,184	46%
1997	215,983	482,467	698,402	45%
1998	241,759	869,001	1,110,883	28%
1999	272,871	706,757	979,583	39%
2000	189,544	187,699	377,323	101%
2001	274,924	533,090	807,999	52%
2002	137,341	134,828	272,231	102%
2003	119,210	246,475	365,690	48%
2004	94,404	257,468	351,855	37%
2005	128,285	191,532	319,794	67%
2006	87,488	91,335	178,818	96%
2007	303,164	497,730	800,904	61%
2008	225,133	763,766	988,945	29%
2009	164,279	390,363	554,510	42%
2010	185,341	989,653	1,175,012	19%
2011	197,126	805,043	1,002,252	24%
2012	80,419	322,298	402,732	25%
2013	111,410	289,462	400,877	38%
2014	178,050	218,313	396,587	82%
2015	192,444	579,230	771,663	33%
2016	232,126	585,891	818,044	40%
2017	204,268	662,954	867,235	31%
2018	220,383	665,970	885,746	33%
2019	251,029	1,999,114	2,273,138	14%

Before the dam was constructed, inflow records are approximated using the gages listed in Table 3-9. The Republican River at Milford, KS and Junction City, KS gages were used with no adjustment from October 1950 to the start of the Milford CWMS data record. The watershed areas of these gages are very similar to the watershed area of the dam. Before October 1950, a linear relationship between the Clay Center gage and the extended inflow was used. The linear relationship is shown in Figure 3-13; it resulted in a very good fit of data. Routing time between Clay Center and Milford Reservoir is minimal, so no time shift was applied. The various methods are outlined in Table 3-12.

The extended Milford inflow is partially regulated by upstream reservoirs. The extended Milford Lake inflow hydrograph is provided as Figure 3-14. The Milford WCM references previous studies which calculated a peak 1935 flow of 168,000 cfs at Junction City. The documentation of that flow was not referenced. The approved USGS flow at Clay Center was 103,000 cfs and the river was fully unregulated at that time. Based on this Clay Center flow, the Milford inflow is estimated to crest at 108,841 cfs for the 1935 event.

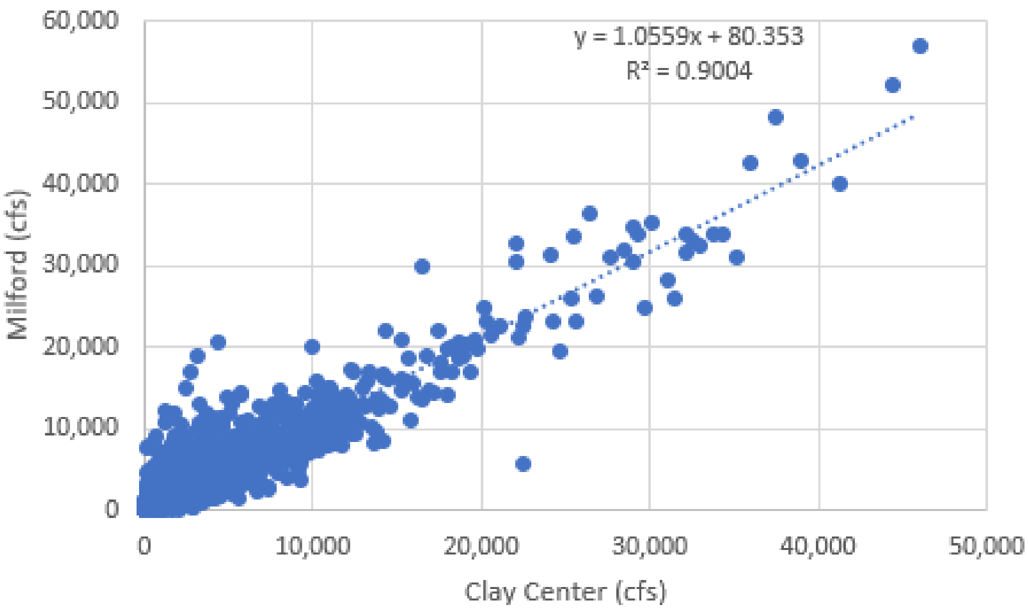


Figure 3-13 Relationship between daily observed Milford Inflow and Clay Center observed flow..

Table 3-12 Data used to extend the daily Milford inflow.

Date Range	Equation Used	Comment
01Jun1917 to 30Sep1950	MILD=1.056*Clay Center+80.356	Based on linear regression between Milford and Clay Center
01Oct1950 to 31Mar1964		Used the USGS daily Milford, KS Flow
01Apr1964 to 22Aug1964		Used the USGS daily Junction City Flow; this was before the dam was regulating Junction City.
23Aug1964 to 31Dec2019		Observed Milford Inflow

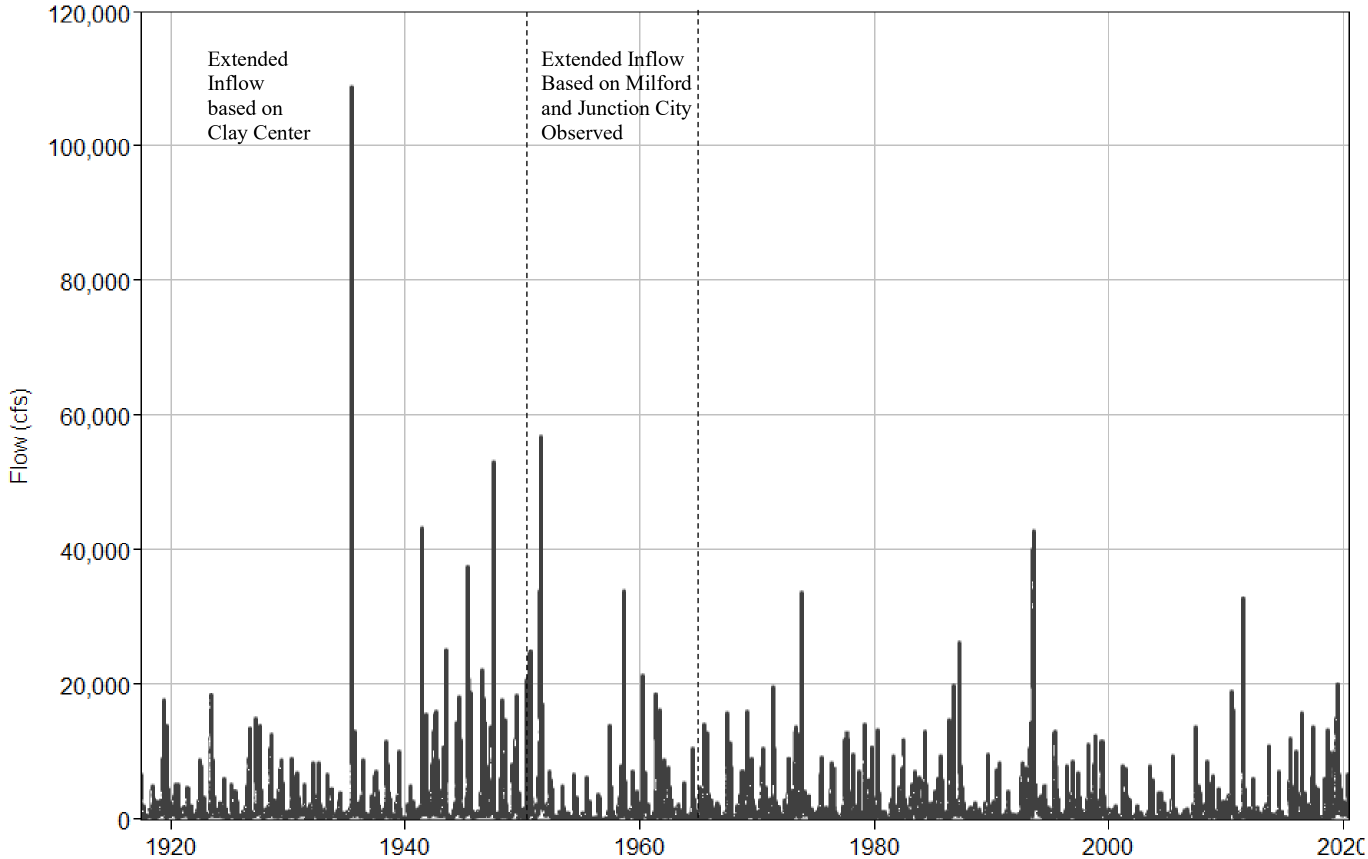


Figure 3-14 Milford Lake extended daily inflow record.

3.1.5 Tuttle Creek Lake

Tuttle Creek Dam is located at river mile 10.0 of the Big Blue River and controls about 9,628 square miles of drainage area. The closure of the dam was on 20 Jul 1959 and the multipurpose pool was initially filled on 29 Apr 1963. Table 3-13 summarizes the available gage information for the Big Blue basin. Inflow gages are Marysville on the Big Blue River, Barnes on the Little Blue River, and Frankfort on the Black Vermillion River. The Waterville gage on the Little Blue River and Randolph gage on the Big Blue River (inundated by the pool) are sources of historic inflow data. The Manhattan gage, which is located 2.5 miles downstream of the dam, provides inflow data for the period prior to 19 Jul 1959 when calculated reservoir inflows were available and dam operation began to impact flows at this gage.

Table 3-13 Gages related to Tuttle Creek Dam.

Gage	Drainage Area (mi^2)	Record
Big Blue River at Randolph, KS	9,100	17Apr1918 to 29Sept1960
Big Blue River at Tuttle Creek Dam	9,628	21Jul1959 to present
Big Blue River at Manhattan, KS	9,640	01Oct1950 to present

The observed Corps of Engineers reservoir stage, inflow, and outflow records are from 21 Jul 1959 through the present. As the stored data is 1200 UTC of the day before to 1200 UTC of the current day, the values have been shifted back 12 hours to make them representative of midnight-to-midnight flows. With the time shift, the observed inflow is used from 20 Jul 1959 through the end of the study period.

Before the dam was constructed, inflow records are approximated using the gages listed in Table 3-13. The pre-dam inflow from October 1950 to the beginning of inflow at Tuttle Creek used the Manhattan gage with no shift as the watershed areas are very similar to the dam. Before October 1950, a linear relationship between the Randolph gage and the extended inflow was used. The linear relationship is shown in Figure 3-15; as can be seen a very good fit of data was observed. Routing time between Randolph and Tuttle Creek Reservoir is minimal, so no time shift was applied. The various methods are outlined in Table 3-14. The extended Tuttle Creek Lake inflow hydrograph is provided as Figure 3-16.

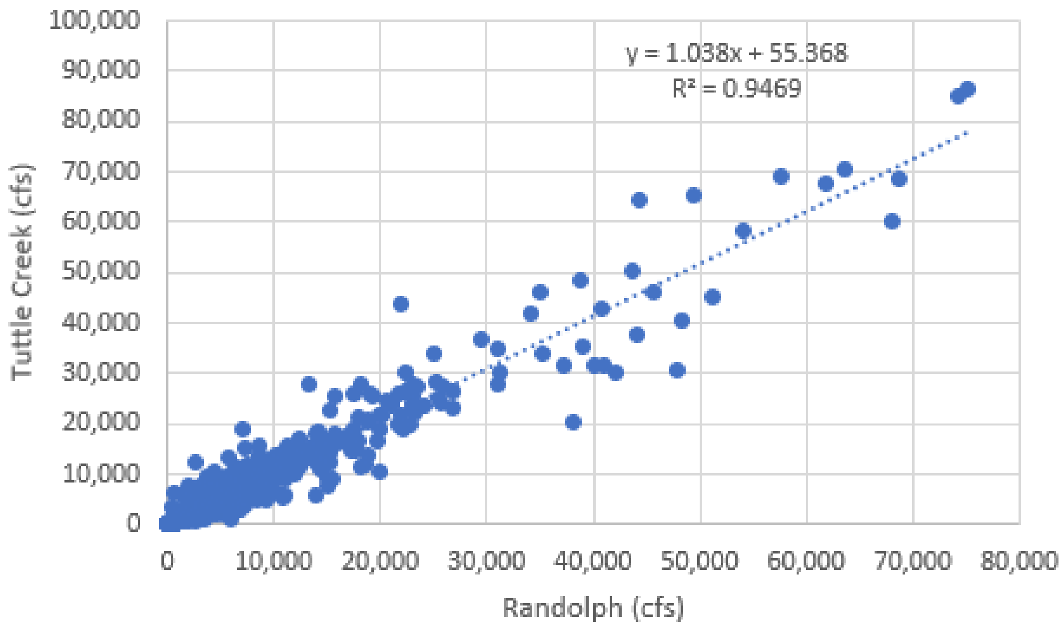


Figure 3-15 Relationship between observed daily Tuttle Creek Inflow and Randolph observed flow.

Table 3-14 Data used to extend the daily Tuttle Creek inflow.

Date Range	Equation Used	Comment
01Jun1917 to 30Sep1950	TUCR=1.038*Randolph+55.368	Based on linear regression between Tuttle Creek and Randolph
01Oct1950 to 19Jul1959		Used the USGS daily Manhattan Flow; this was before the dam was regulating Manhattan.
20Jul1959 to 31Dec2019		Observed Tuttle Creek Inflow

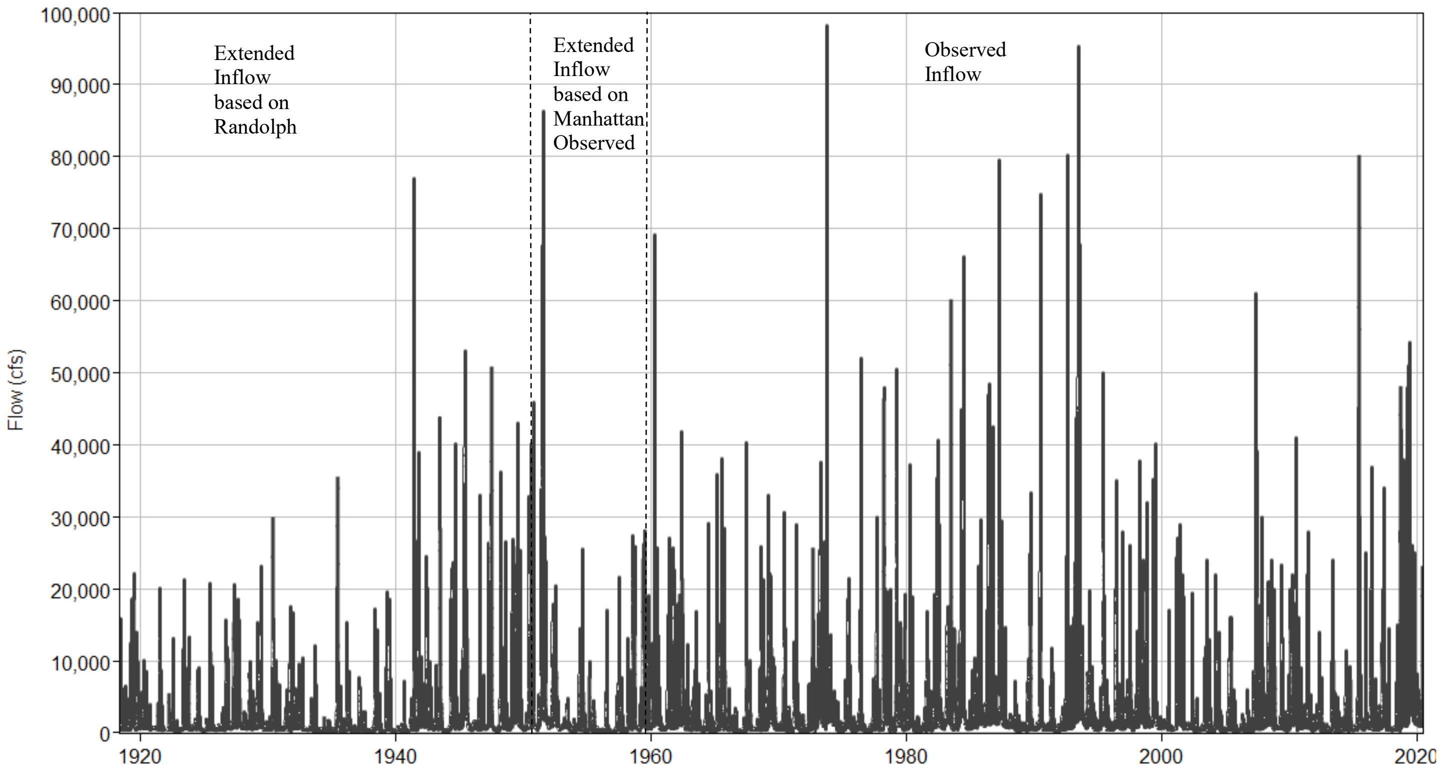


Figure 3-16 Tuttle Creek Lake extended daily inflow record.

3.1.6 Perry Lake

The Perry Lake dam, which is located at river mile 5.3 of the Delaware River, controls about 1,117 square miles of the drainage area. The dam started impounding water on January 15, 1969 (even though data storage started before that date). Table 3-15 shows the available gage information. Muscotah is the current inflow gage on the Delaware River approximately 20 miles upstream from the full reservoir. The Valley Falls gage on the Delaware River (inundated by the pool) provides historic inflow data.

Table 3-15 Gages related to Perry Dam.

Gage	Drainage Area (mi^2)	Record
Delaware River at Muscotah, KS	431	16Jul1969 to present
Delaware River at Valley Falls, KS	922	16Jun1922 to 29Sept1967
Delaware River at Perry Dam	1,117	01Aug1966 to present
Kansas River at Topeka, KS	56,720	12Jun1917 to present
Kansas River at Lecompton, KS	58,460	16Mar1936 to present
Kansas River at Desoto, KS	59,756	08Jul1917 to present

The observed Corps of Engineers reservoir stage, inflow, and outflow records extend from 01 Aug 1966 through the present. As the stored data is 1200 UTC of the day before to 1200 UTC of the current day, the values have been shifted back 12 hours to make them representative of midnight-to-midnight flows. With the time shift, the observed inflow is used from 31 Jul 1966 through the end of the study period. The ratio of the Perry Lake drainage area and the Valley Falls drainage area is 1.21 (1,117 mi^2/ 922 mi^2).

Before the dam was constructed, inflow records are approximated using the Valley Falls gage. There is just over one year of overlap data after Perry Dam inflow records began and Valley Falls gage data ended. A linear relationship between these two data sources is shown in Figure 3-17. The data appears to be a good fit, but the small overlap of data could lead to some errors. Routing time between Valley Falls and Perry Reservoir is minimal, so no time shift was applied.

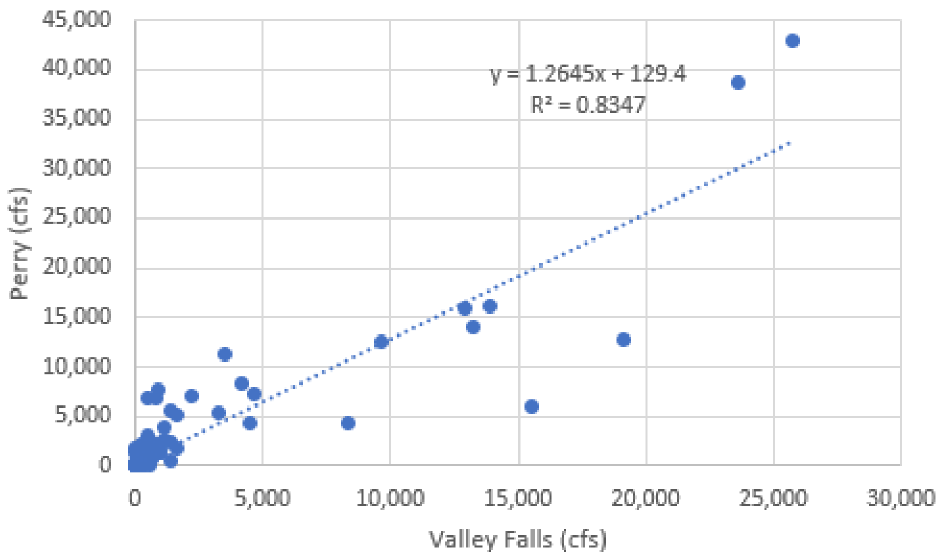


Figure 3-17 Relationship between observed daily Perry Inflow and Valley Falls flow.

For the period before the Valley Falls gage came into existence, the inflow record was estimated by looking at the Kansas River flow. This was to provide inflow data for 1919 (used as lookback in the model), 1920, 1921, and January through June of 1922. The Kansas River at Lecompton data record was extended as detailed in Section 3 by using the relationship between the Topeka and Desoto data. The Delaware River is the largest tributary between Topeka and Lecompton and a relationship was developed based on the annual flow volume of the extended Lecompton flow record. There is a lot of variability of where rains fall in the basin, so the estimated inflows are subject to judgement. However, the Kansas River flow gives insights into the wetness of these years.

Annual flow volume was calculated for the extended Kansas River at Lecompton and the extended Perry inflow data sets then the percent of Lecompton flow that comes from the Delaware River at Perry Dam was determined. The average was 10.7% but it ranged anywhere from 4.2% to 29.7% depending on the rain patterns for any given year. The annual flow volume of the local flow was also calculated. Some years the flow volume resulted in an annual negative flow. This came from comparing observed flow between gages, so the negative flow could be the result of water withdrawals from the river, seepage, or data errors. Because the gage record demonstrates that 1920-1922 were relatively low flow years at Topeka and DeSoto, the Perry inflow volume was estimated to be 5.5% of the extended Kansas River at Lecompton flow in 1920 and 8.5% in 1921 and 1922. The 1920 Lecompton flow volume and 5.5% are similar to 2003. The 1921 and 1922 Lecompton flow volumes and 8.5% are similar to 1990 and 2004.

Once the annual flow volume for Perry inflow was determined, the daily Lecompton flow was multiplied times a pair of high and low factors that were selected to result in the desired annual flow volume. Review of the gage data indicated that when Lecompton is high more flow tends to come from the Delaware River and when there are low flow conditions less flow is coming from the Delaware. The threshold between flow regime differs depending on the event, but higher flow contributions from the Delaware River tended to occur above 5000 cfs. Below this threshold, a greater contribution of the Kansas River at Lecompton flow tends to come from sources upstream of the Delaware River. Table 3-16 illustrates the flow thresholds and percentages applied. An "if statement" was used to determine if Lecompton flow was above the flow threshold, then the Lecompton flow was multiplied by the high flow percentage to get the Perry inflow. If Lecompton flow was below the flow threshold, then the Lecompton flow was multiplied by the low flow percentage to generate the Perry inflow values. These percentages were used to match the annual flow volume but are not indicative of accuracy during a specific event.

Table 3-16 Data used to extend the Perry inflow.

Year	Lecompton Flow Threshold (cfs)	Percent of Lecompton High Flow that Comes from Perry	Percent of Lecompton Low Flow that Comes from Perry
1919	5000	13.8%	1.38%
1920	5000	11.0%	1.10%
1921	5000	14.8%	1.48%
1922	5000	12.4%	1.10%

Table 3-17 summarizes the equations used to extend the Perry inflow. The extended Perry Lake inflow hydrograph is provided as Figure 3-18.

Table 3-17 Data used to extend the daiy Perry inflow.

Date Range	Equation Used	Comment
01Jan1919 to 31Dec1919	If LEKS>5000, PERY=0.138*LEKS If LEKS<5000, PERY=0.02*LEKS	Based on extended Lecompton (LEKS) flow.
01Jan1920 to 31Dec1920	If LEKS>5000, PERY=0.11*LEKS If LEKS<5000, PERY=0.011*LEKS	Based on extended Lecompton (LEKS) flow.
01Jan1921 to 31Dec1921	If LEKS>5000, PERY=0.148*LEKS If LEKS<5000, PERY=0.0148*LEKS	Based on extended Lecompton (LEKS) flow.
01Jan1922 to 15Jun1922	If LEKS>5000, PERY=0.124*LEKS If LEKS<5000, PERY=0.011*LEKS	Based on extended Lecompton (LEKS) flow.
16Jun1922 to 30Jul1966	PERY=1.26*Valley Falls+129.4	Based on linear regression between Perry and Valley Falls
31Jul1966 to 31Dec2019		Observed Perry Inflow

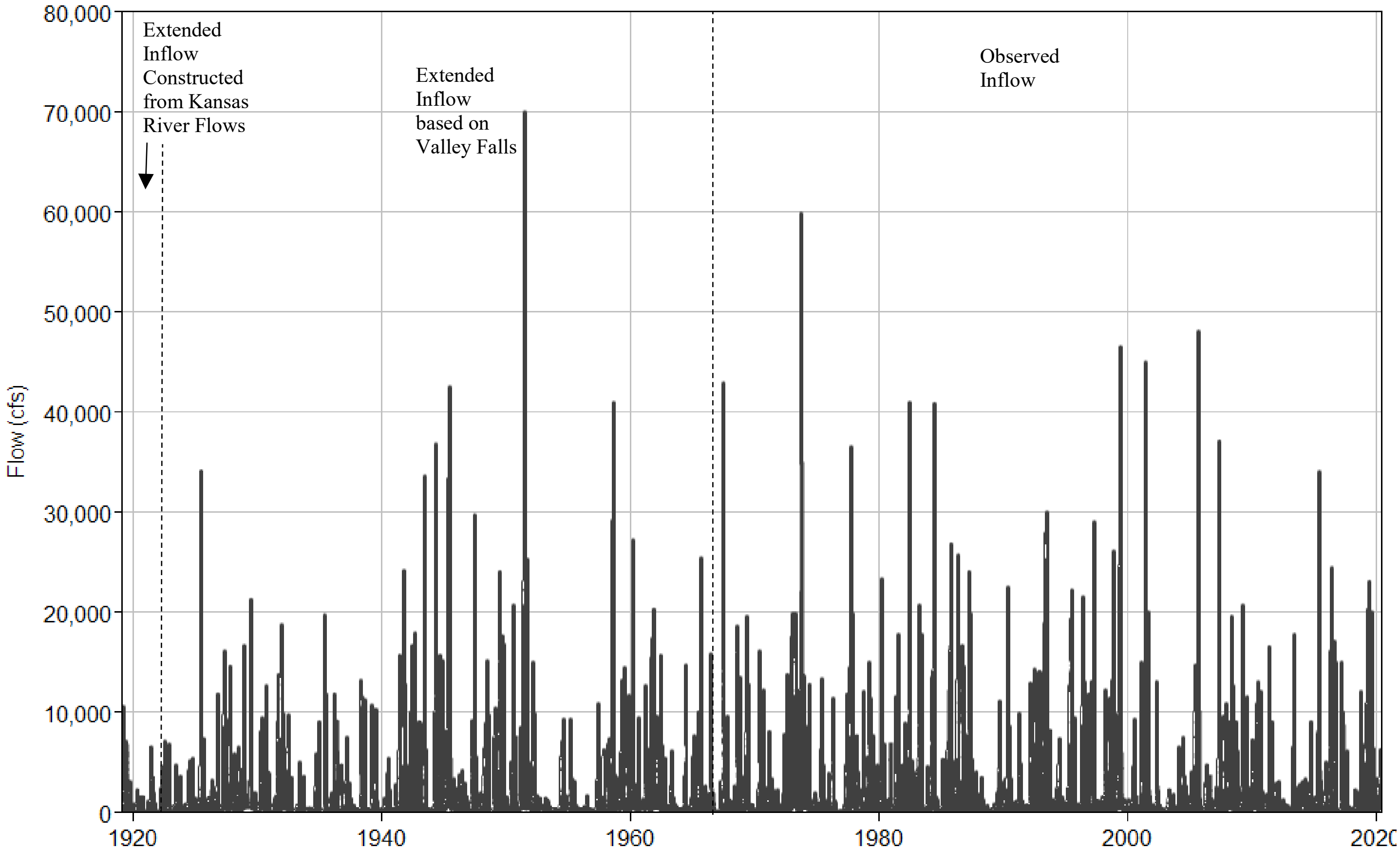


Figure 3-18 Perry Lake extended daily inflow record.

3.1.7 Clinton Lake

Clinton Dam, which is located at river mile 22.2 of the Wakarusa River, controls about 367 square miles of drainage area. The dam closure occurred 23 Aug 1975 and the dam started impounding water on 30 Nov 1977. The lake first filled to multipurpose level on 03 Apr 1980. Table 3-18 shows the available gage information. The Richland gage is upstream of Clinton Dam and represents a little less than half the drainage area. The Lawrence gage is located approximately six miles downstream of the dam on the Wakarusa River, and provides down stream flow data and a historic record. The Richland gage was placed into service after the closure of the dam and is used as an inflow gage. The Lawrence gage has a very long record but is six miles downstream of the dam and includes 58 square miles of additional drainage area.

Table 3-18 Gages related to Clinton Dam.

Gage	**Drainage Area (mi^2)**	**Record**
Wakarusa River at Richland, KS	164	22Oct2002 to present
Wakarusa River at Clinton Dam	367	01Dec1977 to present
Wakarusa River near Lawrence, KS	425	27Apr1929 to present
Kansas River at Topeka, KS	56,720	12Jun1917 to present
Kansas River at Lecompton, KS	58,460	16Mar1936 to present
Kansas River at Desoto, KS	59,756	08Jul1917 to present

The observed Corps of Engineers reservoir stage, inflow, and outflow records extend from 01 Dec 1977 through the present. As the stored data is 1200 UTC of the day before to 1200 UTC of the current day, the values have been shifted back 12 hours to make them representative of midnight-to-midnight flows. With the time shift, the observed inflow is used from 30 Nov 1977 through the end of the study period.

The daily flows values for the Lawrence gage were taken from the USGS database and represent mean daily flows. The percentage of the Lawrence gage watershed controlled by Clinton Lake is:

$$367 \text{ mi}^2 / 425 \text{ mi}^2 = 86.4\%$$

From the start of the Clinton outflow record, a comparison can be made between the regulated releases and the Wakarusa River at Lawrence gage data. While this is all a regulated data set, it provides insight into the relationship between the gages and how much flow comes in below the dam and the gage. The gages' relationship is provided in Figure 3-19. This relationship was used to extend the Clinton inflow from 27 Apr 1929 to the start of the inflow record. No time shift was conducted on the gage data as travel time from Clinton Dam to the Lawrence gage is approximately 6 hours. The regression equation indicates that about 83% of the Lawrence flow comes from Clinton. The other 17% comes from below the dam which is very similar to the watershed area. This relationship was compared to the annual flow volume at each gage from 1978 through 2019 and similar results were found. The Clinton outflow ranged from 78% to 128% of the Lawrence flow with an average of 93%.

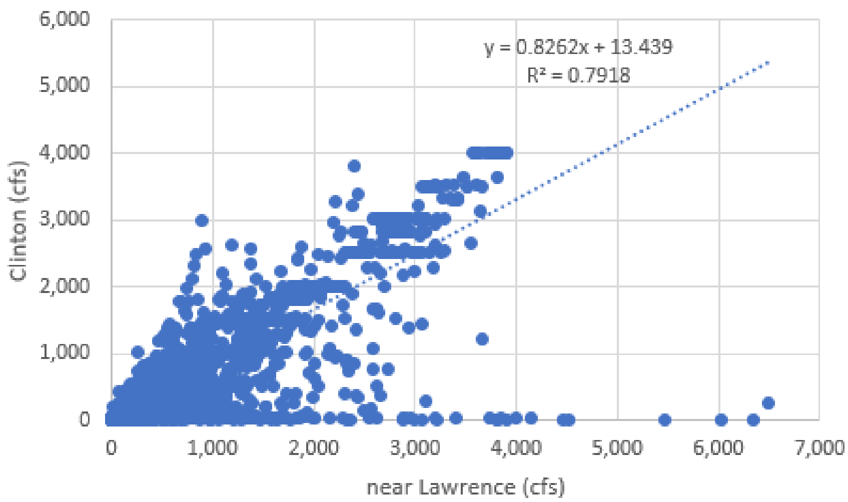


Figure 3-19 Relationship between Clinton daily outflow and regulated Lawrence daily observed flow data.

For the period before the Wakarusa River at Lawrence gage came into existence, the Clinton inflow record was estimated by looking at the Kansas River flow, in a process analogous to how Perry's inflows were extended. This was to provide inflow data for 1919 (used as lookback in the model) and 1920 through April 1929. The Kansas River at Lecompton data record was extended as detailed in Section 3 by using the relationship between the Topeka and Desoto data. The Wakarusa River is the largest tributary between Lecompton and Desoto although it is similar in size with Stranger Creek. A relationship with the Clinton inflow was developed based on the annual flow volume of the Desoto flow record. There is a lot of variability of where rains fall in the basin, so the estimated inflows are subject to judgement. However, the Kansas River flow gives insights into the wetness of these years.

Annual flow volume was calculated for the Kansas River at Desoto and the previously extended Clinton inflow (from April 1929 through 2019) data sets. The percent of Desoto flow that comes from the Wakarusa River at Clinton Dam was then determined. The average was 2.79% but it ranged anywhere from 0.5% to 7.2% depending on the rain patterns for any given year. The annual flow volume of the local flow was also calculated. The annual flow volume at Desoto was average to below average for 1919-1929 except for 1927 which was above average by a little. However, the calculated local flow was above average for 1921, 1922, 1925, and 1927. Because of this, it was assumed that 4% of the Desoto flows came from the Wakarusa during those years. Local flow was low in 1920, 1923, and 1928, so it was assumed that 1% of the Desoto flows came from the Wakarusa those years. The other four years used the long-term average of 2.79% of the Desoto flows coming from the Wakarusa.

Once the annual flow volume for Clinton inflow was determined, the daily Desoto flow was multiplied times a pair of high and low factors that were selected to result in the desired annual flow volume. Review of the gage data indicated that when Desoto is high more flow tends to come from the Wakarusa River and when there are low flow conditions less flow is coming from the Wakarusa. The threshold between flow regime differs depending on the event, but higher flow conditions tended to occur above 7500 cfs. Table 3-19 identifies the flow thresholds and percentages used. As can be seen, the percentage changes quite a bit per year depending on the type of flow year. An "if statement" was used to determine if Desoto flow was above the flow threshold, then the Desoto flow was multiplied by the high flow percentage to get the Clinton inflow. If Desoto flow was below the flow threshold, then the Desoto flow was multiplied by the low flow percentage to generate the Clinton inflow values. These percentages were used to match the annual flow volume but are not indicative of accuracy during a specific event.

Table 3-19 Data used to extend the Clinton inflow.

Year	High Flow Threshold (cfs)	Percent of Desoto High Flow that Comes from Clinton	Percent of Desoto Low Flow that Comes from Clinton
1919	7500	3.90%	0.37%
1920	7500	3.30%	0.29%
1921	7500	7.50%	1.19%
1922	7500	7.26%	1.00%
1923	7500	1.49%	0.09%
1924	7500	7.91%	1.65%
1925	7500	8.20%	1.59%
1926	7500	6.14%	0.70%
1927	7500	4.92%	0.50%
1928	7500	1.68%	0.05%
1929	7500	4.40%	0.39%

Table 3-20 summarizes the equations used to extend the Clinton inflow. The extended Clinton Lake inflow hydrograph is provided as Figure 3-20.

Table 3-20 Data used to extend the daily Clinton inflow record.

Date Range	Equation Used	Comment
01Jan1919 to 31Dec1919	If DESO>7500, CLIN=0.039*DESO If DESO<7500, CLIN=0.0037*DESO	Based on observed Desoto (DESO) flow.
01Jan1920 to 31Dec1920	If DESO>7500, CLIN=0.033*DESO If DESO<7500, CLIN=0.0029*DESO	Based on observed Desoto (DESO) flow.
01Jan1921 to 31Dec1921	If DESO>7500, CLIN=0.075*DESO If DESO<7500, CLIN=0.0119*DESO	Based on observed Desoto (DESO) flow.
01Jan1922 to 31Dec1922	If DESO>7500, CLIN=0.0726*DESO If DESO<7500, CLIN=0.010*DESO	Based on observed Desoto (DESO) flow.
01Jan1923 to 31Dec1923	If DESO>7500, CLIN=0.0149*DESO If DESO<7500, CLIN=0.0009*DESO	Based on observed Desoto (DESO) flow.

01Jan1924 to 31Dec1924	If DESO>7500, CLIN=0.0791*DESO If DESO<7500, CLIN=0.0165*DESO	Based on observed Desoto (DESO) flow.
01Jan1925 to 31Dec1925	If DESO>7500, CLIN=0.082*DESO If DESO<7500, CLIN=0.0159*DESO	Based on observed Desoto (DESO) flow.
01Jan1926 to 31Dec1926	If DESO>7500, CLIN=0.0614*DESO If DESO<7500, CLIN=0.007*DESO	Based on observed Desoto (DESO) flow.
01Jan1927 to 31Dec1927	If DESO>7500, CLIN=0.0492*DESO If DESO<7500, CLIN=0.005*DESO	Based on observed Desoto (DESO) flow.
01Jan1928 to 31Dec1928	If DESO>7500, CLIN=0.0168*DESO If DESO<7500, CLIN=0.0005*DESO	Based on observed Desoto (DESO) flow.
01Jan1929 to 26Apr1929	If DESO>7500, CLIN=0.044*DESO If DESO<7500, CLIN=0.0039*DESO	Based on observed Desoto (DESO) flow.
27Apr1929 to 29Nov1977	CLIN=0.826*Lawrence+13.441	Based on linear regression with Lawrence
30Nov1977 to 31Dec2019		Observed Clinton Inflow

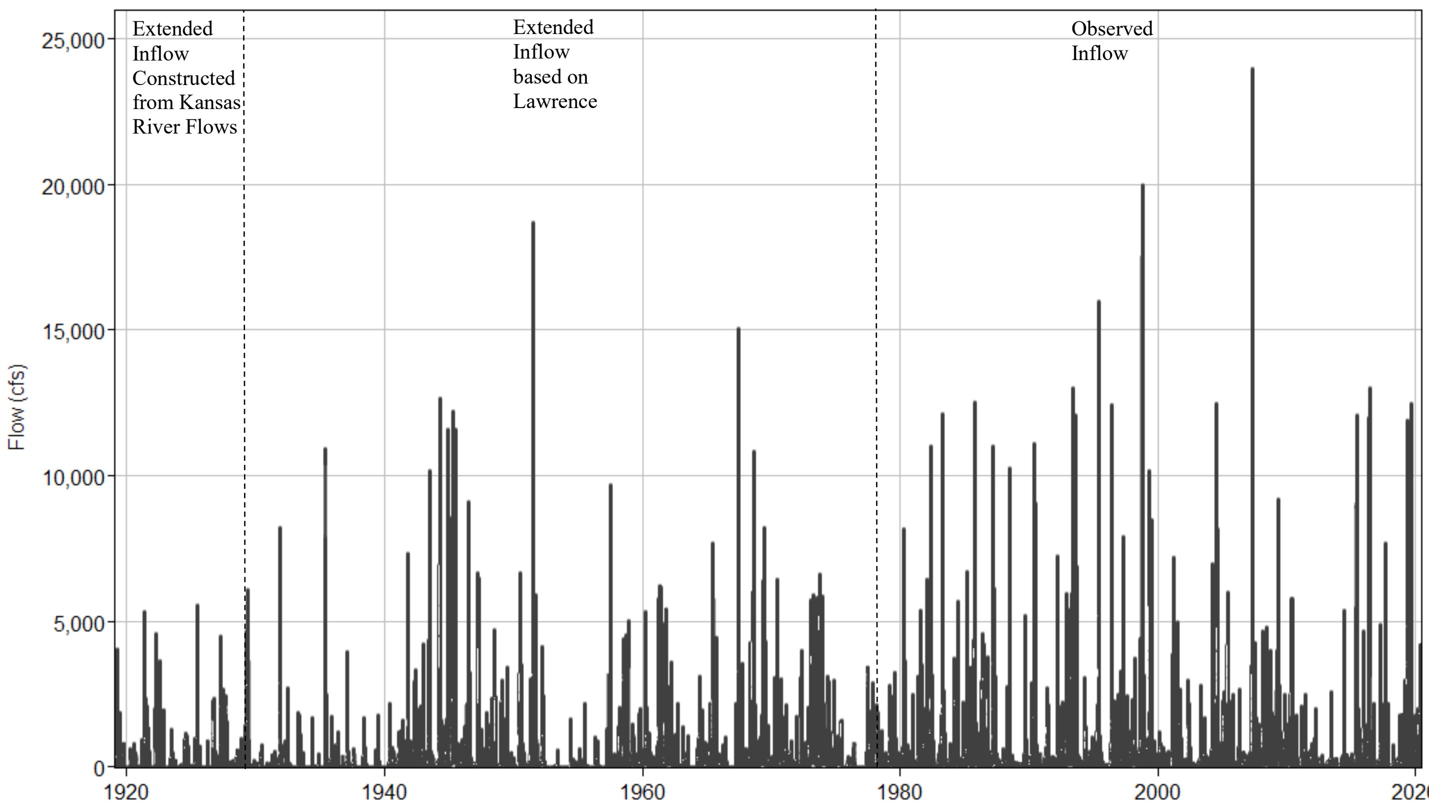


Figure 3-20 Clinton Lake extended daily inflow record.

3.2 Gage Data Extension

The HEC-ResSim model requires inputs at the reservoir inflow locations and some tributaries. In addition, several gages are set up to receive local flows which enter the river at a given stream gage location and model junction. The local flows are all input at the downstream gage. Each of these flow locations required the full data set of 1920 to 2019 therefore it was best to pick gages that had long periods of record. The model input locations for flow are detailed in Table 3-21.

Table 3-21 HEC-ResSim flow locations requiring daily data input

River	Location	Parameter
Smoky Hill River	Kanopolis Dam	Inflow
Smoky Hill River	Lindsborg, KS	Local Flow
Smoky Hill River	Mentor, KS	Local Flow
Saline River	Wilson Dam	Inflow
Saline River	Tescott, KS	Local Flow
Smoky Hill River	New Cambria, KS	Local Flow
Solomon River	Waconda Dam	Inflow
Solomon River	Beloit, KS	Local Flow
Salt Creek	Ada, KS*	Flow
Solomon River	Niles, KS	Local Flow
Smoky Hill River	Enterprise, KS	Local Flow
Chapman Creek	Chapman, KS*	Flow
Republican River	Clay Center, KS	Flow
Republican River	Milford Dam	Local Flow
Kansas River	Fort Riley, KS	Local Flow
Big Blue River	Tuttle Creek Dam	Inflow
Kansas River	Wamego, KS	Local Flow
Vermillion Creek	Wamego, KS*	Flow
Mill Creek	Paxico, KS*	Flow
Kansas River	Topeka, KS	Local Flow
Soldier Creek	Topeka, KS*	Flow
Delaware River	Perry Dam	Inflow
Kansas River	Lecompton, KS	Local Flow
Wakarusa River	Clinton Dam	Inflow
Wakarusa River	Lawrence, KS	Local Flow
Stranger Creek	Tonganoxie, KS*	Flow
Kansas River	Desoto, KS	Local Flow
Missouri River	Saint Joseph, MO	Flow
Platte River	Sharps Station*	Flow
Missouri River	Kansas City, MO	Local Flow
Blue River	Kansas City, MO*	Flow
Little Blue River	Lake City, MO*	Flow
Missouri River	Waverly, MO	Local Flow

*Tributary boundary condition locations used observed flow with no data extension. When observed gage data was unavailable, the tributary flow was set to zero and all flow from that tributary was incorporated into the local flow for its respective river reach.

3.2.1 Smoky Hill River at Lindsborg, KS

The Smoky Hill River at Lindsborg, KS data record was filled in using a combination of Ellsworth, Langley and Mentor observed flows. Table 3-22 shows the various relationships used. Linear and multi-linear relationships were developed depending on the availability of data. The final method used for a given time period was based on the best R^2 value and the availability of data. Figure 3-21 shows the relationship between Lindsborg and Ellsworth. Figure 3-22 shows the relationship between Lindsborg and Mentor. Figure 3-23 shows the multi-linear relationship between Lindsborg, Langley, and Mentor. Some small differences exist between the equations in the table and those in excel. The equations in the table were developed in DSS and used for the data extension. The equations shown in the plots that were developed in Excel to graphically show the relationship. DSS and Excel may have slightly different methods of optimizing the best fit curve.

Table 3-22 Data relationships used to extend the Smoky Hill River at Lindsborg daily data.

Date Range	Equation Used	Comment
01Jan1919 to 31July1919		Lindsborg observed flow
01Aug1919 to 29Feb1920	Lindsborg = 0.71*Ellsworth(shifted) + 100.22	Linear relationship with Ellsworth shifted forward two days
01Mar1920 to 30Sep1920		Lindsborg observed flow
01Oct1920 to 28Feb1921	Lindsborg = 0.71*Ellsworth(shifted) + 100.22	Linear relationship with Ellsworth shifted forward two days
01Mar1921 to 30Sep1921		Lindsborg observed flow
01Oct1921 to 28Feb1922	Lindsborg = 0.71*Ellsworth(shifted) + 100.22	Linear relationship with Ellsworth shifted forward two days
01Mar1922 to 30Sep1922		Lindsborg observed flow
01Oct1922 to 28Feb1923	Lindsborg = 0.71*Ellsworth(shifted) + 100.22	Linear relationship with Ellsworth shifted forward two days
01Mar1923 to 29Sep1923		Lindsborg observed flow
30Sep1923 to 30Nov1923	Lindsborg = 0.71*Ellsworth(shifted) + 100.22	Linear relationship with Ellsworth shifted forward two days
01Dec1923 to 31July1930	Lindsborg = 0.911*Mentor + 16.053	Linear relationship with Mentor
01Feb1930 to 29Sep1965		Lindsborg observed flow
29Sep1965 to 30Jul2014	Lindsborg = 0.41988*Langley + 0.59612*Mentor + 0.95137	Multi-linear relationship between Langley and Mentor
30Jul2014 to present		Lindsborg observed flow

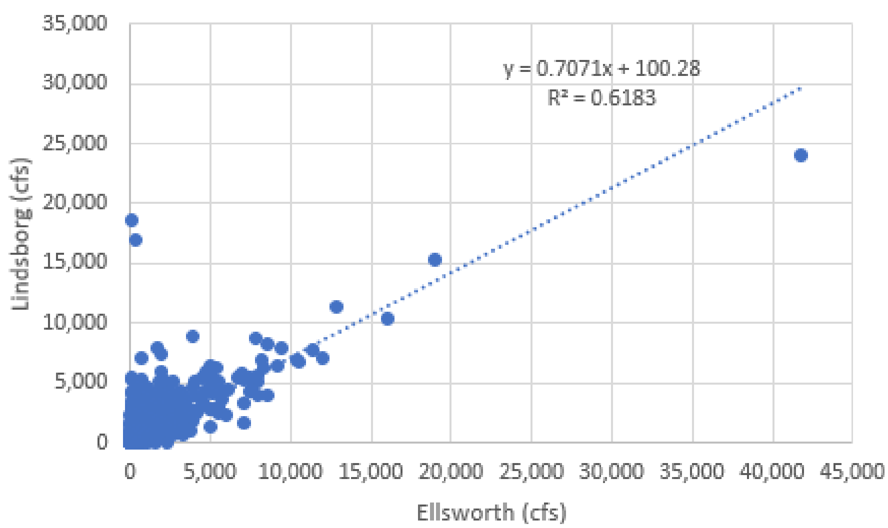


Figure 3-21 Linear relationship between Lindsborg and Ellsworth daily flow data.

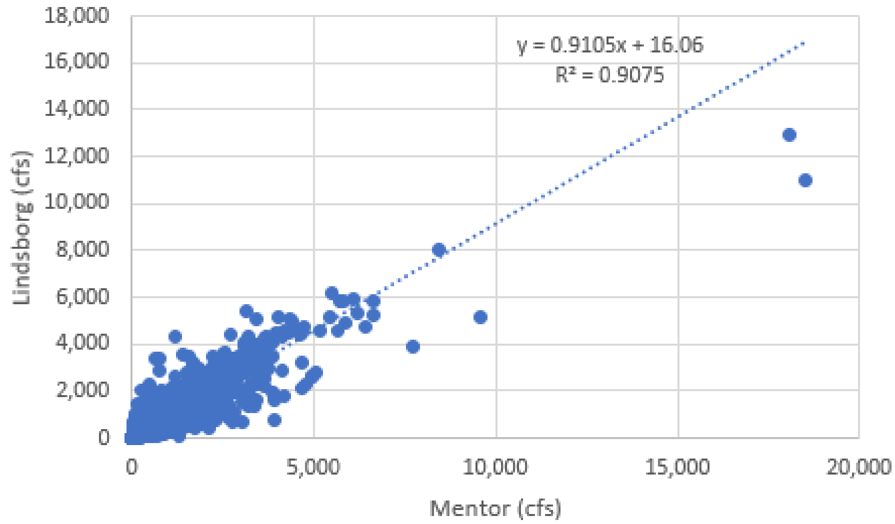


Figure 3-22 Linear relationship between Lindsborg and Mentor daily flow data.

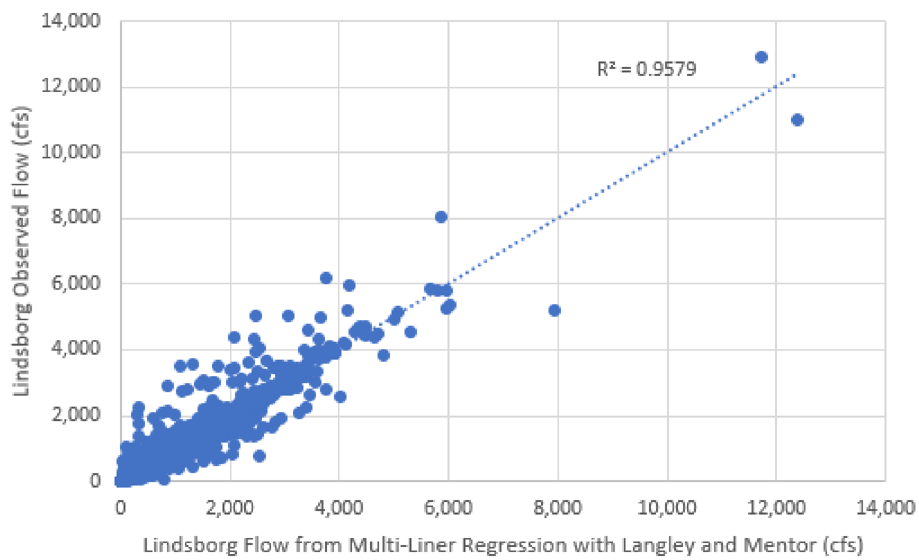


Figure 3-23 Multi-linear relationship between Lindsborg, Langley, and Mentor daily flow data.

3.2.2 Smoky Hill River at Mentor

The Smoky Hill River at Mentor has data from Dec 1923 to Oct 1930, May 1931 to June 1932, and Oct 1947 to present. To fill in the missing data, a linear relationship was developed with the Lindsborg observed data. The linear relationship is Mentor = 0.997*Lindsborg + 23.097. Lindsborg was missing a few months of data prior to Dec 1923, and during that time the extended Lindsborg record was used rather than building a relationship between Ellsworth and Mentor. This simplifying assumption appears to be reasonable considering it is filling in a few months of data. Figure 3-24 shows the linear relationship between Mentor and Lindsborg.

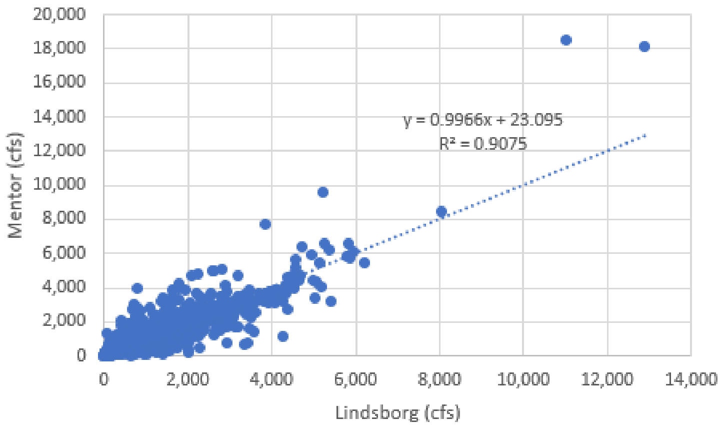


Figure 3-24 Linear relationship between Mentor and Lindsborg daily flow data.

3.2.3 Saline River at Tescott, KS

The Saline River at Tescott was used directly from the USGS since it covers the full modeling period. A little missing data from December 11-30, 1926 and January 5-29, 1927 was linearly interpolated.

3.2.4 Smoky Hill River at New Cambria, KS

The Smoky Hill River at New Cambria was extended using combinations of the Mentor, Tescott, and Enterprise gages. The historic Smoky Hill River at Solomon gage was also used to extend the Enterprise data as detailed below. Table 3-23 documents the final regression equation that was used for a given time period. The final method used was based on the best R^2 value and the availability of data. The relationship between New Cambria and Tescott is detailed in Figure 3-25. The relationship between New Cambria, Tescott, and Mentor is shown in Figure 3-26. The relationship between New Cambria, Tescott, and Enterprise is shown in Figure 3-27. The relationship between New Cambria and the Smoky Hill River at Enterprise/Solomon is shown in Figure 3-28. Finally, the relationship between New Cambria, Tescott, Enterprise and Mentor is shown in Figure 3-29.

Table 3-23 Data relationships used to extend the Smoky Hill River at New Cambria daily data.

Date Range	Equation Used	Comment
01Sep1919 to 29Sep1921	New Cambria = 0.458*Tescott + 0.378*Enterprise + 25.786	Multi-linear relationship between Tescott and Enterprise (extended using Solomon, KS)
30Sep1921 to 30Sep1922	New Cambria = 2.01*Tescott + 266.17	Linear relationship with Tescott
01Oct1922 to 30Nov1923	New Cambria = 0.458*Tescott + 0.378*Enterprise + 25.786	Multi-linear relationship between Tescott and Enterprise (extended using Solomon, KS)
01Dec1923 to 01Nov1930	New Cambria = 0.483*Tescott + 0.226*Enterprise + 0.750*Mentor - 25.869	Multi-linear relationship between Tescott, Enterprise (extended), and Mentor, due to missing data 11-30Dec1926 and 05-29Jan1927 were filled with linear interpolation
01Nov1930 to 21May1931	New Cambria = 0.458*Tescott + 0.378*Enterprise + 25.786	Multi-linear relationship between Tescott and Enterprise (extended using Solomon, KS), the three-part multi-linear equation was used for 17Feb and 09May1931 as data was available for those days
22May1931 to 30Jun1932	New Cambria = 0.483*Tescott + 0.226*Enterprise + 0.750*Mentor - 25.869	Multi-linear relationship between Tescott, Enterprise (extended), and Mentor

01Jul1932 to 31Dec1933	New Cambria = 0.4489*Enterprise	Linear relationship with Enterprise (extended using Solomon, KS)
01Jan1934 to 30Sep1947	New Cambria = 0.458*Tescott + 0.378*Enterprise + 25.786	Multi-linear relationship between Tescott and Enterprise (extended using Solomon, KS)
01Oct1947 to 30Nov1948	New Cambria = 0.483*Tescott + 0.226*Enterprise + 0.750*Mentor - 25.869	Multi-linear relationship between Tescott, Enterprise (extended), and Mentor
01Dec1948 to 29Sep1953		New Cambria observed data, the three-part multi-linear regression was use 7-15June1951, 22Jun-08Jul1951, 10-21July1951, 05-14Sep1951
29Sep1953 to 30Sep1962	New Cambria = 0.483*Tescott + 0.226*Enterprise + 0.750*Mentor - 25.869	Multi-linear relationship between Tescott, Enterprise (extended), and Mentor
01Oct1962 to 28Feb2007		New Cambria observed data
01Mar2007 to 29Nov2007	New Cambria = 0.483*Tescott + 0.226*Enterprise + 0.750*Mentor - 25.869	Multi-linear relationship between Tescott, Enterprise (extended), and Mentor
30Nov2007 to 29Sep2010		New Cambria observed data, the three-part multi-linear regression was use 29,30Jul2008, 26,27,29,30Apr and 01May2009, 12-14Aug2009, 17-19Aug2009,23Aug-18Sep2009,07Oct2009,05-08Jun2010
30Sep2010 to present	New Cambria = 0.483*Tescott + 0.226*Enterprise + 0.750*Mentor - 25.869	Multi-linear relationship between Tescott, Enterprise (extended), and Mentor

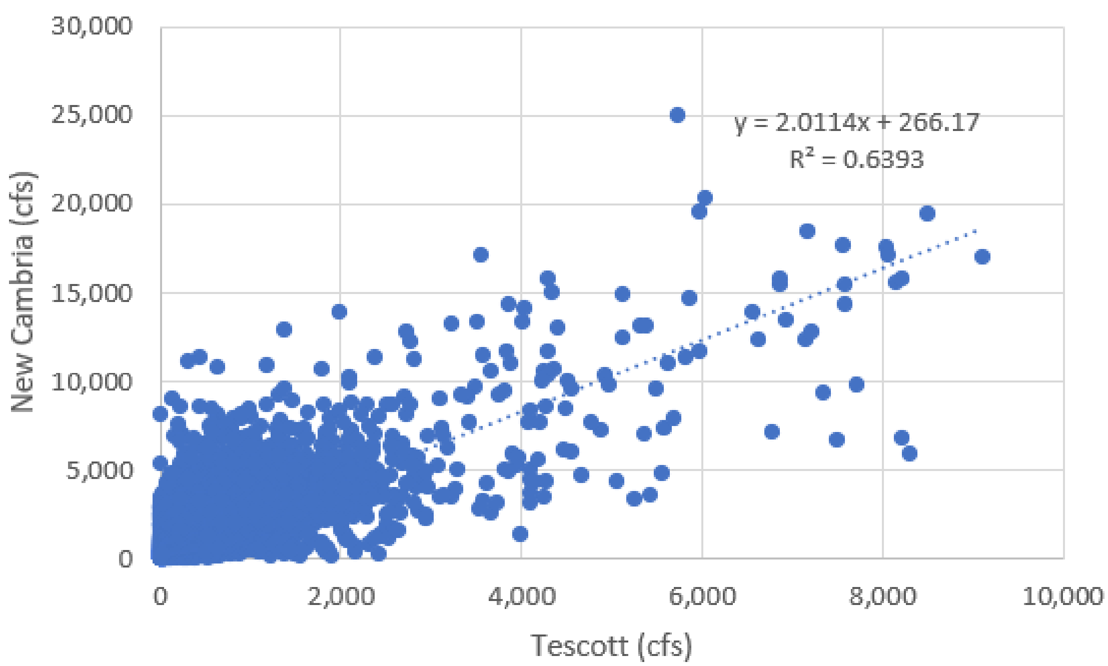


Figure 3-25 Linear relationship between New Cambria and Tescott daily flow data.

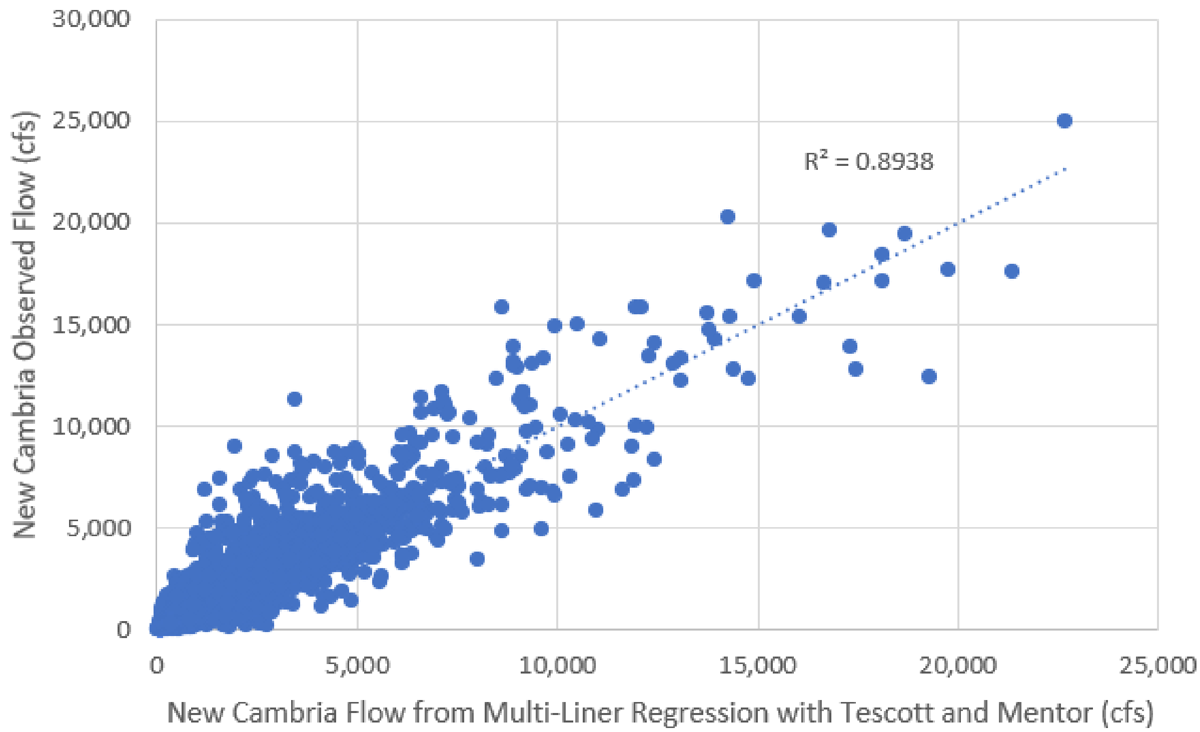


Figure 3-26 Multi-linear relationship between New Cambria, Tescott, and Mentor daily flow data.

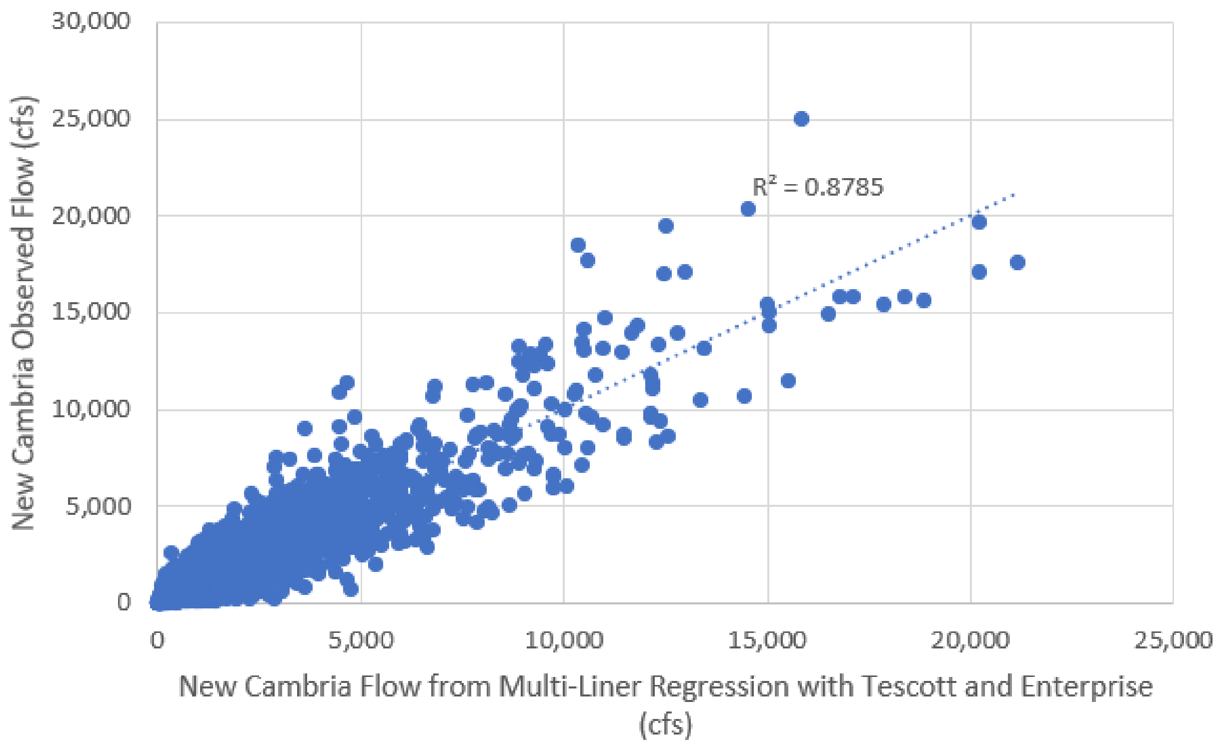


Figure 3-27 Multi-linear relationship between New Cambria, Tescott, and Enterprise daily flow data.

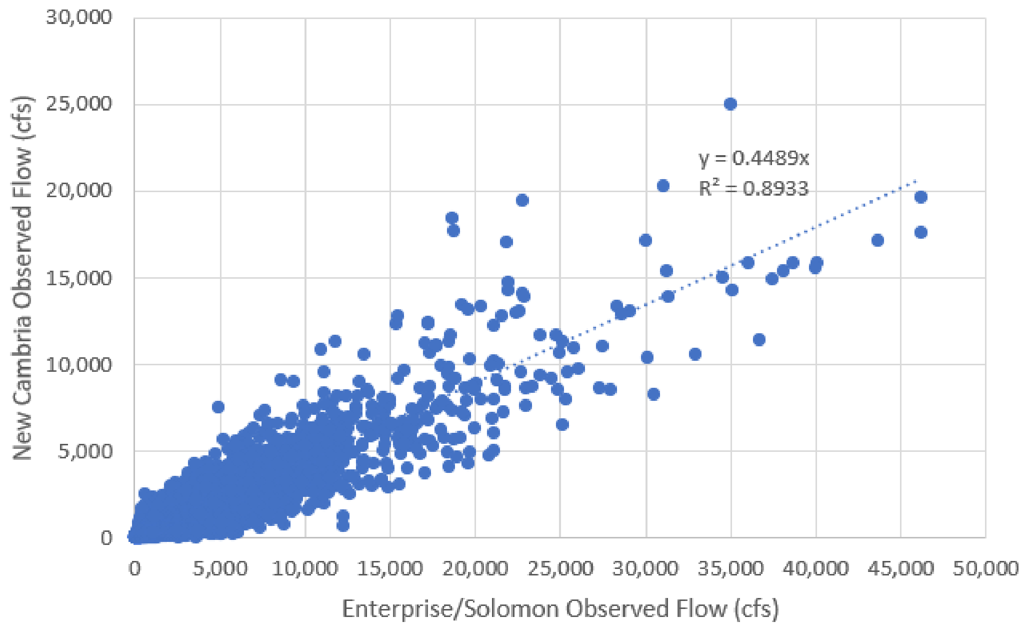


Figure 3-28 Linear relationship between New Cambria and Enterprise/Solomon daily flow data.

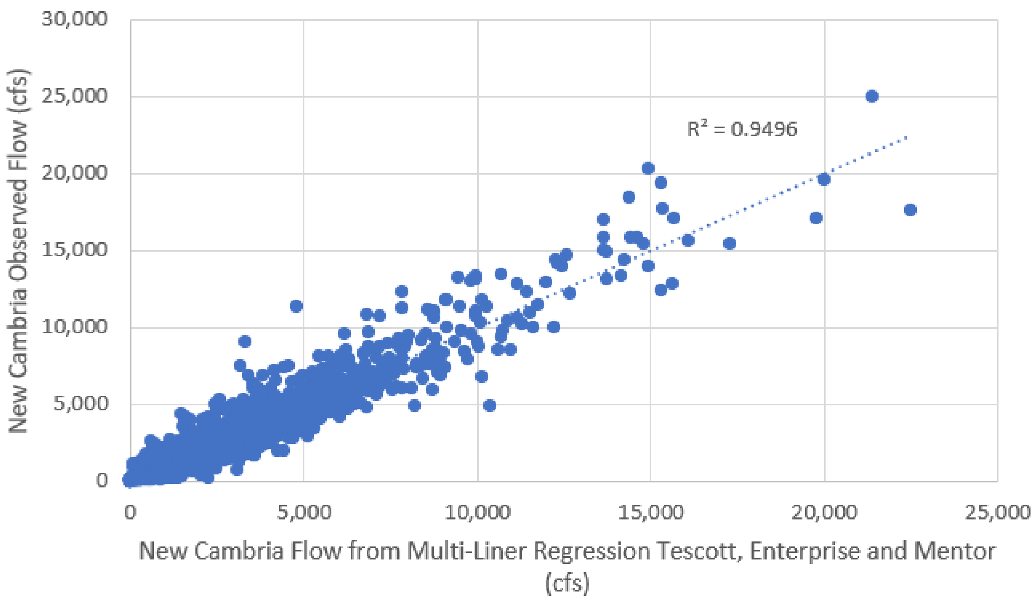


Figure 3-29 Multi-linear relationship between New Cambria, Tescott, Enterprise, and Mentor daily flow data.

3.2.5 Solomon River at Beloit, KS

The Solomon River at Beloit was extended before 1929 as part of the Waconda inflow extension process. That method is detailed in the Waconda inflow discussion in Section 3.1.3. For the regulated period from Oct 1966 to July 2012, Beloit data needed to be estimated as the gage was not operational during that time. The Solomon River at Simpson was in operation from September 1990 to September 2005; it is downstream of Beloit and has less than 100 mi^2 additional watershed. Beloit accounts for 98.2% of the Simpson contributing area. The Simpson data never overlapped Beloit so a regression could not be developed, but the Simpson data was multiplied by 0.982 and used as Beloit for the period extending from 01 Sep 1990 to 29 Sep 2005. The rest of the missing Beloit data was filled using a multi-linear relationship between Glen Elder and Niles. The relationship used was Beloit = 0.9857*Glen Elder + 0.0670*Niles -4.0981. Table 3-24 shows the gages that were used to extend the Beloit data both before and after the construction of Waconda. The regression relationship of the Glen Elder and Niles correlation is shown in Figure 3-30.

Table 3-24 Data relationships used to extend the Solomon River at Beloit daily data.

Date Range	Equation Used	Comment
01Sept1919 to 01July1925	Beloit=0.871*Kirwin+1.398*Alton +0.295*Niles+42.605	Based on multi-linear regression with Kirwin plus 1 day, Alton plus 1 day, and Niles minus 2 days
02July1925 to 12Aug1928	Beloit=0.648*Niles+12.365	Based on linear regression with Niles minus 1 day
13Aug1928 to 13Apr1929	Beloit=0.871*Kirwin+1.398*Alton +0.295*Niles+42.605	Based on multi-linear regression with Kirwin plus 1 day, Alton plus 1 day, and Niles minus 2 days
14Apr1929 to 29Sep1965		Observed Beloit data
30Sep1965 to 31Aug1990	Beloit = 0.9857*Glen Elder + 0.0670*Niles -4.0981	Based on multi-linear regression with Glen Elder and Niles
01Sep1990 to 29Sep2005	Beloit = 0.982*Simpson	Watershed area adjustment on the Simpson data
30Sep2005 to 16Jul2012	Beloit = 0.9857*Glen Elder + 0.0670*Niles -4.0981	Based on multi-linear regression with Glen Elder and Niles
17Jul2012 to Present		Observed Beloit data

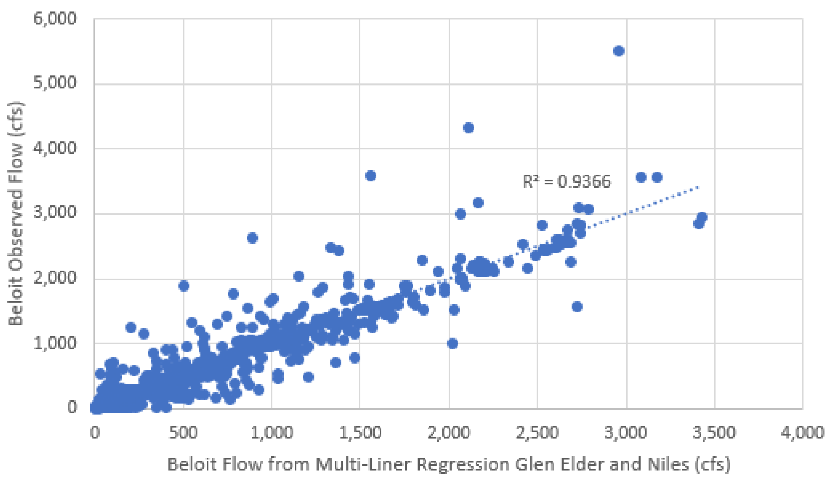


Figure 3-30 Multi-linear relationship between Beloit and Glen Elder and Niles daily flow data.

3.2.6 Salt Creek at Ada, KS

The Salt Creek at Ada data set starts in June 1959. Before that time flows were set to zero and the Salt Creek flow was included in the local flow calculation between Beloit and Niles.

3.2.7 Solomon River at Niles, KS

The Solomon River at Niles was used directly from the USGS since it covers the full modeling period. A little missing data from March 12 to April 15, 2014 was linear interpolated.

3.2.8 Smoky Hill River at Enterprise, KS

Smoky Hill River at Enterprise began collecting data on 01Oct1934. Prior to this time, data was extended using the historic record from USGS 06877000 Smoky Hill River at Solomon, KS. This gage has data from 01

October 1918 to 29 September 1934. This gage was near the mouth of the Solomon River. Using basin delineation in the Kansas CWMS HEC-HMS model it is estimated that 448 mi2 of watershed exists between the Solomon and Smoky Hill River confluence and the Enterprise gage. Approximately 97.7 percent of the Enterprise drainage area is accounted for by the Solomon gage. The Solomon data was multiplied by 1.023 to account for this small increase in watershed. Solomon is missing data from October 1921 to September 1922. To fill in this gap, a multi-linear regression was developed between upstream Niles and Tescott and downstream Kansas River at Ogden (near the current Fort Riley gage). This relationship provided a reasonable correlation as shown below. The regression equation is Enterprise = 0.301*Ogden + 0316*Tescott + 0.809*Niles -66.028. The multi-linear regression is shown below in Figure 3-31.

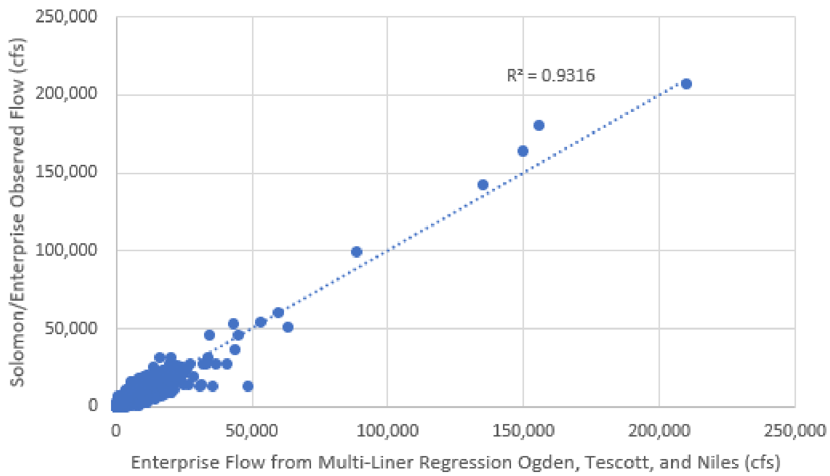


Figure 3-31 Multi-linear relationship between Enterprise and Ogden, Tescott, and Niles daily flow data.

3.2.9 Chapman Creek at Chapman, KS

The Chapman Creek at Chapman data set starts in December 1953. Before that time flows were set to zero and the Chapman Creek flow was included in the local flow calculation between Enterprise and Fort Riley.

3.2.10 Republican River at Clay Center

Republican River at Clay Center was used directly from the USGS since it covers the full modeling period.

3.2.11 Kansas River at Fort Riley

Kansas River at Fort Riley begins December 1963. From June 1917 to September 1951 data was collected at USGS 06879500 Kansas River at Ogden which is just downstream of the current Fort Riley gage. Fort Riley accounts for 99.2% of the Ogden watershed and Ogden was used as observed. There is a little missing data in the Ogden data set from Nov 1926 to Mar 1927 that needed to be estimated in addition to the gap between the two gage data sets. To fill these gaps a multi-linear relationship was developed utilizing the Republican River at Clay Center (upstream) and the Kansas River at Wamego (downstream). This relationship is Fort Riley = 0.47*Wamego + 0.42*Clay Center – 350.35. The R^2 is shown in Figure 3-32 below. For data gaps between Sept 1951 and Dec 1963, a multi-linear relationship was developed based on Enterprise and Clay Center. This relationship is Fort Riley = 0.55*Clay Center + 1.21*Enterprise + 158.37. The R^2 is shown in Figure 3-33 below.

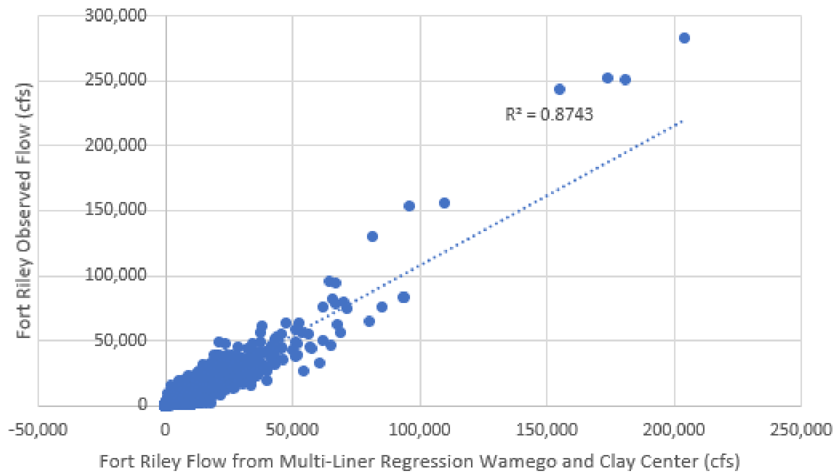


Figure 3-32 Multi-linear regression between Fort Riley and Wamego and Clay Center daily flow data.

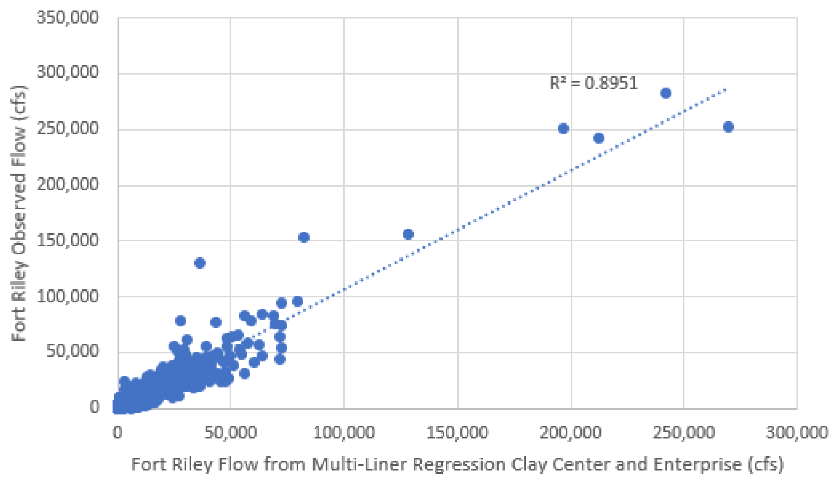


Figure 3-33 Multi-linear regression between Fort Riley and Clay Center and Enterprise daily flow data.

3.2.12 Kansas River at Wamego, KS

Kansas River at Wamego was used directly from the USGS since it covers the full modeling period.

3.2.13 Vermillion Creek at Wamego, KS

Vermillion Creek at Wamego has data from April 1936 through June 1946, January 1954 to June 1972, and February 2002 to current. Where there is missing data, flows were set to zero and the Vermillion Creek flow was included in the local flow calculation between Wamego and Topeka.

3.2.14 Mill Creek at Paxico, KS

Mill Creek at Paxico data set starts in December 1953. Before that time flows were set to zero and the Mill Creek flow was included in the local flow calculation between Wamego and Topeka.

3.2.15 Kansas River at Topeka, KS

Kansas River at Topeka was used directly from the USGS since it covers the full modeling period.

3.2.16 Soldier Creek at Topeka, KS

Soldier Creek at Topeka has data from May 1929 through September 1932 and July 1935 to current. Where there is missing data, flows were set to zero and the Soldier Creek flow was included in the local flow calculation between Topeka and Lecompton.

3.2.17 Kansas River at Lecompton, KS

Kansas River at Lecompton data record begins in March 1936. Before this time the data record was extend using a multi-linear relationship utilizing Topeka (upstream) and Desoto (downstream). This relationship is Lecompton = 0.3801*Desoto + 0.6723*Topeka – 9.3797. The R^2 is shown in Figure 3-34 below.

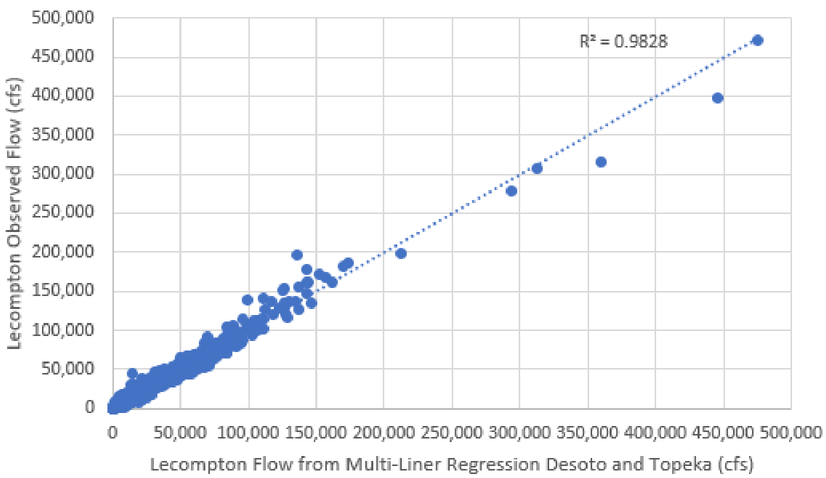


Figure 3-34 Multi-linear Regression between Lecompton and Desoto and Topeka daily flow data.

3.2.18 Stranger Creek at Tonganoxie, KS

Stranger Creek at Tonganoxie data set starts in April 1929. Before that time flows were set to zero and the Stranger Creek flow was included in the local flow calculation between Lecompton and Desoto.

3.2.19 Kansas River at Desoto, KS

Kansas River at Desoto was used directly from the USGS since it covers the full modeling period.

3.2.20 Missouri River at Saint Joseph, MO

HEC-ResSim was used to produce regulated Missouri River at Saint Joseph flows for the time period 31 Jan 1930 through Feb 2020. The HEC-ResSim model is developed and maintained by the Northwest Division Missouri River Basin Water Management office. The period of record data set was developed as part of the ongoing Missouri River Flow Frequency Study. Before 31 Jan 1930, data was extended using regulated flow data from the peer-reviewed Upper Mississippi River System Flow Frequency Study (UMRSFFS).

3.2.21 Platte River at Sharps Station, MO

Platte River at Sharps Station data starts in Dec 1978. Before this time, data was estimated using the Platte River at Agency and the Little Platte River at Smithville gages where available. If these gages were not available, flows were set to zero and the Platte River flow was included in the local flow calculation between St.

Joseph and Kansas City. Table 3-25 details the data used. Figure 3-35 show the multi-linear relationship between Sharps Station and the Platte River at Agency and the Little Platte River at Smithville. Figure 3-36 shows the linear relationship between Sharps Station and Agency.

Table 3-25 Data relationships used to extend the Platte River at Sharps Station daily data.

Date Range	Equation Used	Comment
01Jan1920 to 21May1924		Estimated based off local flow between St. Joseph and Kansas City
22May1924 to 10Aug1930	Sharps Station = 0.92*Agency + 665.9	Linear relationship with Agency
10Aug1930 to 12May1932		Estimated based off local flow between St. Joseph and Kansas City
13May1932 to 31May1965	Sharps Station = 0.92*Agency + 665.9	Linear relationship with Agency
01Jun1965 to 29Nov1978	Sharps Station = 1.11*Smithville + 0.90*Agency + 494.79	Multi-linear relationship between Agency and Smithville
01Dec1978 to present		Observed USGS Data

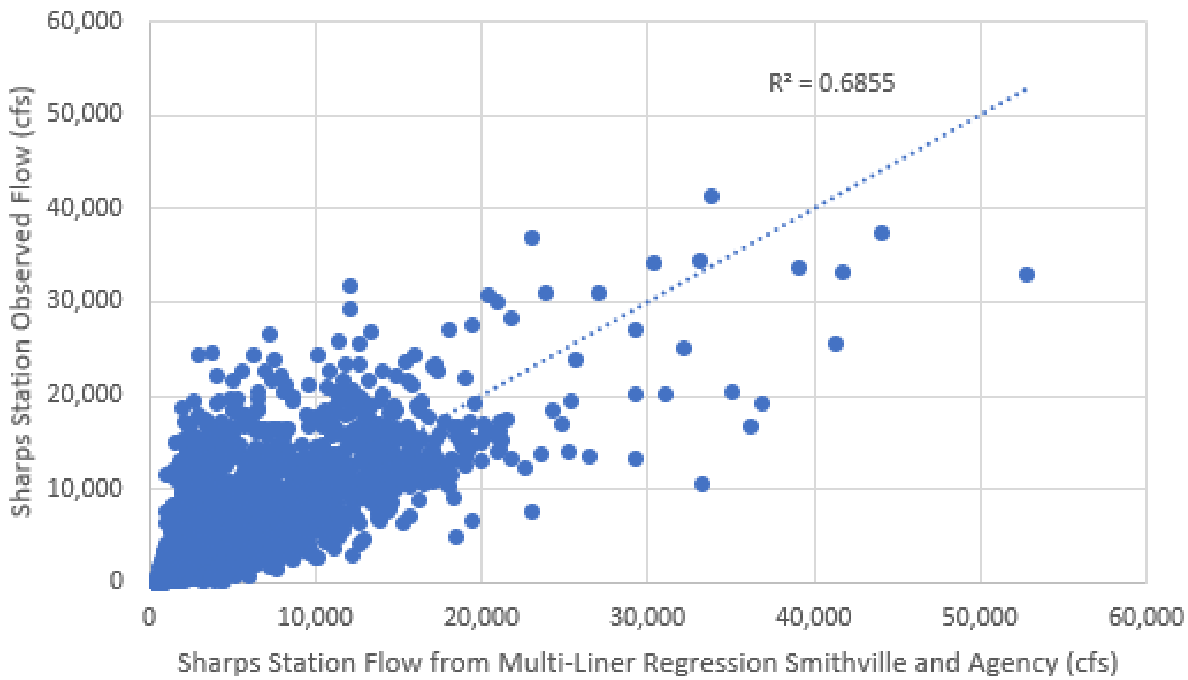


Figure 3-35. Multi-linear relationship between Sharps Station and Smithville and Agency daily flow data.

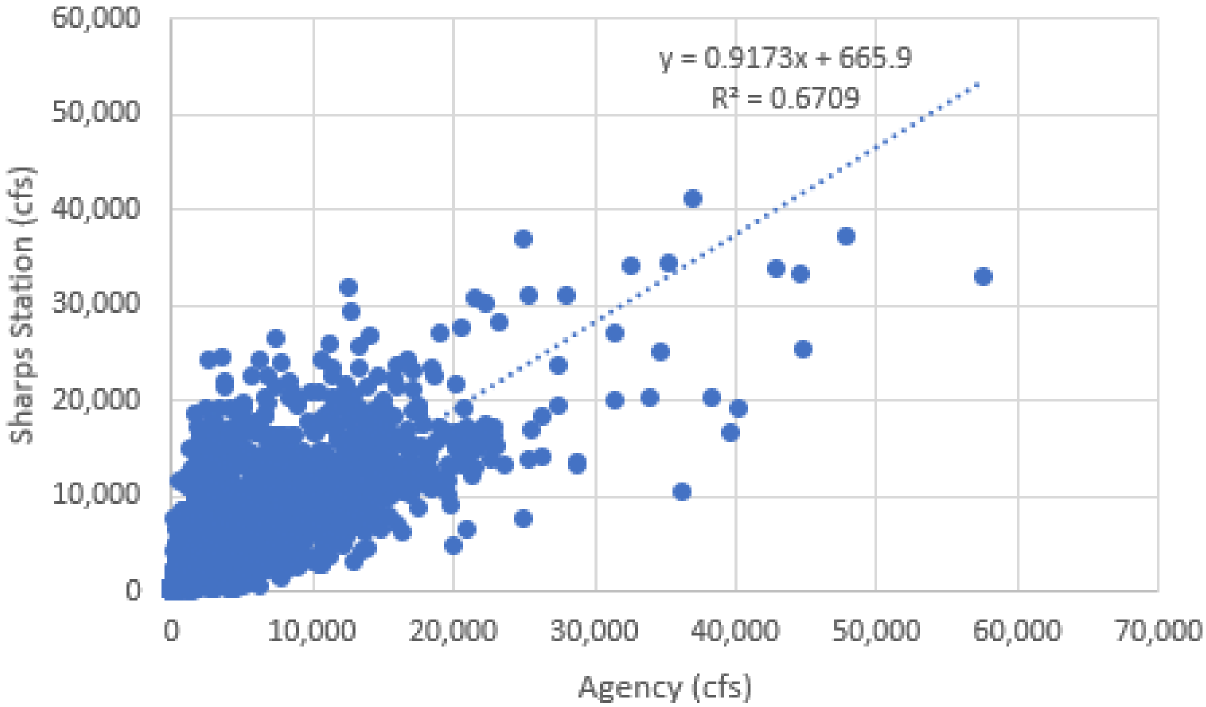


Figure 3-36 Linear Relationship between Sharps Station and Agency daily flow data.

3.2.22 Missouri River at Kansas City, MO

Missouri River at Kansas City data set starts in October 1928. Before this time, data was extended using the peer-reviewed data extension from the UMRSFFS.

3.2.23 Blue River at Kansas City, MO

Blue River at Kansas City data set starts in May1939. Before that time flows were set to zero and the Blue River flow was included in the local flow calculation between Kansas City and Waverly.

3.2.24 Little Blue River at Lake City, MO

Little Blue River at Lake City data set starts in April 1948. Before that time flows were set to zero and the Blue River flow was included in the local flow calculation between Kansas City and Waverly.

3.2.25 Missouri River at Waverly, MO

Missouri River at Waverly data set starts in October 1928. Before this time, data was extended using the peer-reviewed data extension from the UMRSFFS. There was also missing data from April 1977 to March 1978 that was filled in with UMRSFFS data.

3.3 Observed Flow and Pool Elevation

HEC-ResSim allows an alternative to be setup that utilizes observed flow in addition to all the necessary model data inputs. The observed flow is ancillary to the necessary model boundary condition data inputs. It is used for a comparison to the model output. It can be viewed in the model output plots or data files, but are not used for model computations. The KRRFSS model was set up with observed reservoir inflow, elevation, and outflow which was pulled directly from the CMWS database. Extended gage records were not utilized for the observed data since it is used for viewing purposes only. All stream-gage junctions were also setup with USGS observed flows when available.

3.4 Reservoir Evaporation

Reservoir evaporation was set up in the model as monthly total evaporation. The amounts varied by lake. The CWMS database has daily pan evaporation values that are provided by each lake project office. During the winter months, an estimated daily evaporation is used since the evaporation pans are not operational during freezing conditions. The monthly evaporation data in the model is calculated by accumulating the CWMS daily pan evaporation values over each month and then calculating each month's period of record average. The pan evaporation was not corrected for the open water body of a reservoir so it may be over-estimating evaporation especially during the warmer months. Any error from the adjustment factor should only have minor impacts on the HEC-ResSim results. Monthly evaporation used in in the model is shown in Table 3-26.

Table 3-26 Monthly evaporation values for each reservoir.

Month	Kanopolis Evap (inches)	Wilson Evap (inches)	Waconda Evap (inches)	Milford Evap (inches)	Tuttle Creek Evap (inches)	Perry Evap (inches)	Clinton Evap (inches)
January	1.42	1.40	1.16	1.14	1.01	1.40	1.16
February	1.54	1.53	1.38	1.35	1.30	1.53	1.35
March	1.58	2.57	2.37	2.24	2.16	2.57	2.04
April	6.24	6.13	6.00	5.99	5.74	6.13	6.15
May	7.21	7.54	7.38	7.39	6.65	7.54	6.92
June	9.07	9.40	9.61	8.89	8.04	9.40	8.24
July	11.21	11.32	11.52	10.71	9.36	11.32	9.42
August	9.45	9.64	9.59	9.27	8.09	9.64	8.17
September	7.43	7.46	7.53	7.28	6.19	7.46	6.70
October	5.03	4.92	4.97	5.21	4.14	4.92	4.51
November	2.80	2.80	2.70	2.65	2.55	2.80	2.50
December	1.47	1.49	1.35	1.27	1.21	1.49	1.15

3.5 Depletions

River depletions can have a large impact on the hydrology of the Kansas River basin especially for low flow conditions. The USBR conducted modeling for historic depletions over the period 31Jan1929 to 31Dec2017 for the Missouri River basin using weather, census, and land use data to model depletions from reservoir operation (evaporation), agriculture, industrial supply, public supply, and trans basin diversion. Depletions are calculated as monthly acre-feet in a Hydrologic Accounting Unit (HUC) 8-digit watershed. The USBR model does not consider water availability in their model which produces results of some unreasonably large depletions during drought years when they would have been restricted due to insufficient flows. The total depletions were provided for historic, present, and present incremental levels. This study utilized the present incremental data set since the historic depletion is already manifest in the observed data. Utilizing the present incremental data set results in the model accounting for all the depletions at the current level for the entire forecast period.

The modeled depletions were further processed by Missouri River Basin Water Management (MRBWM) to accumulate the full depletion contributing to a reservoir or gage location. The HUC8s were added, and the monthly acre-feet were converted to daily cubic feet per second. A 15-day running average was used to smooth flows between months. If a partial HUC8 contributed to a gage or reservoir, a percent of the HUC depletion was calculated based on the watershed area that contributed. The data was also extended from 31Dec2017 to Jan 2020. For the present incremental data, the most recent depletion was generally zero, so zero depletion was continued for the most recent years after 2017.

NWK further processed the depletion data as some of the large depletions were causing extended periods of negative inflows or river flows. The negative flows probably took place because of lack of water to supply the modeled depletion. A script was set-up to process the data. First, the script extended the depletions to start in 1919. The average daily depletion from 31Jan1929 to 01Jan1940 was used to extend the dataset back to 1919. This average was used without regard to weather or land use data. After the data was extended, the 5th percentile flow was calculated to use as minimum threshold. If the inflow or gage flow added to the depletion was less than the 5th percentile then the depletion was adjusted so the final sum would match the threshold. If the inflow or gage flow was lower than the 5th percentile before adding depletions, the depletion was set to zero.

The processed depletion data set was added as a local flow time series in the ResSim junction. Using the processed depletion data resulted in reasonable model results that account for present level depletions throughout the full period of record.

3.6 Navigation Flows

The HEC-ResSim model is set up with a rule to provide navigation flows from Milford, Tuttle Creek, and Perry, if necessary, to support Missouri River navigation. Because navigation support is provided on an ad-hoc basis, simulations were set up with and without navigation to help quantify the impact that navigation releases may or may not have on the water levels in the basin. Navigation releases can target a flow of 4,000 cfs or less at the Kansas River at Desoto, KS. The Missouri River Master Manual specifies flow for several navigation targets including the Missouri River at Kansas City, MO which is the only target that is impacted by the Kansas River flows. The Kansas City navigation season is officially from March 28 to Nov 27 during a typical year and flows can range from the full service 41,000 cfs to the minimum service 35,000 cfs. The navigation season can be shortened by one or two months based on the July 1 system storage check for the Missouri River reservoir system storage. Missouri River Basin Water Management can call for Kansas River navigation flow support whenever necessary. However, the main use of the Kansas River navigation storage is in dry years simply to balance overall regional system storage. Other times, it becomes necessary during the nesting season of endangered species of birds that take up residence either on the shores of the mainstem reservoirs above Gavins Point, South Dakota or on the banks of the Missouri River below Gavins Point. Either circumstance prevents necessary release increases from Gavins Point.

Tuttle Creek is the only Kansas Basin reservoir allocated with specific navigation storage. It has 72,000 acre-feet allocated for navigation, water quality and other purposes. Future use water supply storage at Milford and Perry can also be utilized for navigation until all this storage is called into service by the State of Kansas. This storage is 198,350 acre-feet at Milford and 125,000 acre-feet at Perry. These storage amounts are limited and 4,000 cfs can deplete available storage in a few weeks. Navigation support is provided in a stepped approach where storage above one threshold can be utilized before October 1 and more storage can be utilized from October 1 until the end of the navigation season. These thresholds are elevation 1072 ft NGVD29 before Oct 1 and 1069 feet NGVD29 after Oct 1 at Tuttle Creek, 1141.4 ft NGVD29 before Oct 1 and 1138.4 after Oct 1 at Milford, and 888.5 feet NGVD29 before Oct 1 and 885.5 feet NGVD29 after Oct 1 at Perry.

To handle the nuances of Kansas River navigation flows, an “if block” was setup to specify the navigation flows to be available during the navigation season and for the correct pool elevations. Also, the if-block checks if the Missouri River at Kansas City drops below the navigation flow target which was derived from a timeseries that was developed by MRBWM for 1930 through 2020. This time series was provided as a time series of Missouri River service level; if the navigation season has ended or if navigation is not being provided for a given year, the service level is set to missing. There were three years that did not have navigation support flows. This time series was modified to be the Missouri River at Kansas City navigation flow target by adding 6,000 cfs to the service level and non-navigation dates were set to zero. The timeseries was extended for the 1920s by assuming full service of 41,000 cfs for the full navigation season. The Tuttle Creek if-block is shown as an example in Figure 3-37. An "else if statement" provides the alternate reservoir elevation that can be utilized after Oct 1. Figure 3-38 shows the Tuttle Creek "else if statement". The Milford and Perry if and else if statements are identical except the elevations represent each lake's elevation thresholds. If all conditions in the if or else if statements are met, the navigation release rule is utilized. The navigation release rule is a downstream control rule that specifies a minimum flow of 4000 cfs at the Kansas River at Desoto. Figure 3-39 shows the navigation release rule. This rule is identical for all three reservoirs. All three lakes work together to provide this flow support. HEC-ResSim balances the releases using the established system storage balance.

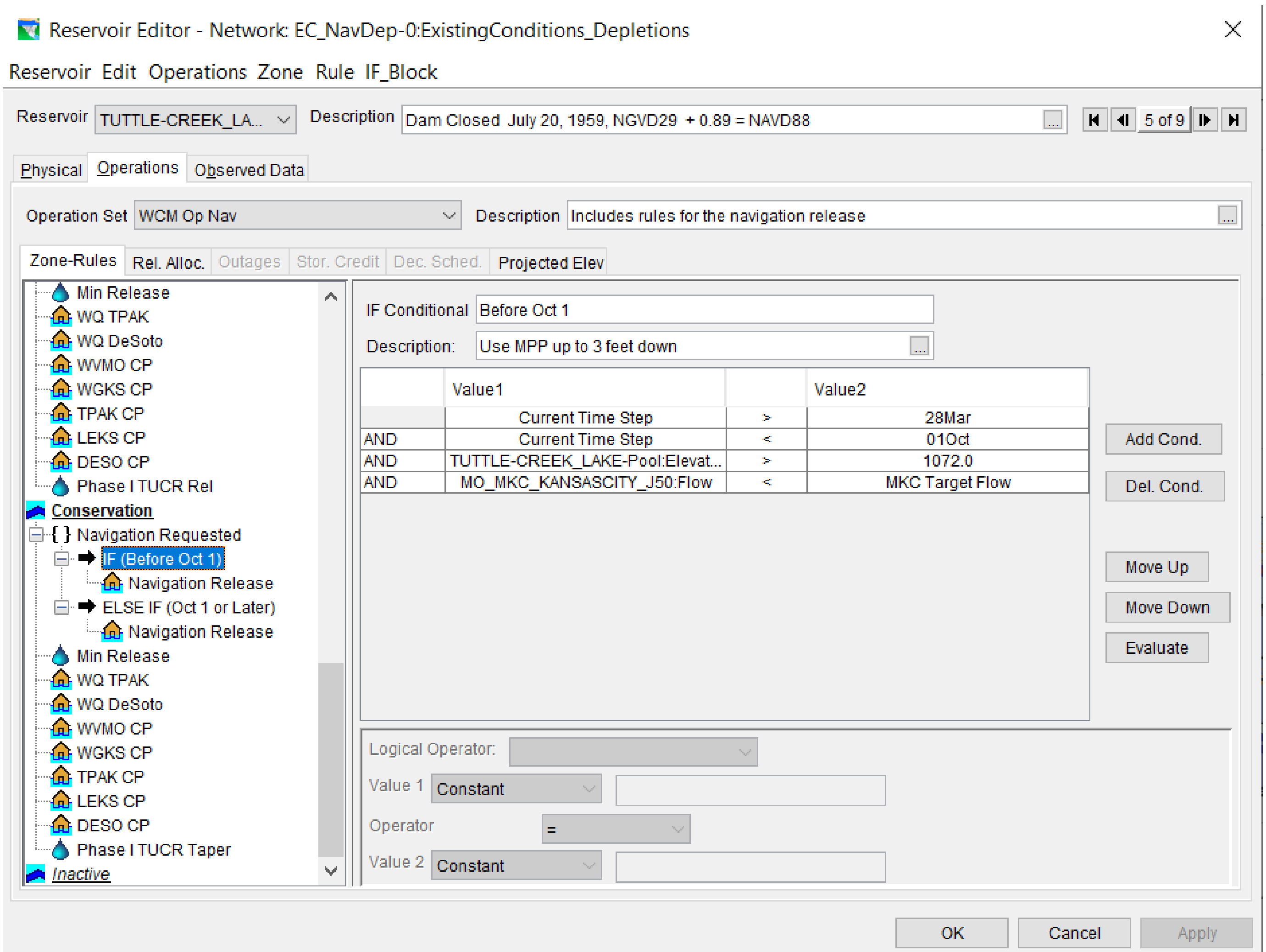


Figure 3-37. Tuttle Creek Navigation "if-statement" for navigation releases.

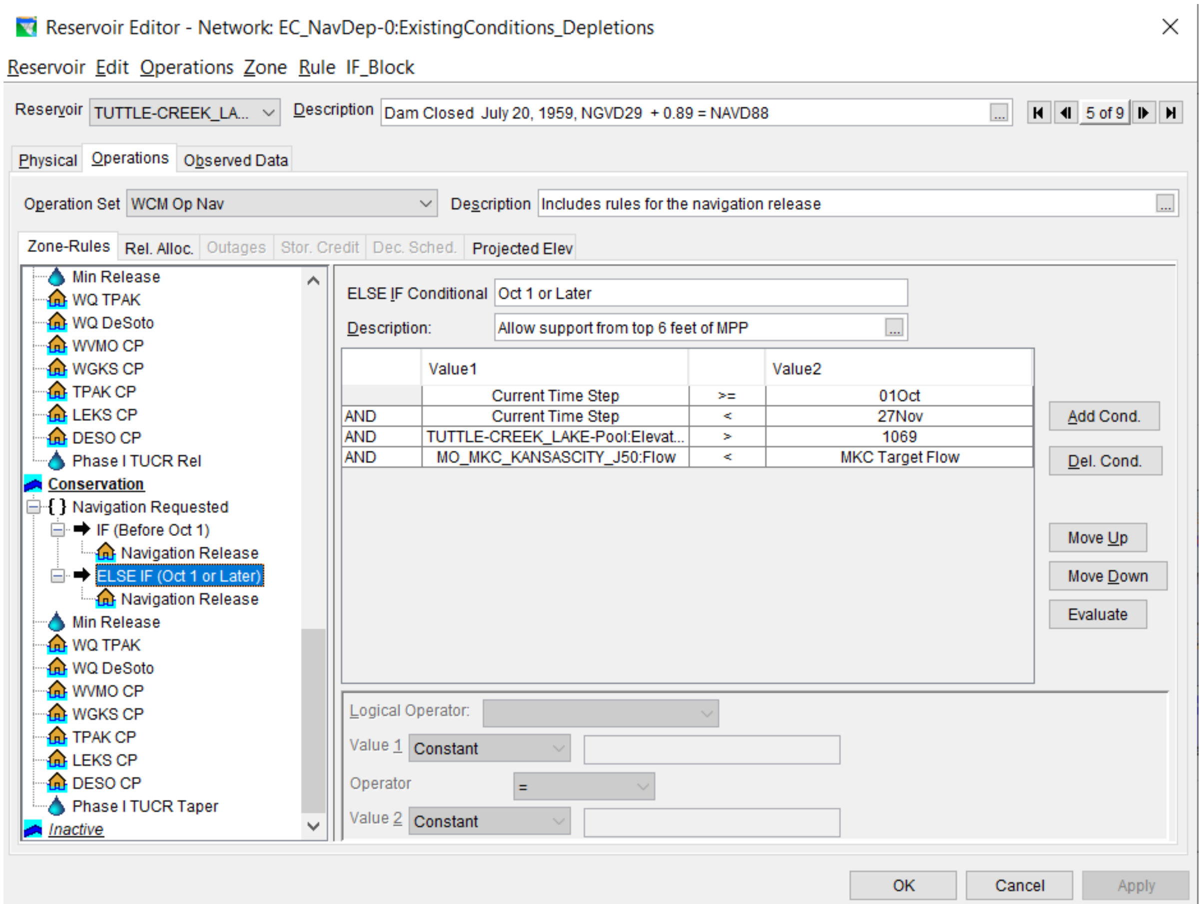


Figure 3-38. Tuttle Creek "else if statement" for navigation releases.

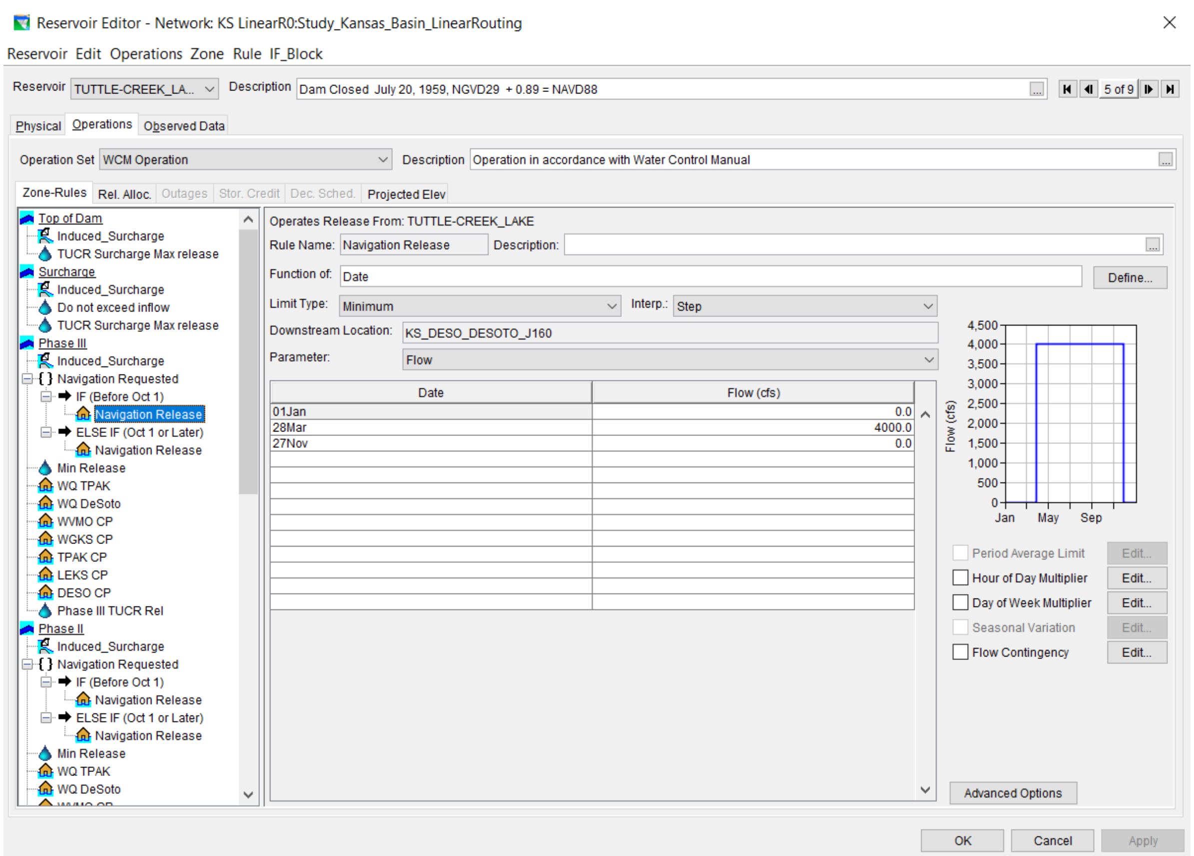


Figure 3-39 ResSim navigation release rule for Tuttle Creek.

3.7 Routing Reaches

The KRRFSS HEC-ResSim was setup using the same routing reaches as the Kansas CWMS ResSim model. However, the routing methods were changed. The Kansas CWMS model uses Muskingum and Modified Puls. The KRRFSS routing was changed to coefficient and null routings for all reaches below the reservoirs to simplify the model and allow better downstream control rule performance during the daily time step in the long-term simulations. The routing reaches that were not below reservoirs use similar routing to the CWMS model other than some adjustments to the number of subreaches because of the change from the model running hourly to daily.

The CWMS model included more junctions and routing reaches than were necessary in the KRRFSS model. Instead of removing or consolidating reaches, the superfluous reaches were maintained with null routing. Coefficient routing was initially estimated using parameters from the water management annual benefits spreadsheet. These routing coefficients are established between gages. If there are multiple reaches between gages generally one reach was established with the coefficient routing and the other reaches were set to null. As the local flow simulations were run, modeled and observed flows were compared and evaluated at each gage. This permitted the coefficient routings to be adjusted as necessary to match the observed flows. The reach routing parameters for the reaches downstream of the reservoirs are shown in Table 3-27. Routing reaches for tributaries with Muskingum routing are shown in Table 3-28. Routing reaches on the Missouri River upstream of Kansas City use Modified Puls routing and were not modified during these analyses. Therefore, the Modified Puls values are not shown.

Table 3-27 Routing Reach Parameters for the reaches downstream of the Kansas River Reservoirs.

Reach	Location	Routing Method	Day 1	Day 2	Day 3	Day 4
SH_SmokyHillR_R20	Kanopolis to Lindsborg	Coef. Routing	0.4	0.6	-	-
SH_SmokyHillR_R30	Lindsborg to Mentor	Coef. Routing	0.3	0.6	0.1	-
SH_SmokyHillR_R40	Mentor to New Cambria	Null	-	-	-	-
SH_SmokyHillR_R50	Mentor to New Cambria	Coef. Routing	0.4	0.6	-	-
SA_SalineR_R30	Wilson to Tescott	Null	-	-	-	-
SA_SalineR_R40	Wilson to Tescott	Null	-	-	-	-
SA_SalineR_R50	Wilson to Tescott	Coef. Routing	0.0	0.0	0.4	0.6
SA_SalineR_R60	Tescott to New Cambria	Coef. Routing	0.2	0.3	0.5	-
SA_SalineR_R70	Tescott to New Cambria	Null	-	-	-	-
SO_SolomonR_R10	Waconda to Beloit	Null	-	-	-	-
SO_SolomonR_R20	Waconda to Beloit	Coef. Routing	0.2	0.8	-	-
SO_SolomonR_R30	Beloit to Niles	Null	-	-	-	-
SO_SolomonR_R40	Beloit to Niles	Coef. Routing	0.0	0.2	0.8	-
SO_SolomonR_R50	Beloit to Niles	Null	-	-	-	-
SO_SolomonR_R60	Beloit to Niles	Null	-	-	-	-
SO_SolomonR_R70	Beloit to Niles	Coef. Routing	0.1	0.9	-	-
SO_SolomonR_R80	Beloit to Niles	Null	-	-	-	-
SO_SolomonR_R90	Niles to the Smoky Hill River	Coef. Routing	0.5	0.4	0.1	-
SH_SmokyHillR_R60	New Cambria to Enterprise	Coef. Routing	0.0	0.7	0.3	-
SH_SmokyHillR_R70	New Cambria to Enterprise	Null	-	-	-	-
SH_SmokyHillR_R80	New Cambria to Enterprise	Null	-	-	-	-
SH_SmokyHillR_R90	New Cambria to Enterprise	Null	-	-	-	-
SH_SmokyHillR_R100	New Cambria to Enterprise	Null	-	-	-	-
SH_SmokyHillR_R110	Enterprise to Fort Riley	Null	-	-	-	-
SH_SmokyHillR_R120	Enterprise to Fort Riley	Coef. Routing	0.1	0.9	-	-

SH_SmokyHillR_R130	Enterprise to Fort Riley	Null	-	-	-	-
RE_RepublicanR_R180	Milford to the Kansas River	Coef. Routing	0.4	0.6	-	-
KS_KansasR_R10	Fort Riley to Wamego	Null	-	-	-	-
KS_KansasR_R20	Fort Riley to Wamego	Coef. Routing	0.4	0.6	-	-
KS_KansasR_R30	Fort Riley to Wamego	Null	-	-	-	-
KS_KansasR_R40	Fort Riley to Wamego	Null	-	-	-	-
BB_BigBlueR_R150	Tuttle Creek to the KS River	Coef. Routing	0.5	0.5	-	-
KS_KansasR_R50	Wamego to Topeka	Null	-	-	-	-
KS_KansasR_R60	Wamego to Topeka	Null	-	-	-	-
KS_KansasR_R70	Wamego to Topeka	Null	-	-	-	-
KS_KansasR_R80	Wamego to Topeka	Null	-	-	-	-
KS_KansasR_R90	Wamego to Topeka	Coef. Routing	0.4	0.6	-	-
KS_KansasR_R100	Topeka to Lecompton	Null	-	-	-	-
KS_KansasR_R110	Topeka to Lecompton	Null	-	-	-	-
KS_KansasR_R120	Topeka to Lecompton	Coef. Routing	0.6	0.4	-	-
DE_DelawareR_R40	Perry to the Kansas River	Coef. Routing	0.7	0.3	-	-
KS_KansasR_R130	Lecompton to Desoto	Coef. Routing	0.5	0.5	-	-
KS_KansasR_R140	Lecompton to Desoto	Null	-	-	-	-
KS_KansasR_R150	Lecompton to Desoto	Null	-	-	-	-
WA_WakarusaR_R30	Clinton to Lawrence	Coef. Routing	0.9	0.1	-	-
WA_WakarusaR_R40	Lawrence to the Kansas River	Coef. Routing	0.5	0.5	-	-
KS_KansasR_R160	Desoto to Kansas City	Null	-	-	-	-
KS_KansasR_R170	Desoto to Kansas City	Coef. Routing	0.8	0.2	-	-
KS_KansasR_R180	Desoto to Kansas City	Null	-	-	-	-
MO_MissouriR_R50	Kansas City to Waverly	Null	-	-	-	-
MO_MissouriR_R60	Kansas City to Waverly	Coef. Routing	0.9	0.1	-	-
MO_MissouriR_R70	Kansas City to Waverly	Null	-	-	-	-
MO_MissouriR_R80	Kansas City to Waverly	Null	-	-	-	-
MO_MissouriR_R90	Kansas City to Waverly	Coef. Routing	0.1	0.8	0.1	-
MO_MissouriR_R100	Kansas City to Waverly	Null	-	-	-	-
MO_MissouriR_R110	Kansas City to Waverly	Null	-	-	-	-

Table 3-28 Routing Parameters for Tributary Reaches.

		Muskingum Parameters		
Reach	Location	K (hrs)	X	Number of Subreaches
SO_SaltCr_R020	Salt Creek to junction with Solomon River	4.0	0.25	1
SH_ChapmanCr_R010	Chapman Creek to junction with Smoky Hill River	2.0	0.25	1
KS_VermillionCr_R010	Vermillion Creek to junction with Kansas River	3.0	0.25	1
KS_MillCr_R010	Mill Creek to junction with Kansas River	3.0	0.25	1
SC_SoldierCr_R020	Soldier Creek to junction with Kansas River	3.0	0.25	1
ST_StrangerCr_R30	Stranger Creek to junction with Kansas River	3.0	0.25	1
MO_BlueR_J10	Blue River to junction with Missouri River	3.0	0.25	1
LM_LittleBlueR_R40	Little Blue River to junction with Missouri River	4.0	0.25	4

3.8 Local Flow Calculation

An HEC-ResSim simulation was setup to pass observed inflows past the dams. The ResSim network was modified to remove reservoirs and all observed inflow was input at the reservoir outflow junction. The observed flows were the extended inflow records to represent the pre-dam period and observed releases after the start of regulation. This combination of data was to pass flows that happened at the dam location. Once the observed flows were routed to the downstream gages, the modeled data was compared to observed to ensure the timing and attenuation matched the observed.

Raw local flows were computed using model output and the extended official streamflow records at each gage location. The equation for the raw computed local flows at a gage is shown below.

$$Gage_{local} = Gage_{obs} - Gage_{model}$$

At each location, all model input parameters were held to 0 cfs except for the gage(s) immediately upstream. The official extended streamflow record at the upstream gage was routed downstream to do the local flow computation. For example, at Lindsborg, the extended data set at Kanopolis was used as the local flow at that location. All other model parameters were held to 0 cfs. The observed record was routed down to Lindsborg, and then the above equation could be used to compute a raw local flow time series.

3.8.1 Local Flow Manipulation

The calculated local flows had some large negative values especially during the time when the data record was extended. This is probably due to uncertainties in routing times and flow at a given location when the data was extended using other gages. To help with some of these data discrepancies, once raw local flows had been computed, flows were blended and distributed using a spreadsheet method as detailed in sections 3.7.1 to 3.7.3. The spreadsheet required the raw local flow and the modeled flow after the initial routing at each location (i.e., $Gage_{local}$ and $Gage_{model}$ from the raw local flow equation). Once data was input, the further calculations could be made as detailed in the following sections.

3.8.2 Blending

Raw local flow was split into positive and negative values, then the negative values were blended using a running average that ranged between 3 and 15 days. The length of the running average depended on the number and magnitudes of the negative values. Where there occurred fewer negatives in the data set, fewer days were used for blending. Those blended negative values were then summed with the positive values to obtain a blended local flow.

3.8.3 Apportioning

After calculating a blended local flow, that flow could be added to the modeled flow to obtain a blended total flow at each location. This time series was checked for negative stream flow. A small percentage of flow from positive values was skimmed from the time series and distributed into the negative local flow when the stream flow went negative. This percentage was very small, with the largest percentage being near 3%.

The apportioned and blended flows were added together to create a final local flow time series. Negatives still existed in the time series but were reduced to the point where the modeled river flow and the final local flow summation did not result in negative total flows in the model. The raw local flow and final local flow time series are plotted together at the Smoky Hill River at Lindsborg, KS and shown in Figure 3-40.

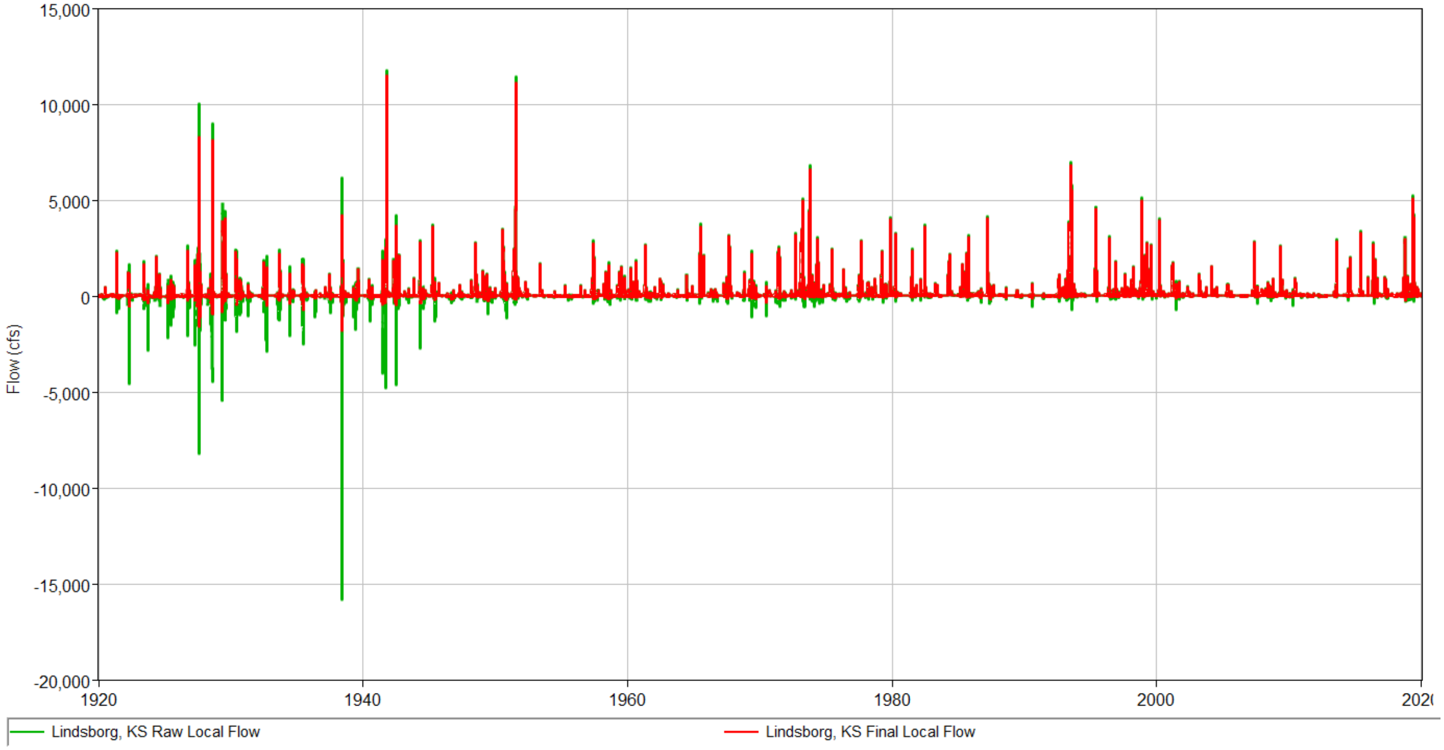


Figure 3-40 Smoky Hill River at Lindsborg, KS raw, calculated, daily local flow compared with the final blended, apportioned, daily local flow.

Much of the large negative flow was removed by this process; however, some negative modeled river gage flows persisted when running the regulated simulation. Small negative flow in the local flow data sets is understandable considering uncertainties in gage rating curves and water usage. The modeled regulated negative flows are not ideal, but they did not appear to have much of an impact on the annual peak stream flow or the annual flow volume. Table 3-29 identifies the number of days that were used for blending the negative local flows and the percentage that was skimmed off for the final apportionment of flows at each local flow location.

Table 3-29 Parameters used to process the final local flow data set.

Stream Gage	Days Used to Blend Negative Local Flows	Percent of Positive Local Flows Used to Fix Negative Stream Flow
Smoky Hill River at Lindsborg	15	2.56%
Smoky Hill River at Mentor	11	2.98%
Saline River at Tescott	15	0.30%
Smoky Hill River at New Cambria	15	0.80%
Solomon River at Beloit	15	0.43%
Solomon River at Niles	11	0.39%
Smoky Hill River at Enterprise	7	0.05%
Republican River at Milford Dam	3	0.18%
Kansas River at Fort Riley	7	0.08%
Kansas River at Wamego	7	0.02%
Kansas River at Topeka	7	0.01%
Kansas River at Lecompton	7	0.29%
Wakarusa River at Lawrence	7	0.81%
Kansas River at Desoto	7	0.01%
Missouri River at Kansas City	3	0.00%
Missouri River at Waverly	3	0.00%

3.9 HEC-ResSim Reservoir Rules

HEC-ResSim rules were used to determine modeled releases throughout the period of record. The rules were set up in accordance with the approved water control manuals at each reservoir. The existing Kansas CWMS HEC-ResSim model rules were utilized for this study, but some rules were modified to get appropriate modeled results.

Release function rules were used to specify maximum and minimum releases in a zone. Separate reservoir zones were setup for Conservation, Phase I, Phase II, Phase III, Surcharge, and Top of Dam. Dividing the flood control pool into the separate phases allowed the model to respond to the seasonal changes in threshold elevations. Maximum releases for a zone were established based on the water control manual limits. In most cases these limits are higher than typical releases, but the authorized maximum was used to allow the full range of releases in the model. A more typical release rate is set to draw the lake down to target in 10 days. For smaller events, HEC-ResSim will often draw down the lake in a day or two if the downstream control allows maximum release.

Downstream control rules were used to set maximum or minimum flows at the downstream control points. The maximum flood control rules utilized a scripted state variable to calculate the current pool zone to determine the maximum release. The downstream control rules did not always maximize the downstream channel space. When this occurred, the rule advanced options were adjusted to help the model calculation. Figure 3-41 shows an example of the downstream control point advanced options. Adjusting the settings in advanced options provided reasonable use of the downstream control point available channel capacity.

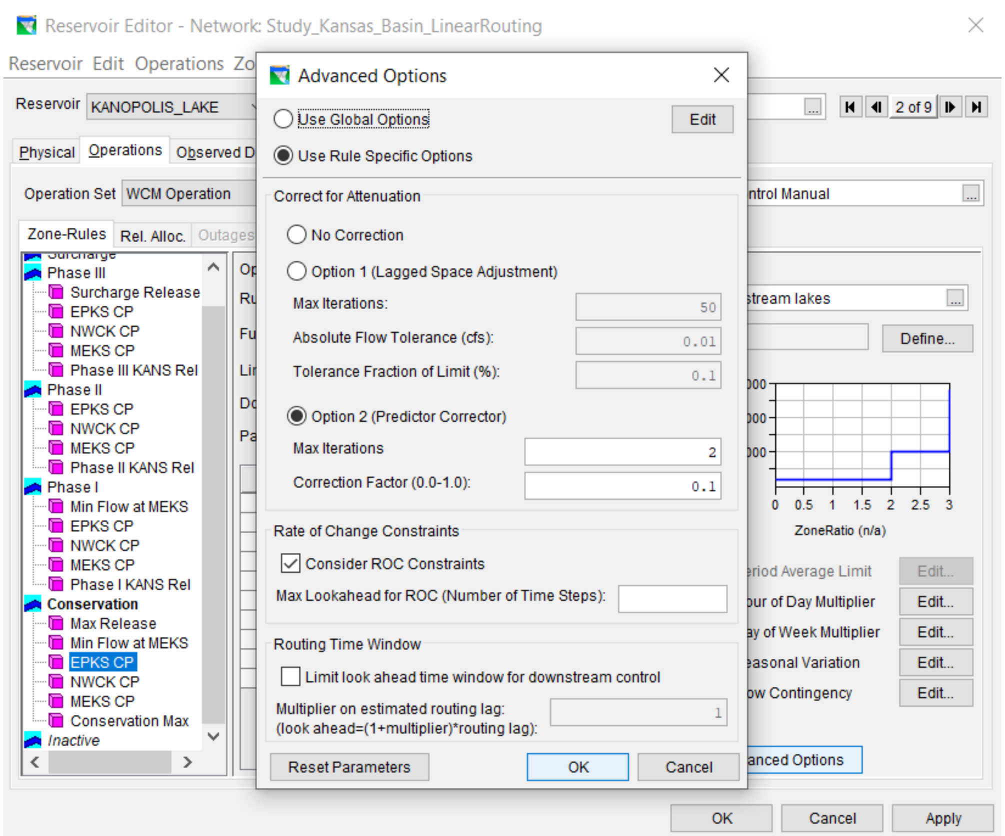


Figure 3-41 Downstream Control Rule Advanced Options.

Reservoir surcharge rules utilized a range of options depending on the physical setup of the dam and the water control manual criteria. Wilson and Clinton did not enter surcharge during the period of analysis. Perry and Milford were both compared to their respective surcharge events and seemed to perform reasonably well. The water control manual surcharge criteria are for hourly reservoir operation during extreme events. The daily time step in the model tends to generalize releases and does not always follow the desired surcharge criteria because of the time step. This became a problem with Waconda surcharge operations during the 1951 flood event. Manual overrides were used to force the model to release a more reasonable rate less than inflows.

4 Model Results

The "Existing Conditions" simulations (with and without navigation) were run using a lookback period of 01Dec1919 to 31Dec1919; the forecast time was 01 Jan 1920 to 02 Jan 2020. The main intent of the HEC-ResSim model is to produce regulated data for the full period of record. Model results were graphically compared to observed time series data where available.

There were many reasons why modeled results may not match observed. Before the dams were in place, the observed flow at the gages downstream of the dams was unregulated. After the dams were constructed, reservoir operations have at times formally deviated from the water control plan (modeled rules) for specific flood control purposes approved by Missouri River Basin Water Management or significant dam maintenance. Also, reservoir release decisions are being made with a certain amount of forecast uncertainty relating to the flow at downstream control points when reservoir releases reach that location. As much as possible decisions are based on water on the ground forecasts, but there is uncertainty about future conditions especially where long travel time from reservoir to gage location exist (such as from Milford to the Missouri River at Waverly). The ResSim downstream control point rules, used in this study, incorporate elements of forecast uncertainty, but these decisions are different than in real-time operations. For instance, some of the Kansas reservoirs are 4-5 days of travel time away from the Missouri River control points. Real-time operations may decide to maintain ongoing reservoir releases even though the Missouri River rises above criteria from a local rainfall, because the river is forecast to drop before any proposed reservoir release reduction could effectively propagate downstream to alleviate conditions at the control point. ResSim does route all inflows and local flows, both present and future, to the downstream control point. However, ResSim does not match the target flows perfectly at the downstream control points because of its internal forecast uncertainty. Factors such as attenuation and routing times were adjusted in this model, but these factors can vairy depending on the event leading to downstream flows missing the desired target at a control point.

The navigation flow support scenario resulted in navigation releases being made in approximately half of the years; however, four main time periods had multi-year reservoir drawdowns as a result the navigation releases. These time periods were 1932 to 1941, 1953 to 1957, 1988 to 1992, and 2002 to 2007. These were some of the dry periods when the Missouri River at Kansas City, MO dropped below the minimum service level during the navigation season. Peak reservoir pool elevations and flows were virtually the same in both existing conditions scenarios. Navigation flow support resulted in slightly lower pool elevations during the drought years, but that additional storage was quickly filled when flood flows occurred.

To compare the observed and modeled data, pool elevation duration graphs were assessed. Figure 4-1 shows the Kanopolis pool elevation duration plot from 01Aug1948 (time of first fill) to 01Jan2020. Both model scenarios result in the same pool duration since navigation flow is not supported from Kanopolis. Comparison of the observed and modeled duration indicate that the model keeps the reservoir at multi-purpose pool more often than in real-time. Seasonal water level management plans will keep the lake above multi-purpose pool during periods of the year, but the water level management plan was not put into the model since it is discretional and may not be followed depending on the basin conditions. The multi-purpose pool elevation has also been raised since the initial fill. Figure 4-2 shows the observed and modeled annual flow volume from 1949 (when outflow data started) through the end of 2019. The modeled scenarios with and without navigation are identical. The volumes match closely with the observed tending to be slightly higher. The differences are due to estimated evaporation in the model, carryover storage from year to year, and the present incremental depletions. The full water balance was analyzed for Wilson and Tuttle Creek ensuring that the model maintains mass balance. This analysis is shown in section 2.2 of "Attachment 1 Supporting Plots".

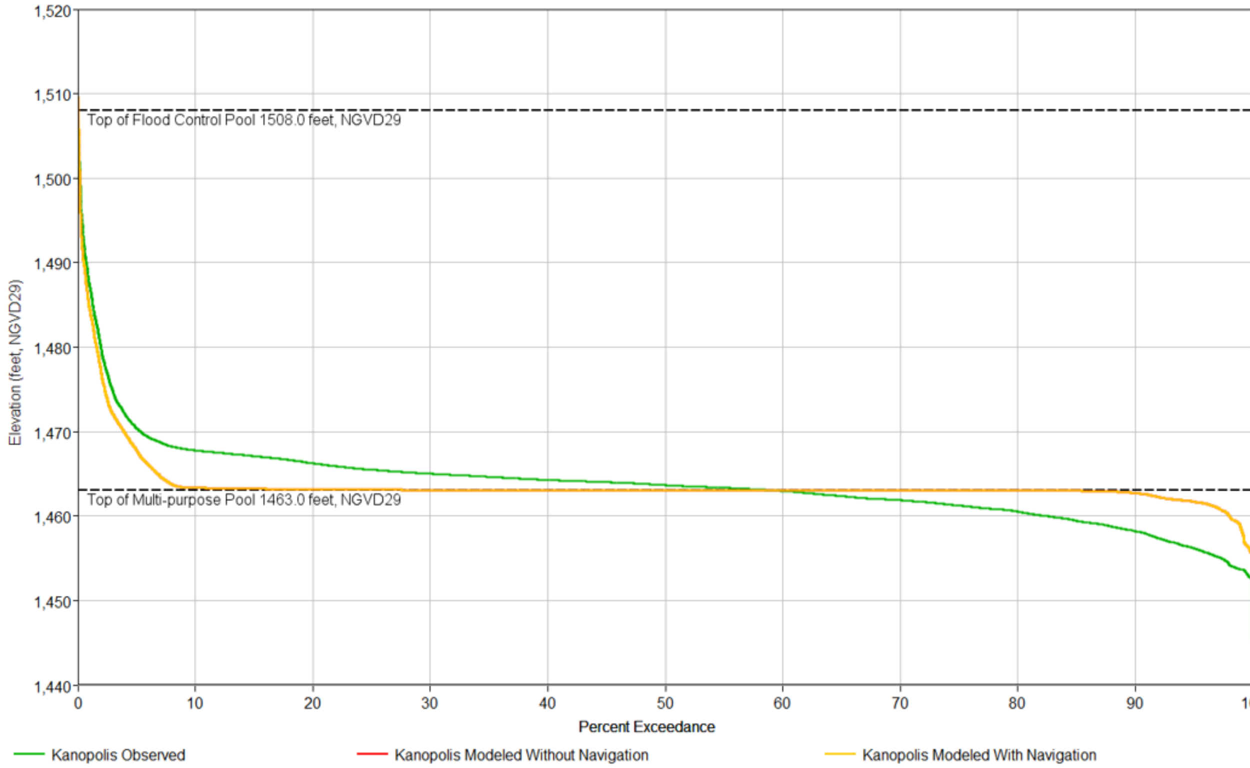


Figure 4-1 Kanopolis observed and modeled pool elevation duration from 01Jul1948 to 01Jan2020.

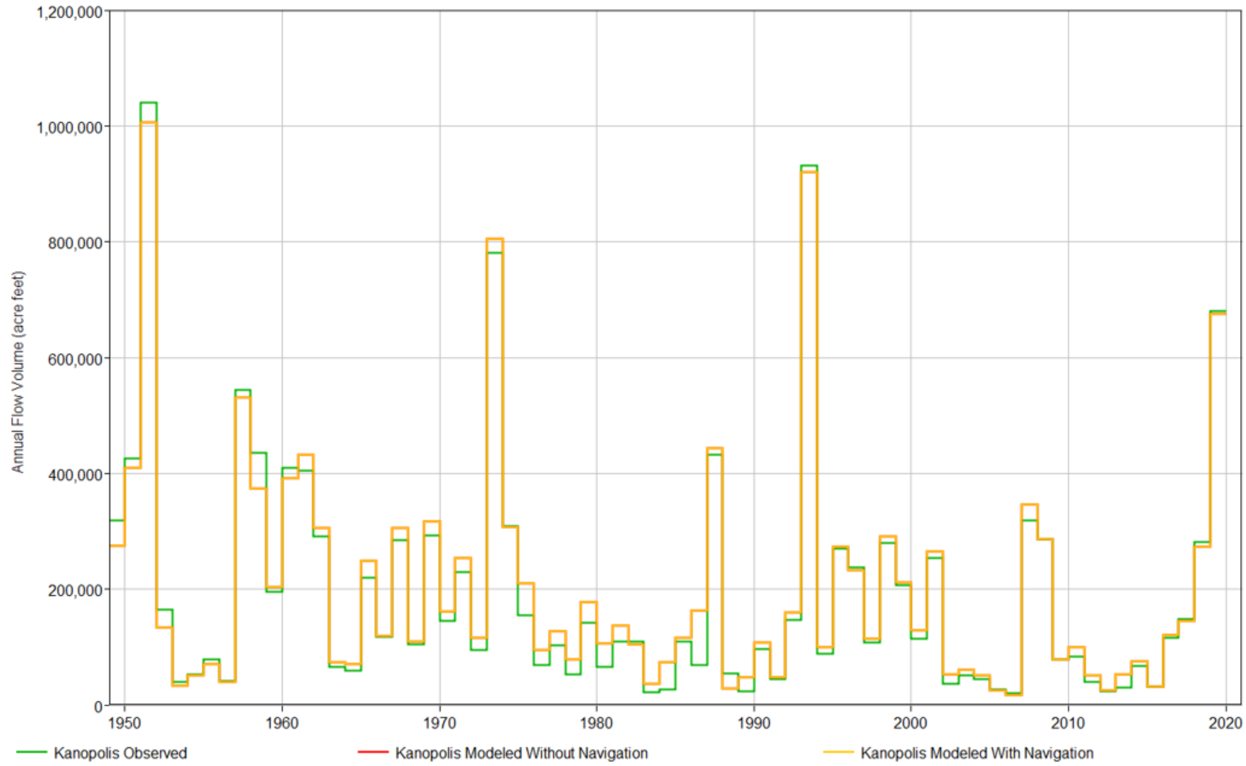


Figure 4-2 Kanopolis Observed and Modeled Annual Flow Volume for 1949 through 2019.

Downstream of Kanopolis the Smoky Hill River at Lindsborg and Mentor annual flow volumes are compared in Figure 4-3 and Figure 4-4. These plots start in 1949 after the effects of the Kanopolis regulation begin at these gages allowing a comparison of regulated observed and modeled. Lindsborg does not have observed data from 1966 through 2013.

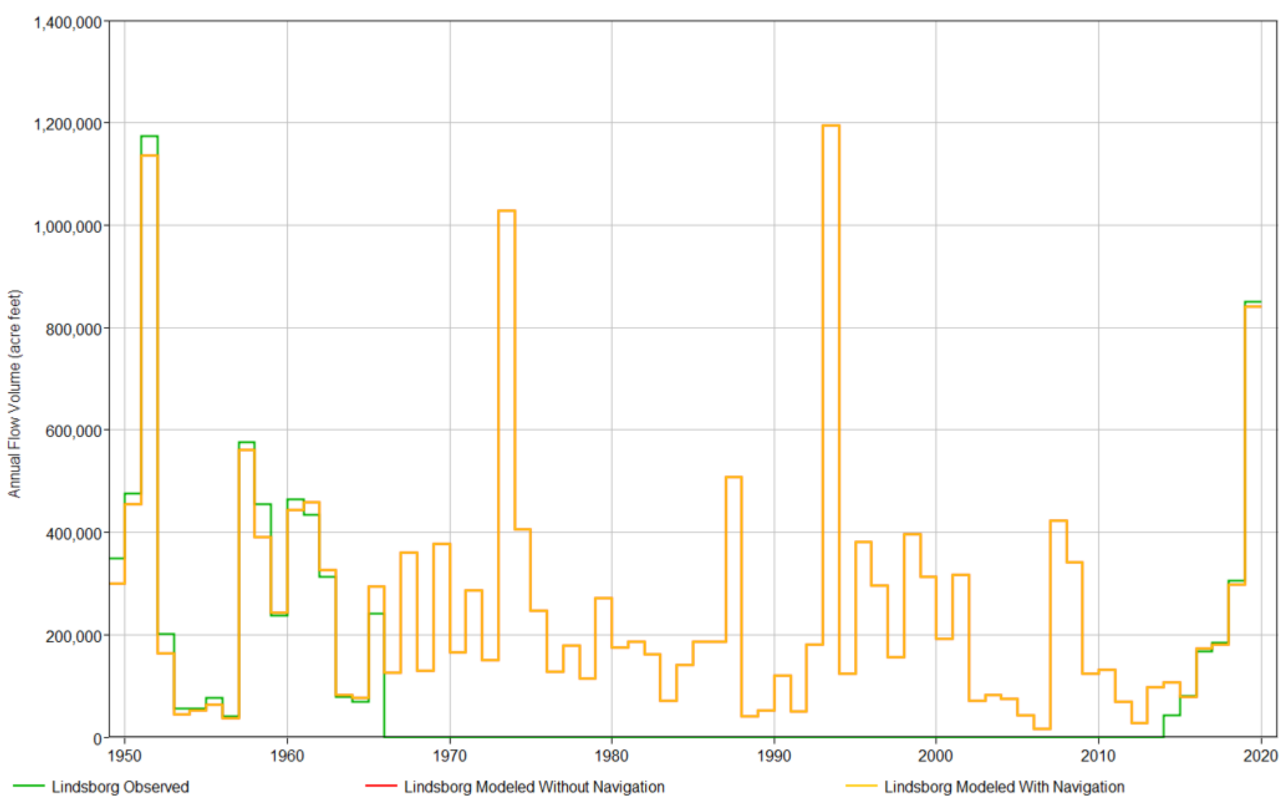


Figure 4-3 Lindsborg Observed and Modeled Annual Flow Volume for 1949 through 2019.

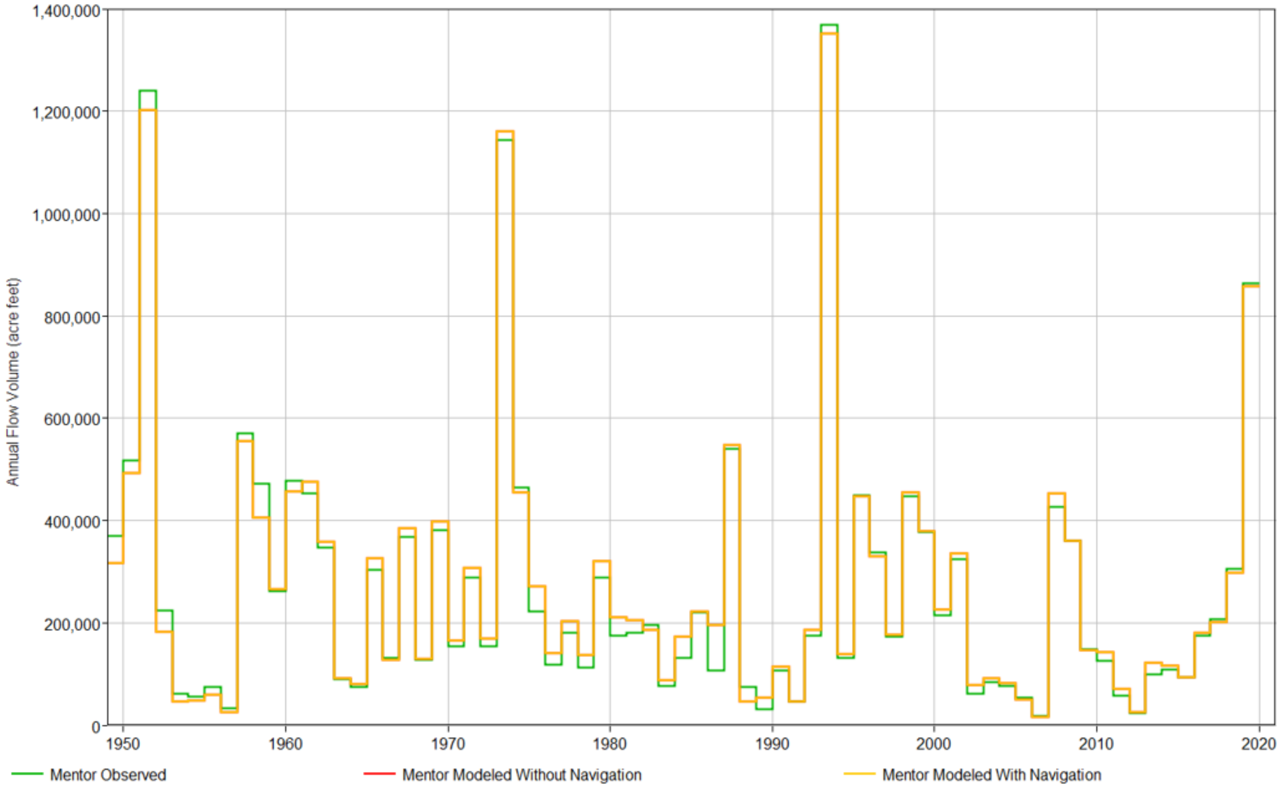


Figure 4-4 Mentor Observed and Modeled Annual Flow Volume for 1949 through 2019.

The Wilson Reservoir pool elevation duration plot from 01 Jan 1973 (approximate time of first fill) to 01 Jan 2020 is shown in Figure 4-5. Both model scenarios result in the same pool duration since navigation flow is not supported from Wilson. Comparison of the observed and modeled duration indicate that, similar to Kanopolis, the model tends to under-predict the pool elevation. This basin is prone to extended droughts. Estimated modeled evaporation and basin depletions are the reason for the modeled pool elevation being lower on the dry end of the curve. Seasonal water level management plans will keep the lake above multi-purpose pool during wet periods which may be the reason for the observed being higher than modeled in the 1516 to 1517 elevation range. The water level management plan was not put into the model since it is discretional and may not be followed depending on the basin conditions. Figure 4-6 shows the observed and modeled annual flow volume from 1964 (when outflow data started) through 2019. The modeled scenarios with and without navigation are identical. The observed volumes tend to be higher than modeled and with greater separation than characterized in the Kanopolis data.

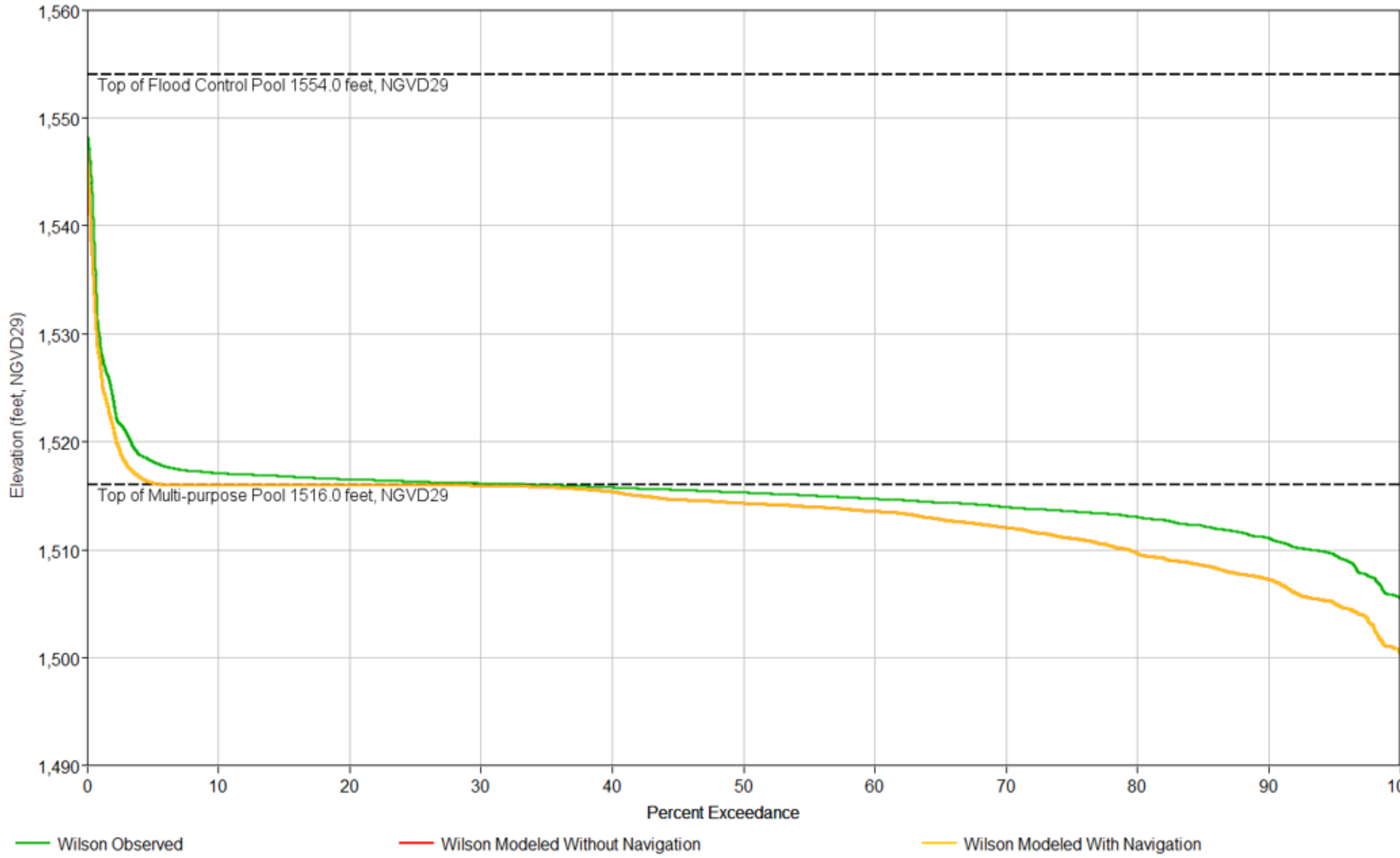


Figure 4-5 Wilson observed and modeled pool elevation duration from 01Mar1973 to 01Jan2020.

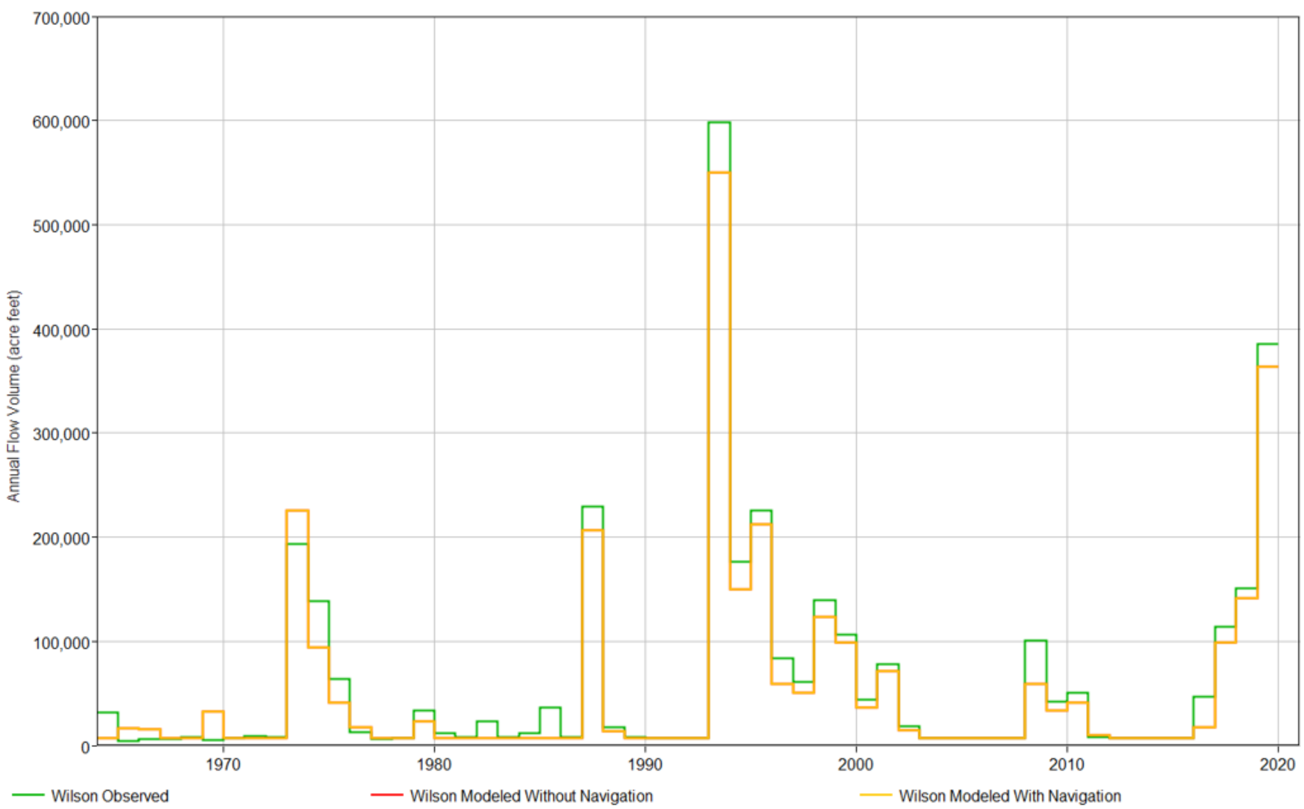


Figure 4-6 Wilson Observed and Modeled Annual Flow Volume for 1964 through 2019.

Downstream of Wilson the Saline River at Tescott and the Smoky Hill River at New Cambria (impacted by Kanopolis and Wilson regulation) annual flow volumes are compared in Figure 4-7 and Figure 4-8. These plots start in 1973 after the effects of the Wilson regulation begin at these gages allowing a comparison of regulated observed and modeled. New Cambria does not have flow data in 2007 and from 2010 through the present.

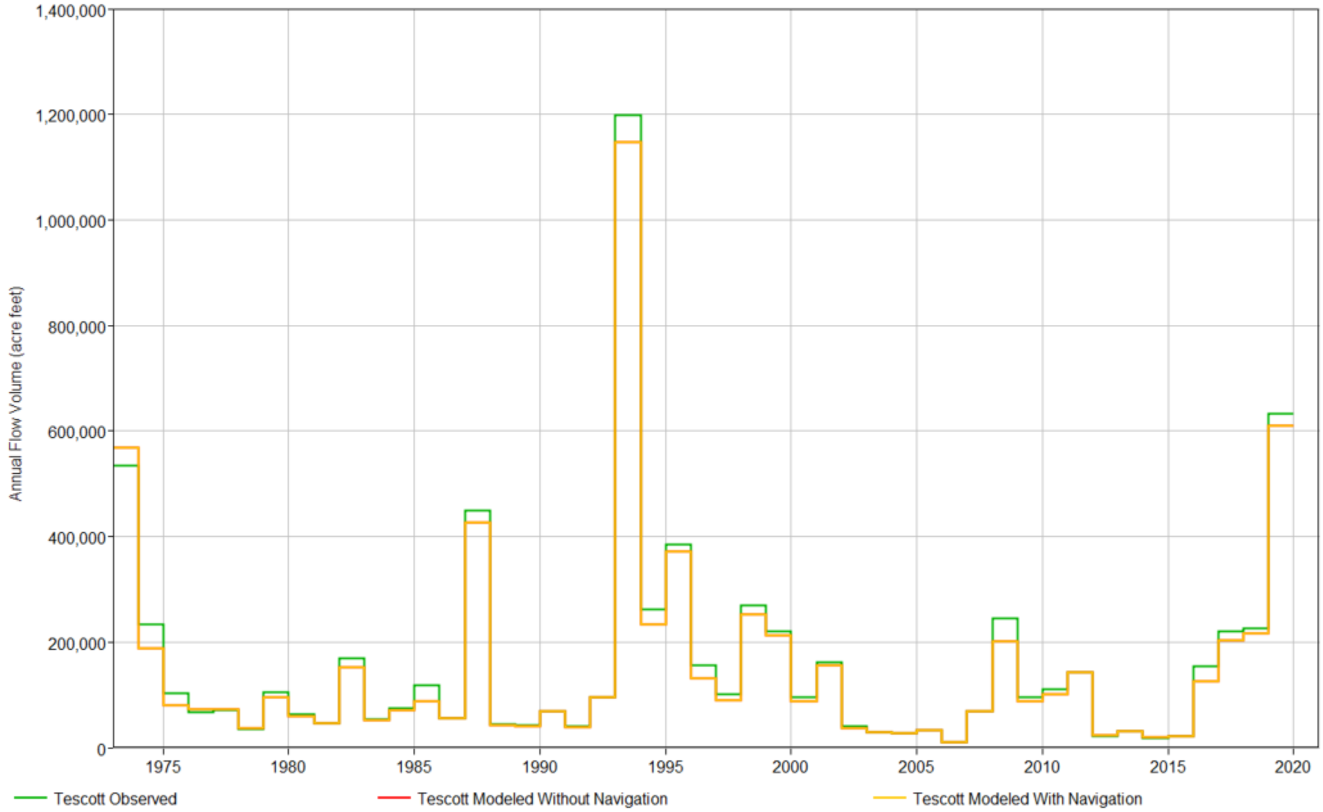


Figure 4-7 Tescott Observed and Modeled Annual Flow Volume for 1973 through 2019.

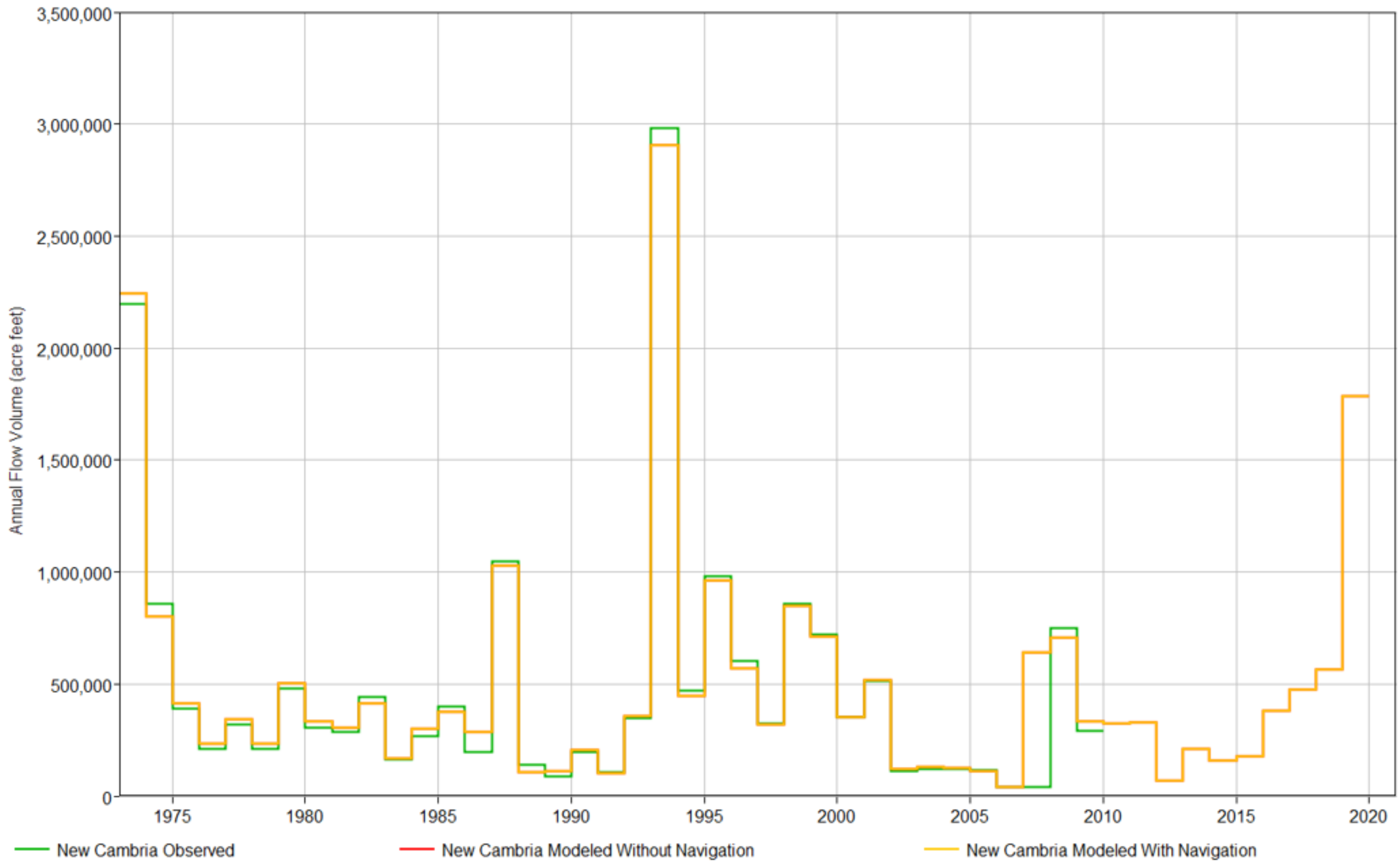


Figure 4-8 New Cambria Observed and Modeled Annual Flow Volume for 1973 through 2019.

The Waconda Reservoir pool elevation duration plot from 15 May 1973 (approximate time of first fill) to 01 Jan 2020 is shown in Figure 4-9. Both model scenarios result in the same pool duration since navigation flow is not supported from Waconda. Comparison of the observed and modeled duration indicate that the model tends to over-predict the pool elevation below the conservation pool. Seasonal water level management plans will keep the lake below the multi-purpose pool during the winter and above the multi-purpose pool during the spring and fall which may be the reason for the observed differing from the modeled. The water level management plan was not put into the model since it is discretional and may not be followed depending on the basin conditions. Figure 4-10 shows the observed and modeled annual flow volume from 1968 (when outflow data started) to 2019. The modeled scenarios with and without navigation are identical. The observed volumes tend to be slightly higher than modeled.

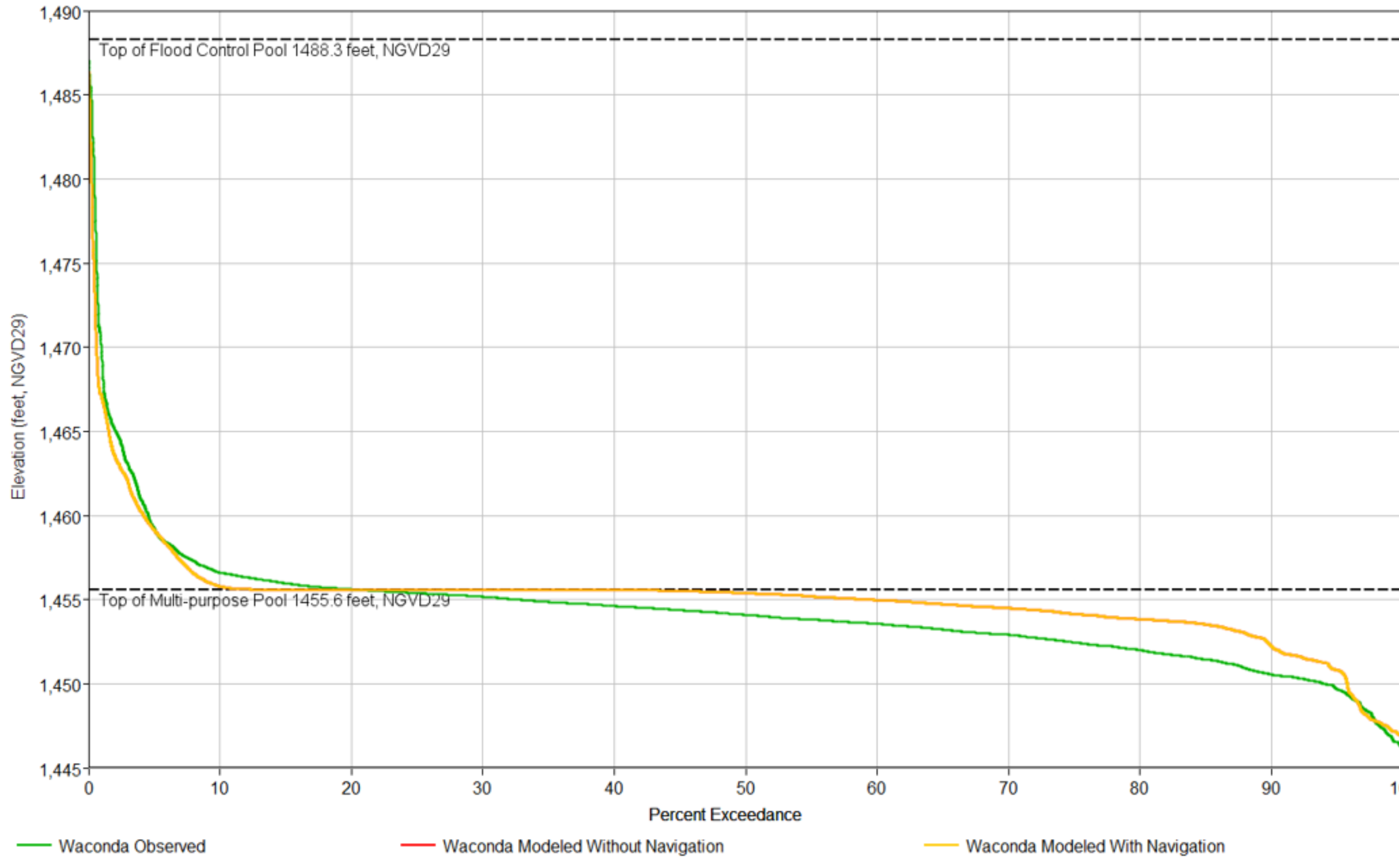


Figure 4-9 Waconda observed and modeled pool elevation duration from 01May1973 to 01Jan2020.

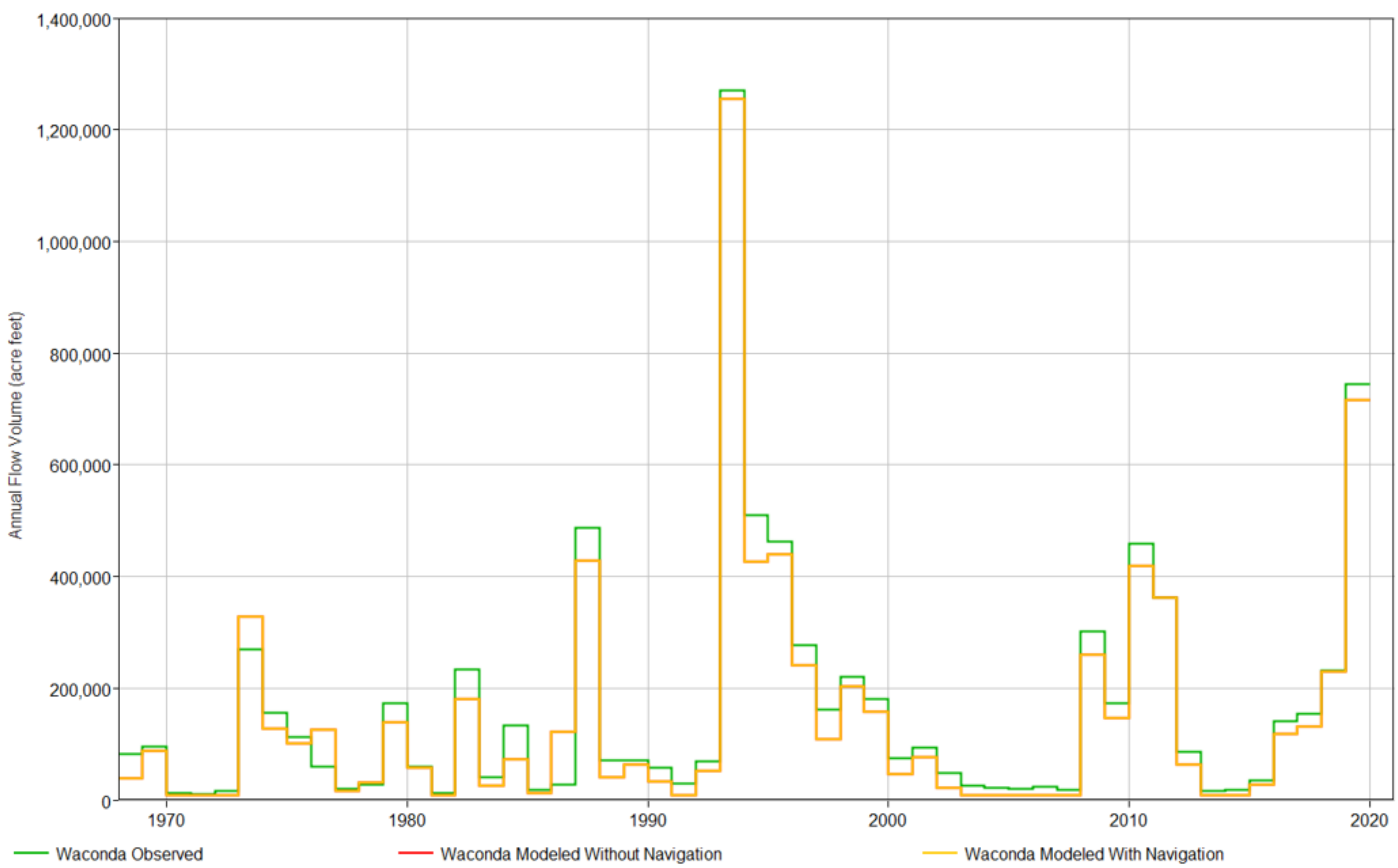


Figure 4-10 Waconda Observed and Modeled Annual Flow Volume for 1968 through 2019.

Downstream of Waconda the Solomon River at Beloit and Niles and the Smoky Hill River at Enterprise (impacted by regulation from all three Smoky Hill reservoirs) annual flow volumes are compared in Figure 4-11 through Figure 4-13. These plots start in 1973 which is about when the impacts of the regulation of all three reservoirs began at these gages allowing a comparison of regulated observed and modeled. During the regulated period, Beloit only has data from 2013 through the present.

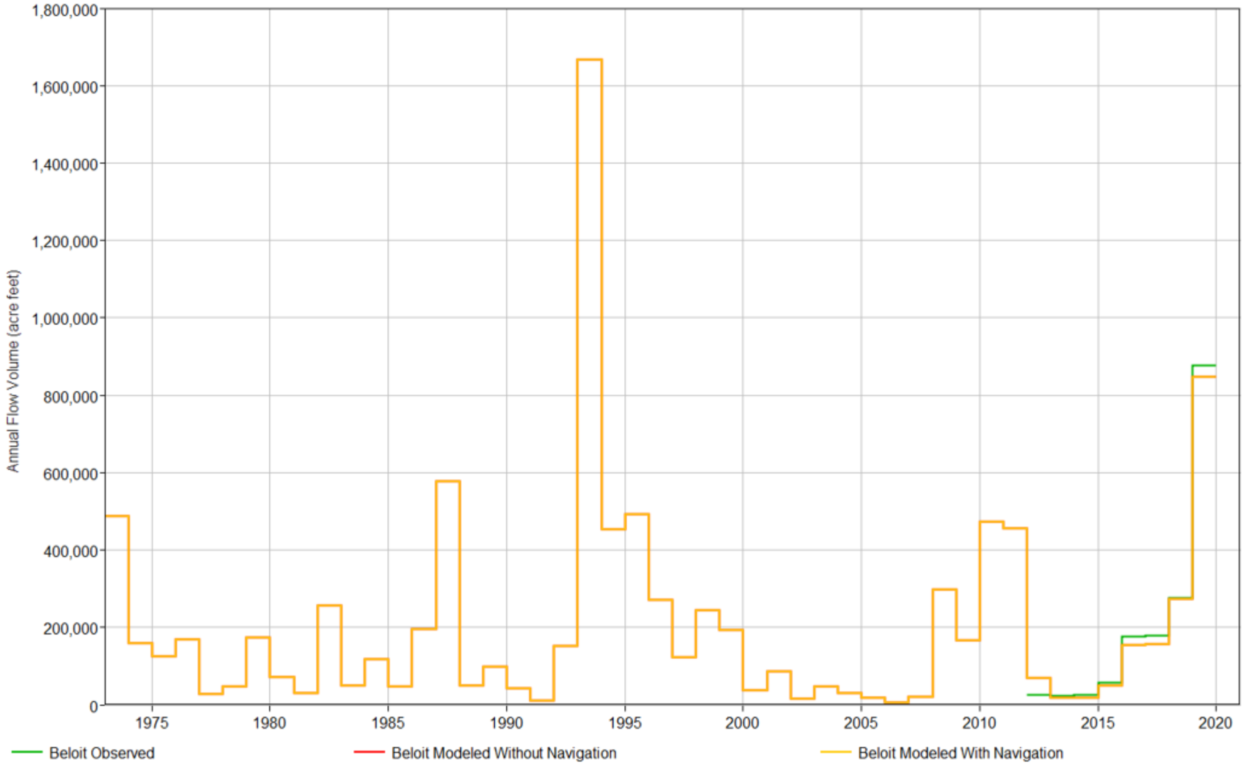


Figure 4-11 Beloit Observed (2013 to 2019) and Modeled Annual Flow Volume for 1973 through 2019.

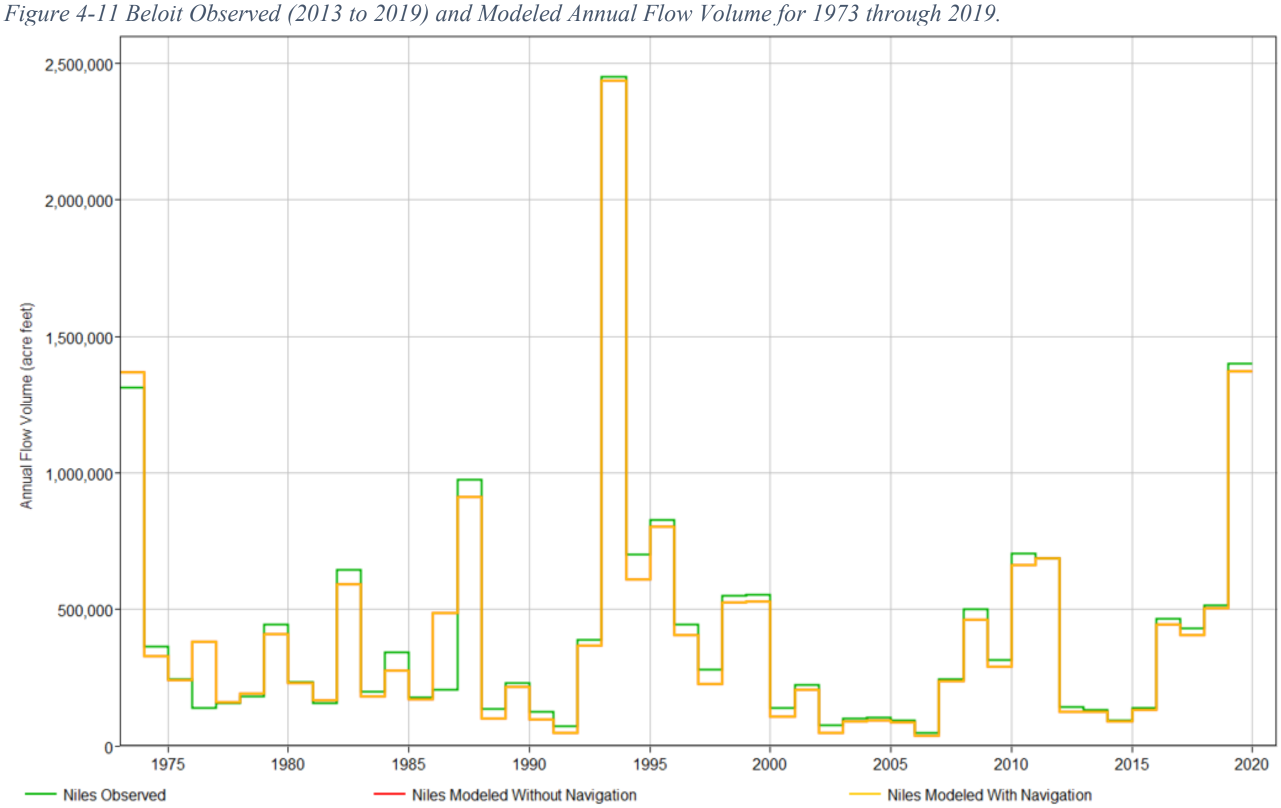


Figure 4-12 Niles Observed and Modeled Annual Flow Volume for 1973 through 2019.

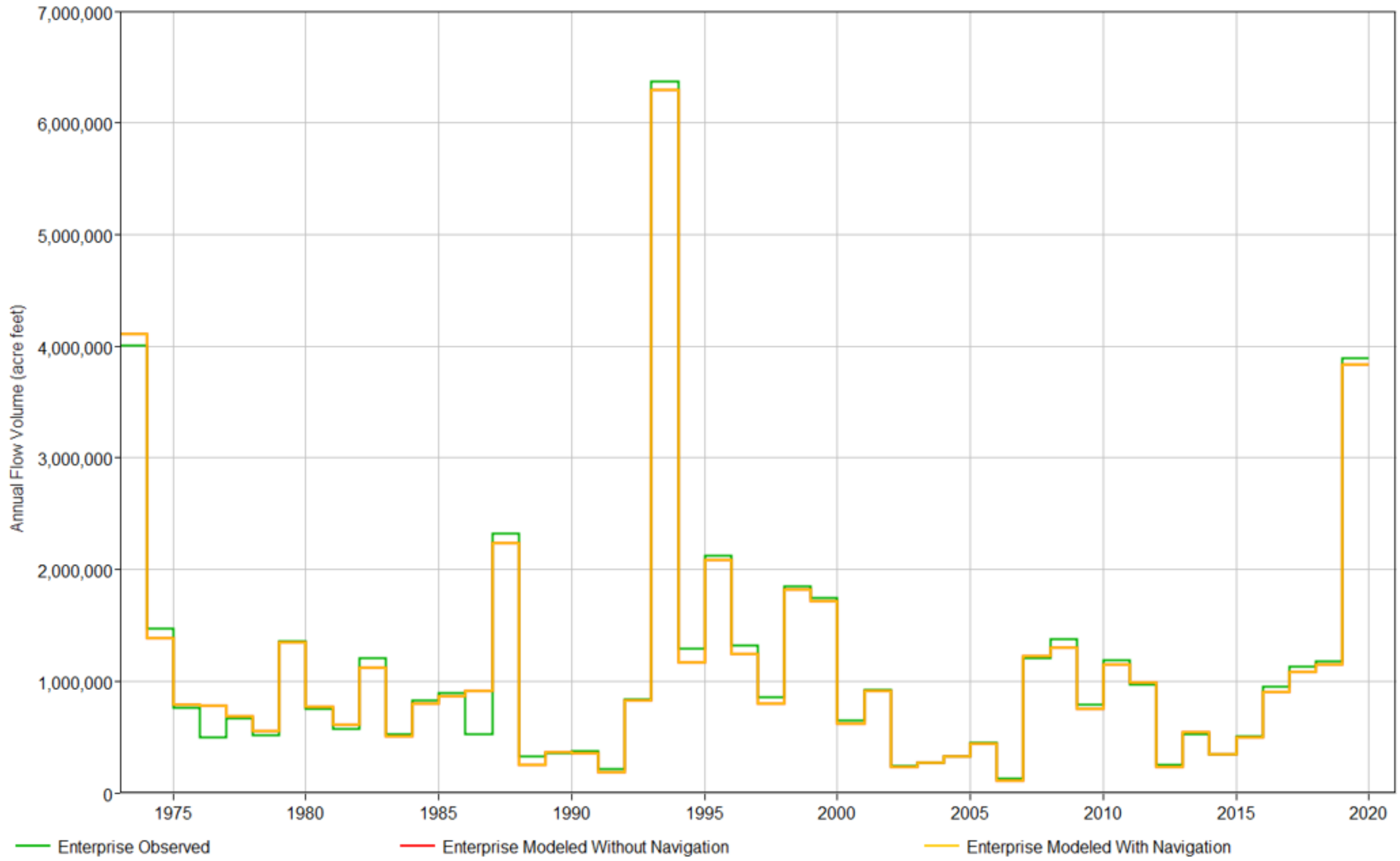


Figure 4-13 Enterprise Observed and Modeled Annual Flow Volume for 1973 through 2019.

The Milford Reservoir pool elevation duration plot from 01 Aug 1967 (approximate time of first fill) to 01 Jan 2020 is shown in Figure 4-14. Comparison of the observed and modeled duration indicate that the model tends to have higher pool elevations in the flood control pool. The low pool durations show that the model tends to stay a little higher than observed except when considering navigation. Seasonal water level management plans will allow the lake below the multi-purpose pool during the winter and one foot above the multi-purpose pool during the spring and fall which may be part of the reason for the observed differing from the modeled. The water level management plan was not put into the model since it is discretional and may not be followed depending on the basin conditions. However, the significant rise in the less frequent portions of the duration curve is probably due to the model constraining releases due to downstream control points especially on the Missouri River. Some of the potential reasons for these differences are discussed at the start of section 4.

Navigation flow support impacts to pool elevation and outflow for selected periods of time are shown in Figure 4-15 to Figure 4-18. These are drought years so pools are already low from reduced inflow and water quality support. Navigation support results in lower pool elevations. When large inflows occur, the without navigation scenario will make larger releases if the multi-purpose pool fills.

Figure 4-19 shows the observed and modeled annual flow volume from 1965 (when outflow data started) to the 2019. The observed volumes tend to be slightly higher than modeled. The model scenarios were very similar, but navigation flow support resulted is small differences for a few years. The large difference in 2019 is due to modeled storage being carried over into 2020. In the observed data set, water was emptied from flood storage before the end of 2019 by using a deviation for higher flow targets on the Missouri River, benefitting flood control operations at Milford, Tuttle Creek and Perry, as well as Clinton.

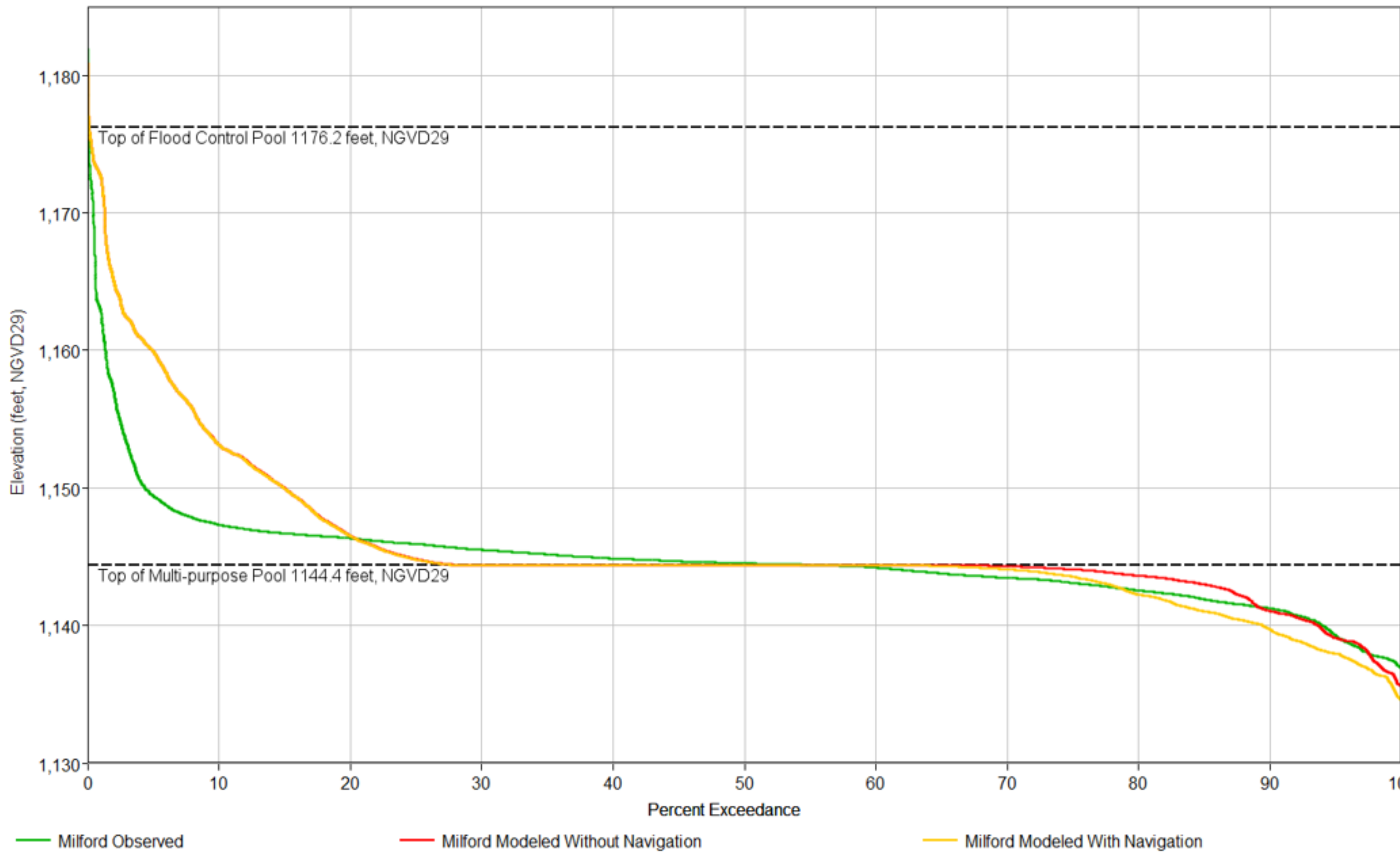


Figure 4-14 Milford observed and modeled pool elevation duration from 01Jul1967 to 01Jan2020.

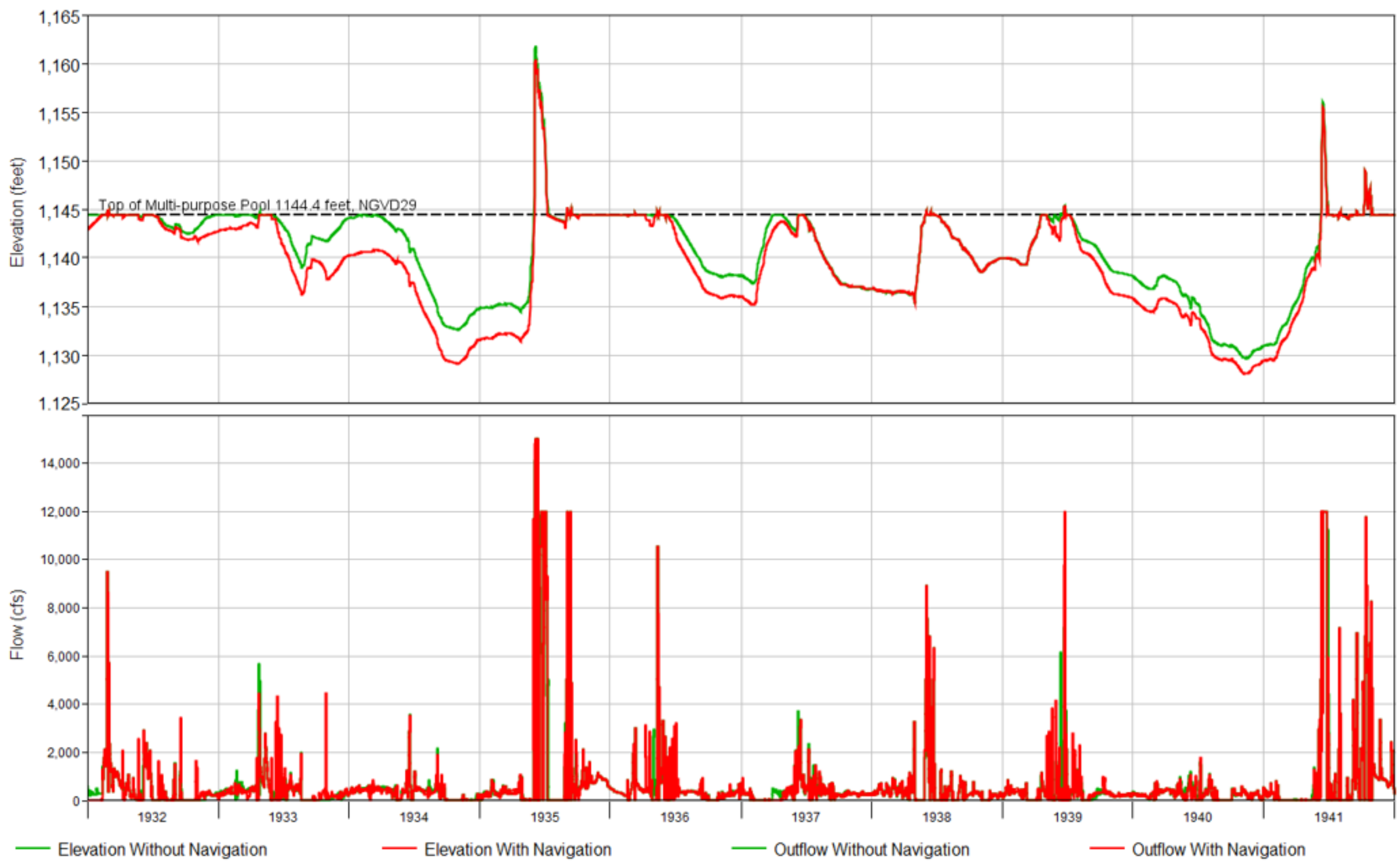


Figure 4-15. Milford pool elevation modeled with and without navigation flow support for the years 1932 through 1941.

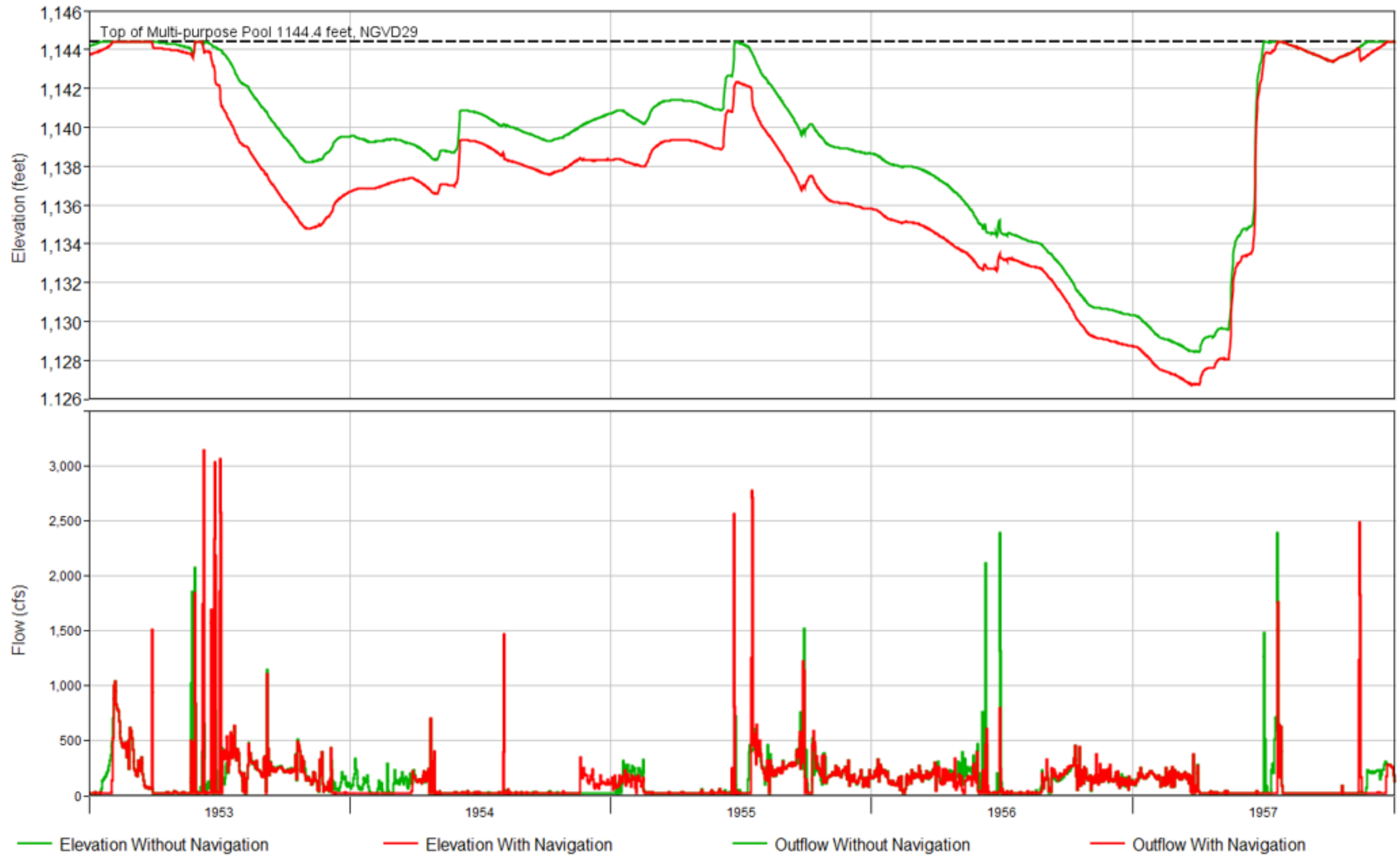


Figure 4-16. Milford pool elevation modeled with and without navigation flow support for the years 1955 through 1958.

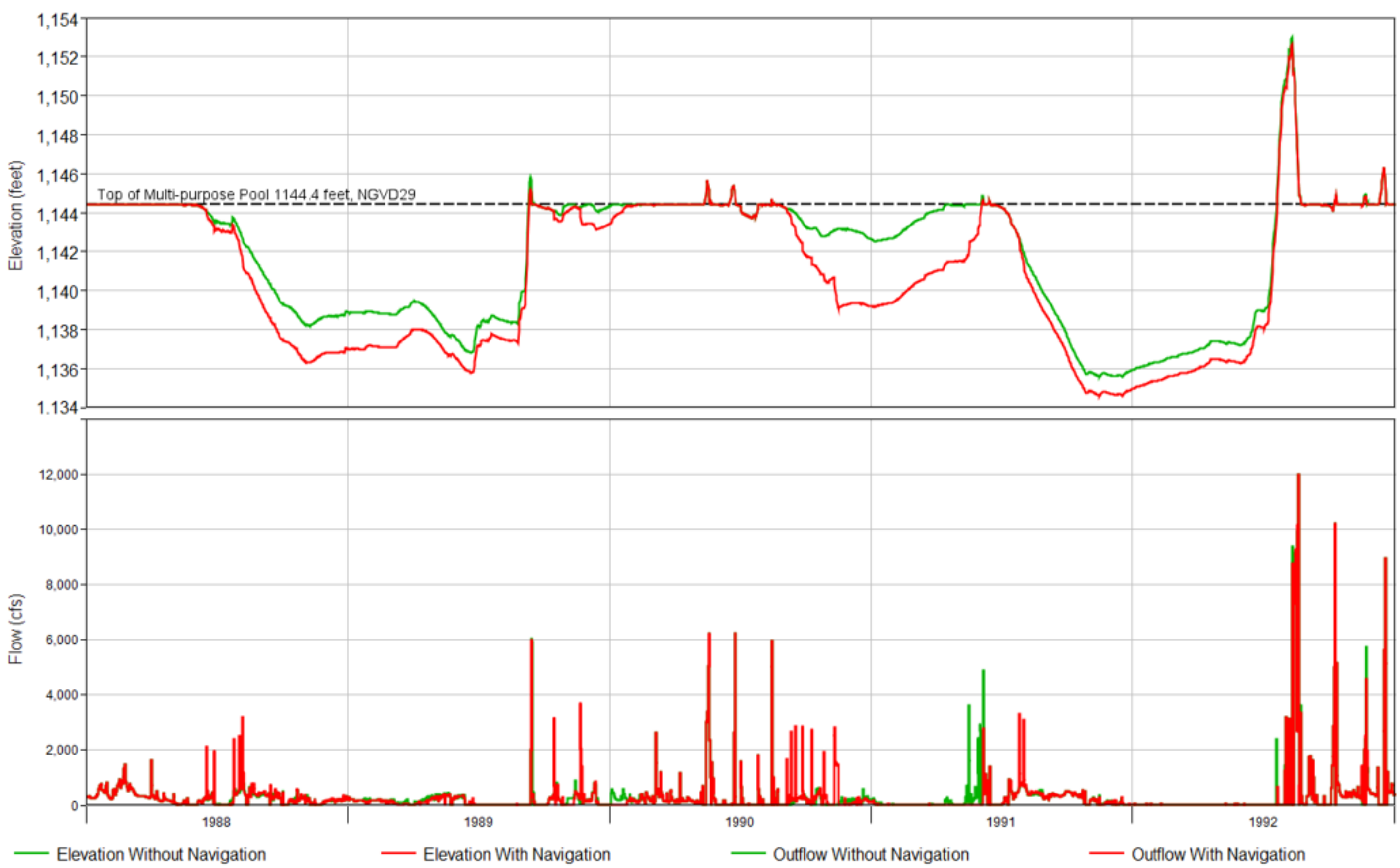


Figure 4-17. Milford pool elevation modeled with and without navigation flow support for the years 1989 through 1991.

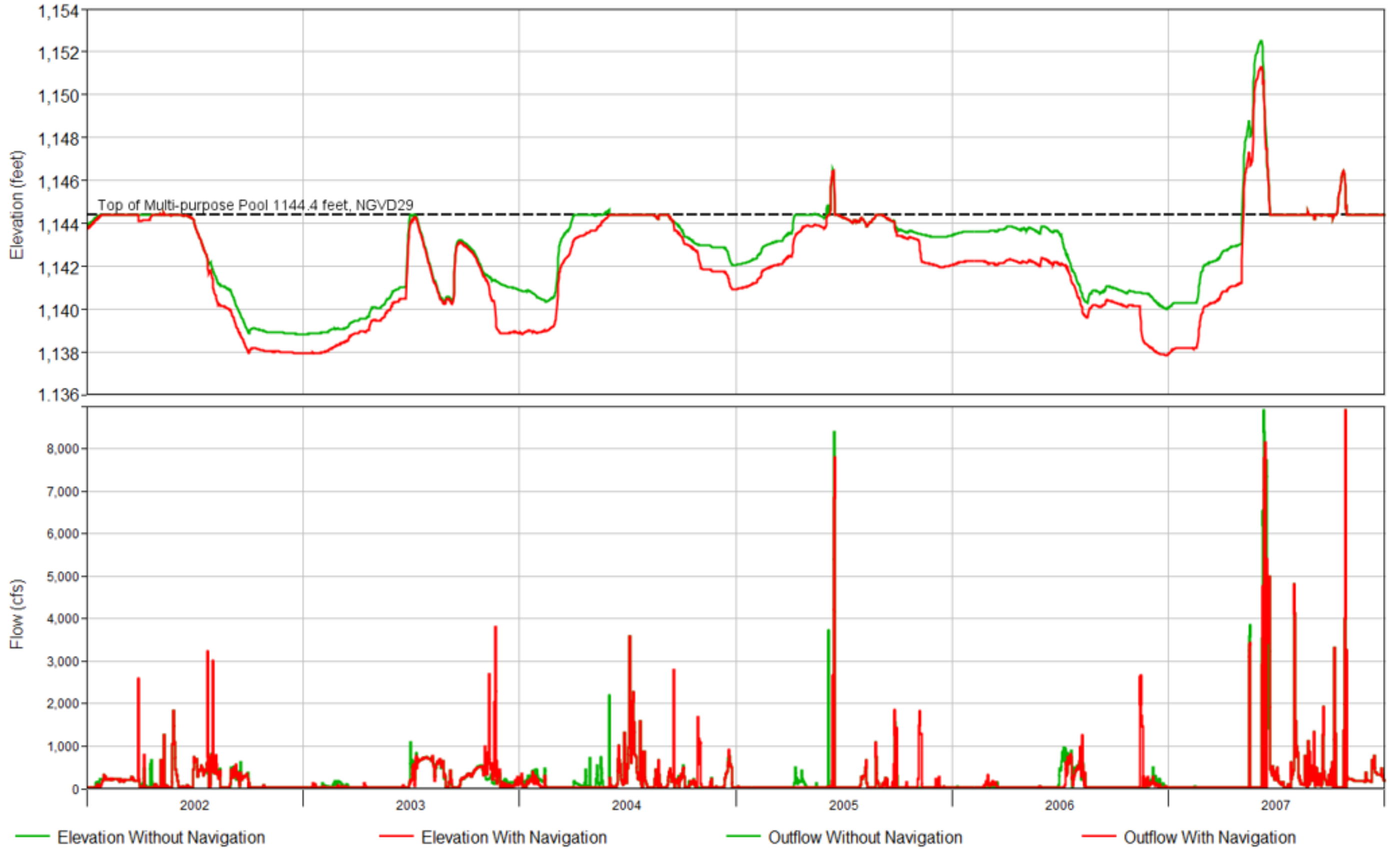


Figure 4-18. Milford pool elevation modeled with and without navigation flow support for the years 2002 through 2007.

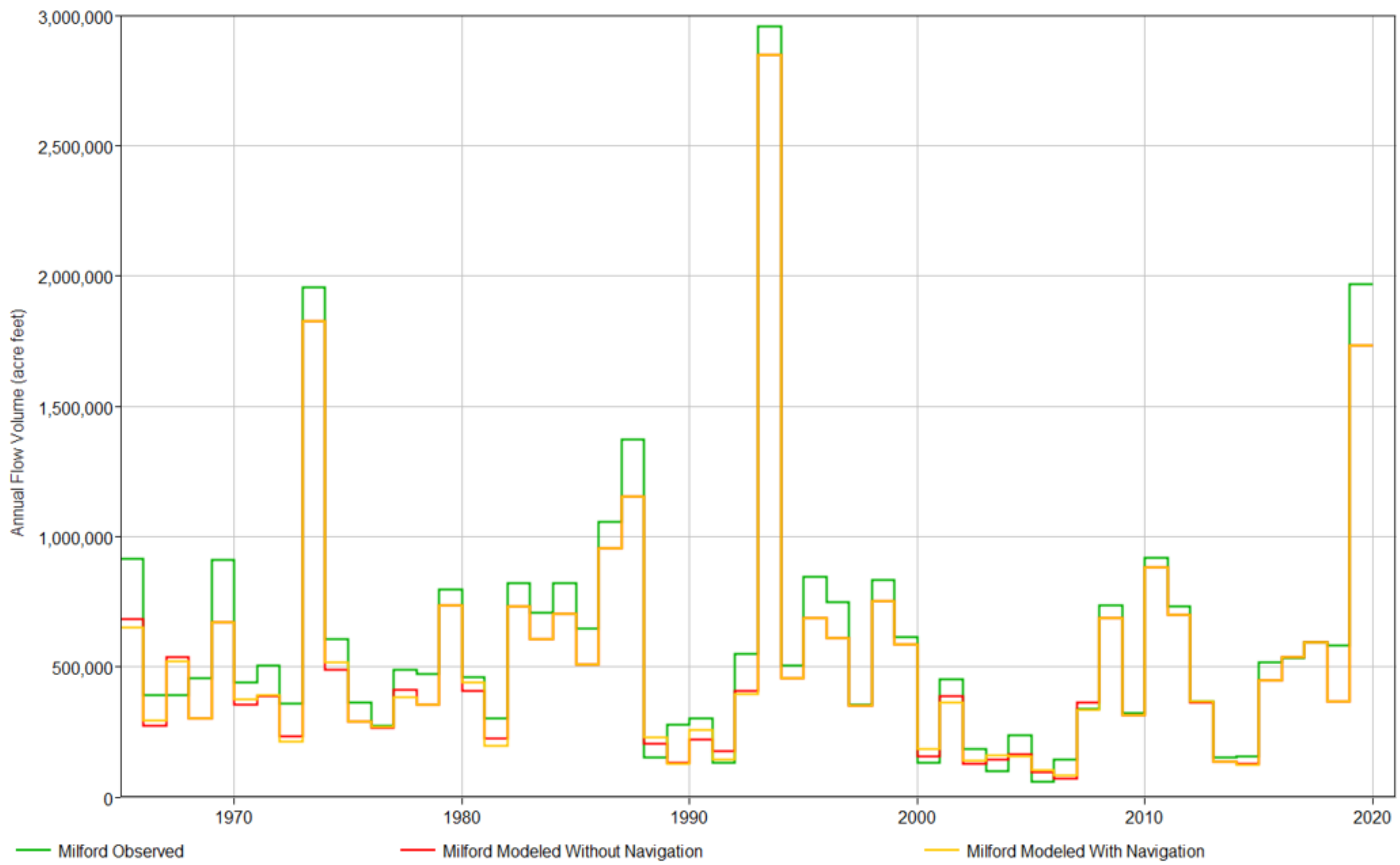


Figure 4-19 Milford Observed and Modeled Annual Flow Volume for 1965 through 2019.

Downstream of Milford the Kansas River at Fort Riley (impacted by regulation from all three Smoky Hill reservoirs and Milford Reservoir) annual flow volume is compared in Figure 4-20. This plot starts in 1973 which is about when the impacts of the regulation of all reservoirs began at these gages allowing a comparison of regulated observed and modeled. The observed volume continues to be slightly higher than modeled at this gage.

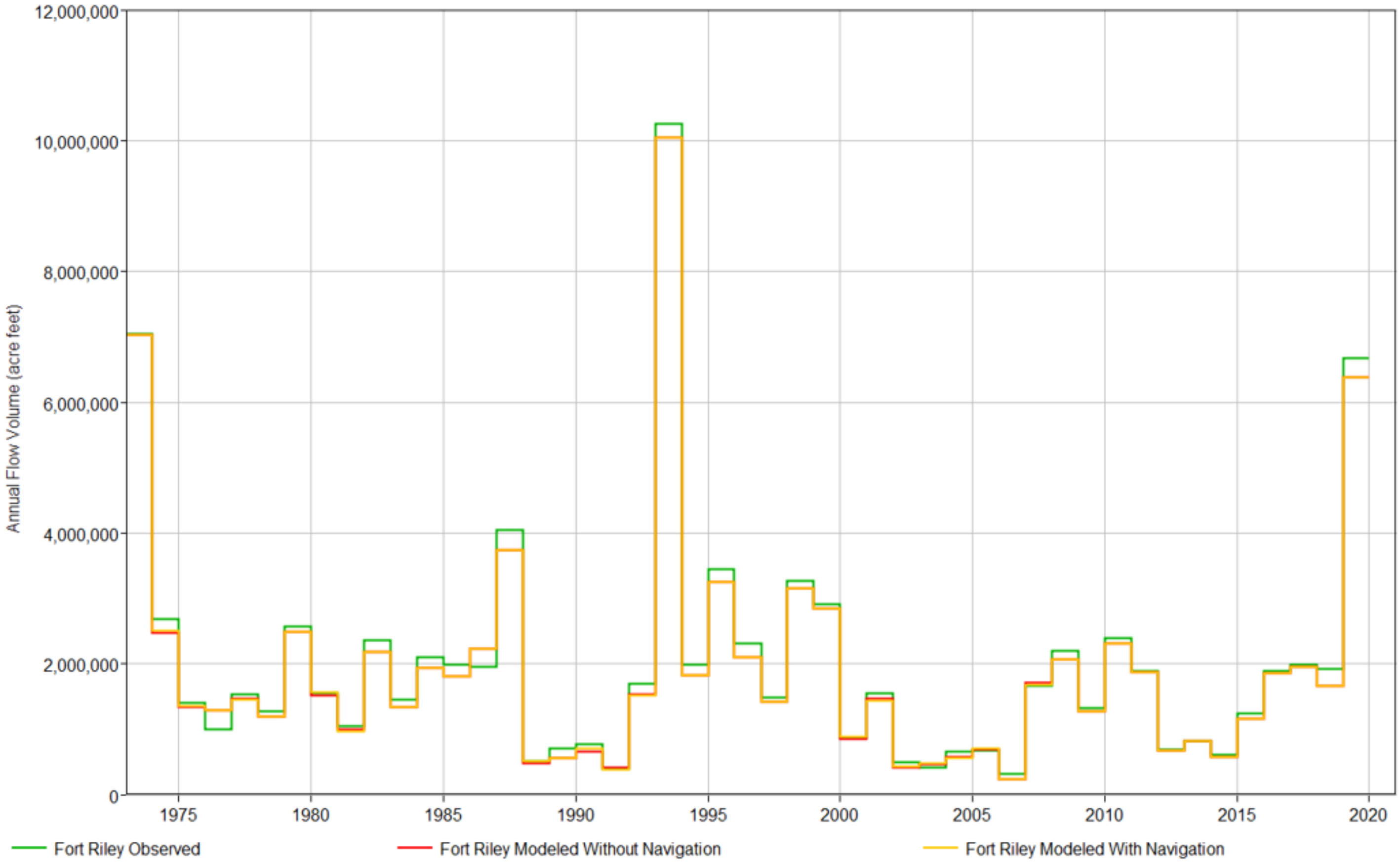


Figure 4-20 Fort Riley Observed and Modeled Annual Flow Volume for 1973 through 2019.

The Tuttle Creek Reservoir pool elevation duration plot from 01May1963 (approximate time of first fill) to 01Jan2020 is shown in Figure 4-21. Comparison of the observed and modeled duration indicate that the model tends to have higher pool elevations in the flood control pool. Seasonal water level management plans will allow the lake below the multi-purpose pool during the winter and five feet above the multi-purpose pool during the spring and fall which may be part of the reason for the observed differing from the modeled. The water level management plan was not put into the model since it is discretional and may not be followed depending on the basin conditions. Navigation results in pool elevations dropping below the multi-purpose pool slightly more often. Like Milford, the significant rise in the less frequent portions of the duration curve is probably due to the model constraining releases due to downstream control points especially on the Missouri River. Some of the potential reasons for these differences are discussed at the start of section 4.

Navigation flow support impacts to pool elevation and outflow for selected periods of time are shown in Figure 4-22 to Figure 4-25. These are drought years so pools are already low from reduced inflow and water quality support. Navigation support results in lower pool elevations. When large inflows occur, the without navigation scenario will make larger releases if the multi-purpose pool fills. Larger encroachments into the flood control pool were very similar for both scenarios.

Figure 4-26 shows the observed and modeled annual flow volume from 1960 (when outflow data started) to the 2019. The observed volumes match modeled closely except during high flow years. Navigation flow support only results in small differences a few years. Small differences between observed and modeled are probably due to estimated modeled evaporation. The large difference in 2019 is due to modeled storage being carried over into 2020. In the observed data set, water was emptied from flood storage before the end of 2019 by using a deviation for higher flow targets on the Missouri River, benefitting flood control operations at Milford, Tuttle Creek and Perry, as well as Clinton.

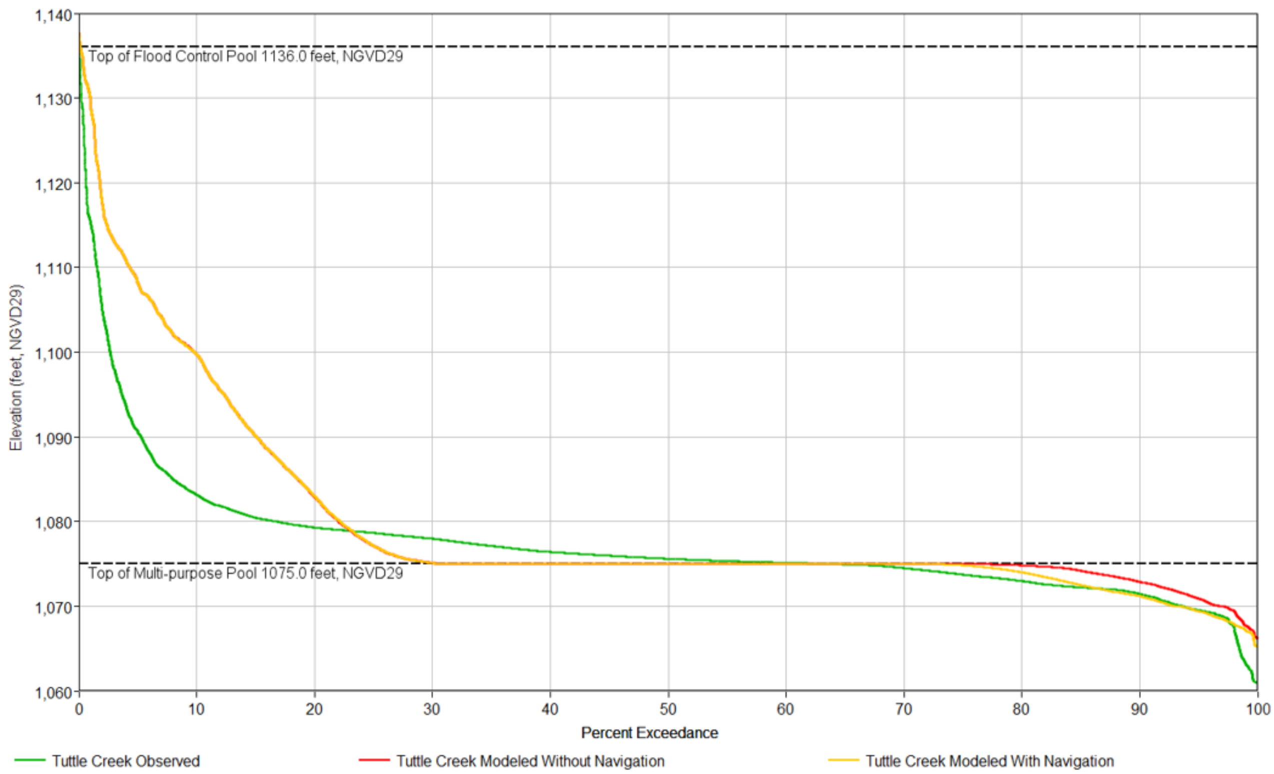


Figure 4-21 Tuttle Creek observed and modeled pool elevation duration from 01Apr1963 to 01Jan2020.

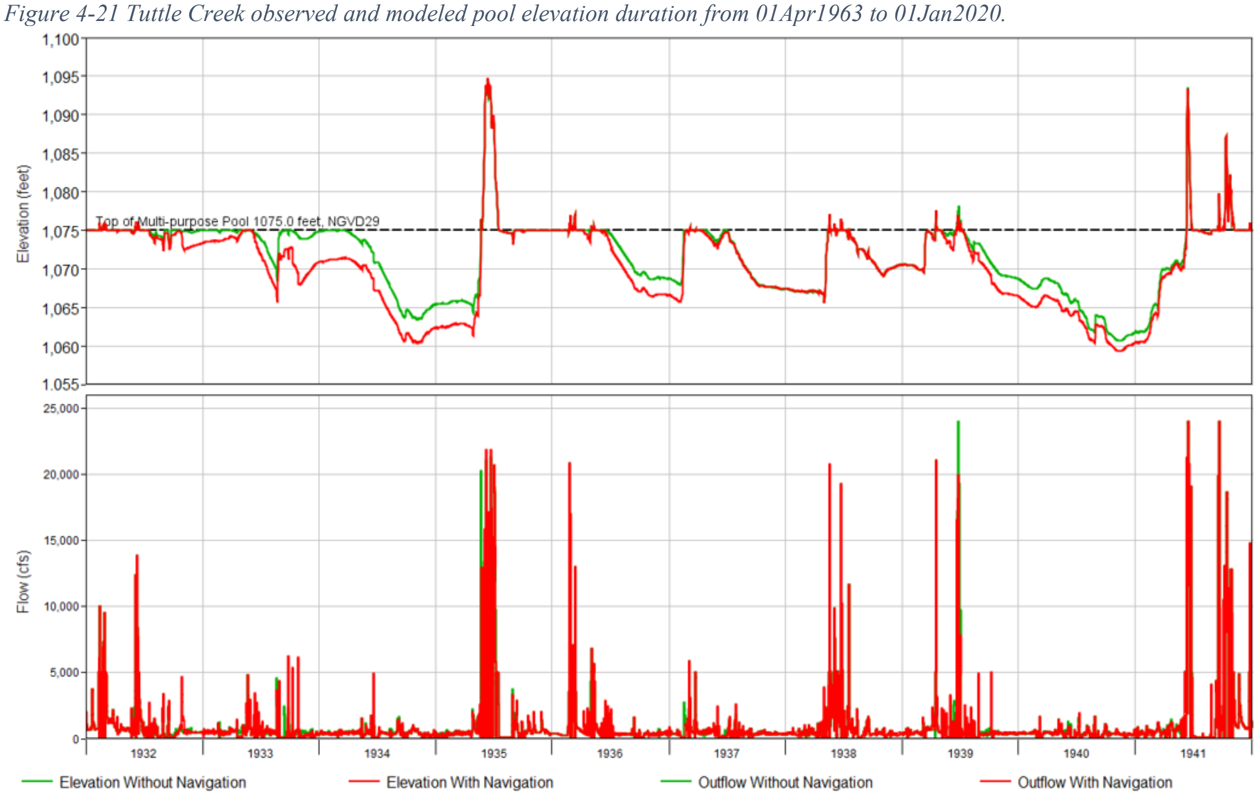


Figure 4-22. Tuttle Creek pool elevation modeled with and without navigation flow support for the years 1932 through 1941.

Figure 4-23. Tuttle Creek pool elevation modeled with and without navigation flow support for the years 1955 through 1959.

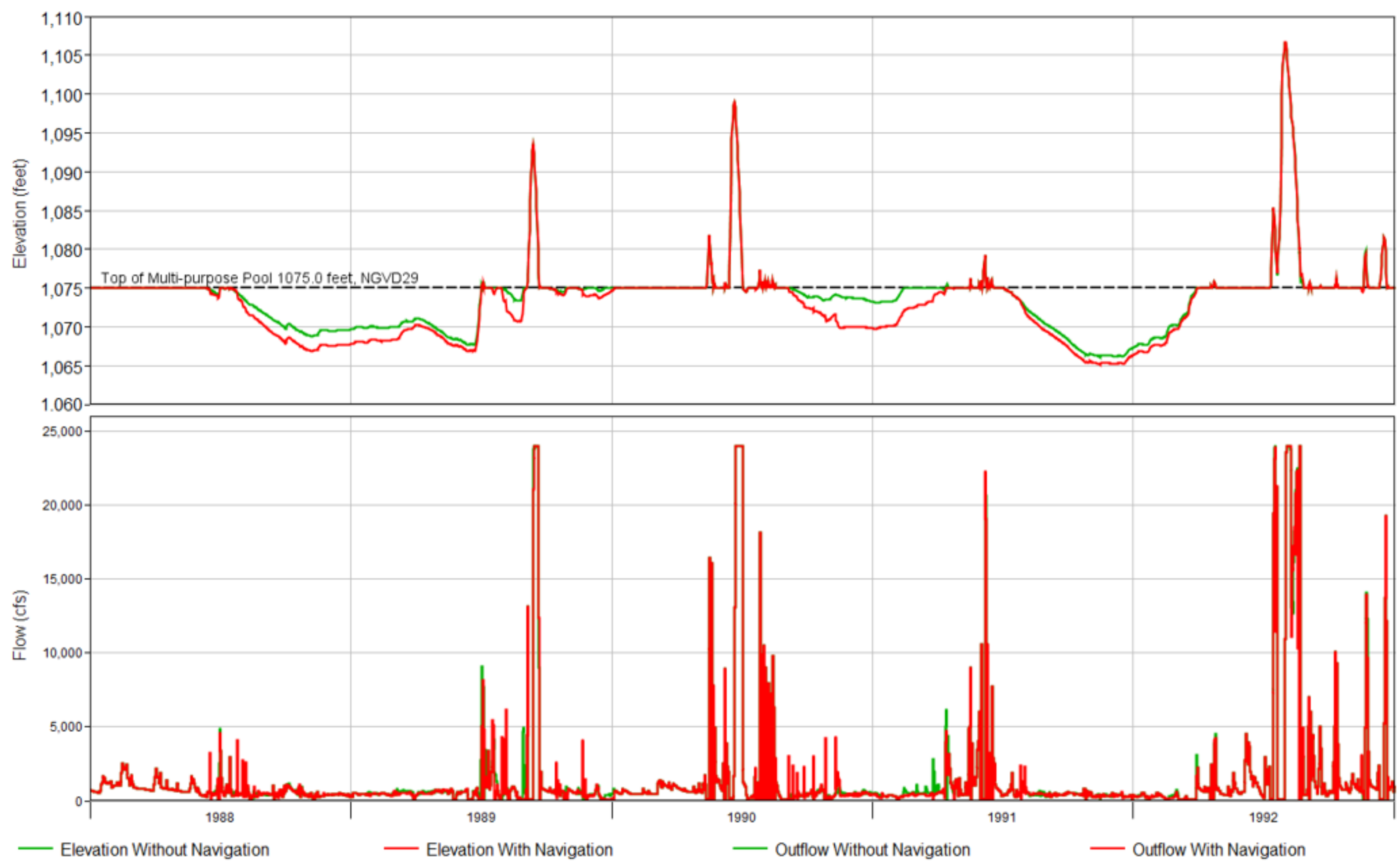


Figure 4-24. Tuttle Creek pool elevation modeled with and without navigation flow support for the years 1989 through 1991.

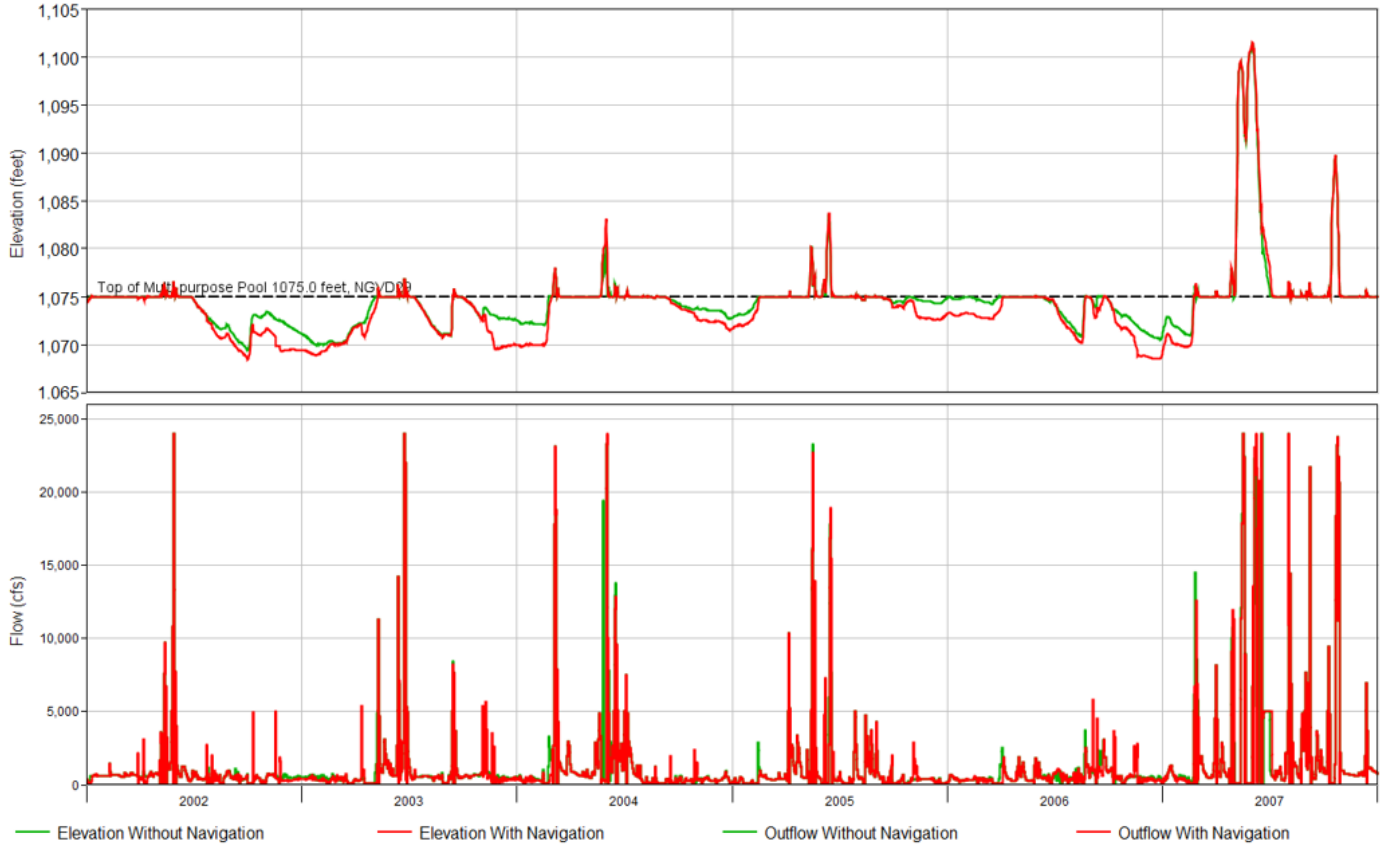


Figure 4-25. Tuttle Creek pool elevation modeled with and without navigation flow support for the years 2002 through 2007.

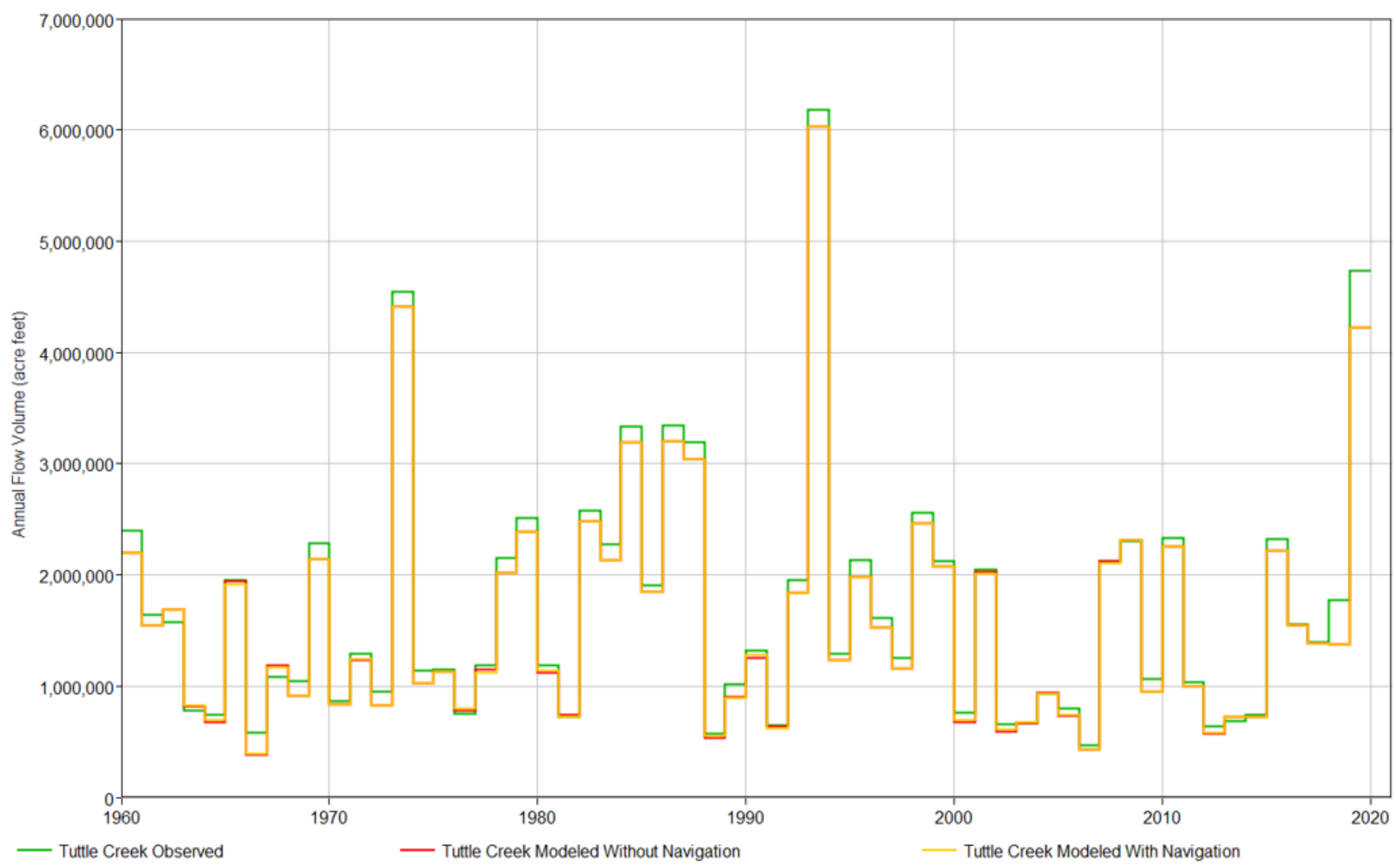


Figure 4-26 Tuttle Creek Observed and Modeled Annual Flow Volume for 1960 through 2019.

Downstream of Tuttle Creek the Kansas River at Wamego and Topeka (impacted by regulation from all three Smoky Hill reservoirs and Milford and Tuttle Creek reservoirs) annual flow volumes are compared in Figure 4-27 and Figure 4-28. These plots start in 1973 which is about when the impacts of the regulation of all reservoirs began at these gages allowing a comparison of regulated observed and modeled. The observed volume continues to be slightly higher than modeled at these gages especially during the larger flow years.

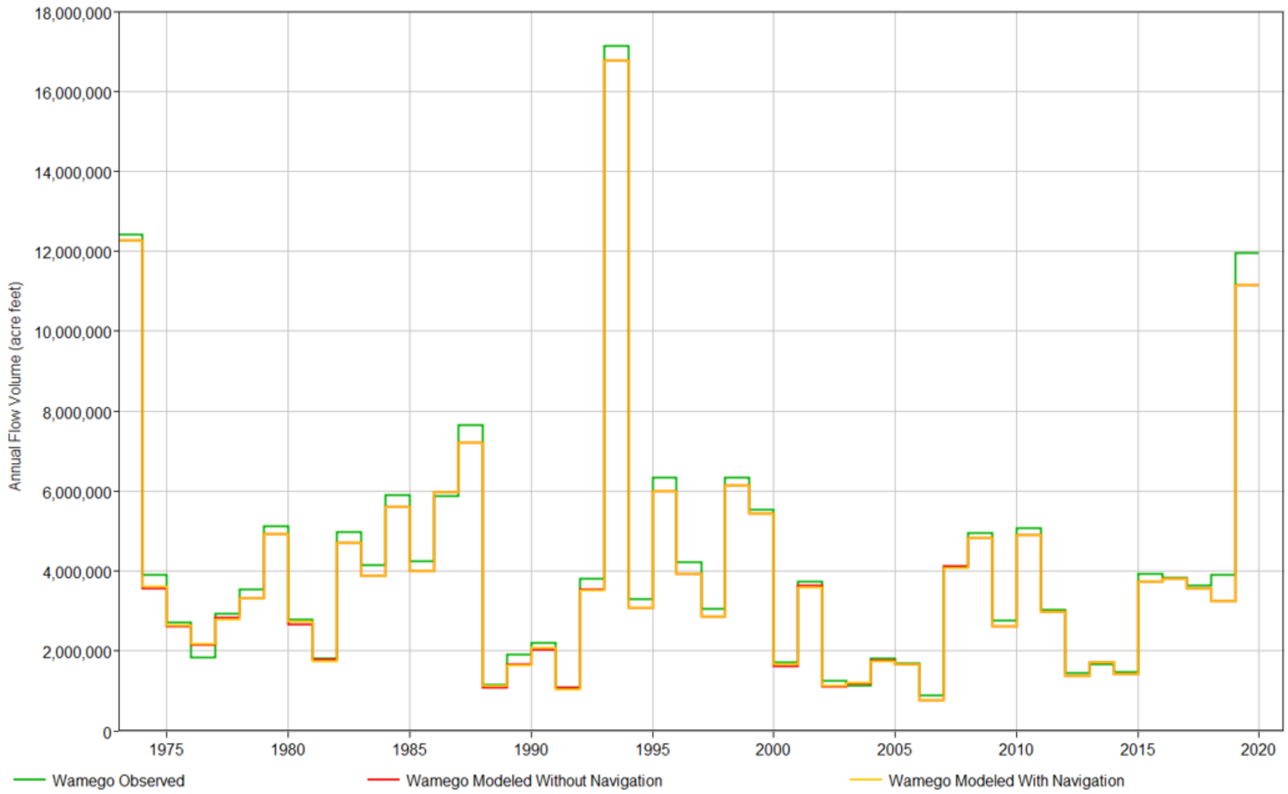


Figure 4-27 Wamego Observed and Modeled Annual Flow Volume for 1973 through 2019.

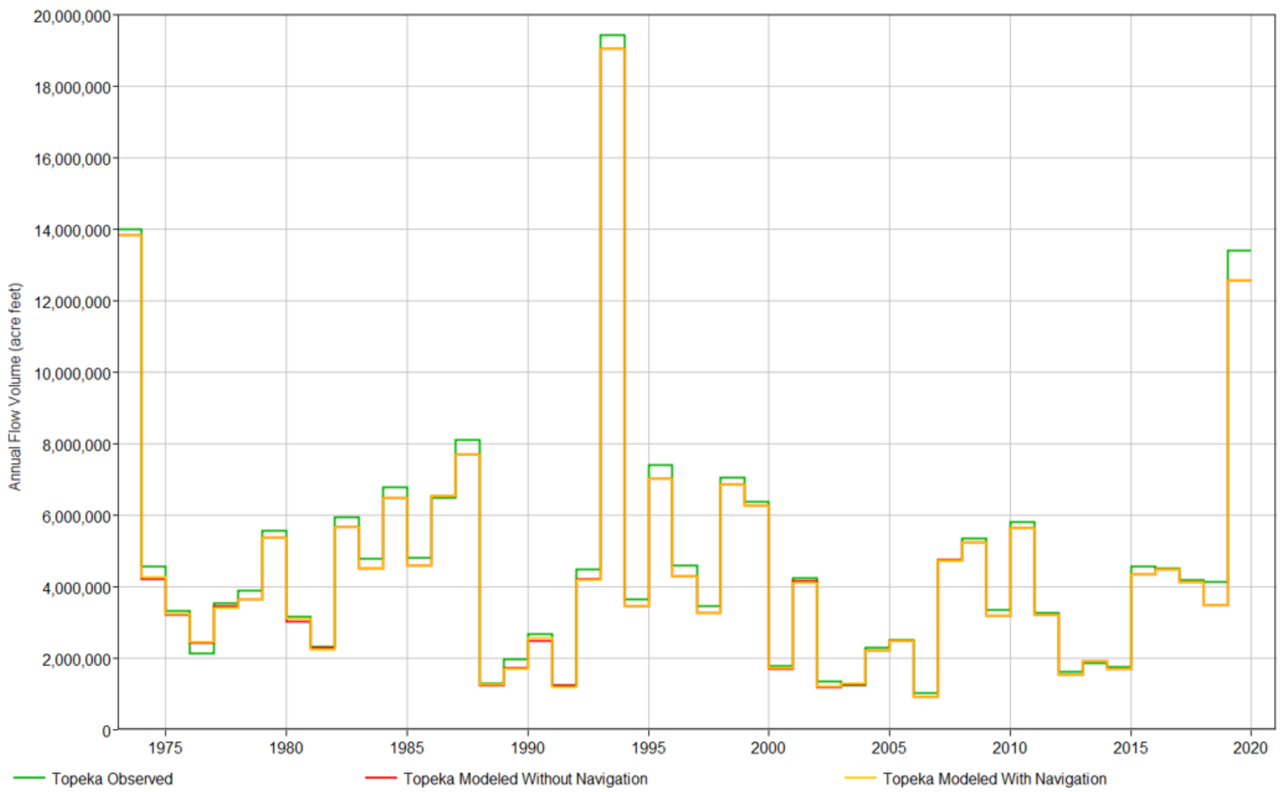


Figure 4-28 Topeka Observed and Modeled Annual Flow Volume for 1973 through 2019.

The Perry Reservoir pool elevation duration plot from 01April1971 (approximate time of first fill) to 01Jan2020 is shown in Figure 4-29. Comparison of the observed and modeled duration indicate that the model tends to be in the flood control pool for longer amounts of time. Seasonal water level management plans will allow the lake below the multi-purpose pool during the winter and 2 to 2.5 feet above the multi-purpose pool during the spring and fall which may be part of the reason for the observed differing from the modeled. The water level management plan was not put into the model since it is discretional and may not be followed depending on the basin conditions. The navigation scenario results in more common pool elevations below multi-purpose pool. Additional model analysis was conducted to see how much of an impact was made by the water level management plans. This analysis is shown in section 2.1 of "Attachment 1 Supporting Plots". Like Milford and Tuttle Creek, the significant rise in the less frequent portions of the duration curve is probably due to the model constraining releases due to downstream control points especially on the Missouri River. Some of the potential reasons for these differences are discussed at the start of section 4.

Navigation flow support impacts to pool elevation and outflow for selected periods of time are shown in Figure 4-30 to Figure 4-33. These are drought years so pools are already low from reduced inflow and water quality support. Navigation support results in lower pool elevations. When large inflows occur, the without navigation scenario will make larger releases if the multi-purpose pool fills. Larger encroachments into the flood control pool were very similar for both scenarios.

Figure 4-34 shows the observed and modeled annual flow volume from 1967 (when outflow data started) to the 2019. The observed volumes match modeled closely except during high flow years. Navigation flow support only results in small differences a few years. Small differences between observed and modeled are probably due to estimated modeled evaporation. The large difference in 2019 is due to modeled storage being carried over into 2020. In the observed data set, water was emptied from flood storage before the end of 2019 by using a deviation for higher flow targets on the Missouri River, benefitting flood control operations at Milford, Tuttle Creek and Perry, as well as Clinton.

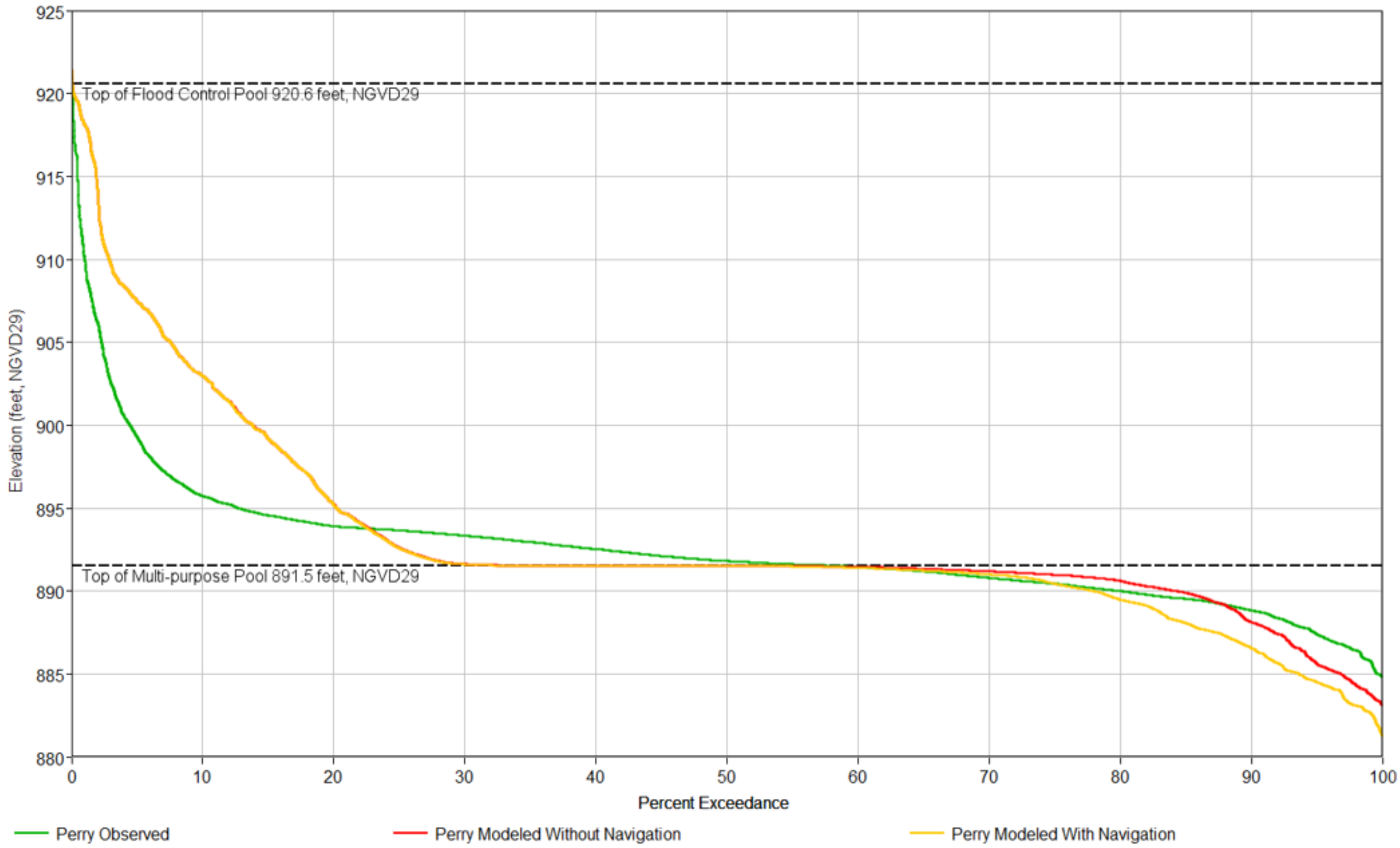


Figure 4-29 Perry observed and modeled pool elevation duration from 01Jun1970 to 01Jan2020.

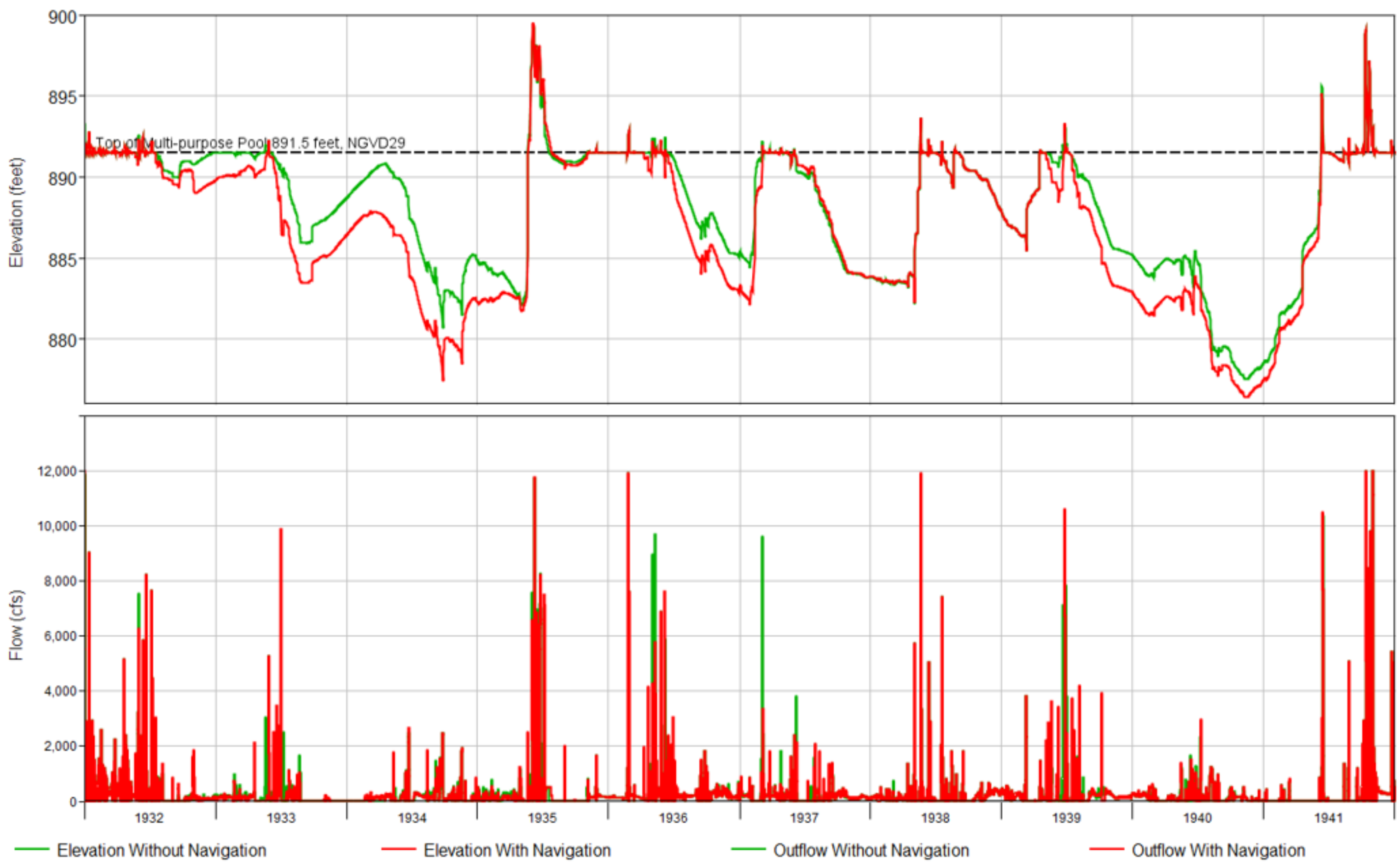


Figure 4-30. Perry pool elevation modeled with and without navigation flow support for the years 1932 through 1941.

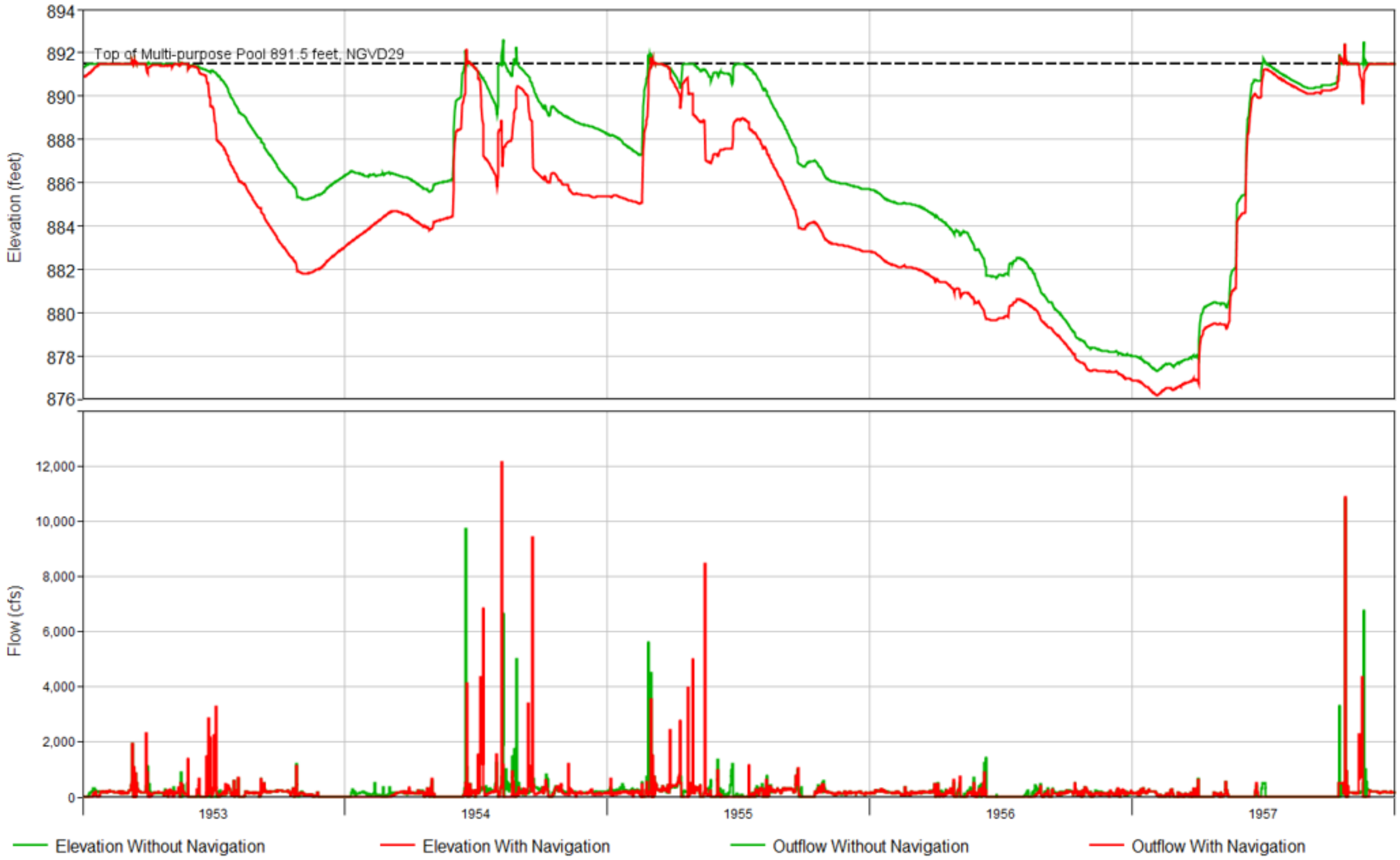


Figure 4-31. Perry pool elevation modeled with and without navigation flow support for the years 1955 through 1958.

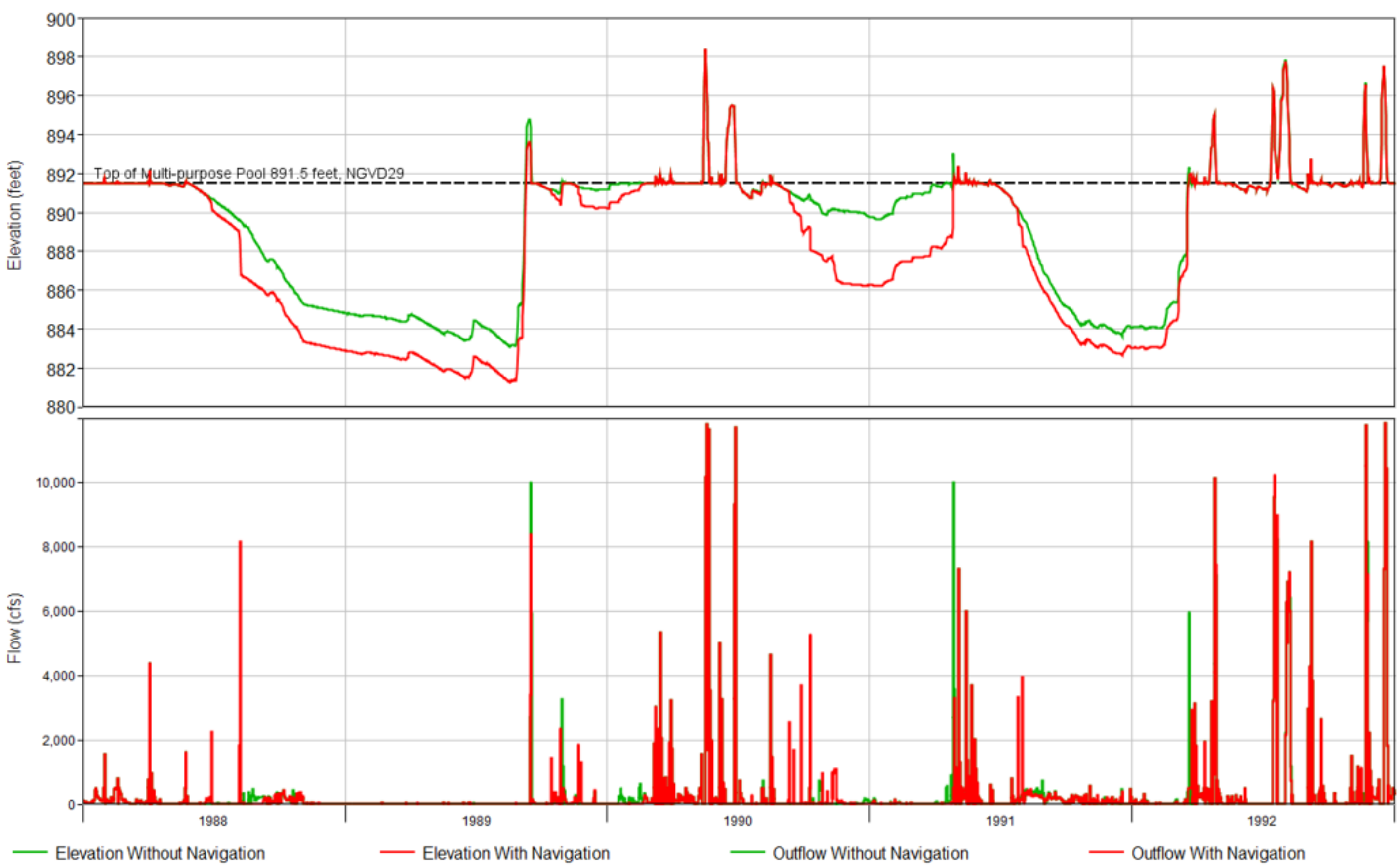


Figure 4-32. Perry pool elevation modeled with and without navigation flow support for the years 1989 through 1991.

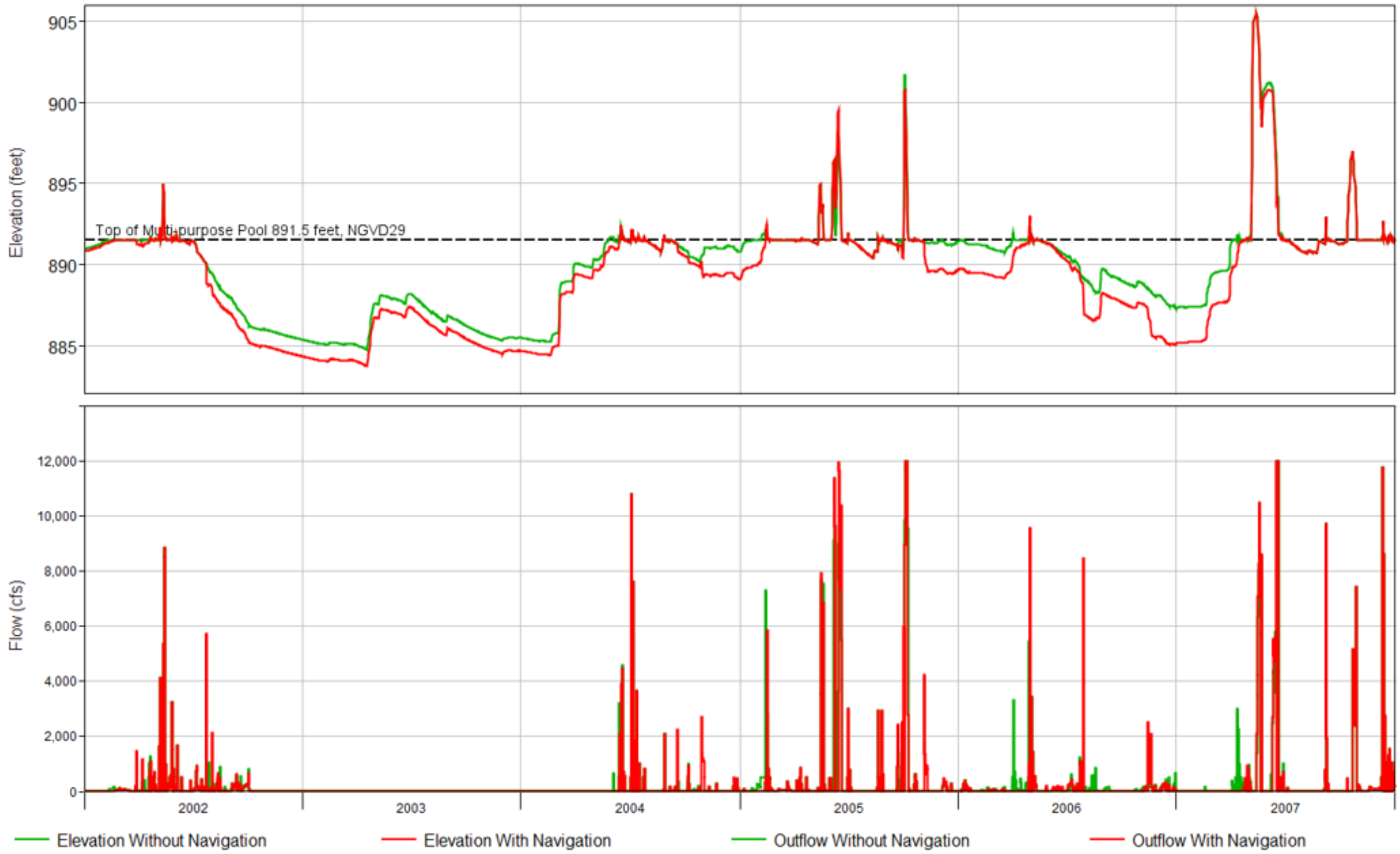


Figure 4-33. Perry pool elevation modeled with and without navigation flow support for the years 2002 through 2007.

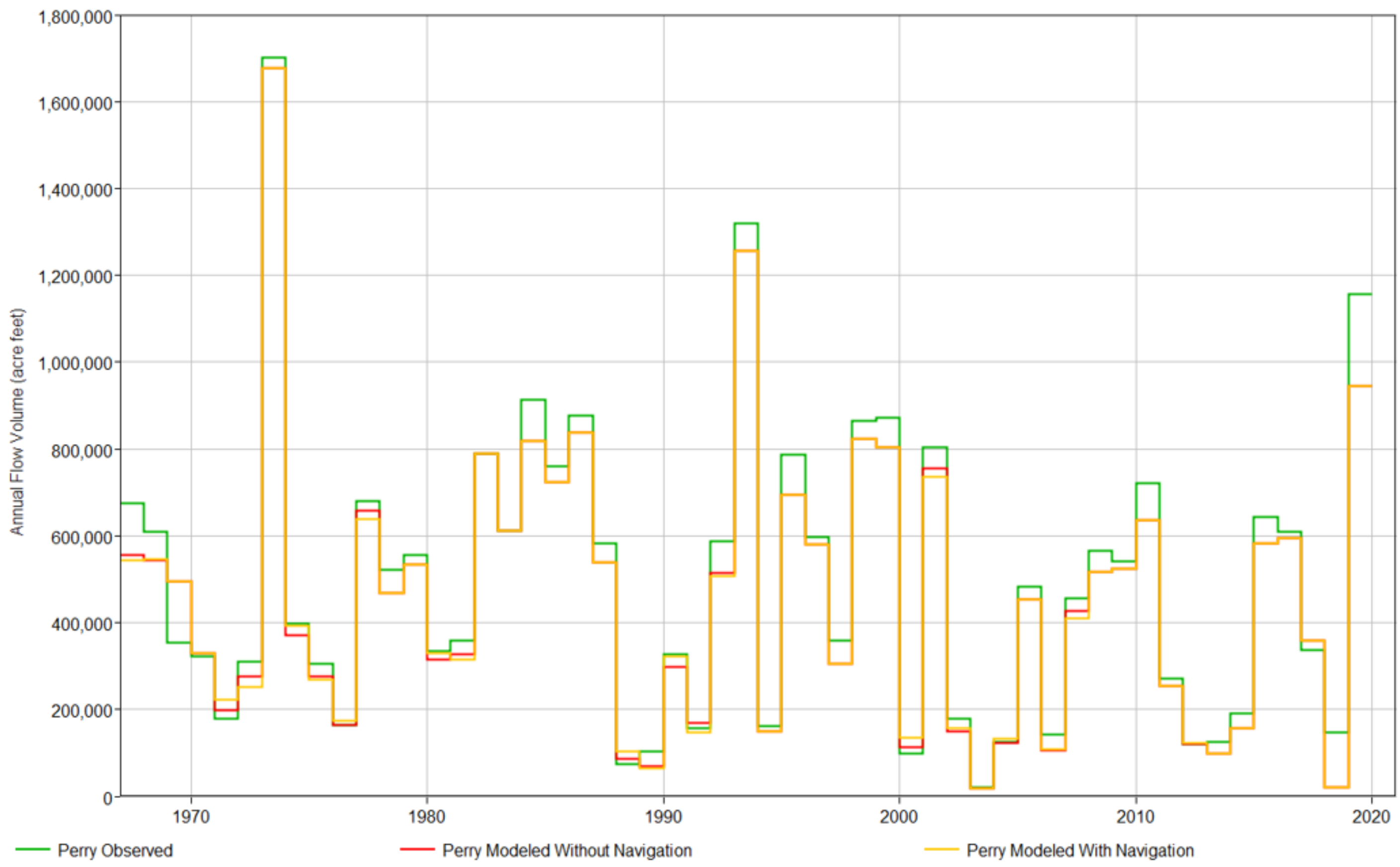


Figure 4-34 Perry Observed and Modeled Annual Flow Volume for 1967 through 2019.

Downstream of Perry the Kansas River at Lecompton (impacted by regulation from all three Smoky Hill reservoirs and Milford, Tuttle Creek, and Perry reservoirs) annual flow volumes are compared in Figure 4-35. This plot starts in 1973 which is about when the impacts of the regulation of all reservoirs began at these gages allowing a comparison of regulated observed and modeled. The observed volume continues to be slightly higher than modeled at these gages especially during the larger flow years.

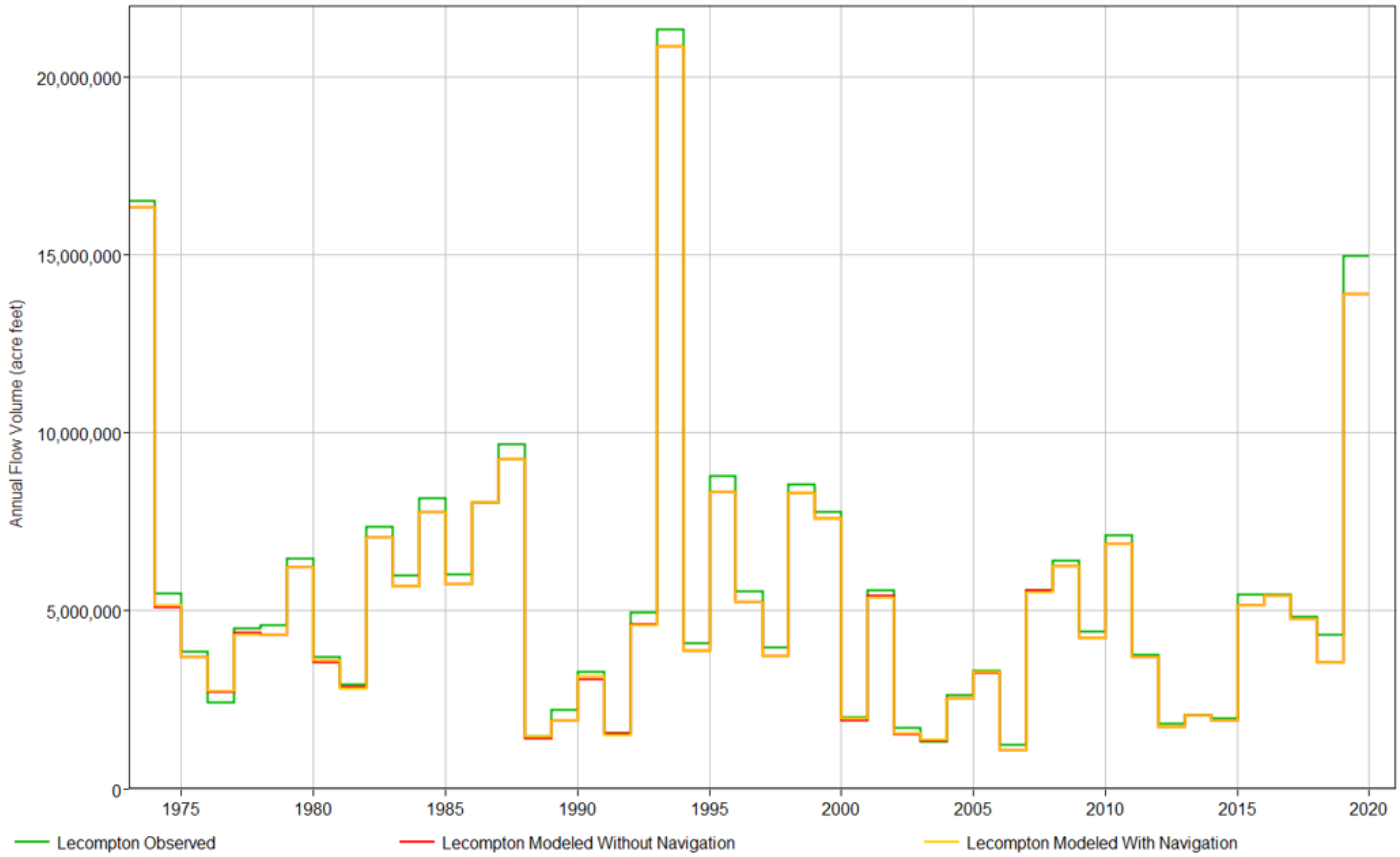


Figure 4-35 Lecompton Observed and Modeled Annual Flow Volume for 1973 through 2019.

The Clinton Reservoir pool elevation duration plot from 01April1980 (approximate time of first fill) to 01Jan2020 is shown in Figure 4-36. Both model scenarios result in the same pool duration since navigation flow is not supported from Clinton. Comparison of the observed and modeled duration indicate that the model tends to be in the flood control pool for longer amounts of time. Seasonal water level management plans will allow the lake below the multi-purpose pool during the winter and two feet above the multi-purpose pool during the spring and fall which may be part of the reason for the observed differing from the modeled. The water level management plan was not put into the model since it is discretional and may not be followed depending on the basin conditions. Like Milford, Tuttle Creek, and Perry, there is a rise in the less frequent portions of the duration curve which are probably due to the model constraining releases due to downstream control points especially on the Missouri River. Some of the potential reasons for these differences are discussed at the start of section 4. These impacts do not appear to be as large as the other lakes. Figure 4-37 shows the observed and modeled annual flow volume from 1978 (when outflow data started) to the 2019. The modeled scenarios with and without navigation are identical. The observed volumes tend to be higher than modeled. Small differences are probably due to estimated modeled evaporation. The large difference in 2019 is due to modeled storage being carried over into 2020. In the observed data set, water was emptied from flood storage before the end of 2019 by using a deviation for higher flow targets on the Missouri River, benefitting flood control operations at Milford, Tuttle Creek and Perry, as well as Clinton.

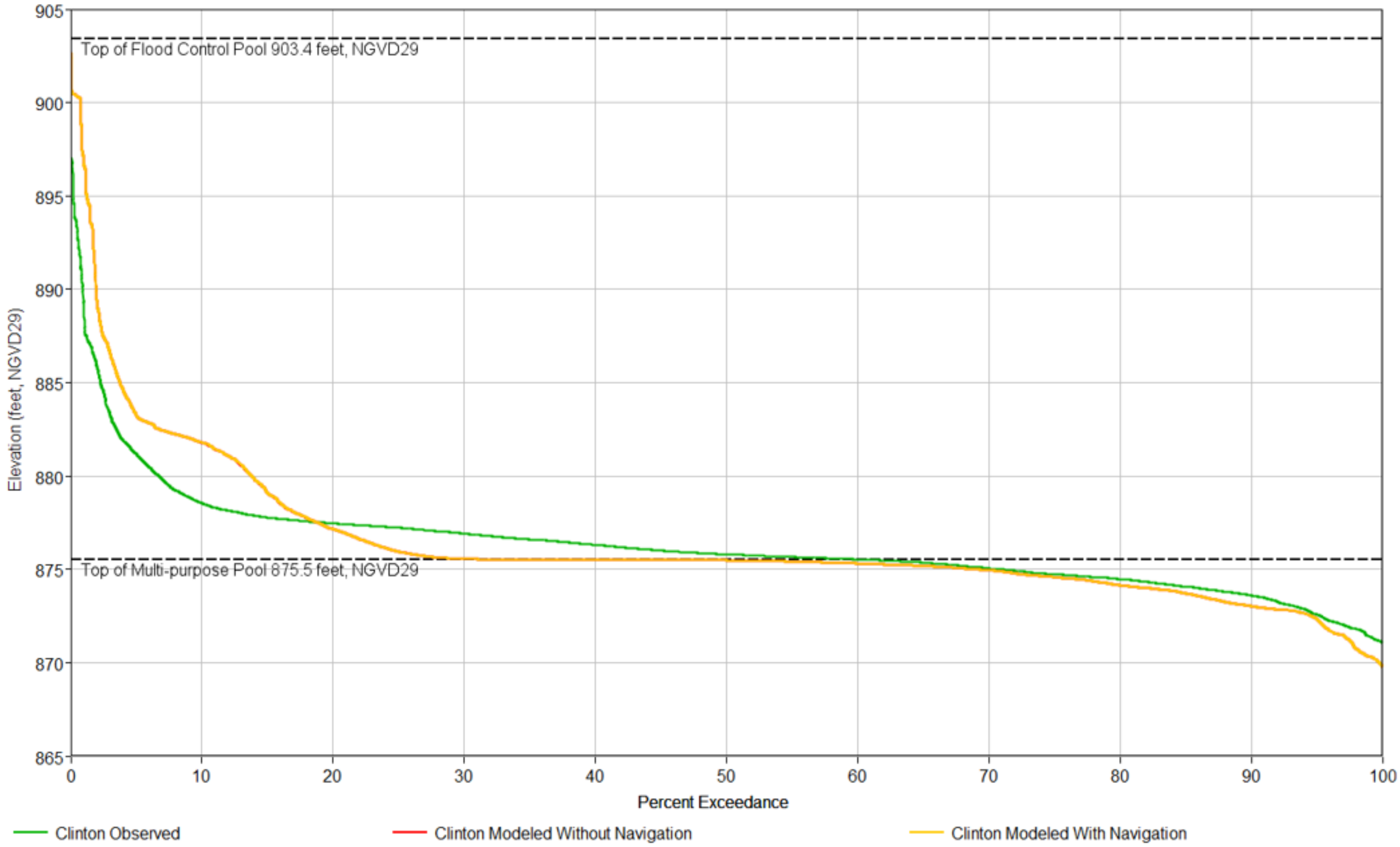


Figure 4-36 Clinton observed and modeled pool elevation duration from 01Apr1980 to 01Jan2020.

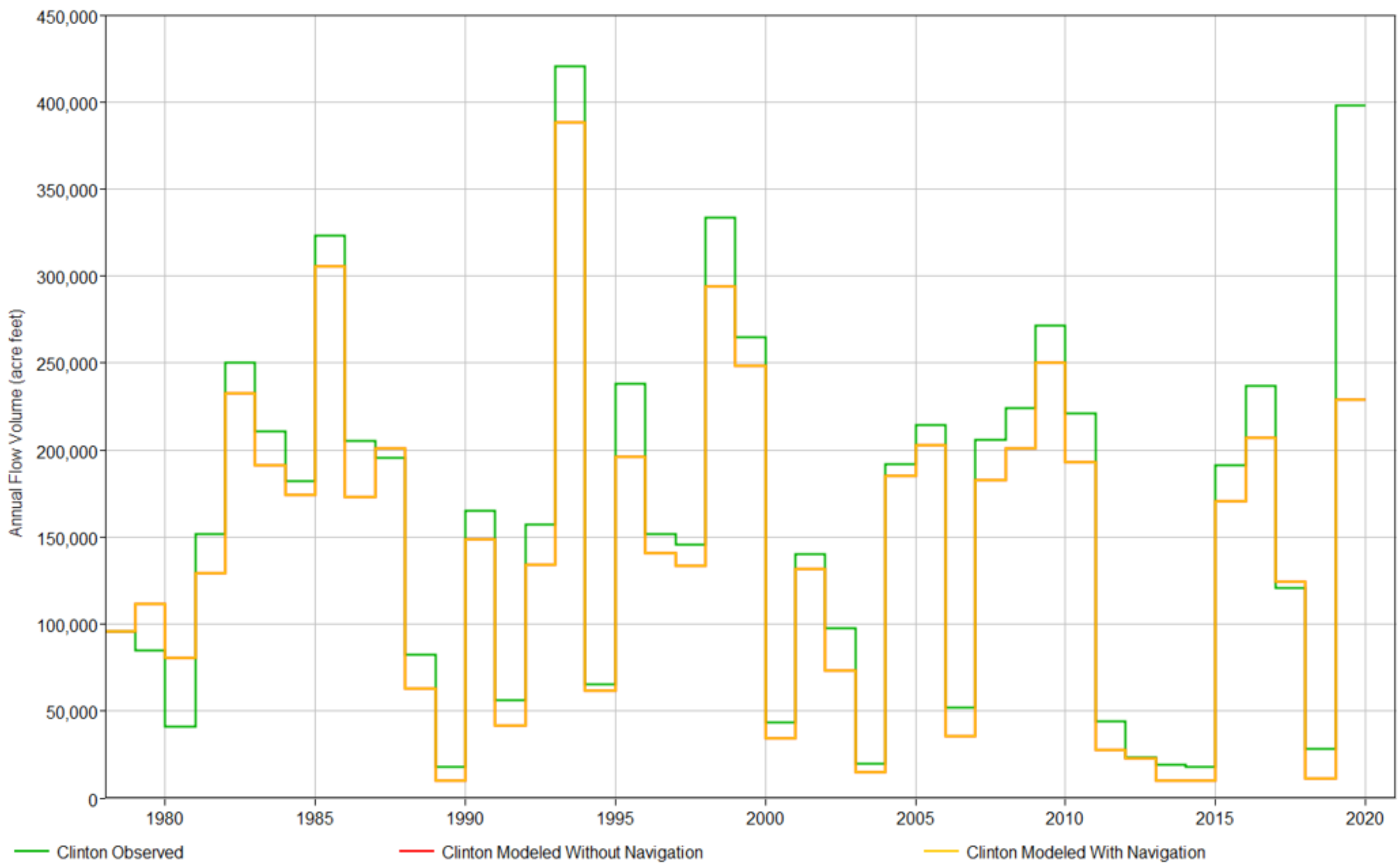


Figure 4-37 Clinton Observed and Modeled Annual Flow Volume for 1978 through 2019.

Downstream of Clinton the Wakarusa River at Lawrence (impacted by regulation from Clinton), Kansas River at Desoto (impacted by regulation from all the Kansas Basin Reservoirs) and the Missouri River at Kansas City and Waverly (impacted by regulation from all the Upper Missouri River and Kansas River reservoirs) annual flow volumes are compared in Figure 4-38, Figure 4-39, Figure 4-44, and Figure 4-45. These plots start in 1980 which is about when the impacts of the regulation of all reservoirs began at these gages allowing a comparison of regulated observed and modeled. Navigation flow support has very little impact to the annual flow volumes as most of the releases are for a short duration. The observed volume continues to be higher than modeled at the Lawrence gage, consistent with the actual passage of flood water in 2019. Desoto modeled is very similar to observed except during the flood years. 2019 observed volume is higher due to modeled flood storage being carried over to 2020 and follows the trend witnessed at Lawrence, potentially diminished somewhat by the much larger flows in the Kansas and Missouri River gages. The Missouri River gages observed flow volume tend to be slightly lower than modeled and do not share the trends observed on the Kansas River. This is probably due to the modeled mainstem Missouri River regulated flows and local inflows overwhelming contributions from the Kansas River.

The effect on the Kansas River at Desoto flow of reservoir releases for navigation flow support is shown in Figure 4-40 to Figure 4-43. Navigation support was provided up to 4000 cfs and the releases are generally made late in the year when the Missouri River dropped. Annual peak flows are generally the same with and without navigation, but some of the dryer years released larger peak flows in the without navigation scenario.

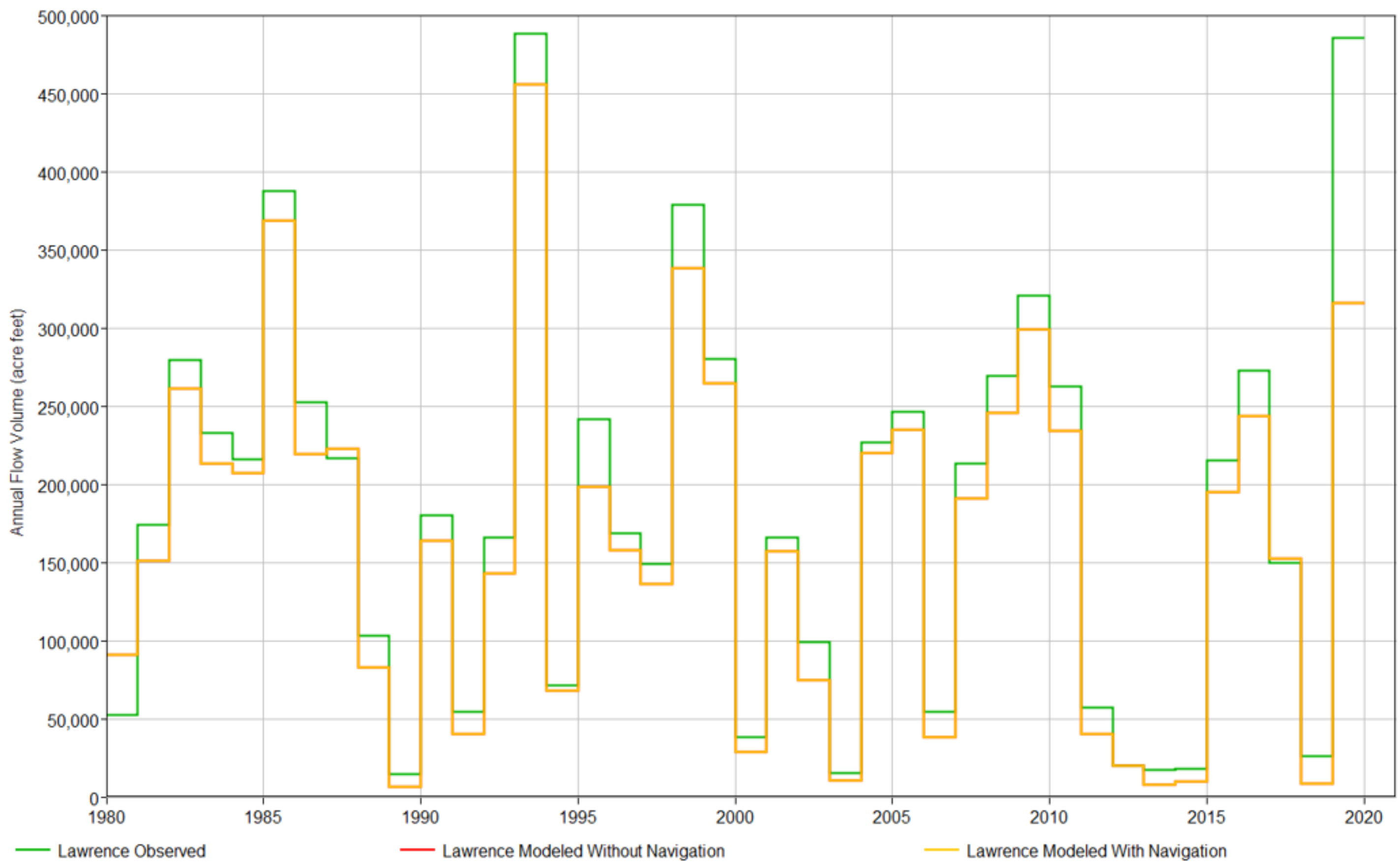


Figure 4-38 Lawrence Observed and Modeled Annual Flow Volume for 1980 through 2019.

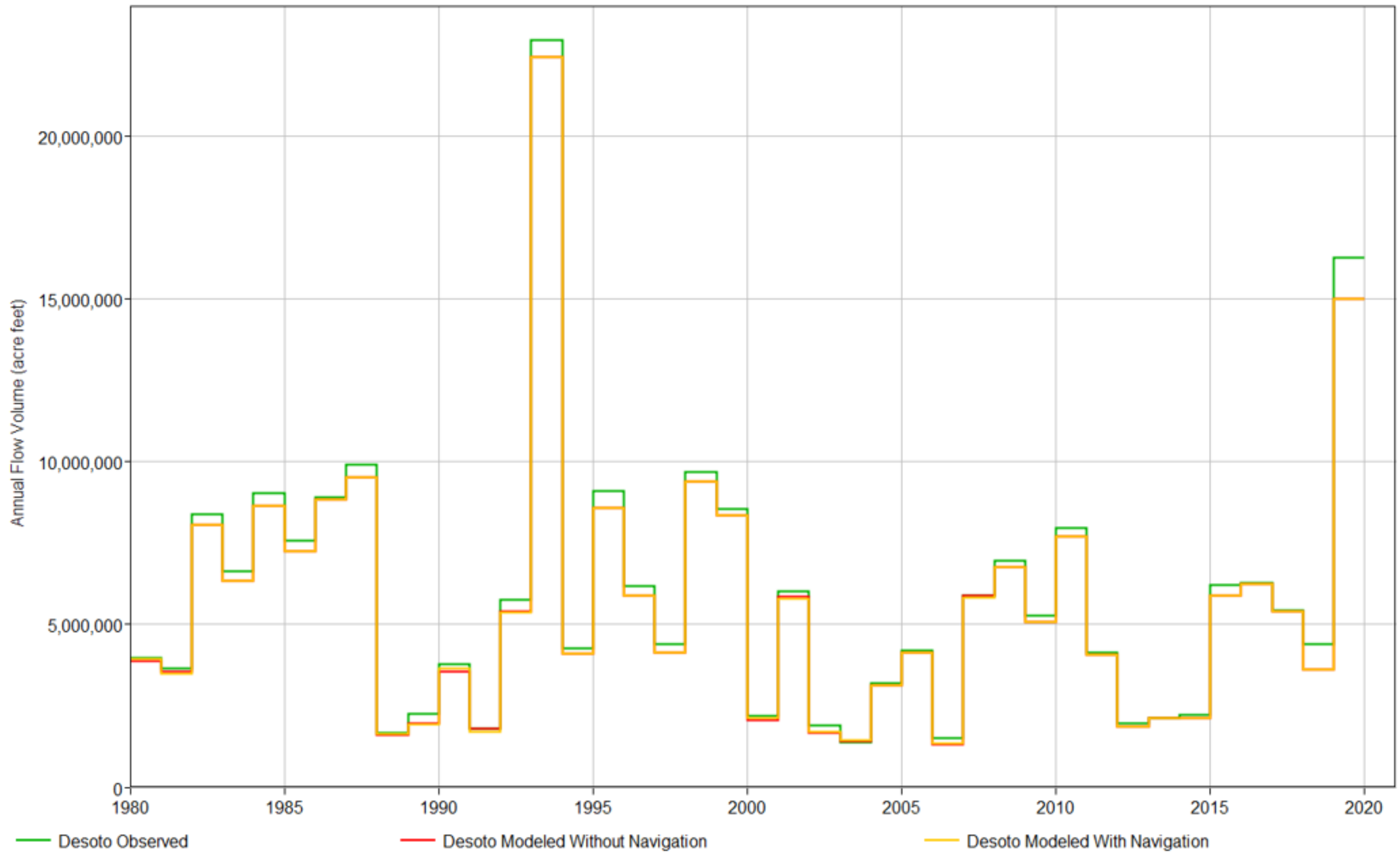


Figure 4-39 Desoto Observed and Modeled Annual Flow Volume for 1980 through 2019.

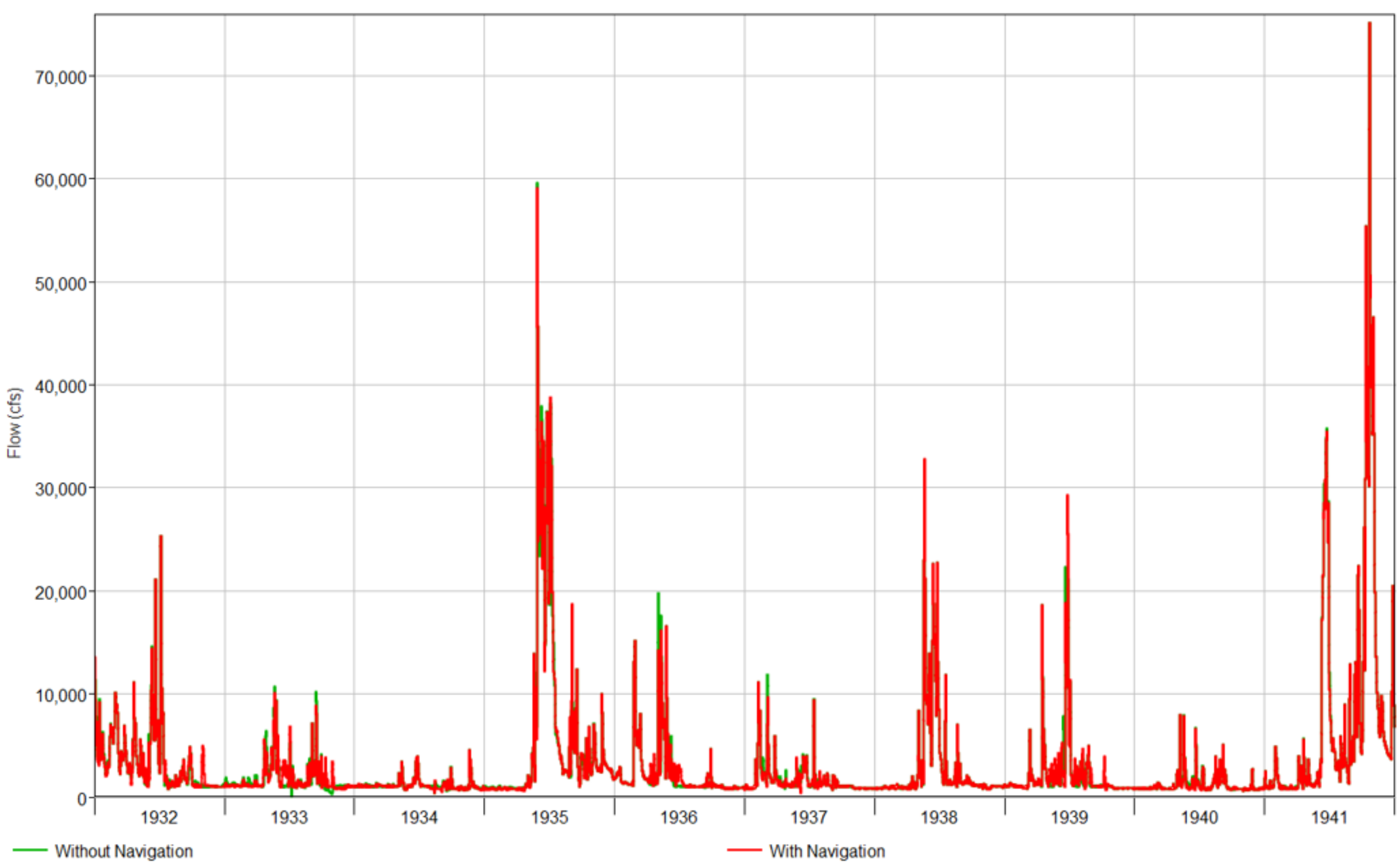


Figure 4-40. Desoto flow modeled with and without navigation flow support for the years 1932 through 1941.

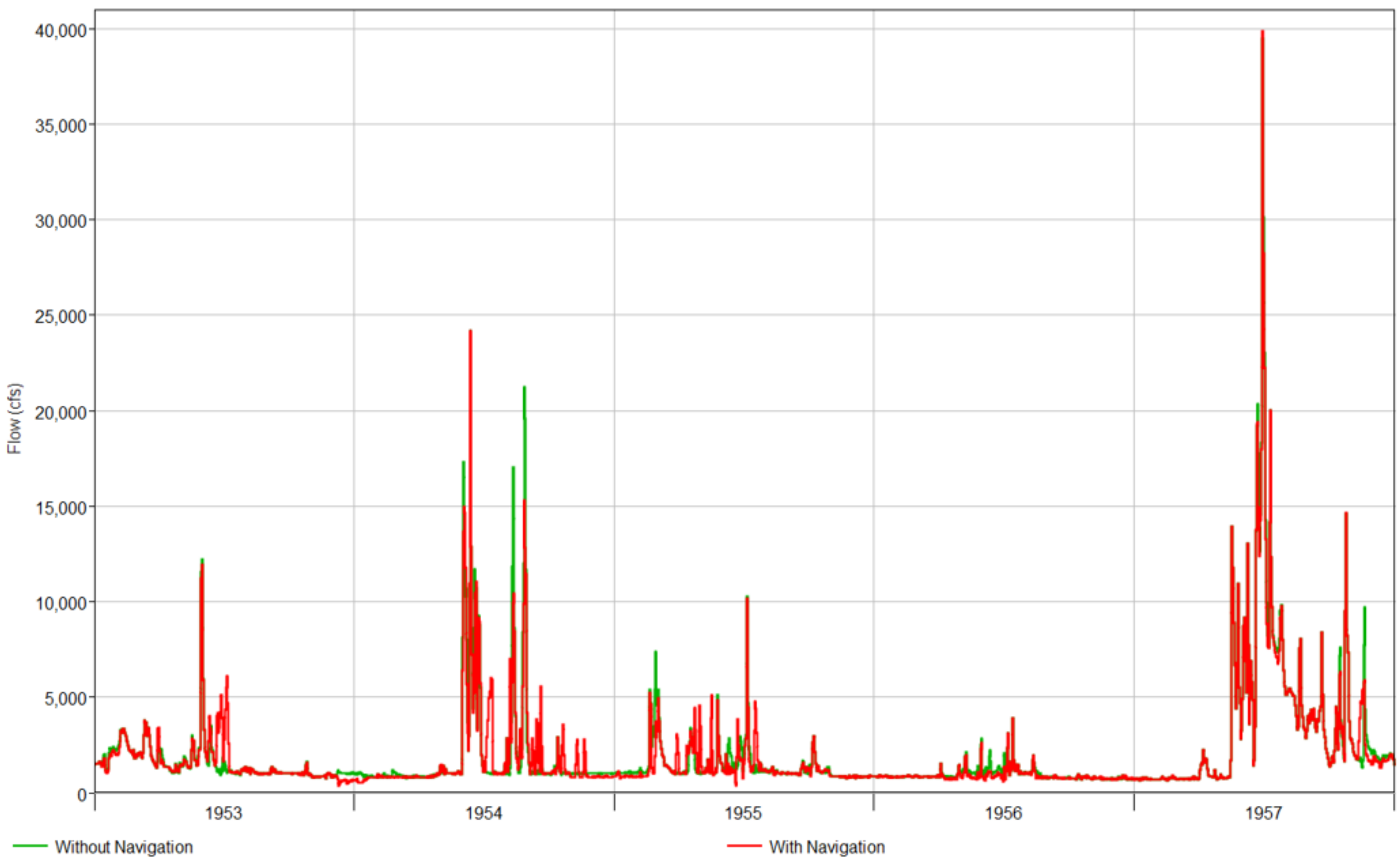


Figure 4-41. Desoto flow modeled with and without navigation flow support for the years 1955 through 1958.

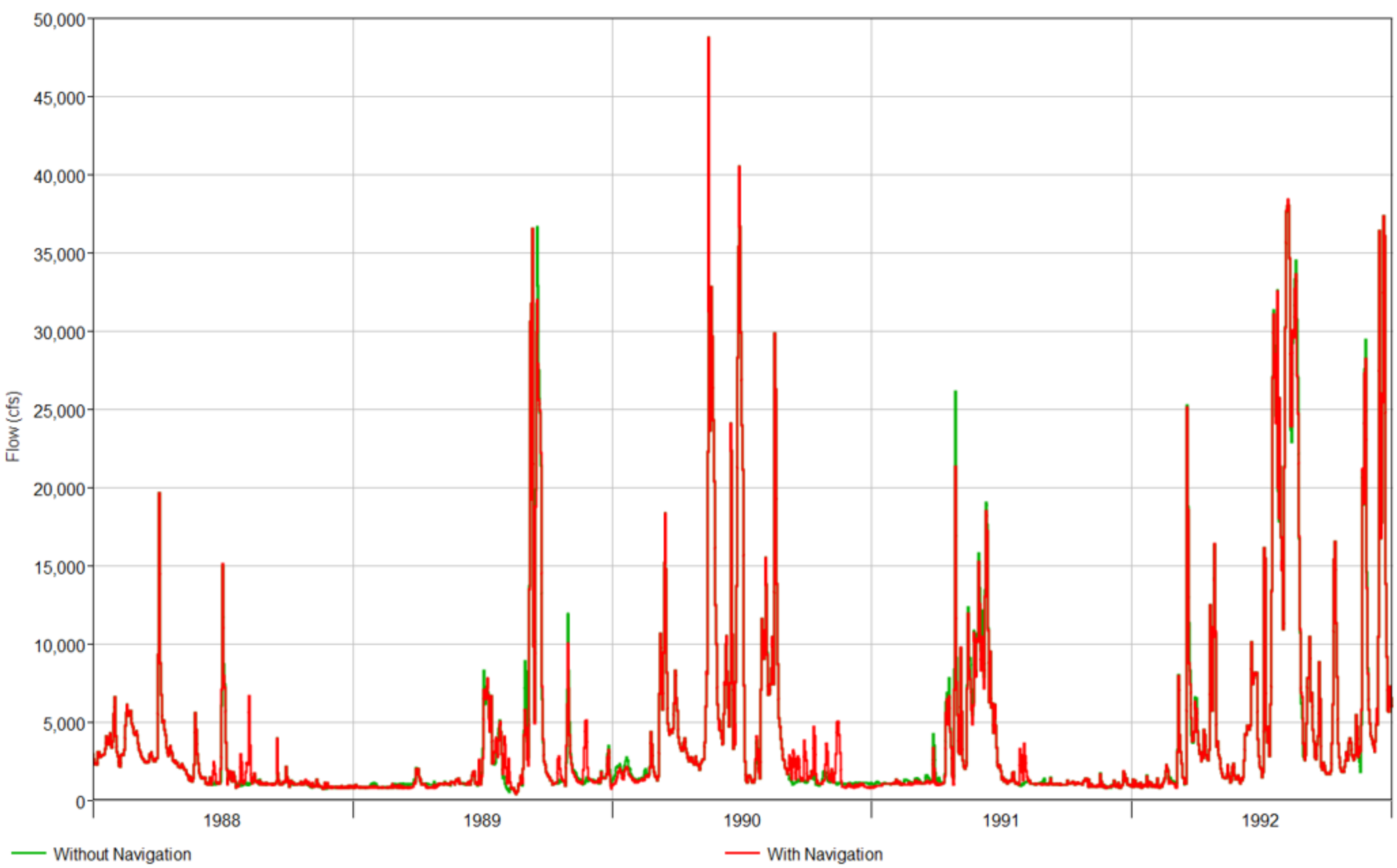


Figure 4-42. Desoto flow modeled with and without navigation flow support for the years 1989 through 1991.

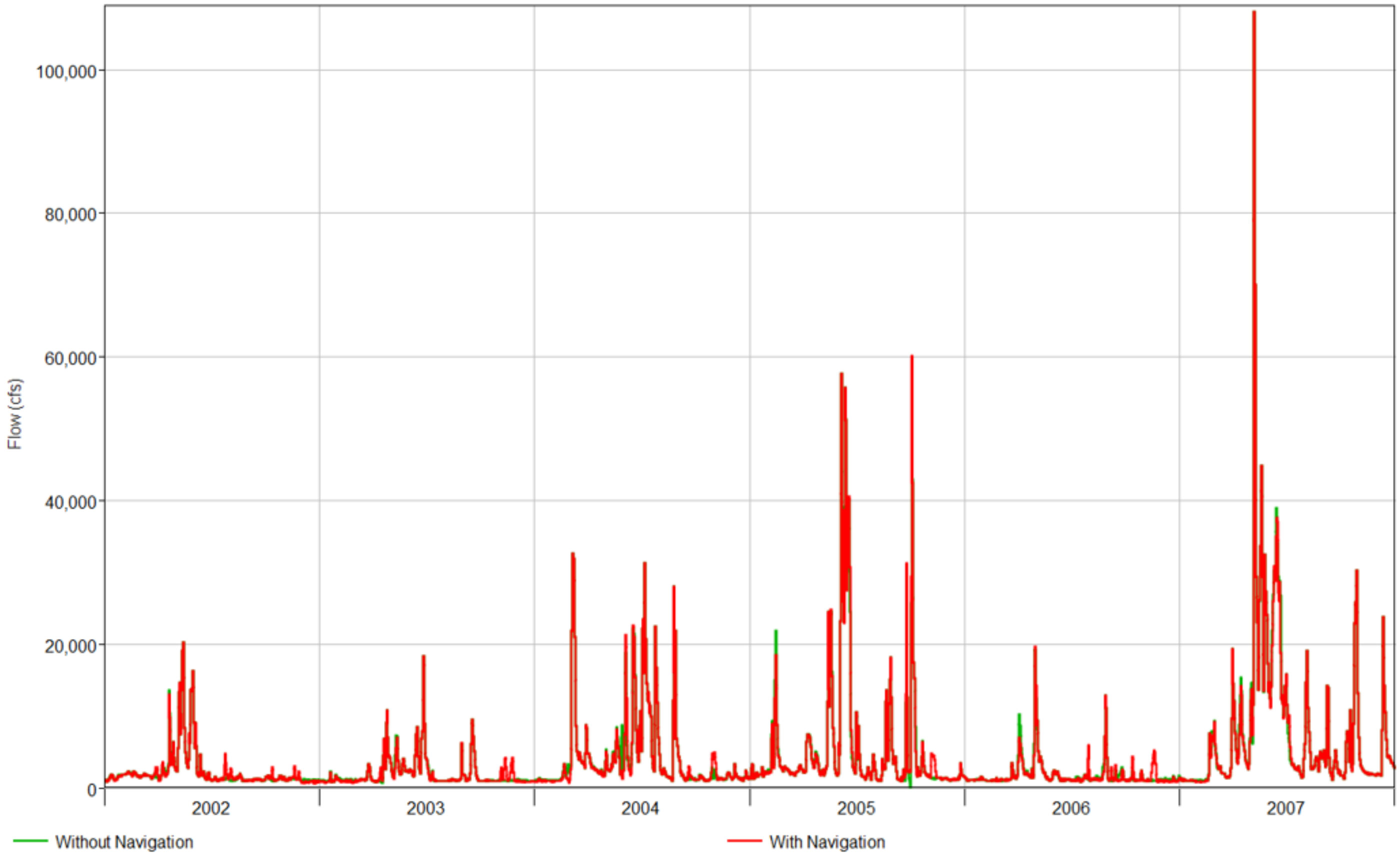


Figure 4-43. Desoto flow modeled with and without navigation flow support for the years 2002 through 2006.

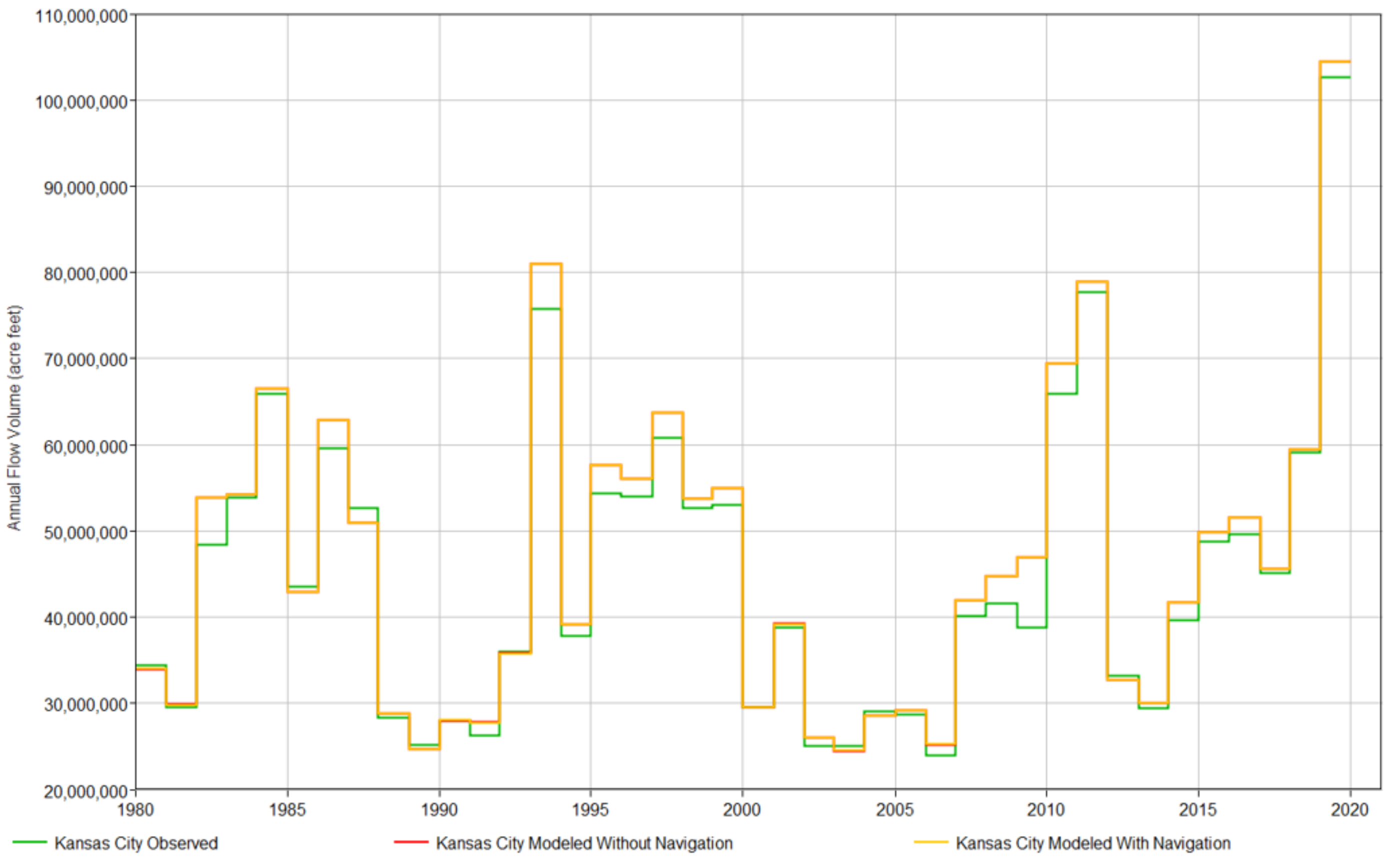


Figure 4-44 Kansas City Observed and Modeled Annual Flow Volume for 1980 through 2019.

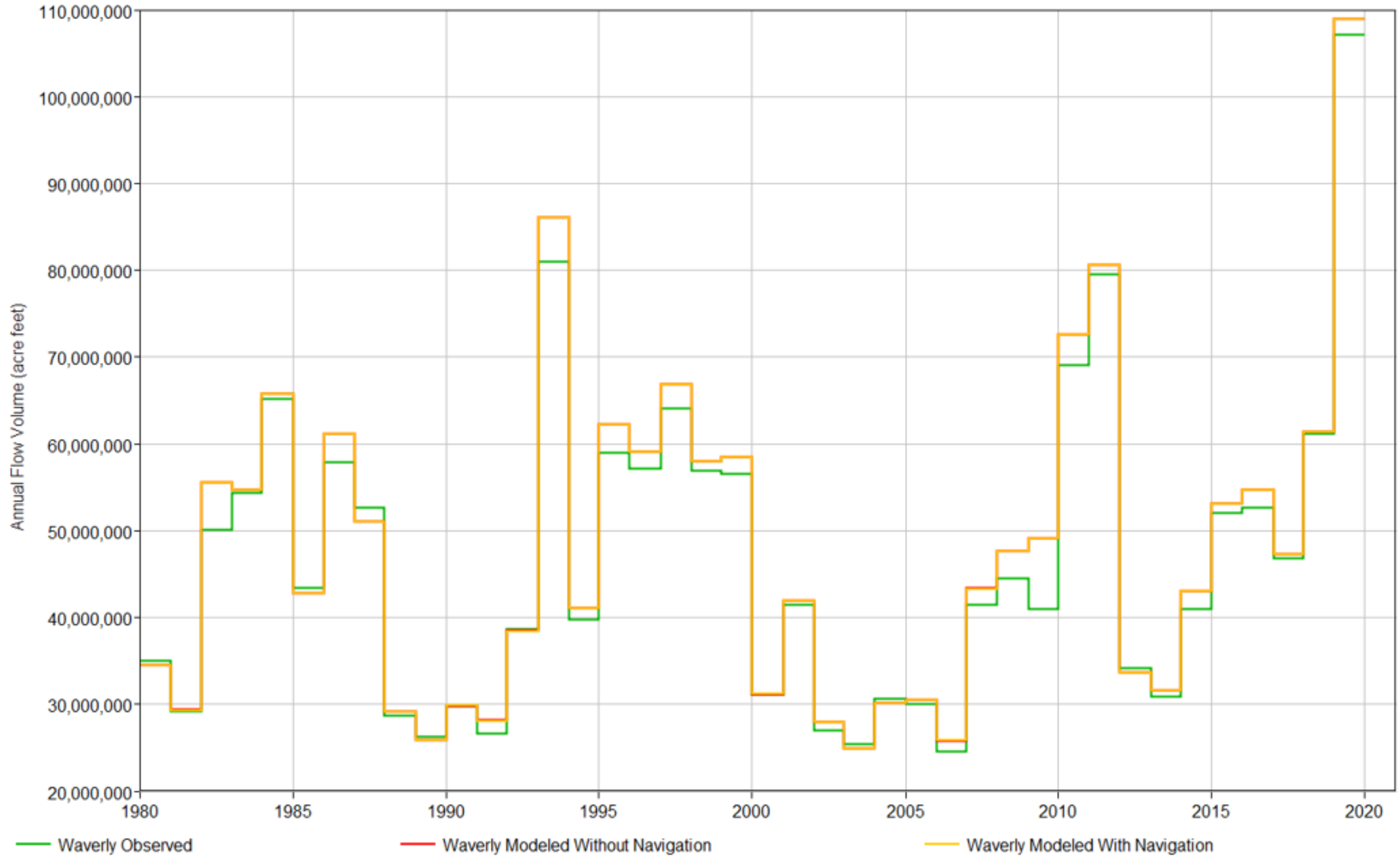


Figure 4-45 Waverly Observed and Modeled Annual Flow Volume for 1980 through 2019.

5 Conclusions

A full set of data was developed for the Kansas River HEC-ResSim model. Data was extended using observed gage data and regression between gages as necessary. When no other methods were available data was extended using watershed ratios. Local flow data sets were developed by routing observed/extended flows from the upstream gages and using a spreadsheet process to smooth negative flows all the while conserving flow volume totals. Some uncertainties exist in the extended gage data, but the data set appears to be a reasonable estimate.

The Lower Kansas River CWMS model was utilized as a start for the KRRFSS HEC-ResSim model. Several adjustments were made to this model, as necessary, including routing methods, input data sets, and reservoir rules.

The reservoir elevation duration curves indicated that the modeled regulation adequately models the actual conditions. Milford, Perry, Tuttle Creek and Clinton model results accumulate water in the flood control pool for longer durations than in the actual data set. Some of these differences may be due to seasonal water level management plans. Some years actual operations have been impacted by formal deviations that allowed higher flow targets on the Missouri River permitting the pool elevations to be maintained at lower levels.

Navigation flow support model scenarios estimate the impact of navigation flows on the reservoirs and downstream gages. Navigation flow support can result in significant reductions in pool elevations, but there is minimal change in the peak flows even for years when navigation releases were made.

Observed and modeled annual flow volumes were compared for all the reservoir outflows and the key gages in the basin. The observed flow volumes tended to be a little higher than modeled. Reservoir evaporation estimates in the model and present incremental depletions are the primary reasons for lower annual flow volume. Also, the modeled 2019 flow volume had flood storage carried over into the following year when actual was able to empty the flood storage because of a deviation. Annual peak flows were less impacted than the flow volume comparison.

The KRRFSS HEC-ResSim model results in a reasonable assumption of basin regulated flows for 1920 to 2019. The existing condition model can be used for ongoing study analysis of future without project and proposed alternative reservoir regulation and flows.

Attachment 1 KRRFSS Water Management Documentation—Supporting Plots

1. Unregulated Reservoir Inflow Analysis

1.1. Background

Calculations are conducted annually to determine unregulated flow if the dams were not in place. From the difference between the observed (regulated) flow and the calculated unregulated flow flood damages prevented in dollars are computed. The unregulated flow is also referred to as natural flow. Although the calculations are made annually, the historical record of natural flows was only calculated for peak annual events. This project undertook calculating the natural flow in the Kansas City District (NWK) from the inception of the reservoir through 2019 using a daily time step.

Stage and flow on the Kansas River are impacted by seven reservoirs owned by the US Army Corps of Engineers (USACE) and eleven flood control reservoirs owned by the U.S. Bureau of Reclamation (USBR). These USBR reservoirs are operated by USACE when they are in flood control operations.

Stage and flow at the Missouri River at Kansas City, MO are impacted by all the Omaha District (NWO) reservoirs including the mainstem Missouri River reservoirs which are operated by the Missouri River Basin Water Management (MRBWM) office. MRBWM calculates unregulated flow for the Missouri River at Saint Joseph, MO which accounts for the impact of all the reservoirs in NWO. The Saint Joseph unregulated flow is then routed to Kansas City for use in the NWK unregulated flow calculations.

This study is interested in unregulated flows in NWK upstream of the Missouri River at Waverly, MO. In addition to the NWO and Kansas River reservoirs, Smithville Reservoir impacts flows at Kansas City and Waverly, and Longview and Blue Springs Reservoirs impact the flow at Waverly. Table 1.1-1 shows all the NWK reservoirs that impact flow at the Missouri River at Waverly.

Table 1.1-1. Kansas City District Reservoirs that impact flow at the Missouri River at Waverly and above.

Reservoir	Ownership	Downstream Reservoir
Bonny	USBR	Trenton
Trenton (Swanson Lake)	USBR	Harlan County
Enders	USBR	Harlan County
Red Willow (Hugh Butler Lake)	USBR	Harlan County
Medicine Creek (Harry Strunk Lake)	USBR	Harlan County
Norton (Keith Sebelius Lake)	USBR	Harlan County
Harlan County	USACE	Milford
Lovewell	USBR	Milford
Milford	USACE	
Cedar Bluff	USBR	Kanopolis
Kanopolis	USACE	
Wilson	USACE	
Kirwin	USBR	Glen Elder
Webster	USBR	Glen Elder
Glen Elder Dam (Waconda Lake)	USBR	

Tuttle Creek	USACE	
Perry	USACE	
Clinton	USACE	
Smithville	USACE	
Longview	USACE	
Blue Springs	USACE	

1.2. Data Preparation

Period of record daily reservoir inflow and outflow was obtained from the USACE database for all the Corps-owned reservoirs. Daily inflow and outflow for all the USBR projects are available in the USACE database from 1980 to the present. Five USBR projects (Cedar Bluff, Glen Elder, Kirwin, Lovewell, and Webster) used USACE data for the full period of record. The rest of the USBR projects had outflow records from USBR for prior to 1980. Inflows for these USBR projects were calculated using USBR storage and inflow data for prior to 1980. Calculated inflows resulted in some unreasonable data spikes that were screened out in the Unregulated_v6.dss file prior to use in calculating the unregulated flow.

Daily, period of record flow for the river gages were obtained from the U.S Geological Survey (USGS).

1.3. Natural Flow Calculation Process

Data calculations were made using the “Benefits_48to2020.xlsx” excel spreadsheet. Reservoir inflows and outflows were loaded into the spreadsheet. These were then used to calculate reservoir holdouts which measure how much water the reservoir stored or added to the river. The holdout is calculated by the following equation:

Holdout = (Inflow – 0.1*Evaporation) - Outflow

Evaporation is the flow evaporation from the reservoir in cfs. A portion of the evaporation is removed from the inflow since it was used in the originally calculation of inflow. If the reservoir were not on the river, the evaporation would be lower from the river channel. If the reservoir is storing water, inflows are greater than the outflow and the holdout is positive. If the reservoir is evacuating storage, the outflow is greater than the inflow and the holdout is negative.

During a typical rain event, the holdouts will be positive while rainfall runoff is occurring. This will also result in the regulated flow at the downstream gages being much lower than in the unregulated situation. After the rainfall runoff subsides, reservoir releases often begin to draw the lake back down at which time the holdouts become negative. This will result in the unregulated flow being higher than the regulated in the downstream gages. This typical reservoir operation results in removing the really large unregulated flows with the tradeoff (and sometimes the benefit) of higher flows after an event.

The calculated holdouts at the Missouri River at Saint Joseph were calculated by the MRBWM office and loaded into the USACE database. This data set was also loaded into the spreadsheet.

All the holdouts are then routed to the downstream gages using coefficient routing parameters. A separate worksheet is set up to show calculations for each gage. Routing coefficient parameters are shown in Table 1.3-1. In each worksheet the reservoir holdouts are routed to the gage. The observed flow is then added to the routed holdouts to determine the unregulated flow. There are also calculations to determine the percent of flow reduction provided by each reservoir.

This approach is based simply on observed flow and routed holdouts. Water depletions in the basin are not part of the calculation; although, any depletions that impacted the observed flow will intrinsically be accounted. During times of low flow and large irrigation use, the calculated unregulated flows can become negative because of the uncertainty associated with the depletions and routing parameters. There is also some uncertainty with the observed flow even though the approved USGS flow was used.

Table 1.3-1. Routing parameters used to calculate unregulated follows.

From	To	Day 0	Day 1	Day 2	Day 3	Day 4
Bonny Reservoir	Republican River at Stratton, NE	0.0	0.3	0.7		
Republican River at Stratton, NE	Swanson Reservoir	1.0				
Enders Reservoir	Frenchman Creek at Palisade, NE	0.0	0.6	0.4		
Frenchman Creek at Palisade, NE	Republican River at Cambridge, NE	0.0	0.1	0.5	0.4	
Swanson Reservoir	Republican River at Cambridge, NE	0.0	0.1	0.5	0.4	
Hugh Butler Reservoir	Republican River at Cambridge, NE	0.0	0.4	0.6		
Harry Strunk Reservoir	Republican River at Cambridge, NE	0.4	0.6			
Republican River at Cambridge, NE	Republican River at Orleans, NE	0.0	0.3	0.6	0.1	
Keith Sebelius Reservoir	Prairie Dog Creek near Woodruff, KS	0.0	0.6	0.4		
Republican River at Orleans, NE	Harlan County Reservoir	1.0				
Prairie Dog Creek near Woodruff, KS	Harlan County Reservoir	1.0				
Harlan County Reservoir	Republican River at Concordia, KS				0.5	0.5
Lovewell Reservoir	Republican River at Concordia, KS		0.4	0.6		
Republican River at Concordia, KS	Republican River at Clay Center, KS		0.4	0.6		
Republican River at Clay Center, KS	Milford Reservoir	1.0				
Cedar Bluff Reservoir	Smoky Hill River at Ellsworth, KS				0.3	0.7
Smoky Hill River at Ellsworth, KS	Kanopolis Reservoir	1.0				
Kanopolis Reservoir	Smoky Hill River near Mentor, KS	0.0	0.4	0.6		
Wilson Reservoir	Saline River at Tescott, KS	0.1	0.2	0.3	0.4	
Saline River at Tescott, KS	Smoky Hill River at New Cambria, KS	0.2	0.3	0.5		
Smoky Hill River near Mentor, KS	Smoky Hill River at New Cambria, KS	0.4	0.6			
Kirwin Reservoir	Waconda Reservoir	0.5	0.5			
Webster Reservoir	Waconda Reservoir	0.5	0.5			
Waconda Reservoir	Solomon River at Niles, KS	0.2	0.7	0.1		
Smoky Hill River at New Cambria, KS	Smoky Hill River at Enterprise, KS	0.0	0.7	0.3		
Solomon River at Niles, KS	Smoky Hill River at Enterprise, KS	0.2	0.7	0.1		
Smoky Hill River at Enterprise, KS	Kansas River at Fort Riley, KS	0.3	0.7			
Milford Reservoir	Kansas River at Fort Riley, KS	0.7	0.3			
Kansas River at Fort Riley, KS	Kansas River at Wamego, KS	0.4	0.6			
Tuttle Creek Reservoir	Kansas River at Wamego, KS	0.8	0.2			
Kansas River at Wamego, KS	Kansas River at Topeka, KS	0.4	0.6			
Kansas River at Topeka, KS	Kansas River at Lecompton, KS	0.8	0.2			
Perry Reservoir	Kansas River at Lecompton, KS	0.8	0.2			
Kansas River at Lecompton, KS	Kansas River at Desoto, KS	0.5	0.5			

Clinton Reservoir	Kansas River at Desoto, KS	0.5	0.5			
Smithville Reservoir	Little Platte River at Smithville, MO	1.0				
Little Platte River at Smithville, MO	Missouri River at Kansas City, MO	0.5	0.5			
Kansas River at Desoto, KS	Missouri River at Kansas City, MO	0.8	0.2			
Missouri River at Saint Joseph, MO	Missouri River at Kansas City, MO	0.1	0.8	0.1		
Blue Springs and Longview Reservoirs	Missouri River at Waverly, MO		1.0			
Missouri River at Kansas City, MO	Missouri River at Waverly, MO	0.1	0.8	0.1		

1.4. Reservoir Inflow Plots

Several historic flood events were evaluated at Kanopolis, Waconda, and Milford to compare regulated and unregulated flow for these reservoirs since they all have reservoir systems above them. Even though many of the upstream reservoirs are in traditionally arid portions of the basin, they can have a large impact on floods depending on where the rain falls. In addition to capturing a peak inflow, releases are often small as much of the inflow goes into filling the often-depleted multi-purpose pool and eventually to supplying irrigation flows that do not reach downstream.

Figure 1.4-1, Figure 1.4-2, and Figure 1.4-3 show Kanopolis inflow plots for 1951, 1993, and 2019, respectively. Cedar Bluff provided a significant amount of flow reduction in 1951. It was newly constructed at the time and filled for the first time. They did reach flood pool and began making releases later in the event as shown by the observed flow being higher than the natural flow from mid-July through September. In 1993, Cedar Bluff stored all its inflow in its conservation pool and did not release throughout the event. The 2019 event had almost all the rainfall downstream of Cedar Bluff. Cedar Bluff did not release for the entire year.

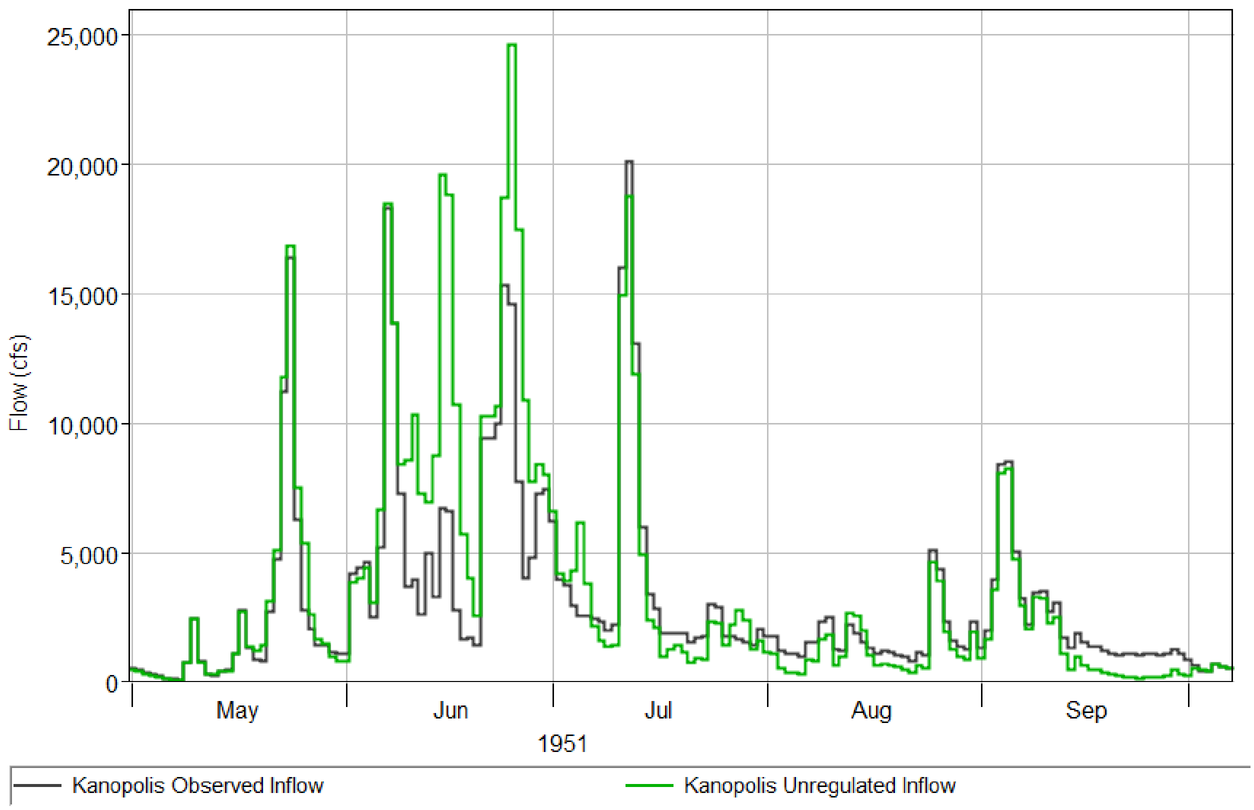


Figure 1.4-1. Kanopolis Reservoir observed and unregulated inflow for the 1951 flood event.

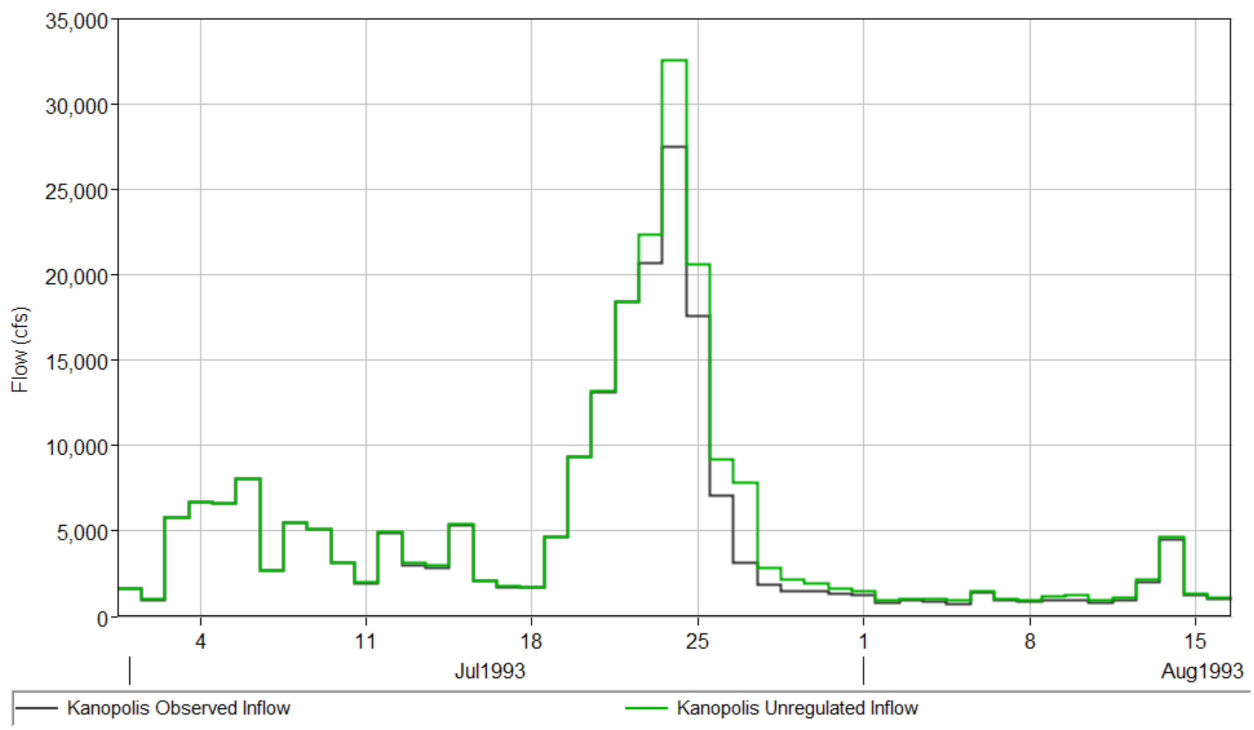


Figure 1.4-2. Kanopolis Reservoir observed and unregulated inflow for the 1993 flood event.

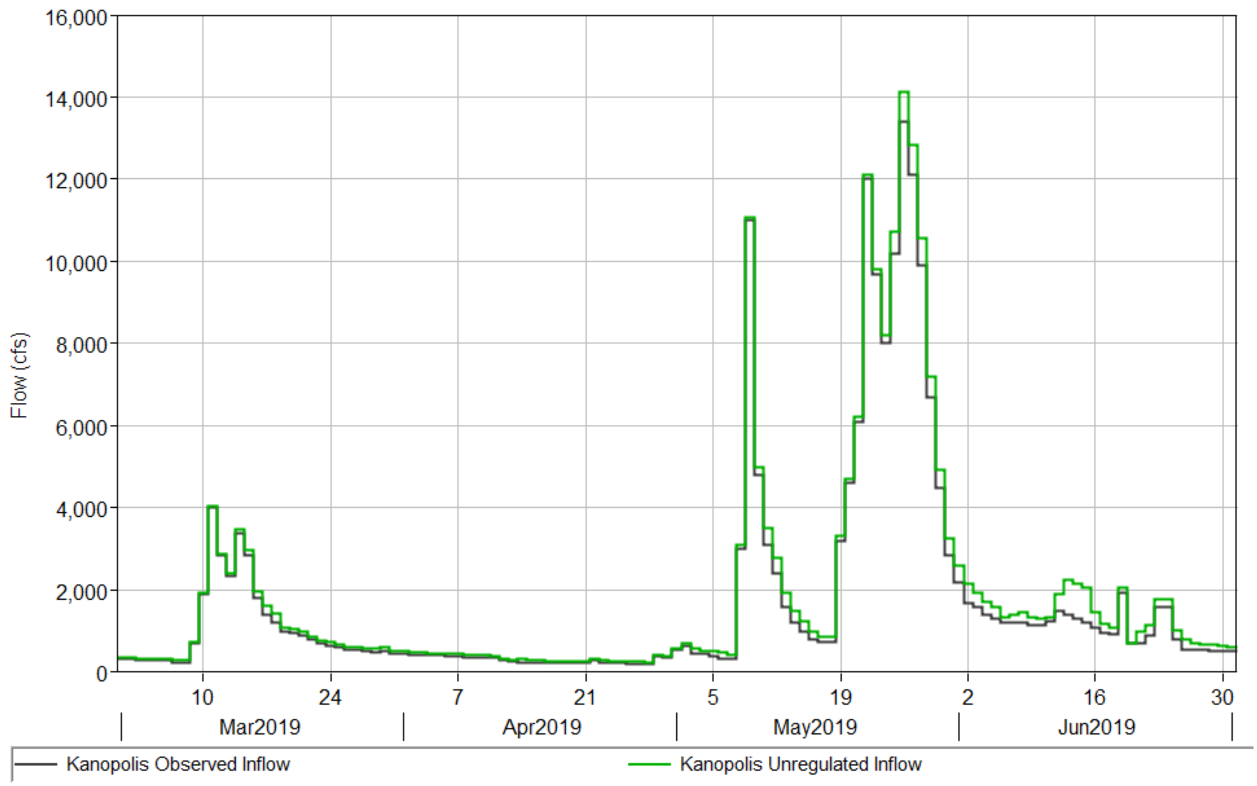


Figure 1.4-3. Kanopolis Reservoir observed and unregulated inflow for the 2019 flood event.

Waconda data collection began in 1967, and unregulated data was also calculated from that time forward. Figure 1.4-4 and Figure 1.4-5 show Waconda inflow plots for 1993 and 2019, respectively. In 1993, the upstream projects both made some releases during this event and entered the flood pool in mid to late summer; however, they were able to provide significant reduction in flow for Waconda. In 2019, Kirwin and Webster both began the event with full multi-purpose pools. All flood storage was passed to Waconda, but peak inflow into Wacanda was reduced during the inflow events because of the time the water was routing through the reservoir. The 2019 inflow was smaller magnitude than many historic events, but the wet period lasted for a long time leading to significant volume passing through the reservoir system.

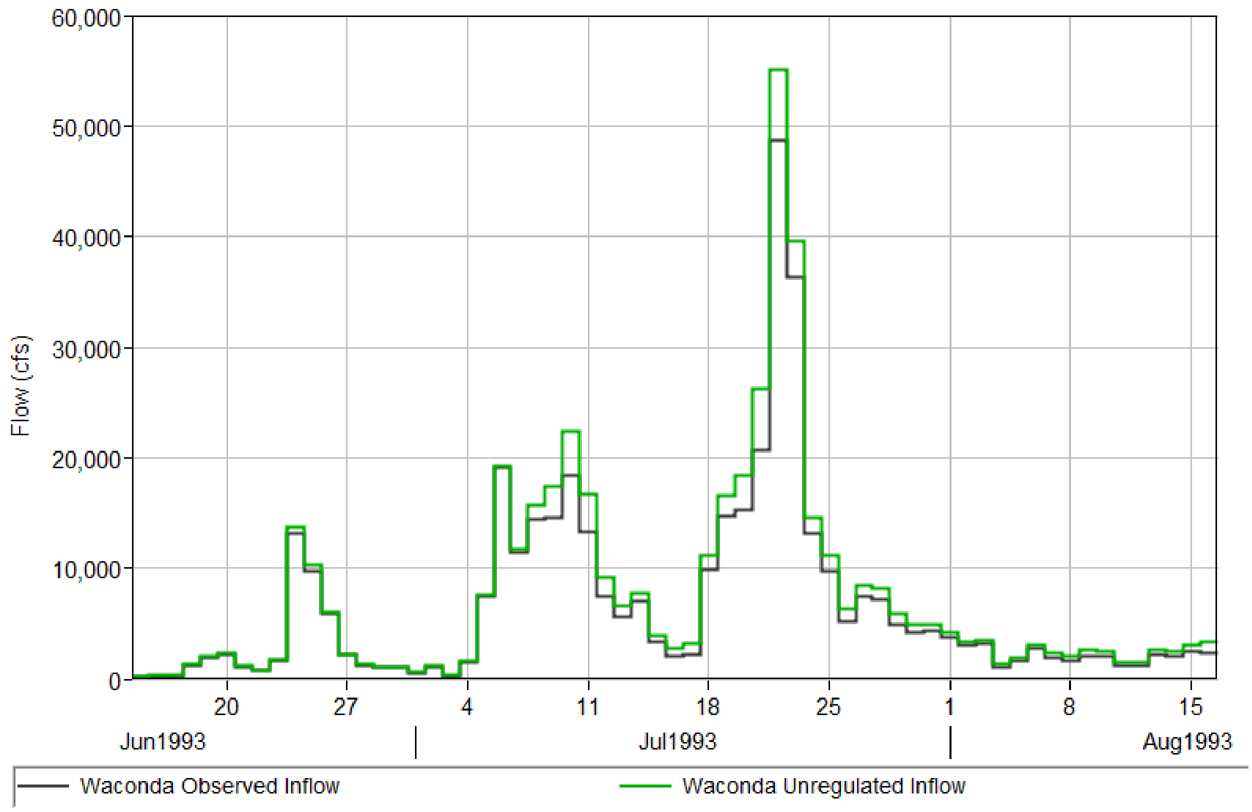


Figure 1.4-4. Waconda Reservoir observed and unregulated inflow for the 1993 flood event.

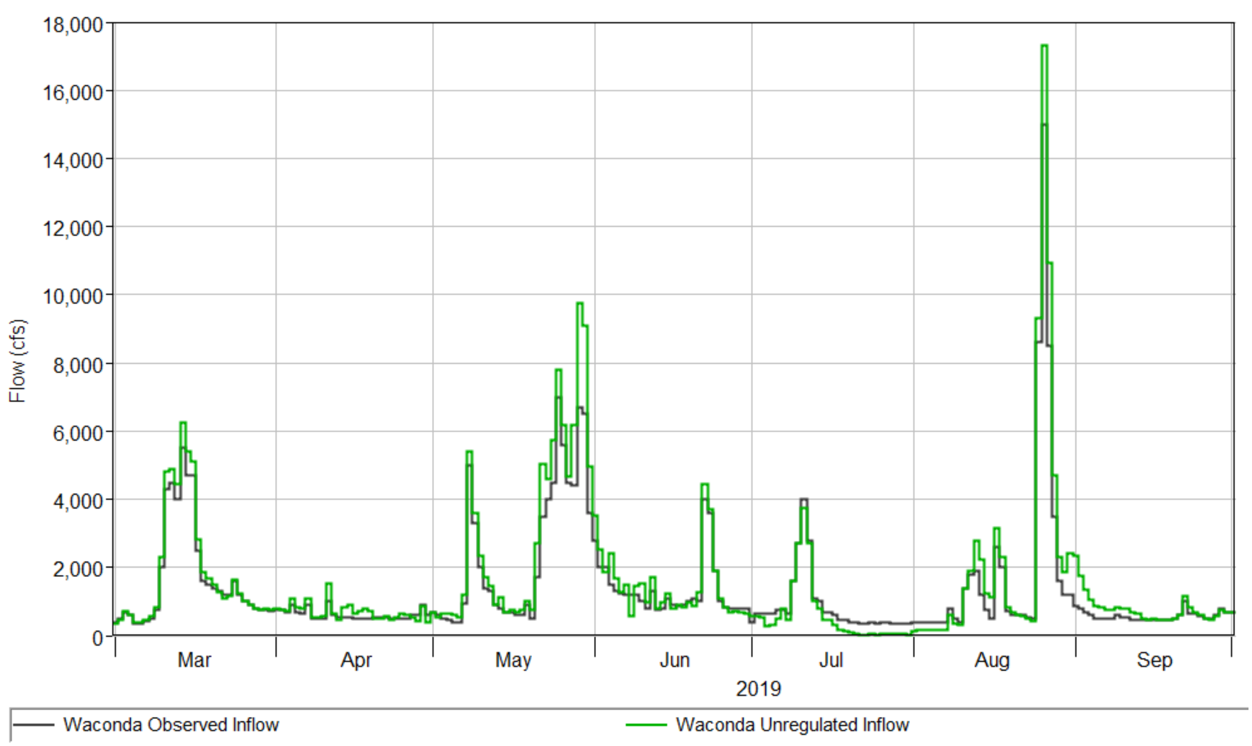


Figure 1.4-5. Waconda Reservoir observed and unregulated inflow for the 2019 flood event.

Milford data collection began in 1964, and unregulated data was also calculated from that time forward. Figure 1.4-6 and Figure 1.4-7 show Milford inflow plots for 1993 and 2019, respectively. In 1993, Lovewell made some large releases of over 4500 cfs in July. Harlan County made minimal releases until late summer. Milford received a lot of local runoff as well. In 2019, Harlan County and Lovewell only made small releases until late July. Some significant reduction of inflow was observed depending on the rainfall location. The reservoirs above Harlan County also provided holdouts that were routed downstream. In general, those reservoirs were ready to store if they got inflow.

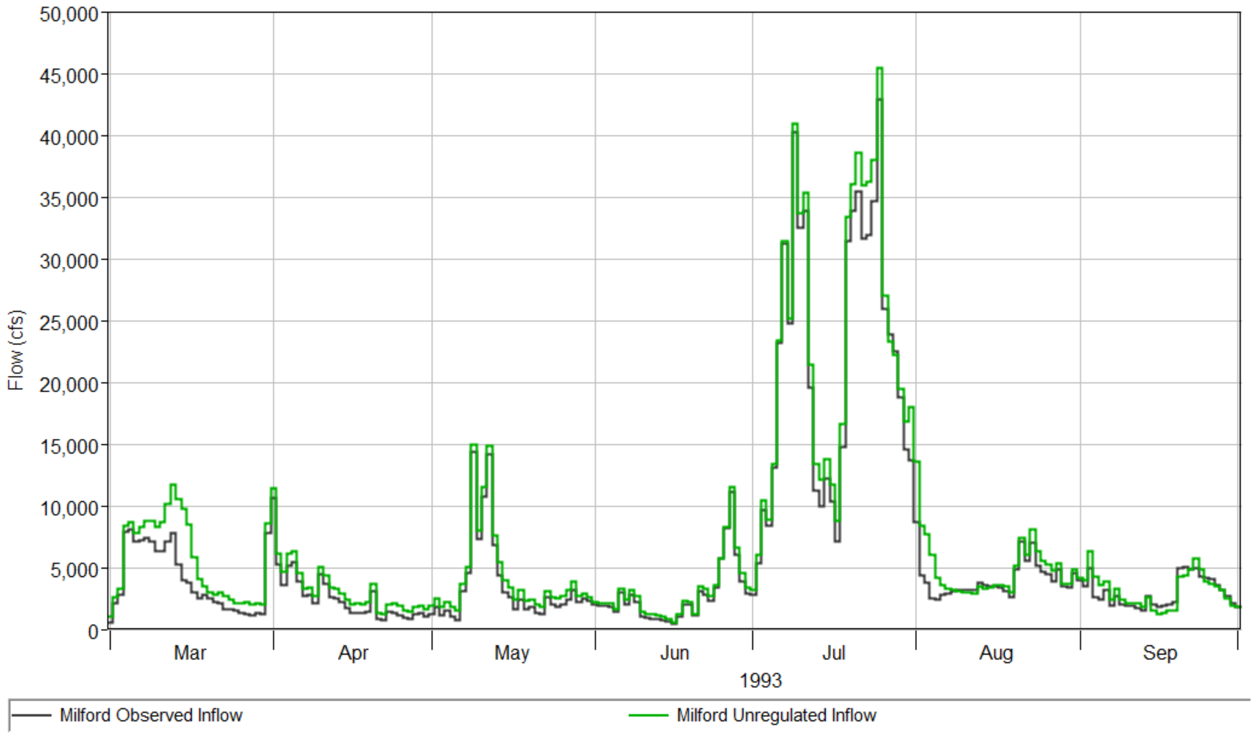


Figure 1.4-6. Milford Reservoir observed and unregulated inflow for the 1993 flood event.

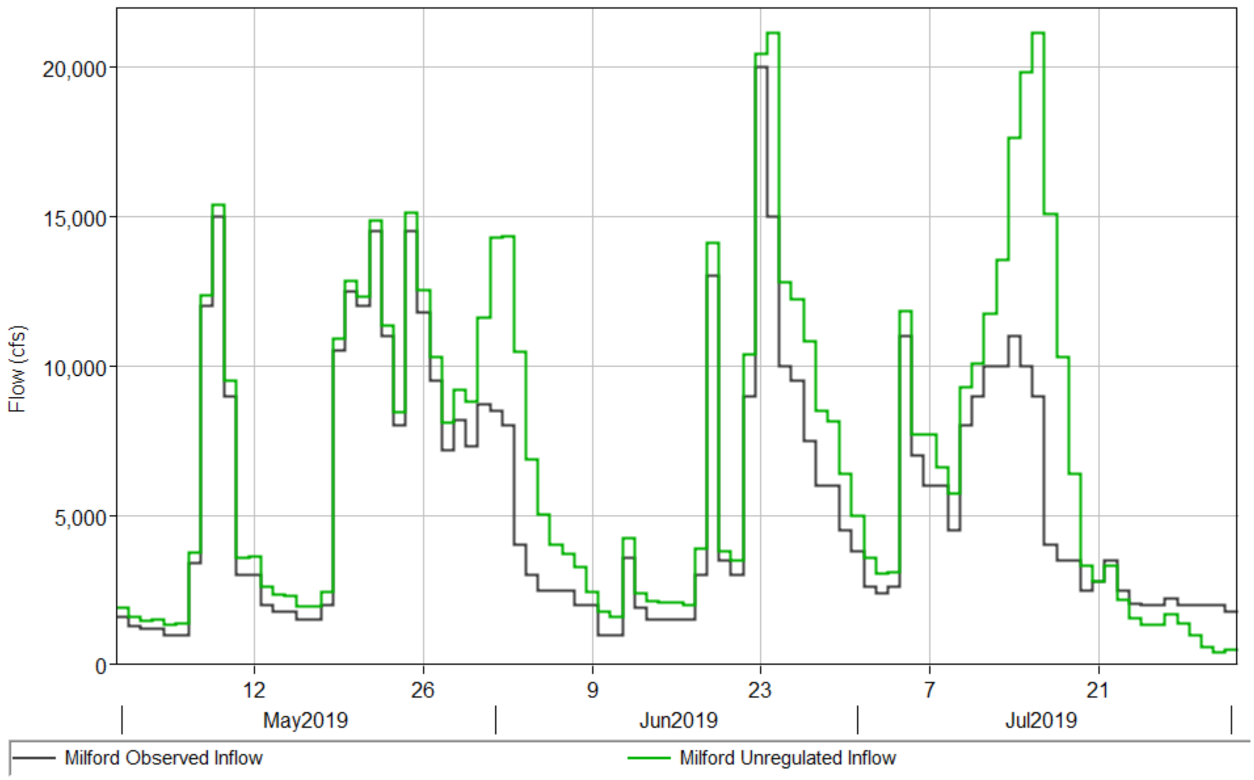


Figure 1.4-7. Milford Reservoir observed and unregulated inflow for the 2019 flood event.

2. Model Results Analysis

2.1. Impact of Water Level Management Plans

To better understand the model results and pool duration analysis that was shown in section 4 of the KRRFSS ResSim Documentation, an additional model simulation was conducted with the typical water level management plan (WLMP) pool elevations used as the guide curve instead of using the top of the multi-purpose pool. This defines how much discrepancy between modeled and observed pool duration can be attributed to the water level management plan. This analysis was conducted before depletions were added into the model; however, it provides insights into the impacts of the water level management plans. Water level management plans are updated annually, so using one plan for the period of analysis in not fully accurate, but the plans do not always have large changes from year to year, so it does give an idea of the impact.

All the model simulations result in different reservoir releases especially centered around the Missouri River downstream control points. The model adheres more strictly to the 90,000 cfs limit at Waverly as opposed to real-time operations that has increased uncertainty about future rainfall conditions.

The Milford water level management plan has changed in recent years to target low pool elevations with the hope of mitigating harmful algal blooms. When the WLMP was included, it resulted in pool elevation durations that were lower than the observed for the more frequent pool elevations. The WLMP only had small impacts for the less frequent events that are more a function of how the model handles releases and the Missouri River at Waverly downstream control point. The Milford pool elevation duration plot is shown in Figure 2-1.

There were many flood control events that stayed above the observed. This would lead to the higher pool elevation duration in the flood control zone. Examples of this are shown in Figure 2-2 and Figure 2-4. Figure 2-3 and Figure 2-5 show the observed versus the modeled Milford outflow for these same flood years. These plots confirm that the model releases nearly the same amount as the observed data; however, the timing is different. Some small differences in the volume can be attributed to differences evaporation.

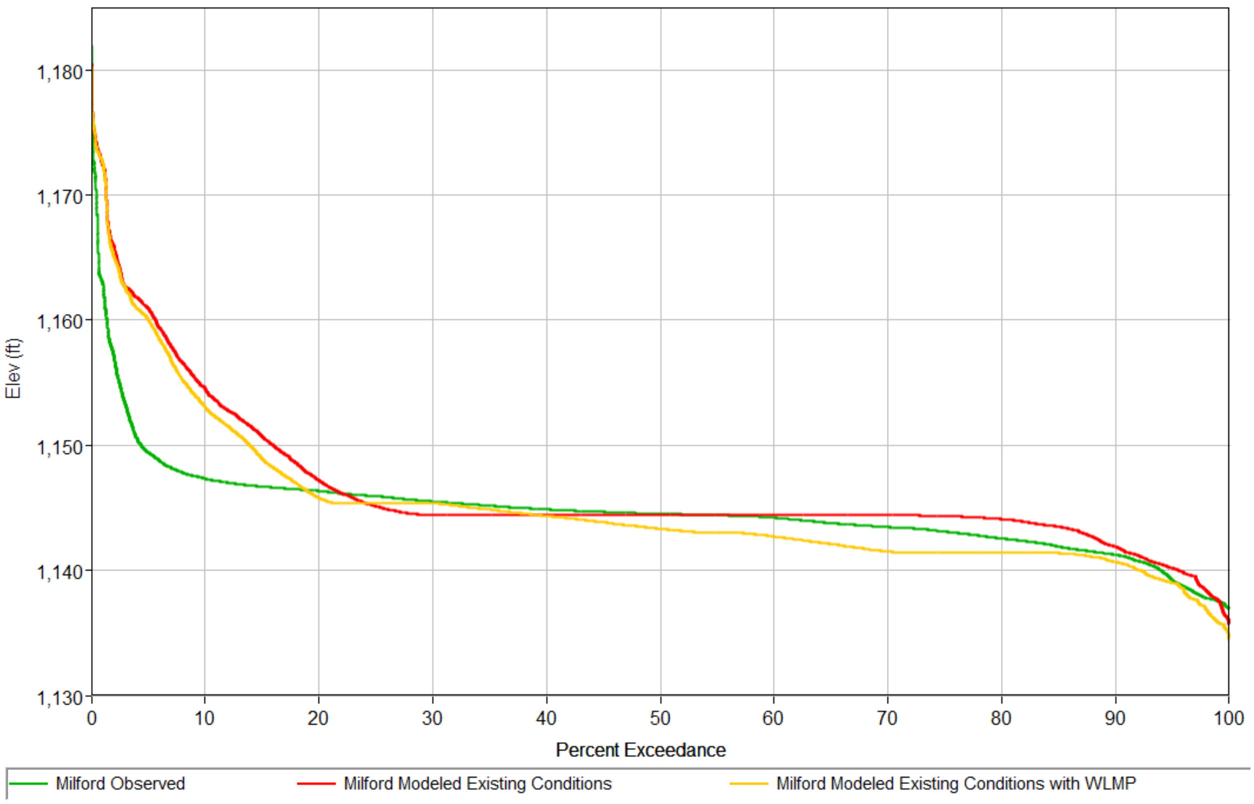


Figure 2-1. Milford observed and modeled pool elevation duration from 01Aug1967 to 01Jan2020.

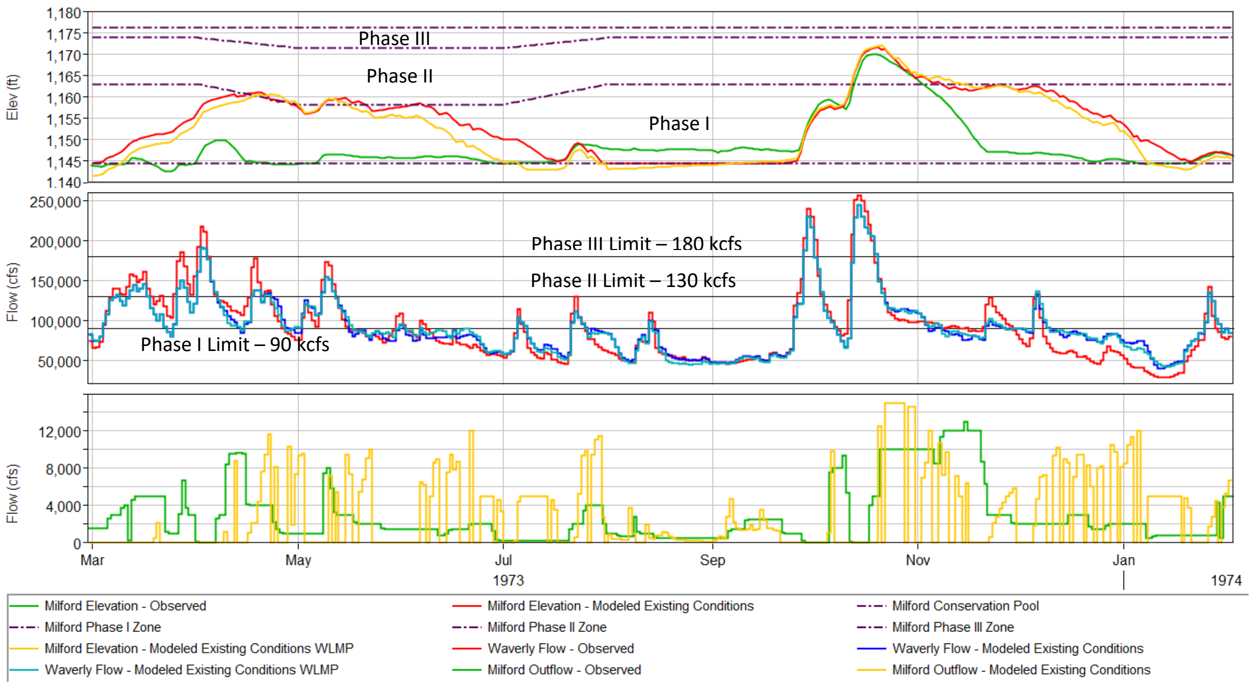


Figure 2-2. Milford 1973 pool elevation compared to the Waverly flow.

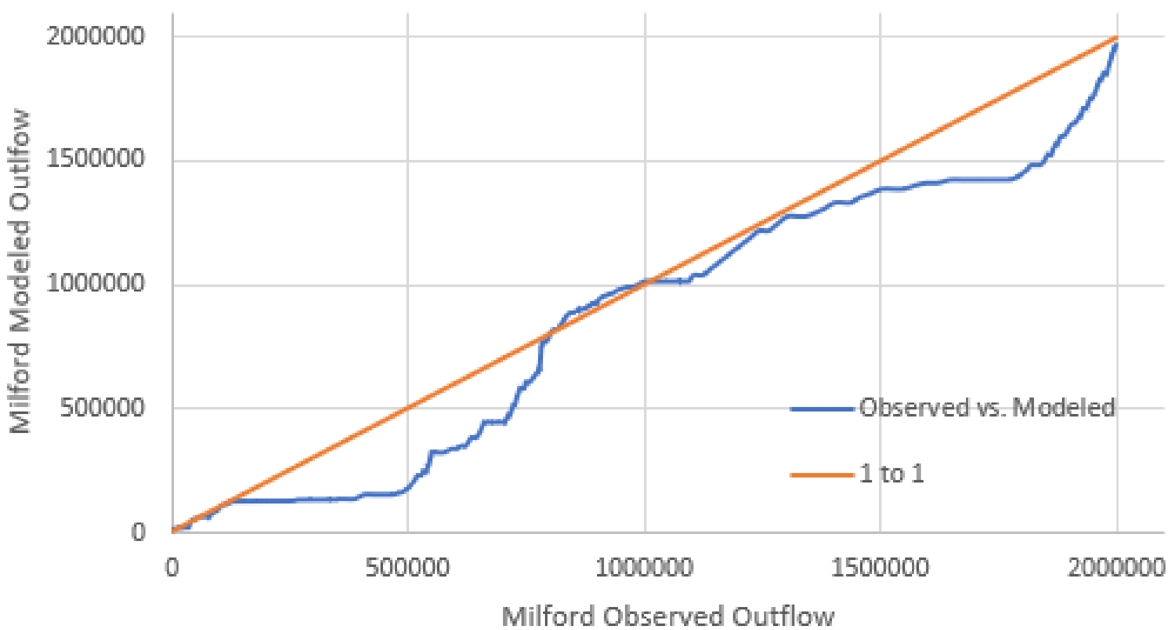


Figure 2-3. Observed versus modeled outflow compared to a 1 on 1 line for 1973.

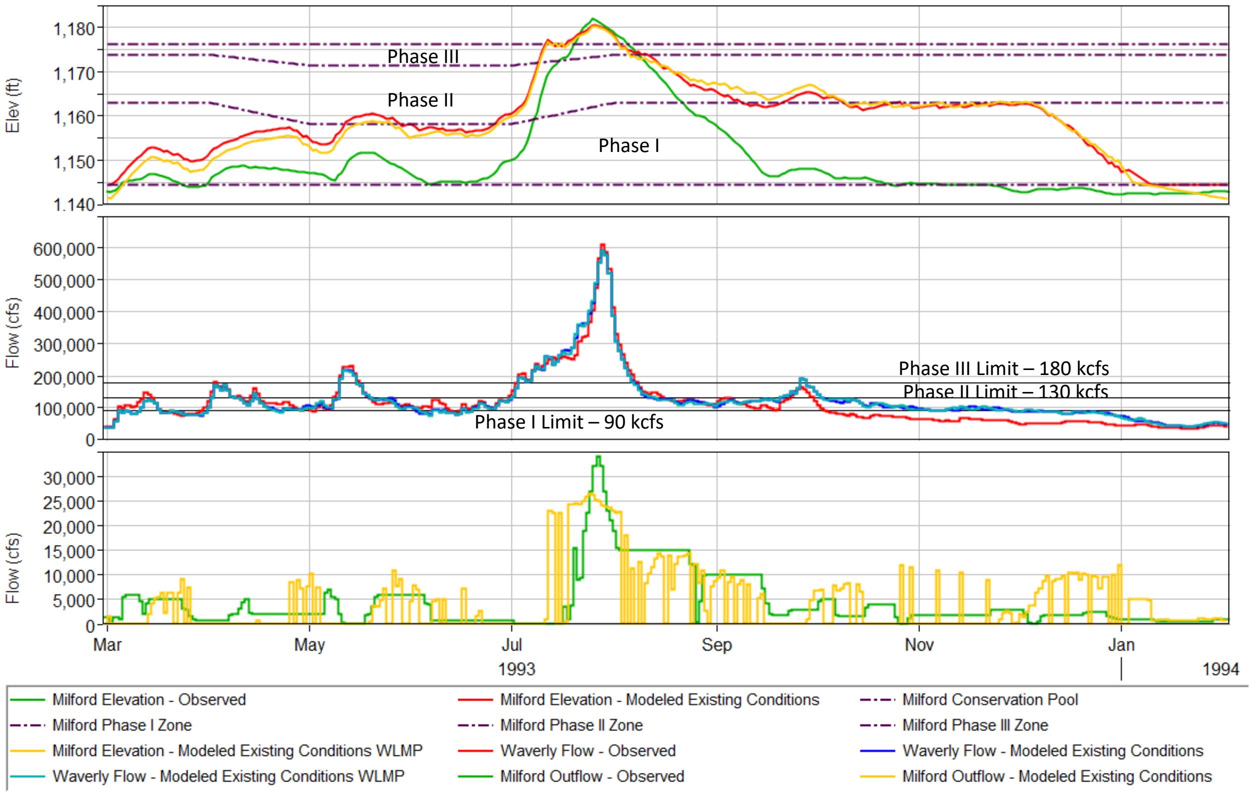


Figure 2-4. Milford 1993 pool elevation compared to the Waverly flow.

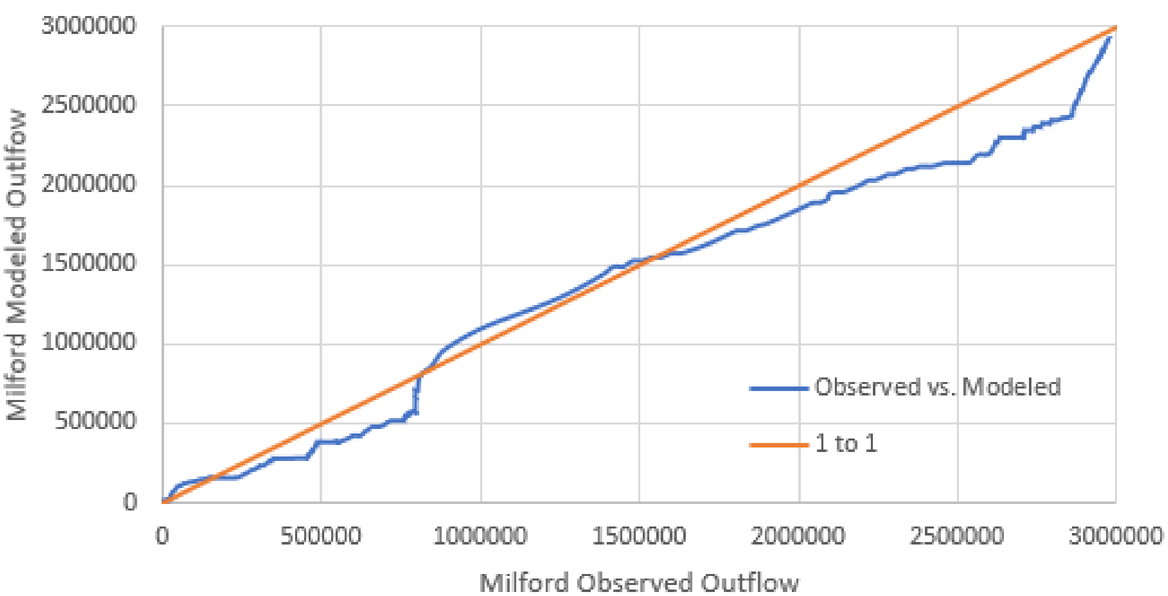


Figure 2-5. Observed versus modeled outflow compared to a 1 on 1 line for 1993.

The Tuttle Creek water level management plan has been mostly unchanged for several years. When the WLMP was included, it resulted in pool elevation durations that were very similar to observed except for the highest and lowest pool elevations. The WLMP only had small impacts for the less frequent events that are more a function of how the model handles releases and the Missouri River at Waverly downstream control point. The lowest observed pool elevations may be a function of navigation flow support coupled with maintaining downstream water quality targets. The Tuttle Creek pool elevation duration plot is shown in Figure 2-6.

There were many flood control events that modeled the pool elevation higher than the observed. This would lead to the higher pool elevation duration in the flood control zone. Examples of this are shown in Figure 2-7 and Figure 2-9. Figure 2-8 and Figure 2-10 show the observed versus the modeled Tuttle Creek outflow for these same flood years. These plots confirm that the model releases nearly the same amount as the observed data; however, the timing is different. Some small differences in the volume can be attributed to differences evaporation.

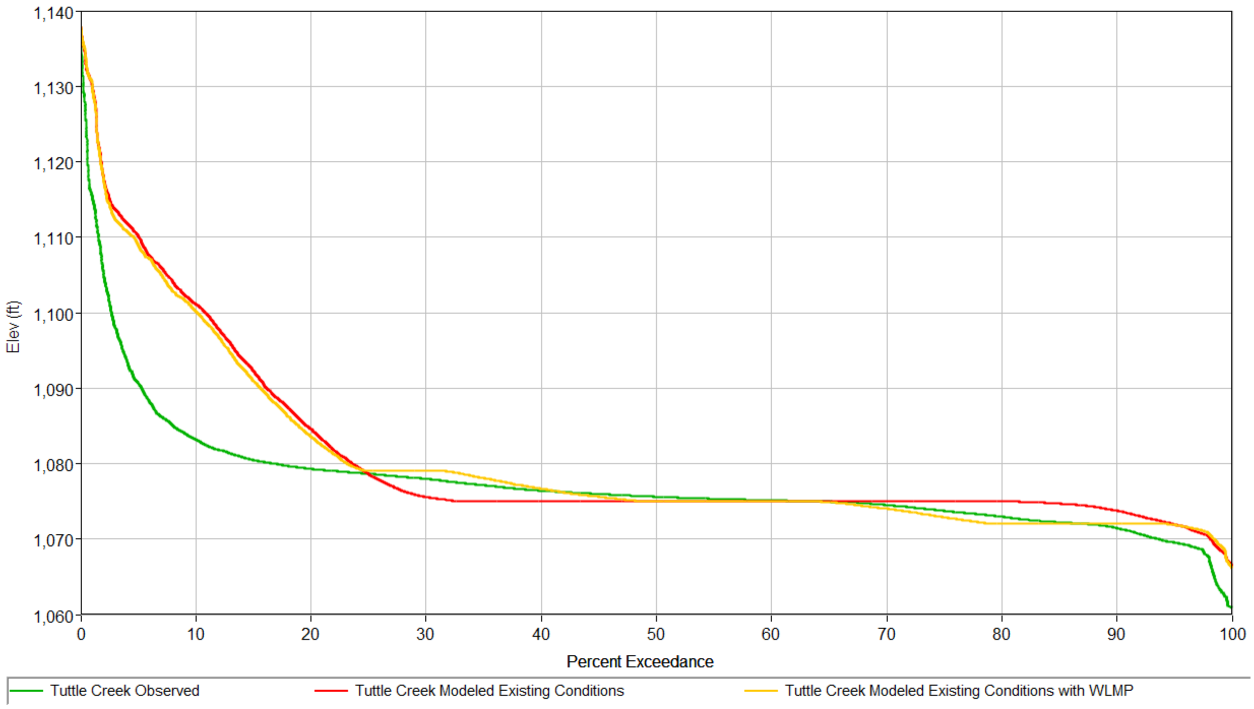


Figure 2-6. Tuttle Creek observed and modeled pool elevation duration from 01May1963 to 01Jan2020.

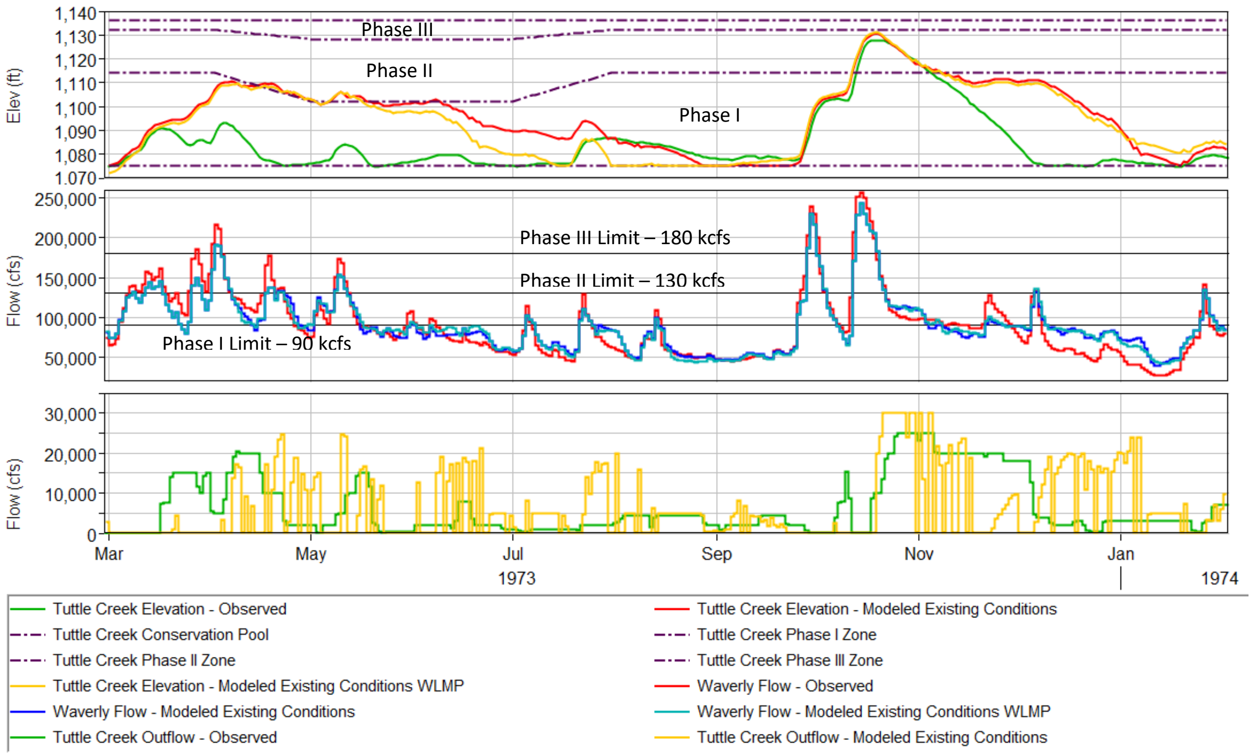


Figure 2-7. Tuttle Creek 1973 pool elevation compared to the Waverly flow.

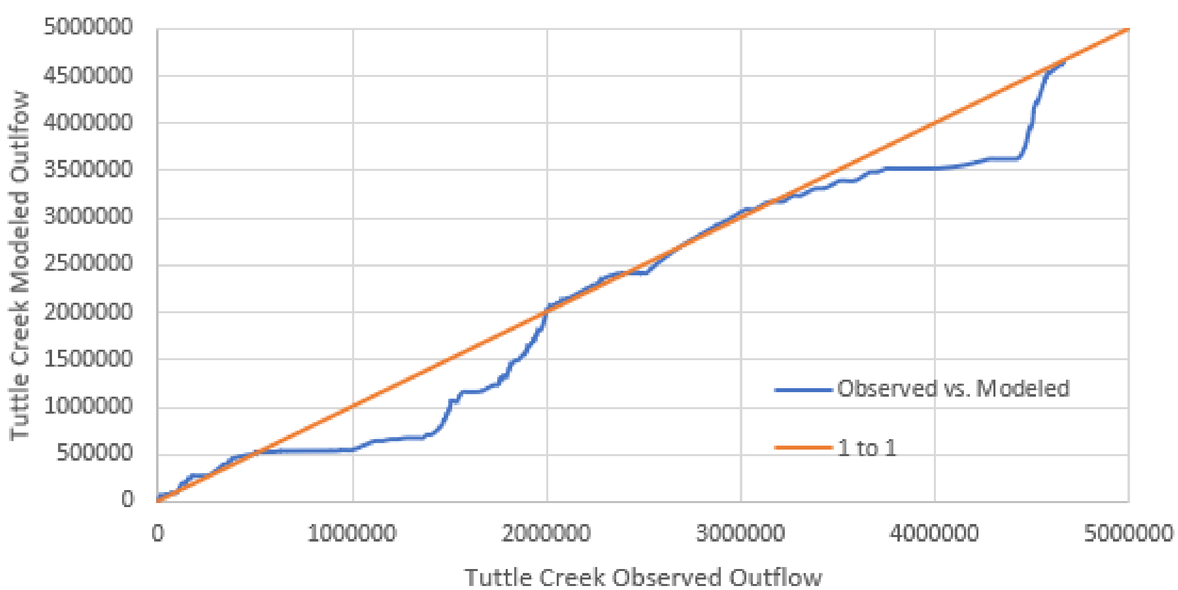


Figure 2-8. Observed versus modeled outflow compared to a 1 on 1 line for 1973.

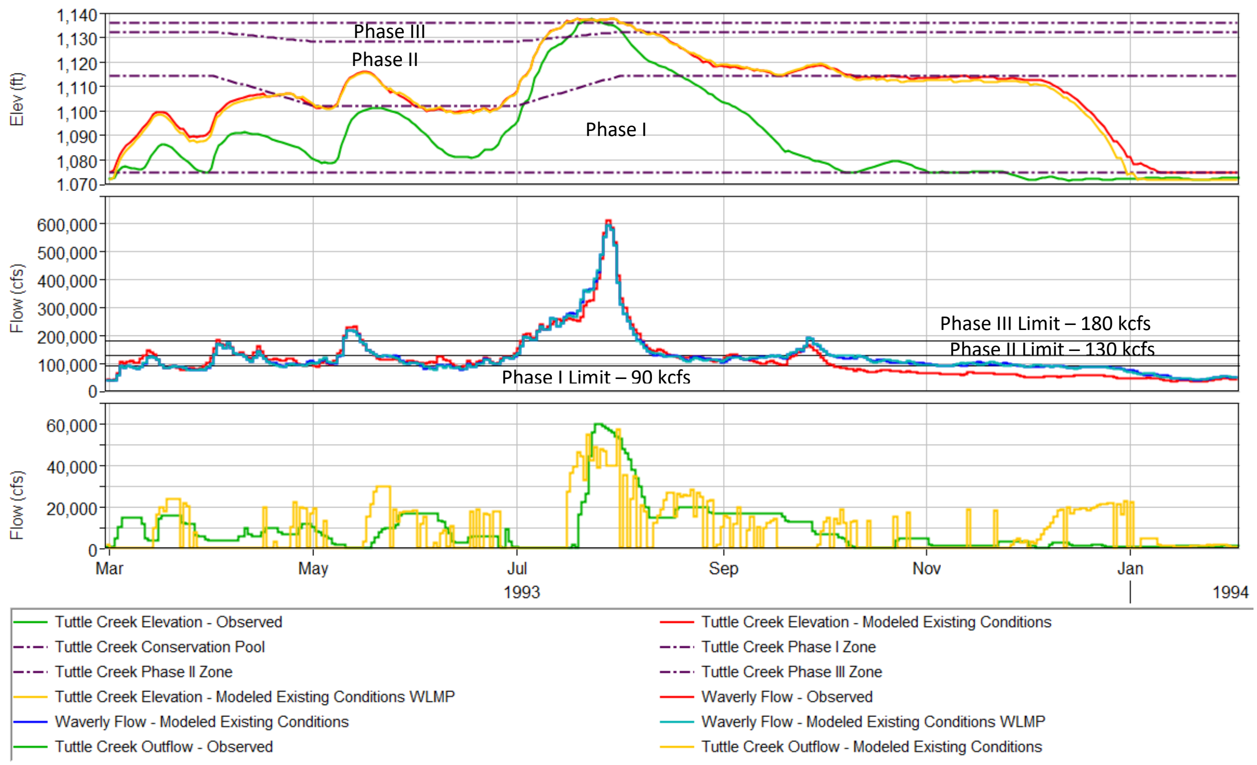


Figure 2-9. Tuttle Creek 1993 pool elevation compared to the Waverly flow.

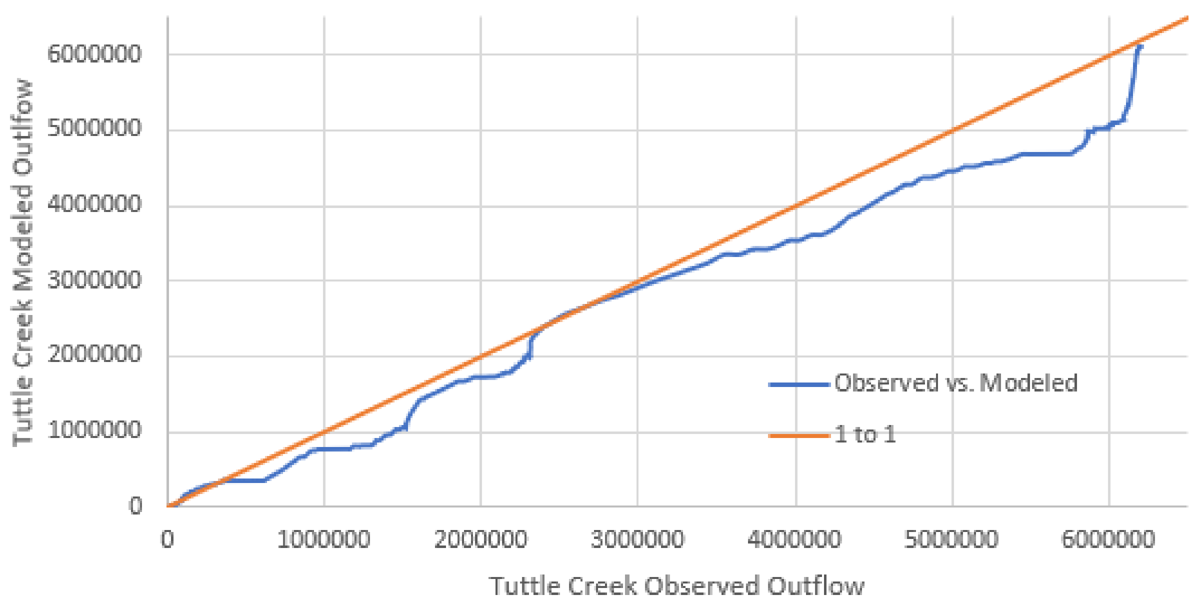


Figure 2-10. Observed versus modeled outflow compared to a 1 on 1 line for 1993.

The Perry water level management plan has been mostly unchanged for several years. When the WLMP was included, it resulted in pool elevation durations that were very similar to observed except for the higher pool elevations. The WLMP only had small impacts for the less frequent events that are more a function of how the model handles releases and the Missouri River at Waverly downstream control point. The Perry pool elevation duration plot is shown in Figure 2-11.

There were many flood control events that modeled the pool elevation higher than the observed. This would lead to the higher pool elevation duration in the flood control zone. Examples of this are shown in Figure 2-12 and Figure 2-14. Figure 2-13 and Figure 2-15 show the observed versus the modeled Perry outflow for these same flood years. These plots confirm that the model does release the same amount as the observed data; however, the timing is different. Some small differences in the volume can be attributed to differences evaporation.

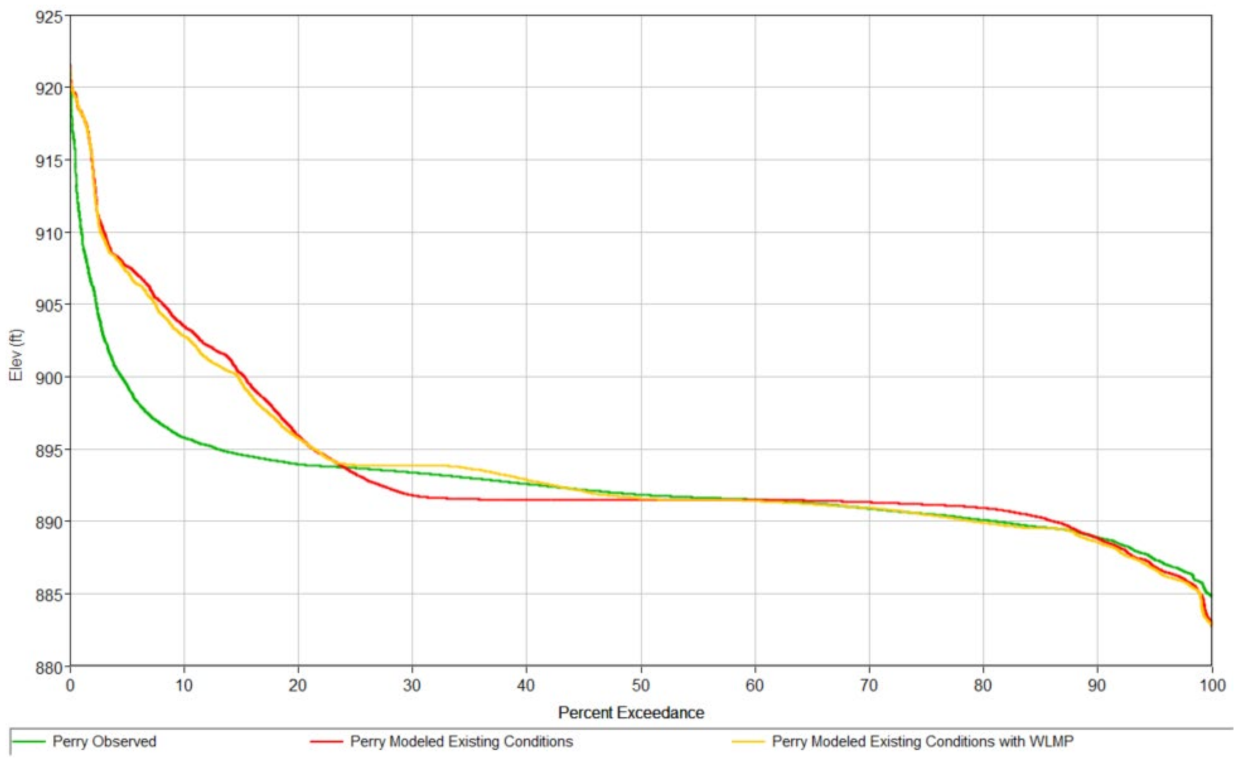


Figure 2-11. Perry observed and modeled pool elevation duration from 01Apr1971 to 01Jan2020.

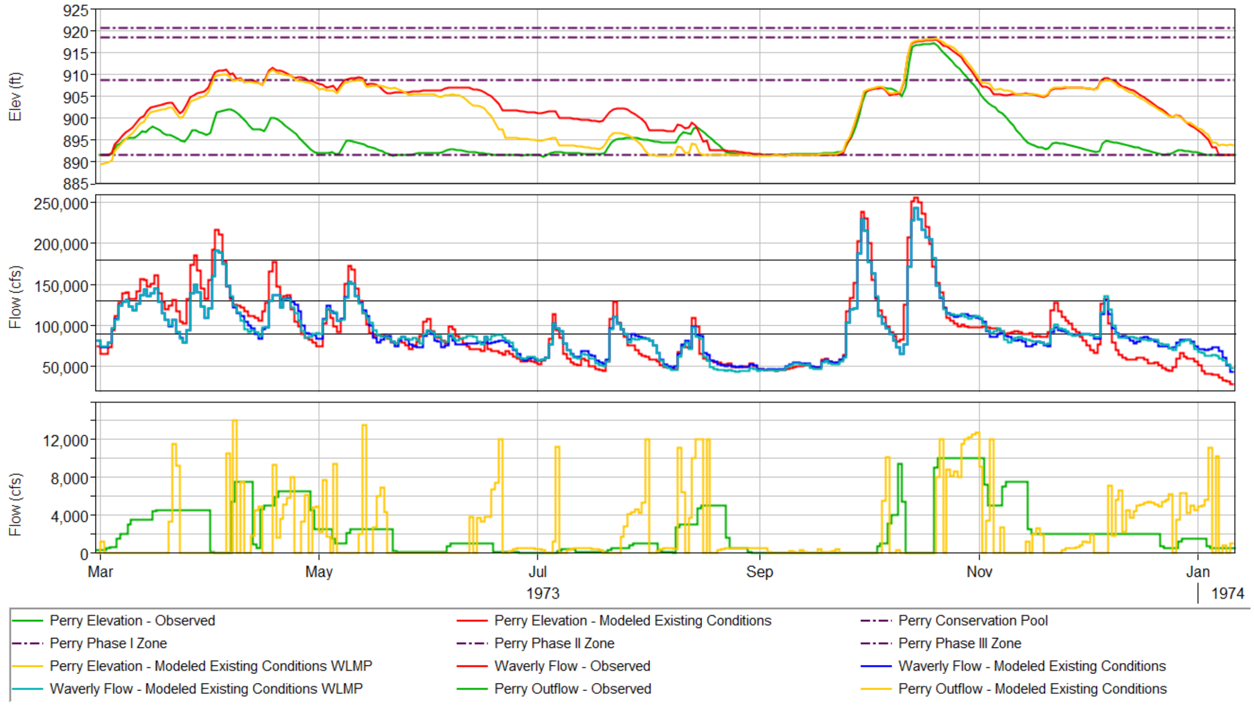


Figure 2-12. Perry 1973 pool elevation compared to the Waverly flow.

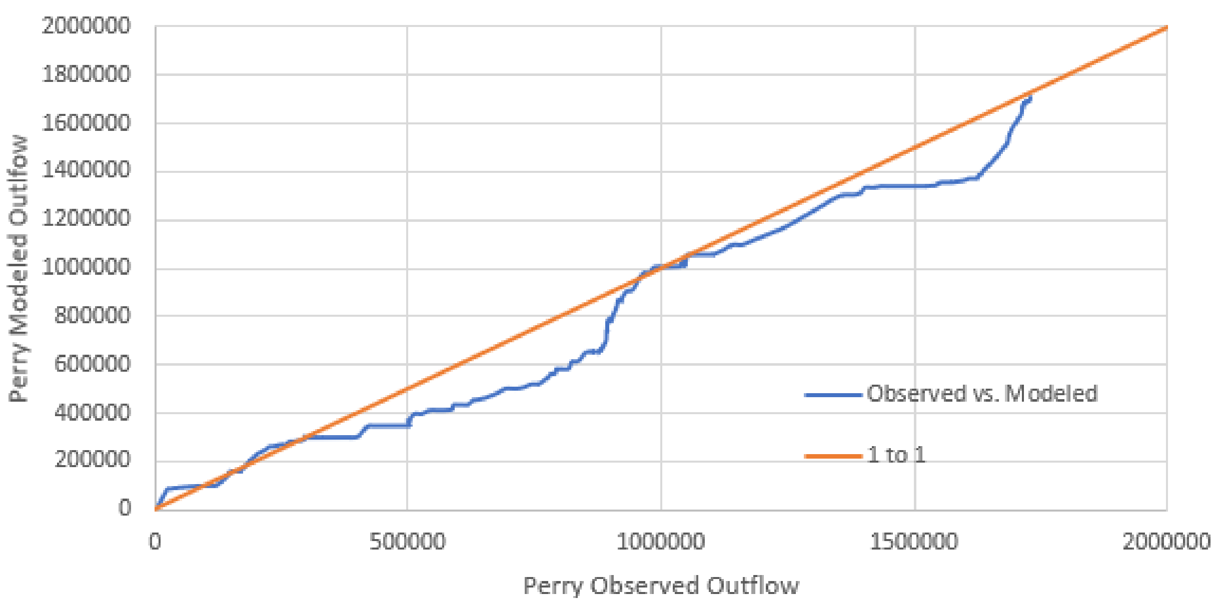


Figure 2-13. Observed versus modeled outflow compared to a 1 on 1 line for 1973.

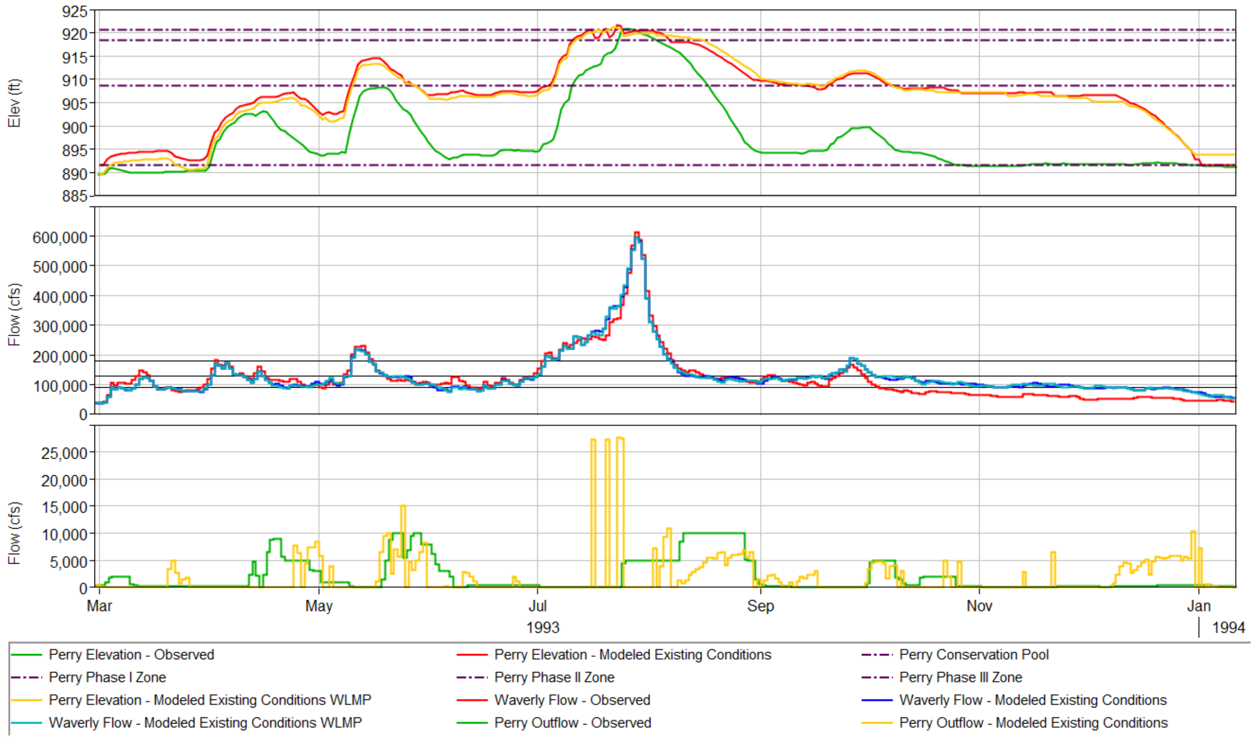


Figure 2-14. Perry 1993 pool elevation compared to the Waverly flow.

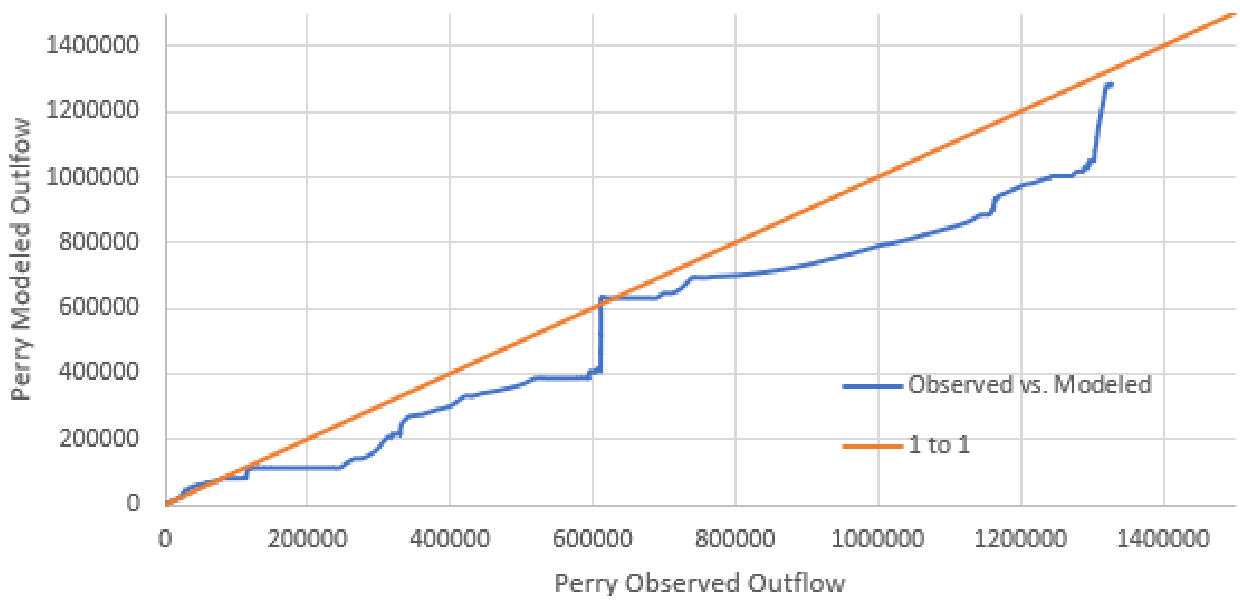


Figure 2-15. Observed versus modeled outflow compared to a 1 on 1 line for 1993.

2.2. Mass Balance Analysis

To ensure mass balance is consistent within ResSim, the sum of all annual reservoir outflow volumes was compared to the inflow volume. The modeled volumes were also compared to the observed data record. This analysis was conducted at Wilson and Tuttle Creek from 1980 to 2019 as a spot-check of the model. Observed flow-evaporation is consistently available starting in 1980 which is why the analysis was started then.

Modeled and observed inflow, outflow, and flow-evaporation were converted to annual flow volumes in acre-feet. Modeled and observed inflow is identical since the reservoirs are used as boundary condition in the ResSim model setup. Modeled and observed end-of-year storage was also tabulated and the annual change in storage was calculated. Reservoir outflow, evaporation, and the change in storage was summed to account for the water balance in a given year. The percent difference between inflow and the total outflow was calculated. The model had no difference between the inflow and the sum of the outflows showing that the model has consistent mass balance. There are some notable differences in the observed data set which are due to large shifts in pool elevation for a gage correction. There were two years where Wilson had a gage correction that impacted the calculation and three years at Tuttle Creek. All other years were less than 1% off mass balance for the observed data set. A deeper analysis can be made on the observed data process, but for the purposes of this study, the model is performing appropriately. All discrepancies between modeled and observed can be attributed to the observed data set.

Table 2.2-1 and Table 2.2-2 show the Wilson and Tuttle Creek analysis, respectively.

Table 2.2-1. Wilson mass balance annual volume comparison.

	Observed							Modeled—Existing Conditions with no Navigation							
Year	Inflow (AF)	Outflow (AF)	Evap (AF)	31Dec Storage (AF)	ΔStorage (AF)	O+E+ΔS (AF)	Inflow / Outflow (%)	Inflow (AF)	Outflow (AF)	Evap (AF)	31Dec Storage (AF)	ΔStorage (AF)	O+E+ΔS (AF)	Inflow / Outflow (%)	Observe / Modeled (%)
1980	48,159	11,385	42,507	233,248				48,159	7,260	46,183	213,325				
1981	35,193	7,876	32,333	228,069	-5,179	35,031	-0.46%	35,193	7,250	44,922	196,347	-16,978	35,193	0.00%	0.46%
1982	68,768	23,572	33,149	240,209	12,140	68,861	0.13%	68,768	7,250	45,433	212,432	16,085	68,768	0.00%	-0.14%
1983	31,661	8,261	37,869	225,993	-14,216	31,915	0.80%	31,661	7,250	44,921	191,922	-20,510	31,661	0.00%	-0.80%
1984	59,908	11,500	35,463	238,526	12,533	59,496	-0.69%	59,908	7,260	44,862	199,708	7,786	59,908	0.00%	0.69%
1985	71,436	36,588	33,365	233,390	-5,136	64,818	-10.21%	71,436	7,250	45,251	218,643	18,935	71,435	0.00%	9.26%
1986	37,865	7,841	33,016	230,361	-3,029	37,828	-0.10%	37,865	7,250	45,367	203,892	-14,751	37,865	0.00%	0.10%
1987	285,227	229,122	37,899	248,531	18,170	285,191	-0.01%	285,227	203,711	49,235	236,173	32,282	285,227	0.00%	0.01%
1988	28,648	17,475	40,456	219,287	-29,245	28,687	0.14%	28,648	14,106	46,386	204,329	-31,845	28,648	0.00%	-0.13%
1989	29,741	8,166	34,343	206,583	-12,704	29,805	0.22%	29,741	7,250	43,732	183,088	-21,241	29,741	0.00%	-0.22%
1990	36,786	7,176	33,773	201,589	-4,994	35,955	-2.31%	36,786	7,250	41,770	170,854	-12,234	36,786	0.00%	2.26%
1991	31,040	7,147	33,751	191,600	-9,989	30,909	-0.42%	31,040	7,250	39,412	155,233	-15,621	31,040	0.00%	0.42%
1992	75,264	7,208	28,395	231,368	39,769	75,371	0.14%	75,264	7,260	39,160	184,076	28,844	75,263	0.00%	-0.14%
1993	737,445	598,552	43,893	326,295	94,927	737,371	-0.01%	737,445	551,357	65,651	304,511	120,435	737,444	0.00%	0.01%
1994	128,761	176,521	35,381	243,063	-83,232	128,670	-0.07%	128,761	149,981	47,670	235,623	-68,889	128,762	0.00%	0.07%
1995	266,089	225,205	35,787	248,441	5,378	266,370	0.11%	266,089	212,658	52,865	236,188	565	266,089	0.00%	-0.11%
1996	106,813	83,284	33,247	238,524	-9,917	106,615	-0.19%	106,813	59,135	47,679	236,188	0	106,813	0.00%	0.19%
1997	97,971	61,205	33,974	241,338	2,814	97,993	0.02%	97,971	50,347	47,624	236,188	0	97,971	0.00%	-0.02%
1998	170,990	139,620	34,884	237,938	-3,400	171,103	0.07%	170,990	123,146	47,844	236,188	0	170,990	0.00%	-0.07%
1999	145,807	106,277	35,067	242,398	4,460	145,804	0.00%	145,807	98,092	47,715	236,188	0	145,807	0.00%	0.00%
2000	71,555	44,160	39,351	230,508	-11,890	71,621	0.09%	71,555	36,238	47,264	224,242	-11,946	71,555	0.00%	-0.09%
2001	130,088	78,501	38,316	243,731	13,223	130,040	-0.04%	130,088	70,368	47,773	236,188	11,946	130,088	0.00%	0.04%
2002	39,136	18,292	38,291	226,311	-17,421	39,163	0.07%	39,136	14,683	46,680	213,962	-22,226	39,137	0.00%	-0.07%
2003	31,893	7,248	36,326	214,764	-11,547	32,027	0.42%	31,893	7,250	44,924	193,682	-20,280	31,893	0.00%	-0.42%
2004	45,630	7,168	33,587	219,472	4,708	45,462	-0.37%	45,630	7,260	43,855	188,198	-5,484	45,631	0.00%	0.37%
2005	30,193	7,210	34,958	207,597	-11,875	30,294	0.33%	30,193	7,250	42,391	168,750	-19,448	30,193	0.00%	-0.33%
2006	21,148	7,289	36,703	184,688	-22,910	21,083	-0.31%	21,148	7,250	37,770	144,878	-23,872	21,148	0.00%	0.31%
2007	74,681	7,313	35,827	216,108	31,421	74,561	-0.16%	74,681	7,250	39,837	172,472	27,594	74,680	0.00%	0.16%
2008	163,323	100,604	34,952	243,407	27,299	162,855	-0.29%	163,323	55,975	43,632	236,188	63,716	163,322	0.00%	0.29%
2009	80,372	42,203	34,688	247,467	4,060	80,951	0.71%	80,371	32,827	47,545	236,188	0	80,371	0.00%	-0.72%
2010	75,353	50,563	36,940	235,104	-12,363	75,140	-0.28%	75,349	40,763	47,171	223,603	-12,585	75,349	0.00%	0.28%
2011	50,407	8,432	38,817	238,507	3,403	50,651	0.48%	50,407	8,681	46,571	218,757	-4,846	50,407	0.00%	-0.48%
2012	19,268	7,143	39,003	205,105	-33,402	12,744	-51.19%	19,268	7,260	44,858	185,908	-32,849	19,268	0.00%	33.86%
2013	27,715	7,211	37,078	188,648	-16,457	27,831	0.42%	27,715	7,250	41,054	165,320	-20,588	27,716	0.00%	-0.42%

2014	20,944	7,160	31,690	170,773	-17,875	20,975	0.15%	20,946	7,250	37,304	141,713	-23,608	20,946	0.00%	-0.14%
2015	22,898	7,218	29,603	156,953	-13,820	23,001	0.45%	22,898	7,250	34,410	122,951	-18,762	22,898	0.00%	-0.45%
2016	166,660	46,905	32,460	244,095	87,142	166,508	-0.09%	166,660	14,919	38,502	236,188	113,237	166,658	0.00%	0.09%
2017	146,547	114,127	38,225	238,288	-5,808	146,545	0.00%	146,547	98,650	47,897	236,188	0	146,547	0.00%	0.00%
2018	190,013	150,827	36,182	240,924	2,636	189,645	-0.19%	190,011	141,298	47,865	237,036	848	190,011	0.00%	0.19%

Table 2.2-2. Tuttle Creek mass balance annual volume comparison.

	Observed							Modeled—Existing Conditions with no Navigation							
Year	Inflow (AF)	Outflow (AF)	Evap (AF)	31Dec Storage (AF)	ΔStorage (AF)	O+E+ΔS (AF)	Inflow / Outflow (%)	Inflow (AF)	Outflow (AF)	Evap (AF)	31Dec Storage (AF)	ΔStorage (AF)	O+E+ΔS (AF)	Inflow / Outflow (%)	Observe / Modeled (%)
1980	1,213,854	1,190,009	68,482	352,343				1,213,854	1,159,155	54,773	256,940				
1981	864,181	726,332	50,446	440,449	88,106	864,884	0.08%	864,181	812,515	51,593	257,014	74	864,181	0.00%	-0.08%
1982	2,621,969	2,575,402	52,412	433,092	-7,357	2,620,457	-0.06%	2,621,969	2,540,191	81,778	257,014	0	2,621,969	0.00%	0.06%
1983	2,295,713	2,279,492	59,569	350,277	-82,815	2,256,246	-1.75%	2,295,713	2,220,189	75,523	257,014	0	2,295,713	0.00%	1.72%
1984	3,422,113	3,332,060	57,387	352,916	2,640	3,392,086	-0.89%	3,422,113	3,305,380	116,732	257,014	0	3,422,113	0.00%	0.88%
1985	1,962,515	1,906,816	42,235	366,328	13,412	1,962,463	0.00%	1,962,515	1,909,146	53,368	257,014	0	1,962,515	0.00%	0.00%
1986	3,360,513	3,341,152	48,905	336,422	-29,907	3,360,151	-0.01%	3,360,513	3,264,529	95,984	257,014	0	3,360,513	0.00%	0.01%
1987	3,199,812	3,191,811	49,735	297,698	-38,724	3,202,822	0.09%	3,199,812	3,122,197	77,615	257,014	0	3,199,812	0.00%	-0.09%
1988	590,895	573,698	48,672	266,222	-31,476	590,894	0.00%	590,895	577,662	50,334	219,912	-37,102	590,895	0.00%	0.00%
1989	1,072,123	1,014,449	44,482	279,833	13,612	1,072,543	0.04%	1,072,123	985,002	50,019	257,014	37,102	1,072,123	0.00%	-0.04%
1990	1,373,990	1,319,748	45,903	288,103	8,270	1,373,921	-0.01%	1,373,990	1,329,737	55,533	245,734	-11,280	1,373,990	0.00%	0.01%
1991	670,740	646,252	46,941	265,261	-22,842	670,351	-0.06%	670,740	669,458	49,038	197,979	-47,756	670,741	0.00%	0.06%
1992	2,030,753	1,950,185	45,148	300,442	35,181	2,030,514	-0.01%	2,030,753	1,910,577	61,140	257,014	59,035	2,030,752	0.00%	0.01%
1993	6,251,189	6,179,354	70,702	301,238	796	6,250,852	-0.01%	6,251,189	6,067,068	166,718	274,417	17,403	6,251,189	0.00%	0.01%
1994	1,326,178	1,286,819	44,248	296,733	-4,505	1,326,563	0.03%	1,326,178	1,292,135	51,446	257,014	-17,403	1,326,178	0.00%	-0.03%
1995	2,180,065	2,134,171	45,525	297,279	546	2,180,242	0.01%	2,180,065	2,062,248	117,817	257,014	0	2,180,065	0.00%	-0.01%
1996	1,671,743	1,616,268	45,060	307,808	10,529	1,671,857	0.01%	1,671,743	1,584,792	86,952	257,014	0	1,671,743	0.00%	-0.01%
1997	1,310,915	1,257,223	45,114	315,822	8,015	1,310,351	-0.04%	1,310,915	1,199,599	111,316	257,014	0	1,310,915	0.00%	0.04%
1998	2,582,775	2,554,712	45,405	298,674	-17,149	2,582,969	0.01%	2,582,775	2,510,508	72,267	257,014	0	2,582,775	0.00%	-0.01%
1999	2,221,800	2,122,752	48,037	313,751	15,078	2,185,866	-1.64%	2,221,800	2,126,279	95,521	257,014	0	2,221,800	0.00%	1.62%
2000	727,697	756,886	51,844	232,863	-80,889	727,841	0.02%	727,697	709,205	50,449	225,057	-31,957	727,697	0.00%	-0.02%
2001	2,153,526	2,051,652	51,886	282,561	49,698	2,153,237	-0.01%	2,153,526	2,068,098	59,285	251,199	26,142	2,153,525	0.00%	0.01%
2002	624,674	656,478	38,645	212,553	-70,008	625,115	0.07%	624,674	602,567	49,114	224,192	-27,007	624,674	0.00%	-0.07%
2003	746,738	671,371	45,470	242,466	29,913	746,754	0.00%	746,738	690,949	49,061	230,920	6,728	746,738	0.00%	0.00%
2004	1,019,370	928,240	45,527	288,326	45,860	1,019,628	0.03%	1,019,370	966,561	51,458	232,271	1,351	1,019,370	0.00%	-0.03%
2005	823,877	799,128	44,432	268,210	-20,116	823,445	-0.05%	823,877	749,511	52,072	254,564	22,293	823,876	0.00%	0.05%
2006	443,253	464,500	39,184	207,810	-60,400	443,284	0.01%	443,253	434,763	49,452	213,603	-40,961	443,253	0.00%	-0.01%

2007	2,244,320	2,125,773	47,936	277,862	70,052	2,243,760	-0.02%	2,244,320	2,137,838	63,071	257,014	43,411	2,244,320	0.00%	0.02%
2008	2,394,382	2,300,787	45,245	325,784	47,923	2,393,954	-0.02%	2,394,382	2,323,114	71,268	257,014	0	2,394,382	0.00%	0.02%
2009	1,026,630	1,065,987	39,979	247,121	-78,664	1,027,302	0.07%	1,026,630	968,761	57,869	257,014	0	1,026,630	0.00%	-0.07%
2010	2,399,585	2,332,743	60,106	253,709	6,589	2,399,437	-0.01%	2,399,585	2,266,060	133,525	257,014	0	2,399,585	0.00%	0.01%
2011	1,128,911	1,034,090	63,413	285,574	31,865	1,129,368	0.04%	1,128,911	1,016,074	112,837	257,014	0	1,128,911	0.00%	-0.04%
2012	554,914	636,755	42,489	142,209	-143,365	535,879	-3.55%	554,914	579,595	48,786	183,548	-73,466	554,915	0.00%	3.43%
2013	843,404	687,215	42,961	255,441	113,233	843,408	0.00%	843,404	729,657	51,653	245,641	62,093	843,403	0.00%	0.00%
2014	792,192	743,689	43,236	260,038	4,597	791,521	-0.08%	793,085	727,998	56,590	254,137	8,496	793,084	0.00%	0.20%
2015	2,447,943	2,319,338	44,785	343,942	83,904	2,448,027	0.00%	2,447,943	2,221,027	93,704	387,346	133,209	2,447,940	0.00%	0.00%
2016	1,494,200	1,555,484	45,474	234,838	-109,103	1,491,854	-0.16%	1,494,200	1,552,894	71,640	257,014	-130,332	1,494,202	0.00%	0.16%
2017	1,441,039	1,392,737	46,041	237,414	2,576	1,441,354	0.02%	1,441,039	1,381,491	73,677	242,885	-14,129	1,441,039	0.00%	-0.02%
2018	1,964,258	1,777,969	50,665	369,701	132,287	1,960,921	-0.17%	1,964,258	1,380,074	85,861	741,201	498,316	1,964,251	0.00%	0.17%

FUTURE WITHOUT PROJECT

Kansas River Reservoirs Flood and Sediment Study
Future Without Project Documentation
Model Data Review, Analysis, and Documentation

Draft Report: November 2021
USACE Kansas City District

Executive Summary

The following work is included as part of the Kansas River Reservoirs Flood and Sediment Study (KRRFSS). This ongoing study investigates water and related land resource issues and opportunities in the Kansas River Basin to recommend comprehensive, long-term, and sustainable water resource solutions and management based on a Shared Vision for the basin.

Future sediment conditions were estimated by the Kansas City District River Engineering and Restoration Section for year zero, 25, 50 and 100 from the end of the project. The existing conditions 100 years of inflow were used for the future modeling scenario. HEC-ResSim was utilized to model the Kansas River basin and evaluate the impacts to reservoirs and stream flows for the future sediment conditions.

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1 Introduction

This document provides the methodology used to simulate future without project regulated flow on the Kansas River for future sediment conditions at the federal flood control reservoirs. Reservoir modeling was conducted using Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) version 3.5. Future reservoir sediment conditions were estimated by the Kansas City District River Engineering and Restoration Section for year zero, 25, 50 and 100 from the end of the project. The flood control reservoirs included in this study are the lower seven reservoirs all on tributaries of the Kansas River: Kanopolis, Wilson, Waconda, Milford, Tuttle Creek, Perry, and Clinton.

All analysis is conducted as part of the Kansas River Reservoirs Flood and Sediment Study (KRRFSS). The future without project simulations will be used to quantify impacts to flood risk management, reservoir operations, infrastructure investment, water supply availability and sustainment, water quality, recreation, and ecosystem preservation and restoration. Several alternatives will also be evaluated including changes to reservoir operations and compared to the existing condition and future without project modeling.

2 Basin Description

2.1 Federal Flood Control Reservoirs

The Kansas River is formed by the confluence of Smoky Hill and Republican Rivers near Junction City, Kansas. It flows approximately 148 miles generally eastward where it joins the Missouri River near Kansas City. There are seven U.S. Army Corps of Engineers (USACE) and eleven U.S Bureau of Reclamation (USBR) reservoirs which are authorized for flood control in the basin. The lower seven reservoirs are included in this study since they are the major contributors to Kansas River Basin flood storage.

These seven reservoirs include three which are in the Smoky Hill River Basin: Kanopolis Reservoir on the Smoky Hill River, Wilson Reservoir on the Saline River, and Waconda Reservoir on the Solomon River. The Smoky Hill River Basin reservoirs and the corresponding control point gages are shown in Figure 2-1. The rest of the seven reservoirs are on tributaries to the lower Kansas River and are Milford Reservoir on the Republican River, Tuttle Creek Reservoir on the Big Blue River, Perry Reservoir on the Delaware River, and Clinton Reservoir on the Wakarusa River. The Kansas River Basin reservoirs and the corresponding control point gages for flood control operations are shown in Figure 2-2.

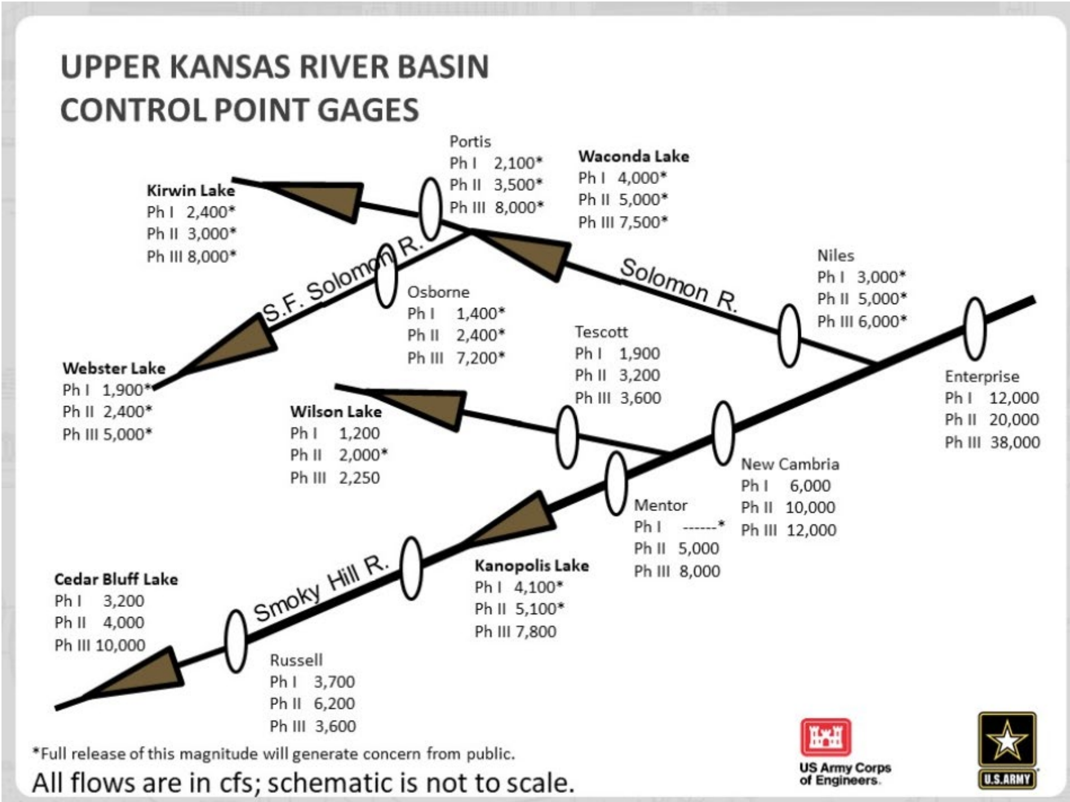


Figure 2-1 Schematic of the Smoky Hill River Basin reservoirs and control points.

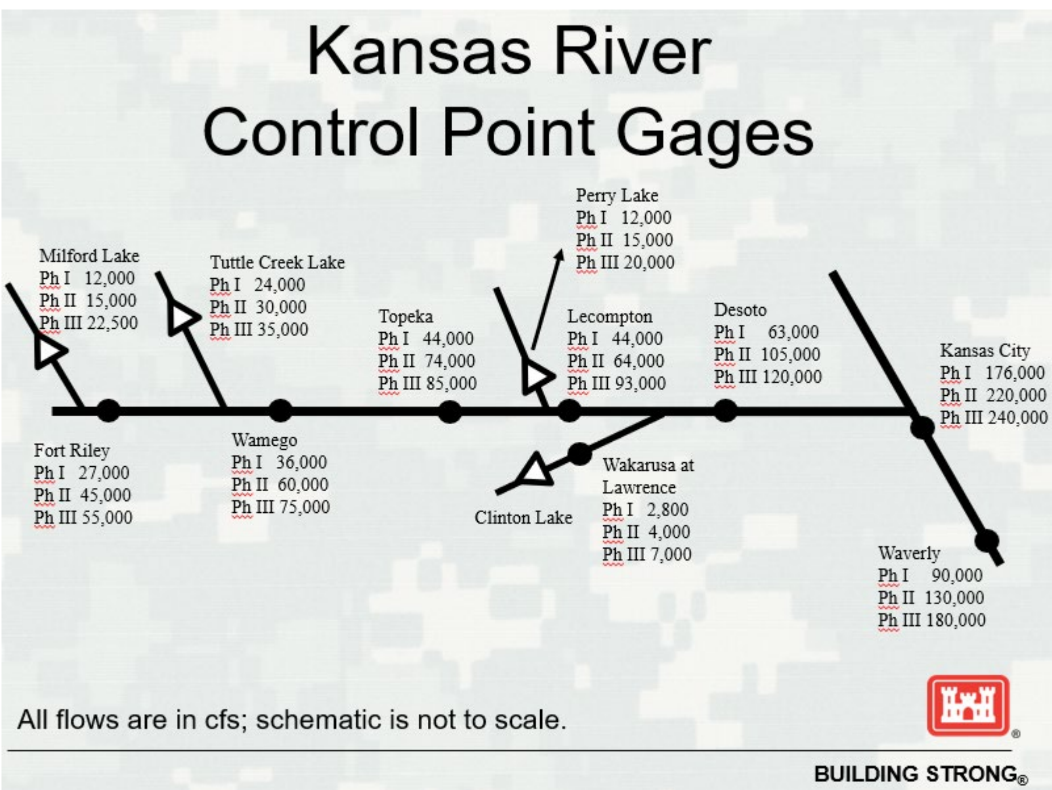


Figure 2-2 Schematic of the Kansas River Basin reservoirs and control points.

These seven reservoirs vary widely in storage and release capacity. Table 2-1 details pertinent information for each reservoir. Generally, the size of the flood storage and the discharge capacity is indicative of how much the reservoir impacts downstream flows. The larger reservoirs also tend to be authorized for more release capacity. Figure 2-3 through Figure 2-9 depict the current reservoir allocation zones and storage capacity of each zone to include the multipurpose or conservation pool.

Table 2-1 Pertinent data for the lower seven reservoirs in the Kansas River Basin

Reservoir	Owner	Date of Closure	Date Multi-purpose Filled	Flood Control Storage (ac-ft)	Outlet Discharge Capacity Top of Flood Pool (cfs)	Surcharge Storage (ac-ft)	Spillway Discharge Capacity Top of Surcharge Pool (cfs)
Kanopolis	USACE	26Jul1946	19July1948	365,143	6,400	484,912	172,000
Wilson	USACE	3Sep1963	12Mar1973	530,152	6,500	899,749	15,700
Waconda	USBR	18Oct1967	16May1973	722,986	5,200	166,572	278,000
Milford	USACE	24Aug1964	14Jul1967	757,874	23,100	1,475,913	560,000
Tuttle Creek	USACE	20Jul1959	29Apr1963	1,884,312	45,900	959,939	579,000
Perry	USACE	2Aug1966	3Jun1970	515,520	27,500	695,362	65,000
Clinton	USACE	23Aug1975	3Apr1980	292,496	7,570	286,875	44,200

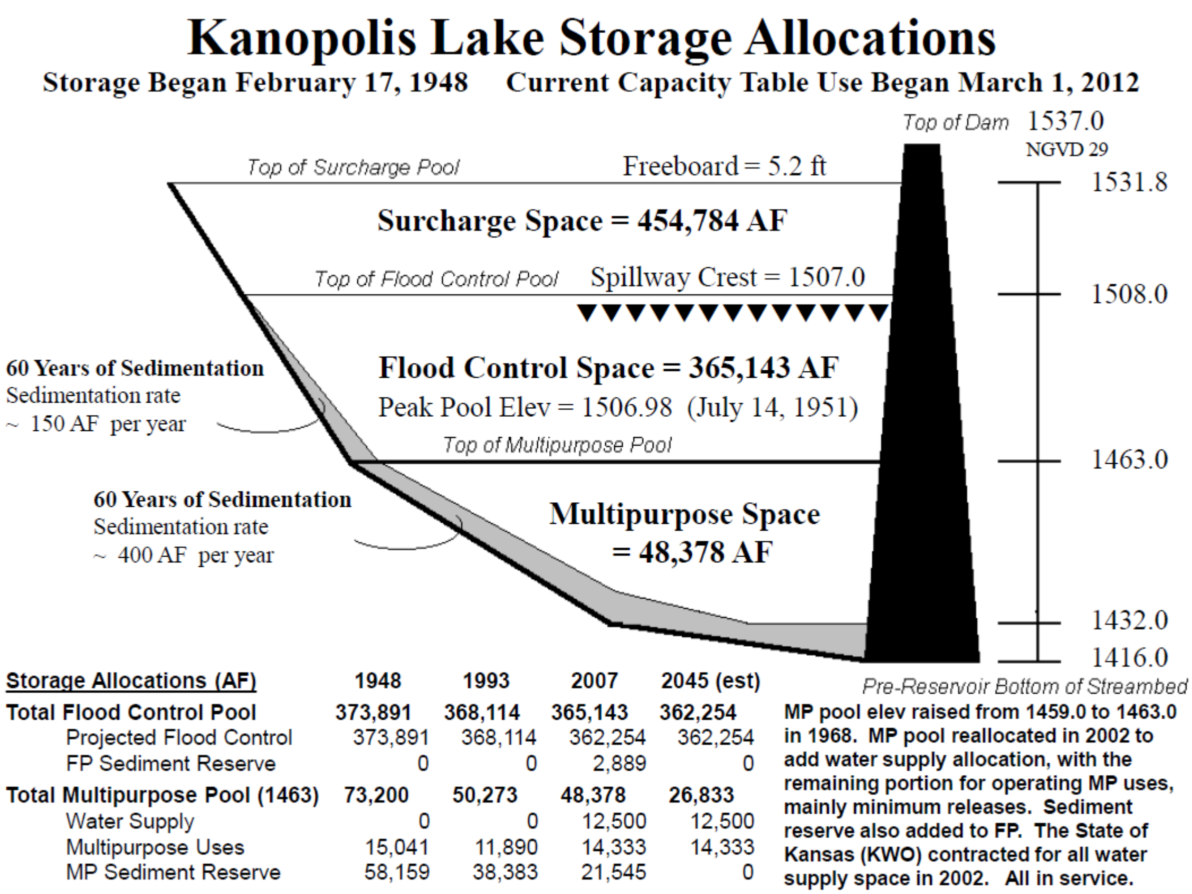
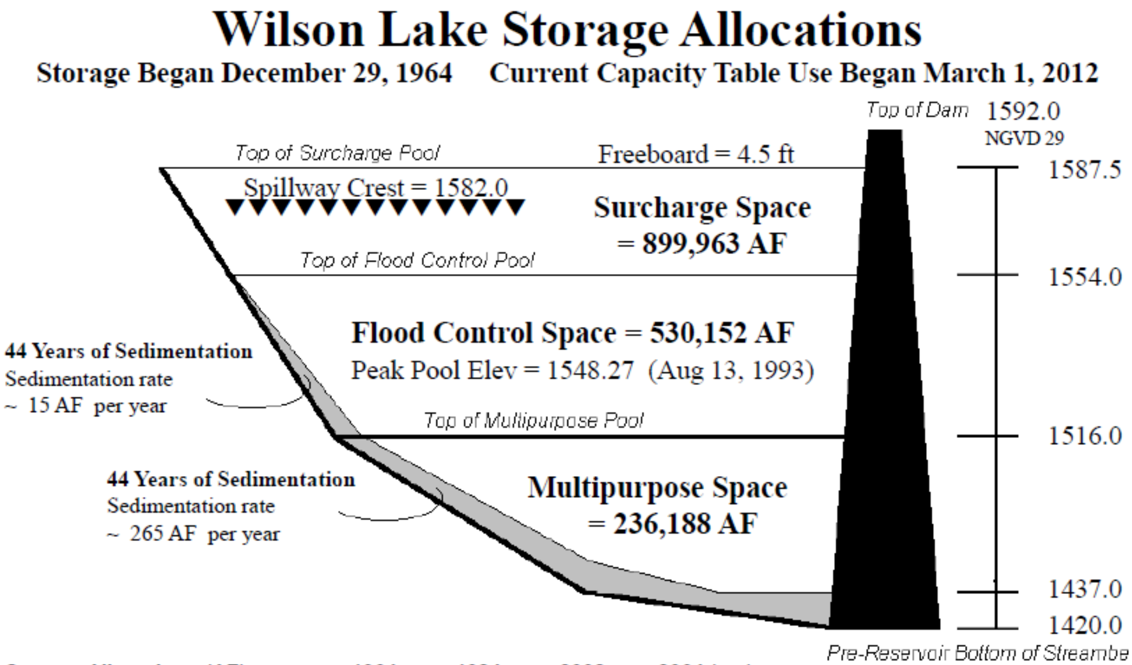


Figure 2-3 Kanopolis Reservoir Storage Allocations



Storage Allocations (AF)	1964	1984	2008	2064 (est)
Total Flood Control Pool	**530,710**	**530,204**	**530,152**	**510,000**
Exclusive Flood Control	510,000	510,000	510,000	510,000
FP Sediment Reserve	20,710	20,204	20,152	0
Total Multipurpose Pool	**247,835**	**242,528**	**236,188**	**225,000**
Multipurpose (all purposes)	225,000	225,000	225,000	225,000
MP Sediment Reserve	22,835	17,528	11,188	0

The tables resulting from the 2008 survey have been used for operations since Mar 2012. The State of Kansas (KWO) has requested a reallocation study of Wilson Lake to make water supply space available, but the study has been put on hold.

Figure 2-4 Wilson Reservoir Storage Allocations

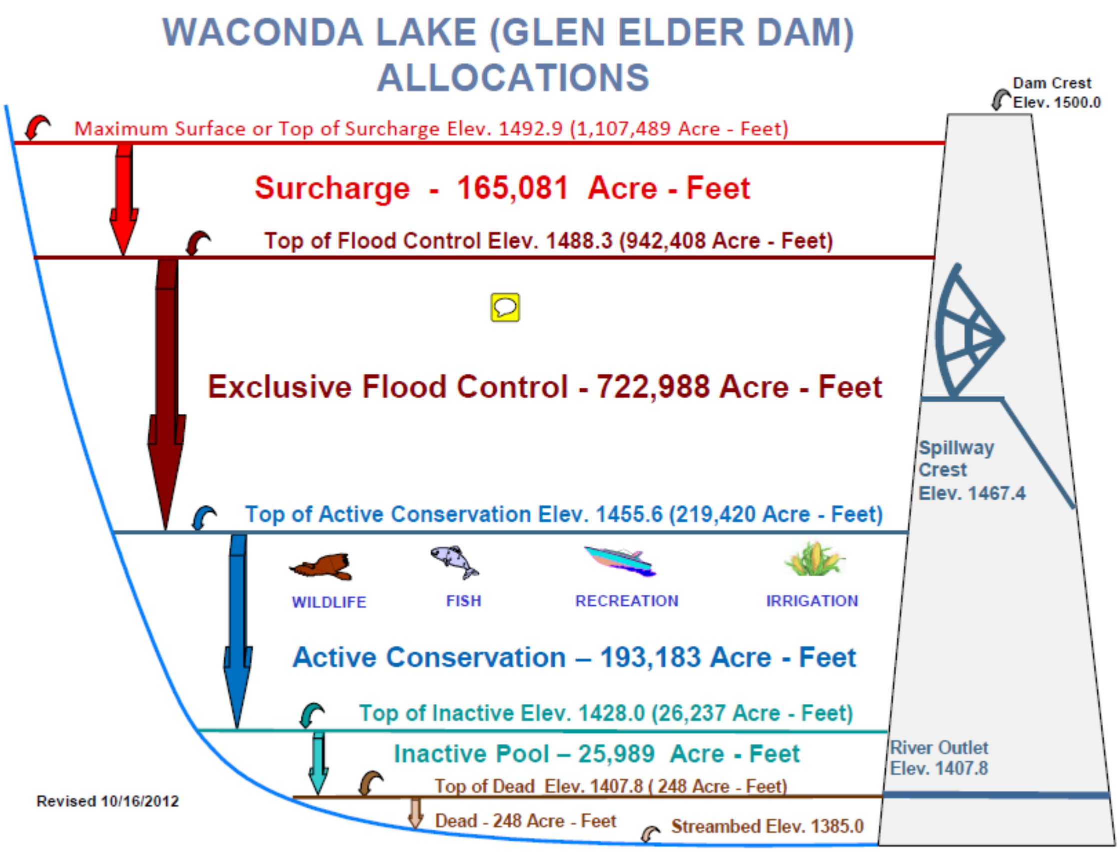
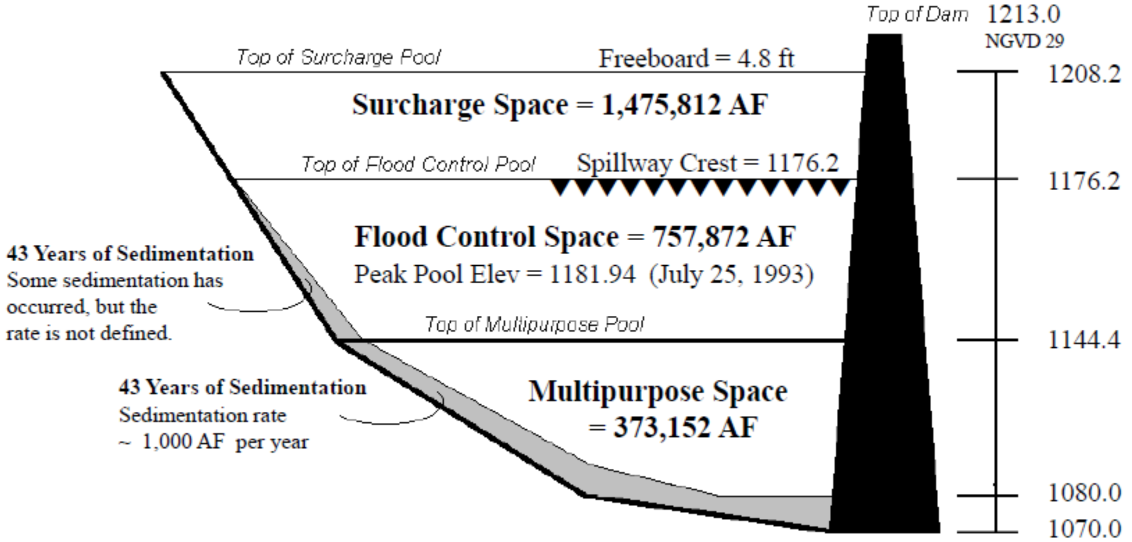


Figure 2-5 Waconda Reservoir Storage Allocations

Milford Lake Storage Allocations

Storage Began January 16, 1967 Current Capacity Table Use Began March 1, 2012



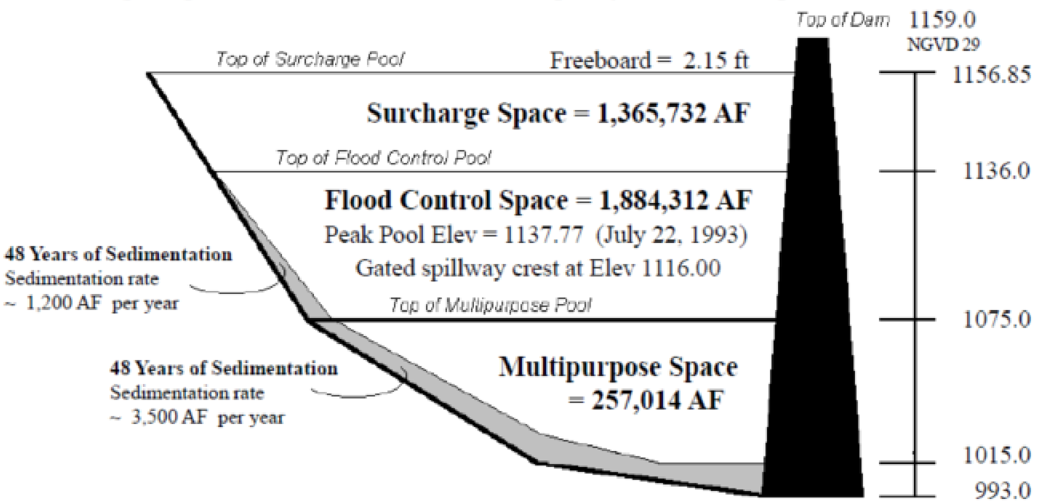
Storage Allocations (AF)	1967	1980	2009	2067 (est)
Total Flood Control Pool	**757,746**	**756,601**	**757,872**	**700,000**
Exclusive Flood Control	700,000	700,000	700,000	700,000
FP Sediment Reserve	57,746	56,601	57,872	0
Total Multipurpose Pool	**415,352**	**388,608**	**373,152**	**300,000**
In-Service Water Supply	0	101,650	101,650	300,000
Future Use Water Supply	300,000	198,350	198,350	0
MP Sediment Reserve	115,352	88,608	73,152	0

2009 tables now used for lake ops. State of Kansas (KWO) contracted for water supply allocation in 1974. The initial in-service increment of 101,650 AF is subcontracted to the Kansas River Water Assurance District and KP&L. Until called into service, the future use space is operated for other MP uses.

Figure 2-6 Milford Reservoir Storage Allocations

Tuttle Creek Lake Storage Allocations

Storage Began March 7, 1962 Current Capacity Table Use Began March 1, 2012



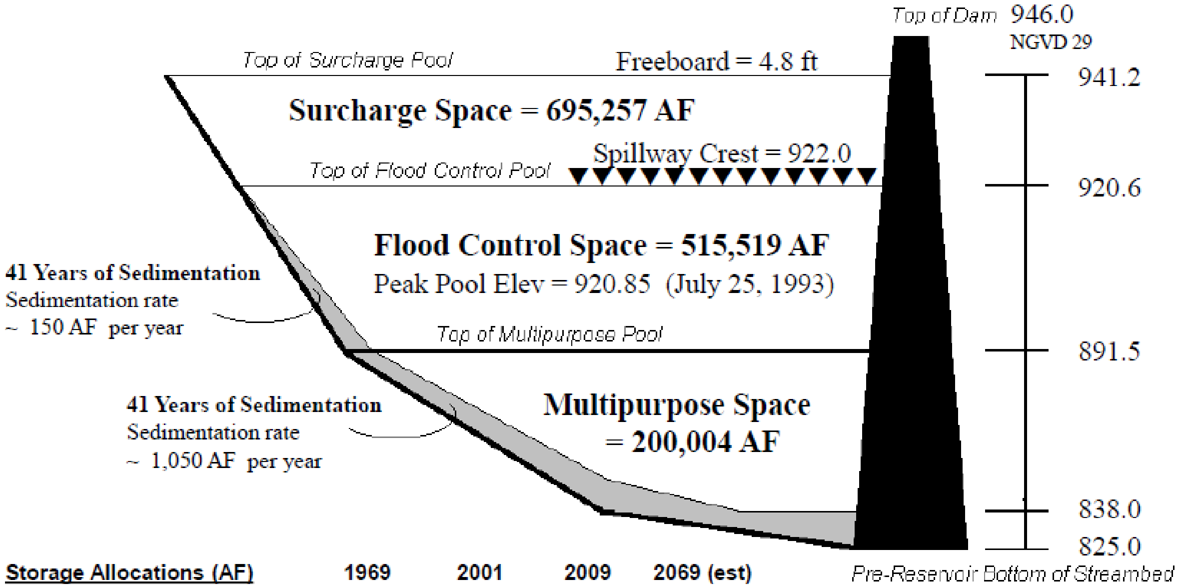
Storage Allocations (AF)	1962	1989	2009	2035 (est)
Total Flood Control Pool	**1,941,705**	**1,922,085**	**1,884,312**	**1,879,000**
Projected Flood Control	1,941,705	1,879,000	1,879,000	1,879,000
Nominal Sediment Reserve	0	43,085	5,312	0
Total Multipurpose Pool	**425,312**	**335,100**	**257,014**	**122,000**
Water Supply (all in-service)	0	50,000	50,000	50,000
WQ, Nav, Other Purposes	185,000	72,000	72,000	72,000
MP Sediment Reserve	240,312	213,100	135,014	0

The 1989 Reallocation added a water supply allocation and added space to the sediment reserve to extend its design life from 2012 to 2035. The State (KWO) contracted for the water supply, all of which is in service.

Figure 2-7 Tuttle Creek Reservoir Storage Allocations

Perry Lake Storage Allocations

Storage Began January 15, 1969 Current Capacity Table Use Began March 1, 2012



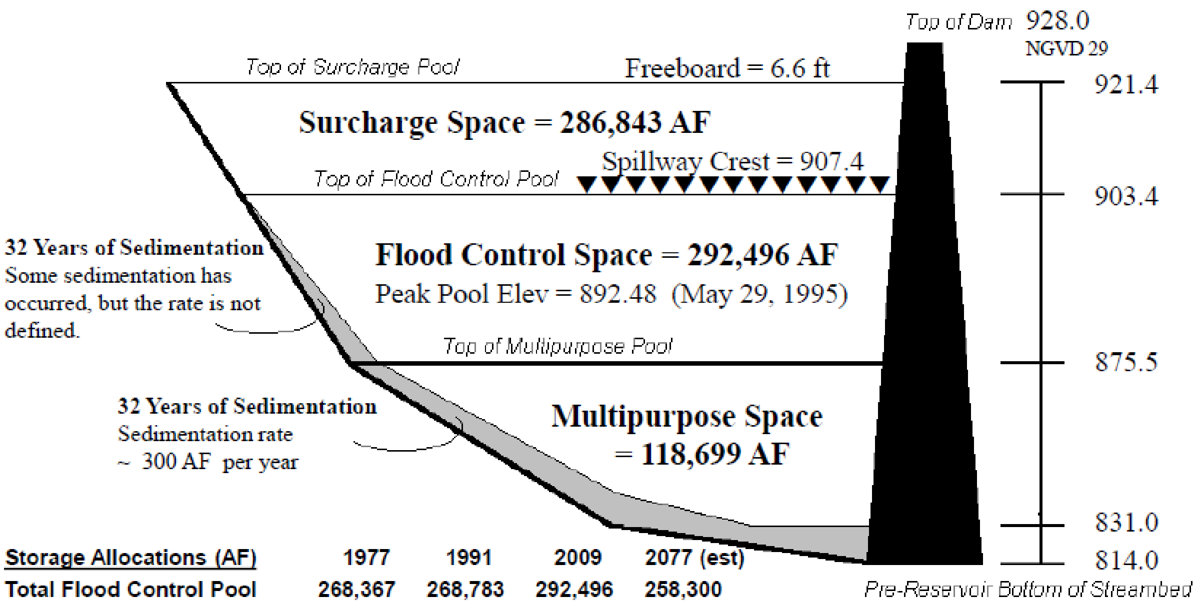
Storage Allocations (AF)	1969	2001	2009	2069 (est)
Total Flood Control Pool	**521,880**	**515,397**	**515,519**	**480,000**
Exclusive Flood Control	480,000	480,000	480,000	480,000
FP Sediment Reserve	41,880	35,397	35,519	0
Total Multipurpose Pool	**243,220**	**206,682**	**200,004**	**150,000**
In-Service Water Supply	0	25,000	25,000	150,000
Future Use Water Supply	150,000	125,000	125,000	0
MP Sediment Reserve	93,220	56,582	50,004	0

2009 tables now used for operations. The State of Kansas (KWO) contracted for the water supply allocation in 1977. The initial 25,000 AF increment is contracted to the Kansas River Water Assurance District. Valley Falls has a separate water withdrawal contract.

Figure 2-8 Perry Reservoir Storage Allocations

Clinton Lake Storage Allocations

Storage Began November 30, 1977 Current Capacity Table Use Began March 1, 2012



Storage Allocations (AF)	1977	1991	2009	2077 (est)
Total Flood Control Pool	**268,367**	**268,783**	**292,496**	**258,300**
Exclusive Flood Control	258,300	258,300	258,300	258,300
FP Sediment Reserve	10,067	10,483	34,196	0
Total Multipurpose Pool	**129,171**	**125,334**	**118,699**	**110,400**
In-Service Water Supply	53,520	53,520	53,520	89,200
Future Use Water Supply	35,680	35,680	35,680	0
Water Quality	21,200	21,200	21,200	21,200
MP Sediment Reserve	18,771	14,934	8,299	0

2012 tables based on 2009 lake survey. Water supply allocation contracted to the State of Kansas (KWO) in 1977, with an initial in-service increment of 53,500 AF; the available water is subcontracted to the cities of Lawrence, Baldwin City, and six Douglas County rural water districts.

Figure 2-9 Clinton Reservoir Storage Allocations

Reservoirs upstream of Kanopolis, Waconda, and Milford have not been included in this study; however, these reservoirs do impact the inflow records of the downstream reservoirs after their respective closure dates since observed inflows are relied upon in the performance of this study. These upstream reservoirs and their dam closure dates are show in Table 2-2.

Table 2-2 Reservoirs upstream of the study area.

Downstream Lake	Upstream Lake(s)	Closure Date	Initial Fill Date
Kanopolis	Cedar Bluff	Sep 10, 1950	Jun 21, 1951
Waconda	Webster	May 3, 1956	Jun 18, 1957
	Kirwin	Mar 7, 1955	Jul 2, 1957
Milford	Lovewell	May 29, 1957	May 20, 1958
	Harlan County	July 22, 1951	Nov 14, 1952
	Norton	Jan 8, 1964	Jun 21, 1967
	Harry Strunk	Aug 8, 1949	Apr 2, 1951
	Hugh Butler	Sep 5, 1961	May 22, 1961
	Swanson	May 4, 1953	May 15, 1957
	Bonny	Jul 6, 1950	Mar 29, 1954
	Enders	Oct 23, 1950	January 1952

2.2 Smoky Hill River Basin

The Smoky Hill River originates in eastern Colorado and flows across Kansas until it merges with the Republican River to form the Kansas River. It is approximately 575 miles long and contained solely in the central Great Plains. There are two federal flood control reservoirs on the Smoky Hill River: Cedar Bluff and Kanopolis. Major tributaries are the Saline River and Solomon River which are both left bank tributaries. Wilson Reservoir is on the Saline River. Webster, Kirwin, and Waconda Reservoirs are on the Solomon River and the headwater tributaries.

The basin has had several periods of droughts and floods. In the past 20 years, the U.S. Drought Monitor shows periods where none of the basin had any drought characterization and one period in 2012 and 2013 where much of the basin was listing in exceptional drought. Figure 2-10 shows the data from the U.S. Drought Monitor.

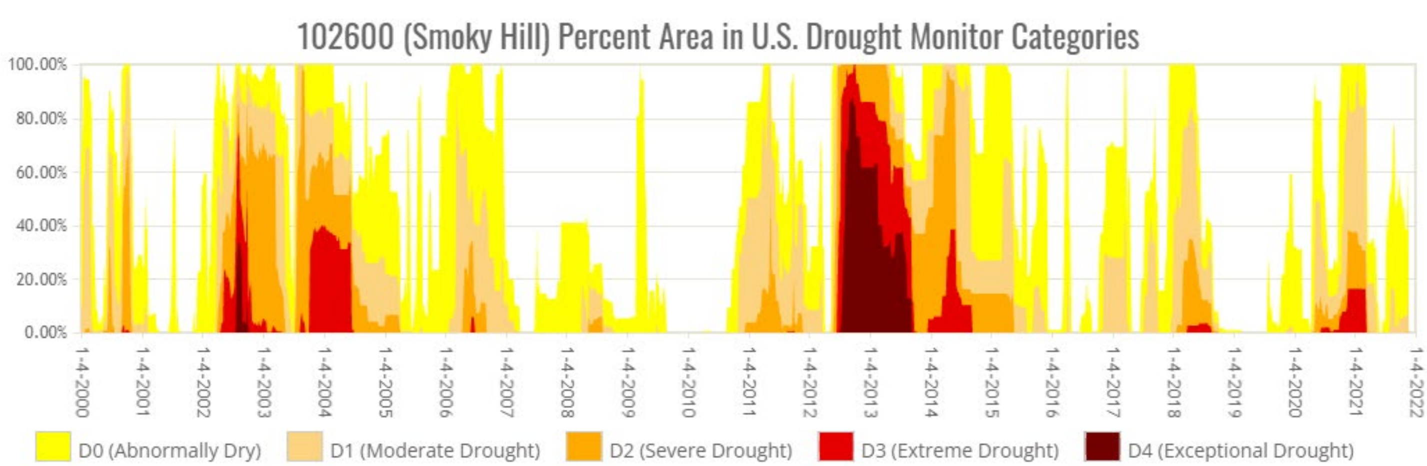


Figure 2-10. Percent of the Smoky Hill River Basin in U.S. Drought Monitor categories of drought from 2000 through 2021.

The furthest downstream gage on the Smoky Hill River is at Enterprise, KS. It has a drainage area of 19,260 square miles. Since data collection began in October 1934, the long-term average flow is 1,535 cfs. The maximum flow of record is 207,000 cfs in July of 1951. During drought conditions flows will often drop below 100 cfs. The annual flow volume is shown in Figure 2-11.

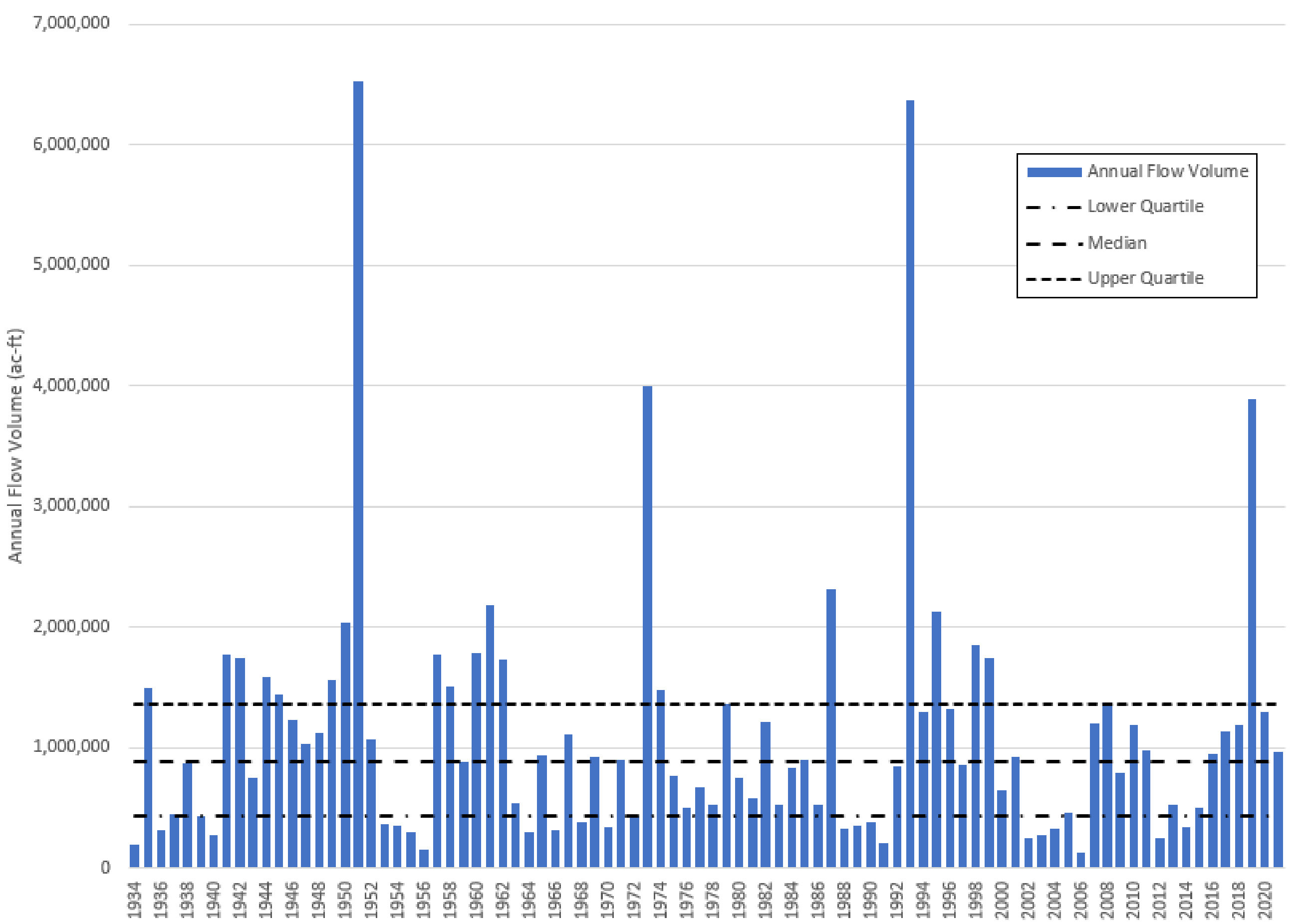


Figure 2-11. Smoky Hill River at Enterprise Annual Flow Volume and Statistical Flow.

2.3 Republican River Basin

The headwaters of Republican River originate in the High Plains of northeastern Colorado and flow eastward along the southern border of Nebraska. It eventually turns south into Kansas until it merges with the Smoky Hill River to form the Kansas River. It is approximately 450 miles long and contained solely in the central Great Plains. There are nine federal flood control reservoirs on the Republican River or its tributaries. The basin has had several periods of droughts and floods. In the past 20 years, the U.S. Drought Monitor shows periods where none of the basin had any drought characterization and periods in 2002 and 2012 where much of the basin was listing in extreme or exceptional drought. Figure 2-12 shows the data from the U.S. Drought Monitor.

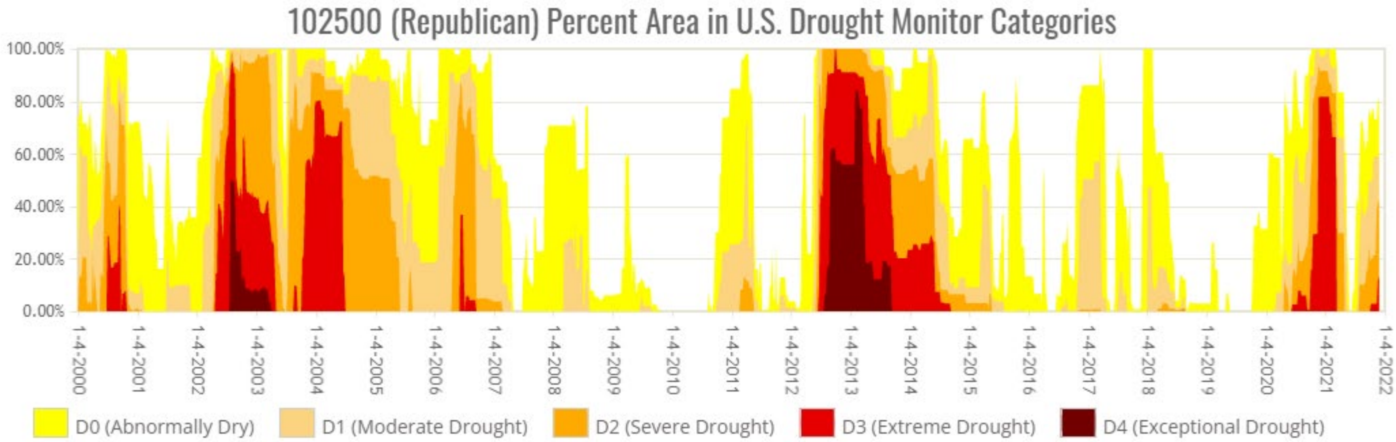


Figure 2-12. Percent of the Republican River Basin in U.S. Drought Monitor categories of drought from 2000 through 2021.

The longest gaged record on the lower Republican River is at Clay Center which has a total drainage of 24,542 square miles (only about 17,042 square miles are contributing). Clay Center data collection began June of 1917 and it is now used as the inflow gage to Milford Reservoir. Since data collection began, the long-term average flow is 913 cfs. The maximum flow of record is 33,300 cfs in July of 1993. During drought conditions flows will often drop below 100 cfs. The annual flow volume is shown in Figure 2-13.

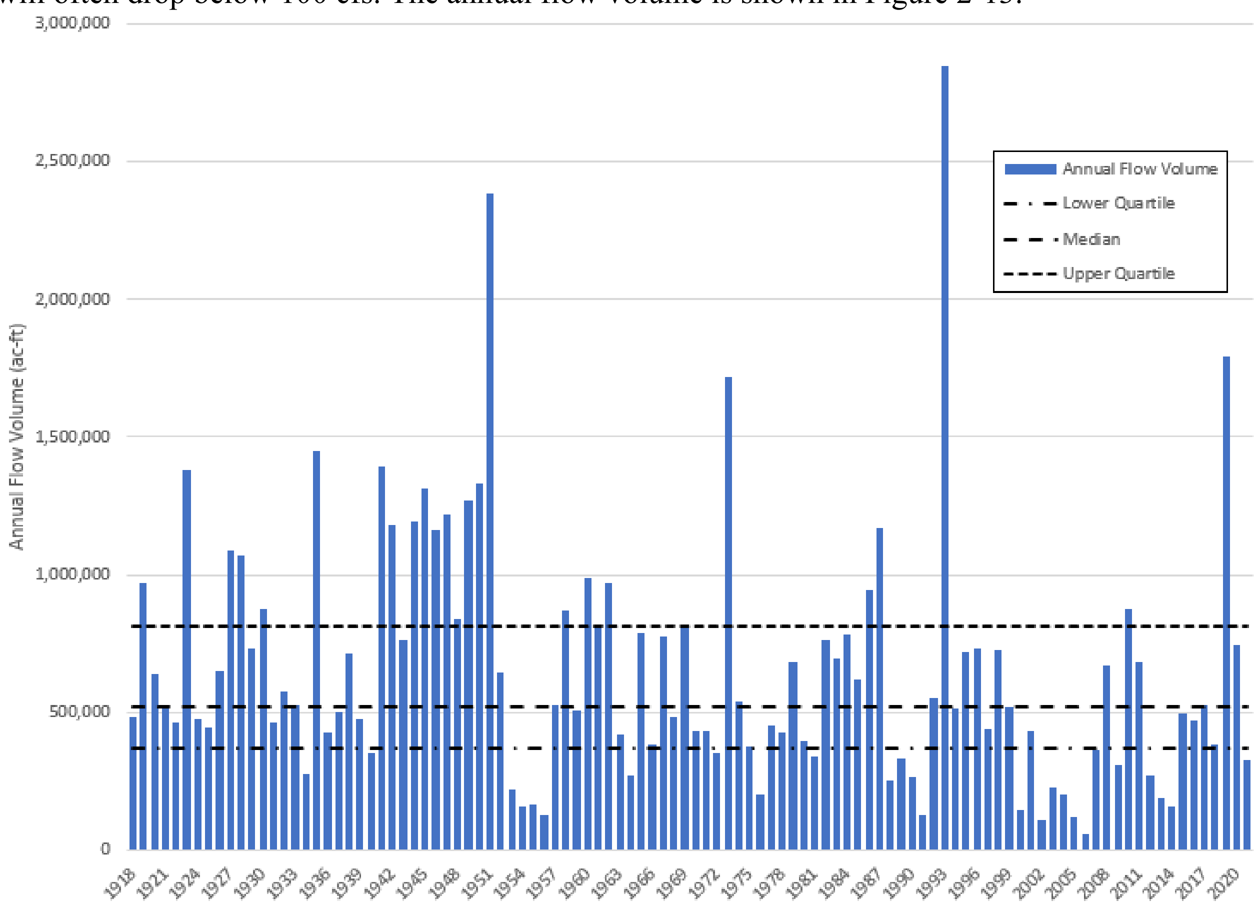


Figure 2-13. Republican River at Clay Center Annual Flow Volume and Statistical Flow.

2.4 Big Blue River Basin

The headwaters of Big Blue River originate in central Nebraska and flow southward into Kansas where it merges with the Kansas River at Manhattan, KS. The Big Blue River is approximately 359 miles long with a largely agricultural watershed. One major right bank tributary is the Little Blue River which also originates in southern Nebraska and is approximately 245 miles long. Tuttle Creek reservoir is near the mouth of the Big Blue River and captures flow from the Big and Little Blue Rivers. The basin has had several periods of droughts and floods; however, it is less prone to drought than the Republican and Smoky Hill Rivers. In the past 20 years, the U.S. Drought Monitor shows periods where none of the basin had any drought characterization and some periods of extreme drought especially in the 2012 and 2013 timeframe. Figure 2-14 shows the data from the U.S. Drought Monitor.

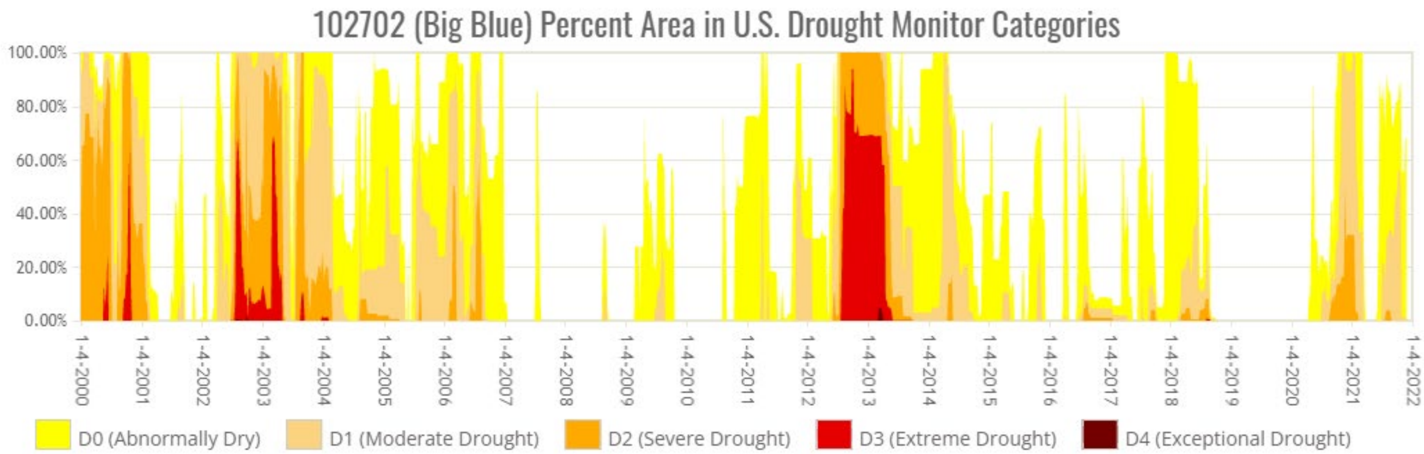


Figure 2-14. Percent of the Big Blue River Basin in U.S. Drought Monitor categories of drought from 2000 through 2021.

The longest gaged record on the lower Big Blue River is obtained by combining the Big Blue River at Randolph and Manhattan to obtain gage data from 1919 to the present. The Big Blue River at Randolph collected data from April 1918 to September 1960 when the gage site was inundated by Tuttle Creek Reservoir. The watershed area above Randolph is 9,100 square miles. The Big Blue River at Manhattan, KS began collecting data in October 1950 and it now the outflow gage for Tuttle Creek Reservoir. The watershed area above Manhattan is 9,640 square miles. In this combined record, the long-term average flow is 2,076 cfs. The maximum flow of record is 86,400 cfs in July of 1951. During drought conditions flows will often drop to around 200 cfs; however, the Tuttle Creek minimum flow of 100 cfs is also possible. The annual flow volume is shown in Figure 2-15.

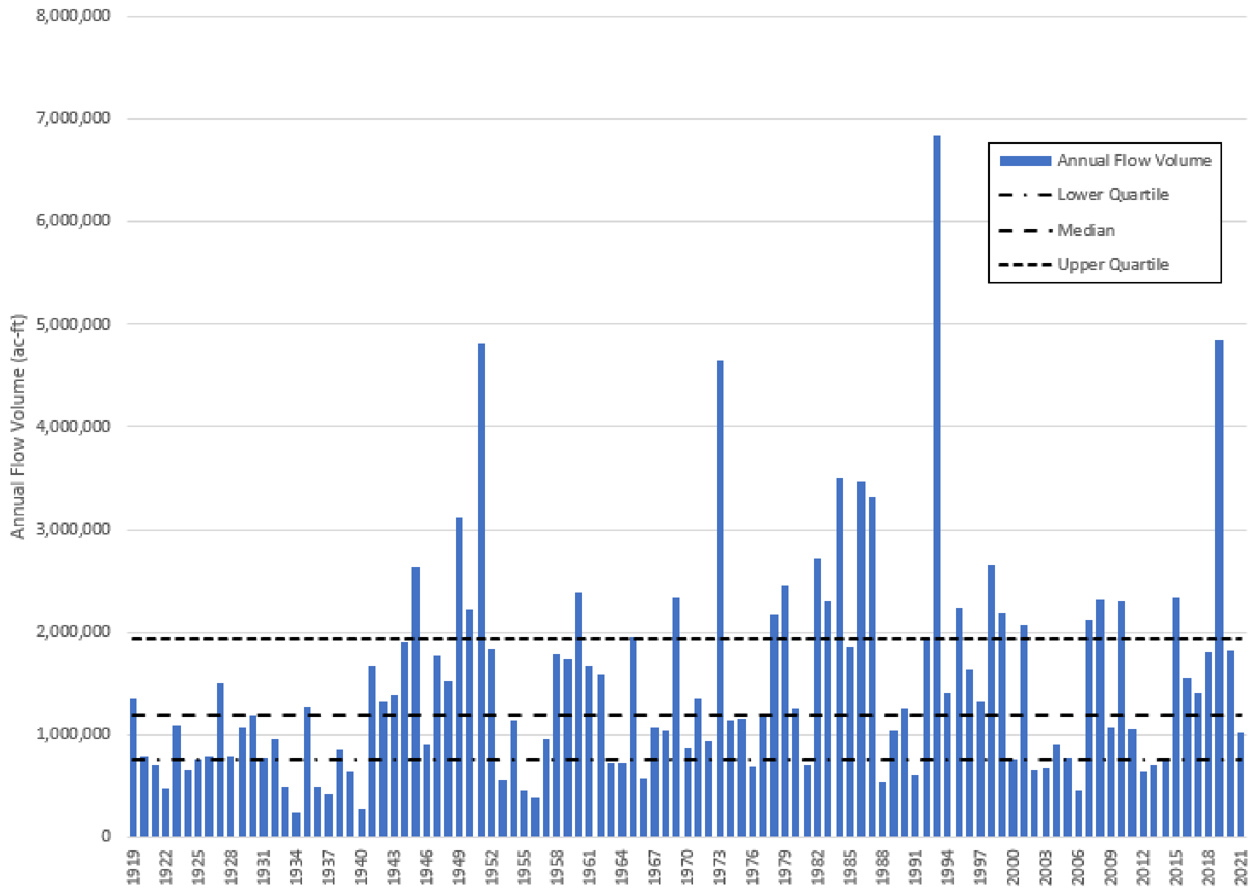


Figure 2-15. Big Blue River at Randolph (1919-1950) and Manhattan (1951 to present) Annual Flow Volume and Statistical Flow.

2.5 Kansas River Basin

The Kansas River begins at the confluence of the Republican and Smoky Hill Rivers and flows east across Kansas approximately 148 miles before merging with the Missouri River at Kansas City, KS. Its watershed is primarily agricultural, but it includes some major cities including Topeka, Lawrence and parts of Kansas City, KS. Besides the rivers already discussed major tributaries include the Delaware River with Perry Reservoir, the Wakarusa River with Clinton Reservoir, and Stranger Creek. The basin has had several periods of droughts and floods; however, it is less prone to drought than the Republican and Smoky Hill Rivers. In the past 20 years, the U.S. Drought Monitor shows periods where none of the basin had any drought characterization and some periods of extreme drought especially in the 2012 and 2013 timeframe. Figure 2-16 shows the data from the U.S. Drought Monitor.

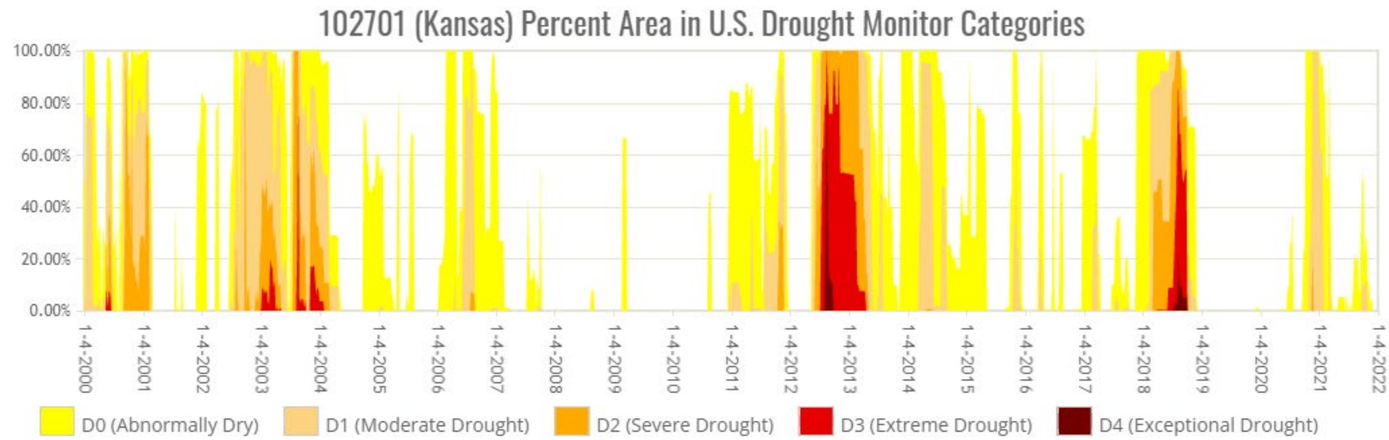


Figure 2-16. Percent of the Kansas River Basin in U.S. Drought Monitor categories of drought from 2000 through 2021.

The longest gaged record on the lower Kansas River is at Desoto which has a total drainage of 59,756 square miles. Desoto data collection began July of 1917 and is utilized as a water quality minimum flow location for the Kansas Reservoirs as well as a control point for flooding. Since data collection began, the long-term average flow is 7,351 cfs. The maximum flow of record is 486,000 cfs in July of 1951. During drought conditions flows will often drop near the water quality target of 1000 cfs; although, natural flows could drop more into the 500 cfs range. The annual flow volume is shown in Figure 2-17.

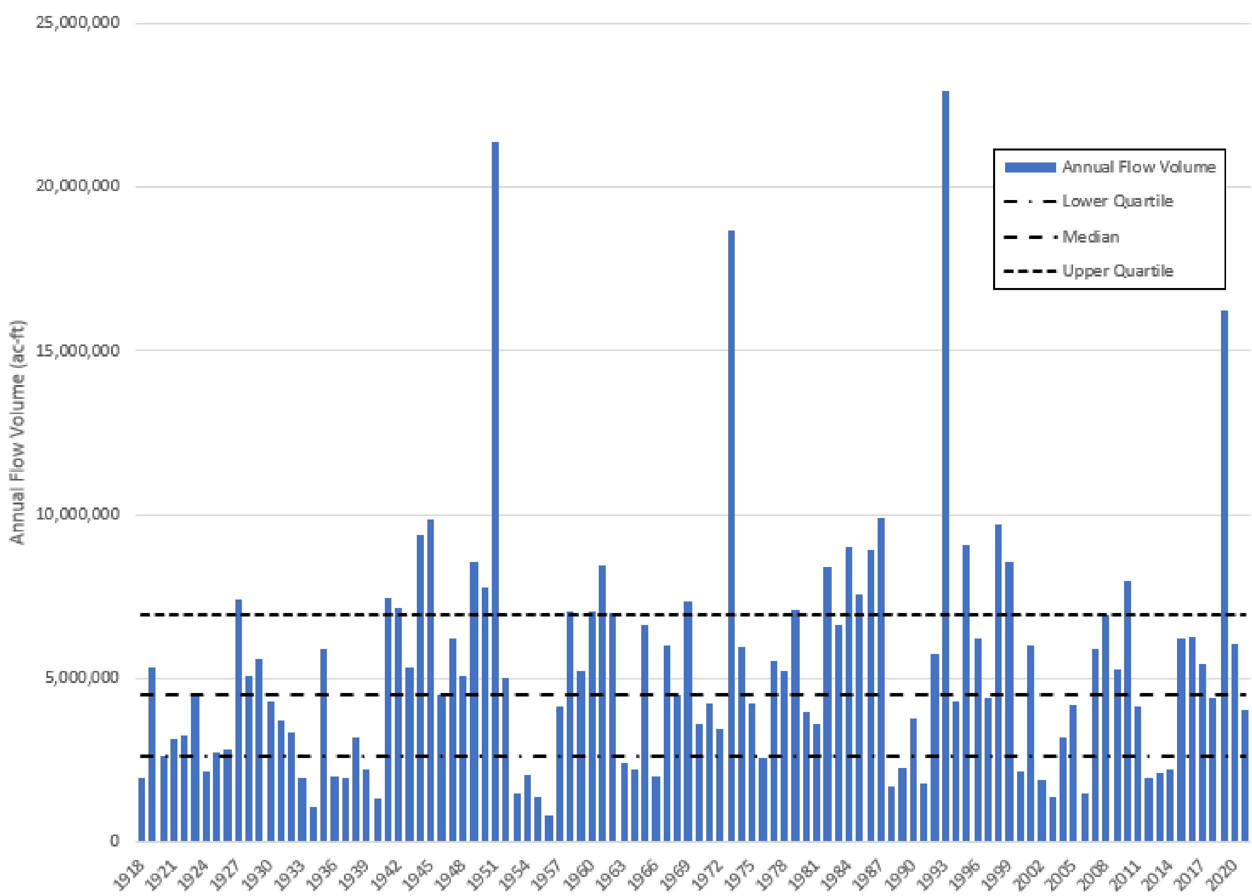


Figure 2-17. Kansas River at Desoto Annual Flow Volume and Statistical Flow.

3 Methodology

The future without project simulations were setup utilizing the HEC-ResSim network, operating sets and data inputs as the existing conditions model which is documented in KRRFSS_ResSim_Documentation_01Nov21.docx. All data inputs were shifted forward in time 104 years to have the simulation starting on January 2024 and ending January 2124. The starting time is considered year zero and corresponds to the end of the watershed study.

Future sedimentation for each reservoir was estimated by engineers in the Reservoir Engineering and Restoration Section. These calculations resulted in elevation/storage and elevation/area curves for four future conditions: year zero (2024), year 25 (2049), year 50 (2074), and year 100 (2124). Calculated storage and area were from zero storage to the top of the flood control pool; beyond this level, it was assumed that the incremental storage and area did not change, and the curves were extended to the top of the dam. The HEC-ResSim network "Study_Kansas_Basin_LinearRouting" was used for the existing conditions modeling. A new reservoir network was created for each FWOP scenario where the future storage and area curves were used for each condition; all other network parameters were unchanged from the existing conditions modeling. The four new networks were named: 2024 FWOP, 2049 FWOP, 2074 FWOP, and 2124 FWOP.

The storage and area curves used in HEC-ResSim are shown in Table 3 to Table 9. The multi-purpose and top of flood pool values are bolded for easy comparison. The 2124 Tuttle Creek storage curve indicates very little multi-purpose storage at that time, and the zero-storage point is at elevation 1057.56 feet NGVD29.

Table 3-1. Kanopolis estimated future sedimentation for years 0, 25, 50 and 100.

2024			2049			2074			2124		
NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area
ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre
1431.64	0	0									
1436.64	603	528	1434.64	0	0	1436.64	0	0			
1441.64	4183	859	1439.64	549	515	1441.64	631	534	1441.64	0	0
1446.64	9168	1221	1444.64	4094	854	1446.64	4228	861	1446.64	386	456
1451.64	16804	1790	1449.64	9041	1208	1451.64	9231	1227	1451.64	3811	837
1456.64	26935	2267	1454.64	16619	1780	1456.64	16898	1795	1456.64	8645	1165
1461.64	39436	2753	1459.64	26700	2257	1461.64	27053	2272	1461.64	16029	1750
1463.00	**43256**	**2911**	**1463.00**	**34797**	**2563**	**1463.00**	**30211**	**2399**	**1463.00**	**18256**	**1879**
1468.00	61783	4133	1468.00	47187	3845	1468.00	39897	3670	1468.00	22614	3147
1473.00	81193	5354	1473.00	69280	5128	1473.00	61185	4941	1473.00	41638	4415
1478.00	111122	6464	1478.00	98700	6354	1478.00	90260	6280	1478.00	69663	6053
1483.00	145855	7408	1483.00	133081	7333	1483.00	124460	7294	1483.00	103272	7168
1488.00	185653	8542	1488.00	172665	8496	1488.00	163959	8478	1488.00	142389	8396
1493.00	231061	9615	1493.00	217917	9582	1493.00	209160	9571	1493.00	187367	9524
1498.00	282316	10913	1498.00	269104	10899	1498.00	260321	10893	1498.00	238418	10870
1503.00	340478	12352	1503.00	327219	12342	1503.00	318440	12343	1503.00	296495	12334
1508.00	**406171**	**14015**	**1508.00**	**392877**	**14008**	**1508.00**	**384101**	**14008**	**1508.00**	**362125**	**14002**
1509.00	420373	14392	1509.00	407079	14392	1509.00	398303	14392	1509.00	376327	14392
1510.00	434948	14759	1510.00	421654	14759	1510.00	412878	14759	1510.00	390902	14759
1511.00	449900	15151	1511.00	436606	15151	1511.00	427830	15151	1511.00	405854	15151
1512.00	465252	15555	1512.00	451958	15555	1512.00	443182	15555	1512.00	421206	15555
1513.00	481009	15963	1513.00	467715	15963	1513.00	458939	15963	1513.00	436963	15963
1514.00	497173	16369	1514.00	483879	16369	1514.00	475103	16369	1514.00	453127	16369
1515.00	513752	16795	1515.00	500458	16795	1515.00	491682	16795	1515.00	469706	16795
1516.00	530760	17221	1516.00	517466	17221	1516.00	508690	17221	1516.00	486714	17221
1517.00	548190	17641	1517.00	534896	17641	1517.00	526120	17641	1517.00	504144	17641
1518.00	566038	18061	1518.00	552744	18061	1518.00	543968	18061	1518.00	521992	18061
1519.00	584316	18498	1519.00	571022	18498	1519.00	562246	18498	1519.00	540270	18498
1520.00	603046	18973	1520.00	589752	18973	1520.00	580976	18973	1520.00	559000	18973
1521.00	622261	19461	1521.00	608967	19461	1521.00	600191	19461	1521.00	578215	19461
1522.00	641968	19954	1522.00	628674	19954	1522.00	619898	19954	1522.00	597922	19954
1523.00	662167	20457	1523.00	648873	20457	1523.00	640097	20457	1523.00	618121	20457
1524.00	682874	20952	1524.00	669580	20952	1524.00	660804	20952	1524.00	638828	20952
1525.00	704069	21432	1525.00	690775	21432	1525.00	681999	21432	1525.00	660023	21432
1526.00	725732	21897	1526.00	712438	21897	1526.00	703662	21897	1526.00	681686	21897
1527.00	747863	22370	1527.00	734569	22370	1527.00	725793	22370	1527.00	703817	22370
1528.00	770478	22862	1528.00	757184	22862	1528.00	748408	22862	1528.00	726432	22862
1529.00	793585	23356	1529.00	780291	23356	1529.00	771515	23356	1529.00	749539	23356
1530.00	817189	23851	1530.00	803895	23851	1530.00	795119	23851	1530.00	773143	23851
1531.00	841293	24366	1531.00	827999	24366	1531.00	819223	24366	1531.00	797247	24366
1532.00	865923	24894	1532.00	852629	24894	1532.00	843853	24894	1532.00	821877	24894
1533.00	891083	25427	1533.00	877789	25427	1533.00	869013	25427	1533.00	847037	25427
1534.00	916785	25988	1534.00	903491	25988	1534.00	894715	25988	1534.00	872739	25988
1535.00	943062	26566	1535.00	929768	26566	1535.00	920992	26566	1535.00	899016	26566
1536.00	969917	27147	1536.00	956623	27147	1536.00	947847	27147	1536.00	925871	27147
1537.00	997365	27761	1537.00	984071	27761	1537.00	975295	27761	1537.00	953319	27761
1538.00	1025448	28410	1538.00	1012154	28410	1538.00	1003378	28410	1538.00	981402	28410
1539.00	1054174	29047	1539.00	1040880	29047	1539.00	1032104	29047	1539.00	1010128	29047
1540.00	1083534	29668	1540.00	1070240	29668	1540.00	1061464	29668	1540.00	1039488	29668

Table 3-2. Wilson estimated future sedimentation for years 0, 25, 50 and 100.

2024			2049			2074			2124		
NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area
ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre
1436.41	0	0	1437.41	0	0	1439.41	0	0			
1441.41	19	14	1442.41	18	14	1444.41	31	18	1442.41	0	0
1446.41	175	56	1447.41	169	55	1449.41	220	65	1447.41	44	21
1451.41	650	137	1452.41	633	135	1454.41	757	151	1452.41	265	76
1456.41	1620	266	1457.41	1588	261	1459.41	1830	301	1457.41	859	164
1461.41	3605	522	1462.41	3543	516	1464.41	4008	558	1462.41	2038	344
1466.41	6807	775	1467.41	6715	767	1469.41	7407	830	1467.41	4379	588
1471.41	12109	1409	1472.41	11940	1392	1474.41	13203	1523	1472.41	7963	887
1476.41	20984	2144	1477.41	20728	2124	1479.41	22636	2286	1477.41	14220	1614
1481.41	33778	2910	1482.41	33430	2893	1484.41	35990	3011	1482.41	24160	2413
1486.41	50103	3642	1487.41	49667	3623	1489.41	52865	3753	1487.41	37970	3104
1491.41	70118	4355	1492.41	69596	4338	1494.41	73409	4458	1492.41	55329	3850
1496.41	93802	5171	1497.41	93183	5152	1499.41	97711	5294	1497.41	76330	4556
1501.41	121809	6016	1502.41	121088	6000	1504.41	126340	6115	1502.41	101179	5414
1506.41	153718	6766	1507.41	152907	6745	1509.41	158825	6915	1507.41	130334	6215
1511.41	190250	7871	1512.41	189307	7849	1514.41	196176	7988	1512.41	163348	7047
1516.00	**228085**	**8433**	**1516.00**	**217956**	**8303**	**1516.00**	**209022**	**8173**	**1516.00**	**190117**	**7868**
1521.00	274028	9891	1521.00	262641	9826	1521.00	251749	9761	1521.00	228773	9609
1526.00	327661	11350	1526.00	316272	11349	1526.00	305380	11349	1526.00	282402	11349
1531.00	387478	12552	1531.00	376088	12552	1531.00	365196	12552	1531.00	342219	12552
1536.00	453525	13897	1536.00	442135	13897	1536.00	431243	13897	1536.00	408266	13897
1541.00	526730	15431	1541.00	515340	15431	1541.00	504448	15431	1541.00	481471	15431
1546.00	608142	17131	1546.00	596752	17131	1546.00	585860	17131	1546.00	562883	17131
1551.00	696427	18911	1551.00	682517	18911	1551.00	667708	18911	1551.00	636789	18911
1554.00	**756624**	**20152**	**1554.00**	**745234**	**20152**	**1554.00**	**734342**	**20152**	**1554.00**	**711365**	**20152**
1555.00	776977	20556	1555.00	765587	20556	1555.00	754695	20556	1555.00	731718	20556
1556.00	797739	20971	1556.00	786349	20971	1556.00	775457	20971	1556.00	752480	20971
1557.00	818912	21370	1557.00	807522	21370	1557.00	796630	21370	1557.00	773653	21370
1558.00	840480	21772	1558.00	829090	21772	1558.00	818198	21772	1558.00	795221	21772
1559.00	862455	22173	1559.00	851065	22173	1559.00	840173	22173	1559.00	817196	22173
1560.00	884823	22563	1560.00	873433	22563	1560.00	862541	22563	1560.00	839564	22563
1561.00	907574	22943	1561.00	896184	22943	1561.00	885292	22943	1561.00	862315	22943
1562.00	930714	23344	1562.00	919324	23344	1562.00	908432	23344	1562.00	885455	23344
1563.00	954263	23759	1563.00	942873	23759	1563.00	931981	23759	1563.00	909004	23759
1564.00	978235	24188	1564.00	966845	24188	1564.00	955953	24188	1564.00	932976	24188
1565.00	1002628	24597	1565.00	991238	24597	1565.00	980346	24597	1565.00	957369	24597
1566.00	1027423	24995	1566.00	1016033	24995	1566.00	1005141	24995	1566.00	982164	24995
1567.00	1052610	25376	1567.00	1041220	25376	1567.00	1030328	25376	1567.00	1007351	25376
1568.00	1078179	25770	1568.00	1066789	25770	1568.00	1055897	25770	1568.00	1032920	25770
1569.00	1104152	26183	1569.00	1092762	26183	1569.00	1081870	26183	1569.00	1058893	26183
1570.00	1130547	26604	1570.00	1119157	26604	1570.00	1108265	26604	1570.00	1085288	26604
1571.00	1157353	27005	1571.00	1145963	27005	1571.00	1135071	27005	1571.00	1112094	27005
1572.00	1184553	27397	1572.00	1173163	27397	1572.00	1162271	27397	1572.00	1139294	27397
1573.00	1212147	27795	1573.00	1200757	27795	1573.00	1189865	27795	1573.00	1166888	27795
1574.00	1240140	28187	1574.00	1228750	28187	1574.00	1217858	28187	1574.00	1194881	28187
1575.00	1268517	28565	1575.00	1257127	28565	1575.00	1246235	28565	1575.00	1223258	28565
1576.00	1297269	28942	1576.00	1285879	28942	1576.00	1274987	28942	1576.00	1252010	28942
1577.00	1326397	29319	1577.00	1315007	29319	1577.00	1304115	29319	1577.00	1281138	29319
1578.00	1355910	29712	1578.00	1344520	29712	1578.00	1333628	29712	1578.00	1310651	29712
1579.00	1385824	30117	1579.00	1374434	30117	1579.00	1363542	30117	1579.00	1340565	30117
1580.00	1416140	30513	1580.00	1404750	30513	1580.00	1393858	30513	1580.00	1370881	30513
1581.00	1446854	30916	1581.00	1435464	30916	1581.00	1424572	30916	1581.00	1401595	30916
1582.00	1477968	31312	1582.00	1466578	31312	1582.00	1455686	31312	1582.00	1432709	31312
1583.00	1509478	31709	1583.00	1498088	31709	1583.00	1487196	31709	1583.00	1464219	31709
1584.00	1541384	32107	1584.00	1529994	32107	1584.00	1519102	32107	1584.00	1496125	32107
1585.00	1573691	32515	1585.00	1562301	32515	1585.00	1551409	32515	1585.00	1528432	32515
1586.00	1606415	32938	1586.00	1595025	32938	1586.00	1584133	32938	1586.00	1561156	32938
1587.00	1639574	33378	1587.00	1628184	33378	1587.00	1617292	33378	1587.00	1594315	33378
1588.00	1673172	33822	1588.00	1661782	33822	1588.00	1650890	33822	1588.00	1627913	33822
1589.00	1707210	34256	1589.00	1695820	34256	1589.00	1684928	34256	1589.00	1661951	34256
1590.00	1741675	34676	1590.00	1730285	34676	1590.00	1719393	34676	1590.00	1696416	34676
1591.00	1776562	35096	1591.00	1765172	35096	1591.00	1754280	35096	1591.00	1731303	35096
1592.00	1811869	35516	1592.00	1800479	35516	1592.00	1789587	35516	1592.00	1766610	35516
1593.00	1847592	35930	1593.00	1836202	35930	1593.00	1825310	35930	1593.00	1802333	35930
1594.00	1883727	36345	1594.00	1872337	36345	1594.00	1861445	36345	1594.00	1838468	36345

Table 3-3. Waconda estimated future sedimentation for years 0, 25, 50 and 100.

2024			2049			2074			2124		
NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area
ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre
1397.00	0	0	1399.00	0	0	1400.00	0	0			
1402.00	15	32	1404.00	17	43	1405.00	16	38	1404.00	4	3
1407.00	29	139	1409.00	35	160	1410.00	32	151	1409.00	20	68
1412.00	245	587	1414.00	318	770	1415.00	287	687	1414.00	59	223
1417.00	886	3296	1419.00	989	3904	1420.00	945	3641	1419.00	490	1326
1422.00	1651	9794	1424.00	1724	10889	1425.00	1693	10424	1424.00	1246	5440
1427.00	2424	19739	1429.00	2567	21359	1430.00	2508	20669	1429.00	1893	13377
1432.00	3658	34950	1434.00	3785	37367	1435.00	3734	36344	1434.00	2930	25125
1437.00	4634	55672	1439.00	4790	58729	1440.00	4723	57435	1439.00	4052	42759
1442.00	6333	82873	1444.00	6530	87047	1445.00	6448	85283	1444.00	5235	65621
1447.00	7928	118517	1449.00	8139	123729	1450.00	8046	121529	1449.00	6967	96338
1452.00	9722	162827	1454.00	9848	169178	1455.00	9795	166507	1454.00	8626	135272
1455.60	**10444**	**199107**	**1455.60**	**10165**	**185172**	**1455.60**	**9912**	**172396**	**1455.60**	**9393**	**149587**
1460.00	13541	261888	1460.00	13337	245972	1460.00	13160	229961	1460.00	12748	200264
1465.00	17059	340372	1465.00	16941	323912	1465.00	16850	307484	1465.00	16560	276451
1470.00	20228	433697	1470.00	20167	416955	1470.00	20135	400378	1470.00	20011	368771
1475.00	23834	543939	1475.00	23795	527016	1475.00	23785	510390	1475.00	23721	478489
1480.00	27352	671930	1480.00	27322	654867	1480.00	27314	638204	1480.00	27266	606076
1485.00	30887	817563	1485.00	30874	800435	1485.00	30870	783754	1485.00	30847	751519
1488.30	**33676**	**924103**	**1488.30**	**33669**	**906951**	**1488.30**	**33667**	**890264**	**1488.30**	**33655**	**857991**
1489.00	34331	947907	1489.00	34331	930755	1489.00	34331	914068	1489.00	34331	881795
1490.00	35258	982702	1490.00	35258	965550	1490.00	35258	948863	1490.00	35258	916590
1491.00	36265	1018463	1491.00	36265	1001311	1491.00	36265	984624	1491.00	36265	952351
1492.00	37272	1055231	1492.00	37272	1038079	1492.00	37272	1021392	1492.00	37272	989119
1492.90	38178	1089184	1492.90	38178	1072032	1492.90	38178	1055345	1492.90	38178	1023072
1493.00	38286	1093007	1493.00	38286	1075855	1493.00	38286	1059168	1493.00	38286	1026895
1494.00	39364	1131832	1494.00	39364	1114680	1494.00	39364	1097993	1494.00	39364	1065720
1495.00	40443	1171736	1495.00	40443	1154584	1495.00	40443	1137897	1495.00	40443	1105624
1496.00	41585	1212750	1496.00	41585	1195598	1496.00	41585	1178911	1496.00	41585	1146638
1497.00	42728	1254907	1497.00	42728	1237755	1497.00	42728	1221068	1497.00	42728	1188795
1498.00	43870	1298206	1498.00	43870	1281054	1498.00	43870	1264367	1498.00	43870	1232094
1499.00	45013	1342647	1499.00	45013	1325495	1499.00	45013	1308808	1499.00	45013	1276535
1500.00	46155	1388231	1500.00	46155	1371079	1500.00	46155	1354392	1500.00	46155	1322119

Table 3-4. Milford estimated future sedimentation for years 0, 25, 50 and 100.

2024			2049			2074			2124		
NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area
ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre
1080.57	0	0	1080.57	0	0	1081.57	0	0	1082.57	0	0
1085.57	219	120	1085.57	148	86	1086.57	206	114	1087.57	187	106
1090.57	2327	717	1090.57	1863	632	1091.57	2249	703	1092.57	2133	682
1095.57	8141	1660	1095.57	7027	1573	1096.57	7960	1644	1097.57	7685	1624
1100.57	18015	2457	1100.57	16377	2288	1101.57	17746	2433	1102.57	17341	2391
1105.57	32601	3443	1105.57	30306	3222	1106.57	32225	3406	1107.57	31657	3347
1110.57	53212	4755	1110.57	49984	4604	1111.57	52690	4730	1112.57	51899	4691
1115.57	79788	5824	1115.57	75819	5685	1116.57	79149	5801	1117.57	78178	5766
1120.57	111605	6875	1120.57	106916	6723	1121.57	110851	6849	1122.57	109703	6810
1125.57	150058	8479	1125.57	144286	8256	1126.57	149128	8444	1127.57	147714	8390
1130.57	196937	10278	1130.57	189911	10078	1131.57	195808	10249	1132.57	194090	10203
1135.57	251017	11258	1135.57	243293	11135	1136.57	249780	11237	1137.57	247895	11207
1140.57	311526	13405	1140.57	302421	12994	1141.57	310055	13337	1142.57	307824	13235
1144.40	**366476**	**15270**	**1144.40**	**355800**	**14918**	**1144.40**	**349881**	**14727**	**1144.40**	**332971**	**14211**
1149.00	446838	17744	1149.00	435135	17526	1149.00	428380	17396	1149.00	409193	17048
1154.00	544514	20432	1154.00	532468	20360	1154.00	525410	20297	1154.00	505439	20133
1159.00	650998	22220	1159.00	638744	22176	1159.00	631536	22145	1159.00	611127	22053
1164.00	770369	25227	1164.00	757999	25202	1164.00	750700	25183	1164.00	730040	25130
1169.00	902436	27733	1169.00	889996	27718	1169.00	882644	27707	1169.00	861837	27676
1174.00	1051894	31717	1174.00	1039409	31708	1174.00	1032022	31700	1174.00	1011117	31680
1176.20	**1123334**	**33169**	**1176.20**	**1110814**	**33153**	**1176.20**	**1103417**	**33149**	**1176.20**	**1082459**	**33124**
1177.00	1150077	33697	1177.00	1137557	33697	1177.00	1130160	33697	1177.00	1109202	33697
1178.00	1184081	34314	1178.00	1171561	34314	1178.00	1164164	34314	1178.00	1143206	34314
1179.00	1218721	34977	1179.00	1206201	34977	1179.00	1198804	34977	1179.00	1177846	34977
1180.00	1254086	35922	1180.00	1241566	35922	1180.00	1234169	35922	1180.00	1213211	35922
1181.00	1290455	36766	1181.00	1277935	36766	1181.00	1270538	36766	1181.00	1249580	36766
1182.00	1327599	37528	1182.00	1315079	37528	1182.00	1307682	37528	1182.00	1286724	37528
1183.00	1365479	38222	1183.00	1352959	38222	1183.00	1345562	38222	1183.00	1324604	38222
1184.00	1404044	38914	1184.00	1391524	38914	1184.00	1384127	38914	1184.00	1363169	38914
1185.00	1443322	39694	1185.00	1430802	39694	1185.00	1423405	39694	1185.00	1402447	39694
1186.00	1483360	40369	1186.00	1470840	40369	1186.00	1463443	40369	1186.00	1442485	40369
1187.00	1524053	41016	1187.00	1511533	41016	1187.00	1504136	41016	1187.00	1483178	41016
1188.00	1565429	41725	1188.00	1552909	41725	1188.00	1545512	41725	1188.00	1524554	41725
1189.00	1607510	42462	1189.00	1594990	42462	1189.00	1587593	42462	1189.00	1566635	42462
1190.00	1650396	43423	1190.00	1637876	43423	1190.00	1630479	43423	1190.00	1609521	43423
1191.00	1694301	44351	1191.00	1681781	44351	1191.00	1674384	44351	1191.00	1653426	44351
1192.00	1739077	45198	1192.00	1726557	45198	1192.00	1719160	45198	1192.00	1698202	45198
1193.00	1784685	46022	1193.00	1772165	46022	1193.00	1764768	46022	1193.00	1743810	46022
1194.00	1831119	46845	1194.00	1818599	46845	1194.00	1811202	46845	1194.00	1790244	46845
1195.00	1878403	47755	1195.00	1865883	47755	1195.00	1858486	47755	1195.00	1837528	47755
1196.00	1926603	48611	1196.00	1914083	48611	1196.00	1906686	48611	1196.00	1885728	48611
1197.00	1975614	49417	1197.00	1963094	49417	1197.00	1955697	49417	1197.00	1934739	49417
1198.00	2025441	50240	1198.00	2012921	50240	1198.00	2005524	50240	1198.00	1984566	50240
1199.00	2076110	51108	1199.00	2063590	51108	1199.00	2056193	51108	1199.00	2035235	51108
1200.00	2127719	52306	1200.00	2115199	52306	1200.00	2107802	52306	1200.00	2086844	52306
1201.00	2180775	53729	1201.00	2168255	53729	1201.00	2160858	53729	1201.00	2139900	53729
1202.00	2235129	54976	1202.00	2222609	54976	1202.00	2215212	54976	1202.00	2194254	54976
1203.00	2290715	56201	1203.00	2278195	56201	1203.00	2270798	56201	1203.00	2249840	56201
1204.00	2347514	57397	1204.00	2334994	57397	1204.00	2327597	57397	1204.00	2306639	57397
1205.00	2405522	58672	1205.00	2393002	58672	1205.00	2385605	58672	1205.00	2364647	58672
1206.00	2464800	59854	1206.00	2452280	59854	1206.00	2444883	59854	1206.00	2423925	59854
1207.00	2525200	60938	1207.00	2512680	60938	1207.00	2505283	60938	1207.00	2484325	60938
1208.00	2586704	62085	1208.00	2574184	62085	1208.00	2566787	62085	1208.00	2545829	62085
1209.00	2649417	63374	1209.00	2636897	63374	1209.00	2629500	63374	1209.00	2608542	63374
1210.00	2713584	65371	1210.00	2701064	65371	1210.00	2693667	65371	1210.00	2672709	65371
1211.00	2779896	67111	1211.00	2767376	67111	1211.00	2759979	67111	1211.00	2739021	67111
1212.00	2847733	68545	1212.00	2835213	68545	1212.00	2827816	68545	1212.00	2806858	68545
1213.00	2916959	69905	1213.00	2904439	69905	1213.00	2897042	69905	1213.00	2876084	69905
1214.00	2987663	71528	1214.00	2975143	71528	1214.00	2967746	71528	1214.00	2946788	71528

Table 3-5. Tuttle Creek estimated future sedimentation for years 0, 25, 50 and 100.

2024			2049			2074			2124		
NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area
ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre
1018.56	880	263	1018.56	470	114	1018.56	1069	340	1018.56	1801	258
1023.56	897	275	1023.56	481	120	1023.56	1080	345	1023.56	1811	264
1028.56	1164	339	1028.56	540	104	1028.56	1128	323	1028.56	1859	241
1033.56	2296	706	1033.56	908	333	1033.56	1295	466	1033.56	1995	369
1038.56	5638	1421	1038.56	2280	552	1038.56	1984	609	1038.56	2226	341
1043.56	14823	2874	1043.56	5981	1135	1043.56	3840	911	1043.56	2588	333
1048.56	32350	4469	1048.56	13173	1976	1048.56	8048	1277	1048.56	2821	323
1053.56	57555	5870	1053.56	27457	3811	1053.56	14518	2023	1053.56	3051	361
1058.56	88556	6832	1058.56	49510	5147	1058.56	26892	3381	1058.56	4010	548
1063.56	123334	7597	1063.56	77083	5906	1063.56	46092	4591	1063.56	6937	999
1068.56	161886	8270	1068.56	107980	6555	1068.56	69956	5254	1068.56	13922	1620
1073.56	203667	8851	1073.56	142571	7158	1073.56	97784	5824	1073.56	25090	2661
1075.00	**216570**	**9415**	**1075.00**	**153046**	**7493**	**1075.00**	**106499**	**6386**	**1075.00**	**29247**	**3237**
1080.00	271899	12550	1080.00	196802	10354	1080.00	144521	8870	1080.00	52377	6164
1085.00	346172	16776	1085.00	257255	14704	1085.00	195529	12325	1085.00	87490	8306
1090.00	437396	19598	1090.00	339009	17872	1090.00	269447	16745	1090.00	137182	12557
1095.00	542125	22354	1095.00	435908	20950	1095.00	361358	20081	1095.00	213027	17472
1100.00	661480	25462	1100.00	547968	24233	1100.00	469216	23434	1100.00	309236	21184
1105.00	798215	28962	1105.00	679053	28036	1105.00	596843	27455	1105.00	425380	25529
1110.00	951821	32533	1110.00	828136	31811	1110.00	743394	31296	1110.00	563409	29654
1115.00	1124966	36621	1115.00	998194	36068	1115.00	911683	35900	1115.00	723733	34621
1120.00	1317158	40323	1120.00	1187410	39874	1120.00	1099797	39699	1120.00	907006	38648
1125.00	1528997	44379	1125.00	1397257	44071	1125.00	1308977	43978	1125.00	1111453	43273
1130.00	1761090	48446	1130.00	1628018	48295	1130.00	1539253	48221	1130.00	1338498	47640
1136.00	**2068238**	**54104**	**1136.00**	**1933993**	**53933**	**1136.00**	**1844821**	**53881**	**1136.00**	**1641594**	**53585**
1137.00	2122842	55071	1137.00	1988479	54953	1137.00	1899251	54908	1137.00	1695736	54652
1138.00	2178400	56025	1138.00	2043932	55922	1138.00	1954656	55878	1138.00	1750925	55692
1139.00	2234908	56980	1139.00	2100356	56884	1139.00	2011102	56931	1139.00	1807129	56691
1140.00	2292357	57962	1140.00	2157744	57906	1140.00	2068516	57936	1140.00	1864281	57673
1141.00	2350845	59029	1141.00	2216190	58984	1141.00	2127002	59102	1141.00	1922496	58790
1142.00	2410402	60096	1142.00	2275725	60061	1142.00	2186627	60165	1142.00	1981846	59904
1143.00	2471062	61249	1143.00	2336355	61202	1143.00	2247350	61308	1143.00	2042303	61019
1144.00	2532904	62460	1144.00	2398143	62393	1144.00	2309222	62590	1144.00	2103892	62201
1145.00	2595923	63608	1145.00	2461115	63558	1145.00	2372295	63773	1145.00	2166646	63345
1146.00	2660110	64746	1146.00	2525257	64668	1146.00	2436553	64897	1146.00	2230568	64467
1147.00	2725447	65946	1147.00	2590523	65849	1147.00	2501928	66180	1147.00	2295599	65621
1148.00	2791993	67139	1148.00	2657005	67066	1148.00	2568582	67448	1148.00	2361794	66791
1149.00	2859705	68296	1149.00	2724675	68228	1149.00	2636446	68638	1149.00	2429150	67938
1150.00	2928563	69425	1150.00	2793512	69368	1150.00	2705499	69791	1150.00	2497687	69133
1151.00	2998544	70558	1151.00	2863319	70497	1151.00	2775512	70905	1151.00	2567397	70296
1152.00	3069702	71767	1152.00	2934269	71683	1152.00	2846657	72077	1152.00	2638260	71489
1153.00	3142078	73009	1153.00	3006513	72893	1153.00	2919081	73296	1153.00	2710295	72653
1154.00	3215711	74266	1154.00	3079996	74140	1154.00	2992764	74544	1154.00	2783556	73879
1155.00	3290584	75494	1155.00	3154723	75387	1155.00	3067680	75764	1155.00	2858049	75135
1156.00	3366701	76753	1156.00	3230703	76627	1156.00	3143822	76997	1156.00	2933807	76382
1157.00	3444112	78092	1157.00	3307944	77930	1157.00	3221250	78355	1157.00	3010840	77696
1158.00	3522887	79463	1158.00	3386525	79315	1158.00	3300030	79686	1158.00	3089237	79076
1159.00	3602976	80760	1159.00	3466426	80563	1159.00	3380105	80925	1159.00	3168905	80264
1160.00	3684409	82112	1160.00	3547643	81923	1160.00	3461435	82460	1160.00	3249789	81523
1161.00	3767153	83392	1161.00	3630174	83166	1161.00	3544092	83792	1161.00	3331995	82883

Table 3-6. Perry estimated future sedimentation for years 0, 25, 50 and 100.

2024			2049			2074			2124		
NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area
ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre
817.72	0	0									
822.72	0	0									
827.72	0	0									
832.72	0	0									
837.72	0	0									
842.72	8	6	842.72	1	0	845.72	1	1			
847.72	120	74	847.72	33	16	850.72	47	22			
852.72	1145	348	852.72	459	191	855.72	616	235	854.72	36	17
857.72	4048	915	857.72	2227	561	860.72	2664	631	859.72	492	202
862.72	11621	2337	862.72	6778	1431	865.72	7925	1694	864.72	2321	577
867.72	26413	3660	867.72	18000	2924	870.72	20220	3123	869.72	7021	1492
872.72	48385	4980	872.72	36243	4417	875.72	39562	4624	874.72	18490	2973
877.72	76123	6148	877.72	61092	5556	880.72	65243	5750	879.72	36980	4464
882.72	109895	7292	882.72	91803	6757	885.72	96839	6954	884.72	62018	5602
887.72	148726	8511	887.72	128139	7702	**890.72**	**133845**	**7848**	889.72	92929	6808
891.50	**182893**	**9771**	**891.50**	**159384**	**9007**	**891.50**	**139945**	**8055**	**891.50**	**105160**	**7191**
896.00	231303	12254	896.00	202026	11565	896.00	175996	10799	896.00	126300	9627
901.00	300944	15012	901.00	268866	14408	901.00	240235	13847	901.00	183512	12333
906.00	382224	17256	906.00	348660	16891	906.00	318801	16589	906.00	258616	15738
911.00	474901	19834	911.00	440551	19612	911.00	410066	19436	911.00	348053	18921
916.00	581309	22779	916.00	546579	22656	916.00	515829	22570	916.00	452963	22295
920.60	**692803**	**25719**	**920.60**	**657882**	**25650**	**920.60**	**626970**	**25591**	**920.60**	**563627**	**25417**
921.00	703157	26030	921.00	668236	26030	921.00	637324	26030	921.00	573981	26030
922.00	729552	26781	922.00	694631	26781	922.00	663719	26781	922.00	600376	26781
923.00	756708	27531	923.00	721787	27531	923.00	690875	27531	923.00	627532	27531
924.00	784641	28332	924.00	749720	28332	924.00	718808	28332	924.00	655465	28332
925.00	813335	29059	925.00	778414	29059	925.00	747502	29059	925.00	684159	29059
926.00	842762	29800	926.00	807841	29800	926.00	776929	29800	926.00	713586	29800
927.00	872929	30520	927.00	838008	30520	927.00	807096	30520	927.00	743753	30520
928.00	903792	31213	928.00	868871	31213	928.00	837959	31213	928.00	774616	31213
929.00	935355	31924	929.00	900434	31924	929.00	869522	31924	929.00	806179	31924
930.00	967659	32689	930.00	932738	32689	930.00	901826	32689	930.00	838483	32689
931.00	1000727	33437	931.00	965806	33437	931.00	934894	33437	931.00	871551	33437
932.00	1034533	34192	932.00	999612	34192	932.00	968700	34192	932.00	905357	34192
933.00	1069154	35074	933.00	1034233	35074	933.00	1003321	35074	933.00	939978	35074
934.00	1104673	35955	934.00	1069752	35955	934.00	1038840	35955	934.00	975497	35955
935.00	1141060	36823	935.00	1106139	36823	935.00	1075227	36823	935.00	1011884	36823
936.00	1178309	37688	936.00	1143388	37688	936.00	1112476	37688	936.00	1049133	37688
937.00	1216454	38611	937.00	1181533	38611	937.00	1150621	38611	937.00	1087278	38611
938.00	1255548	39602	938.00	1220627	39602	938.00	1189715	39602	938.00	1126372	39602
939.00	1295699	40681	939.00	1260778	40681	939.00	1229866	40681	939.00	1166523	40681
940.00	1336967	41927	940.00	1302046	41927	940.00	1271134	41927	940.00	1207791	41927
941.00	1379450	43039	941.00	1344529	43039	941.00	1313617	43039	941.00	1250274	43039
942.00	1423030	44119	942.00	1388109	44119	942.00	1357197	44119	942.00	1293854	44119
943.00	1467653	45112	943.00	1432732	45112	943.00	1401820	45112	943.00	1338477	45112
944.00	1513249	46075	944.00	1478328	46075	944.00	1447416	46075	944.00	1384073	46075
945.00	1559787	47007	945.00	1524866	47007	945.00	1493954	47007	945.00	1430611	47007
946.00	1607272	47968	946.00	1572351	47968	946.00	1541439	47968	946.00	1478096	47968
947.00	1655714	48910	947.00	1620793	48910	947.00	1589881	48910	947.00	1526538	48910

Table 3-7. Clinton estimated future sedimentation for years 0, 25, 50 and 100.

2024			2049			2074			2124		
NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area	NGVD29	Storage	Area
ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre	ft	acre-ft	acre
833.92	0	0									
838.92	13	12	835.92	0	0	836.92	0	0	838.92	0	0
843.92	595	318	840.92	28	23	841.92	27	22	843.92	28	23
848.92	4412	1231	845.92	938	475	846.92	919	466	848.92	943	477
853.92	12968	2175	850.92	5586	1404	851.92	5530	1396	853.92	5598	1405
858.92	26039	3086	855.92	14971	2327	856.92	14878	2320	858.92	14992	2328
863.92	44042	4119	860.92	28854	3241	861.92	28725	3234	863.92	28884	3243
868.92	68860	5751	865.92	47834	4447	866.92	47657	4428	868.92	47875	4453
873.92	100598	7066	870.92	74082	5978	871.92	73843	5968	873.92	74136	5980
875.50	**112150**	**7512**	**875.50**	**103854**	**7224**	**875.50**	**96669**	**6799**	**875.50**	**83853**	**6333**
880.00	147849	8448	880.00	138041	8261	880.00	129084	7990	880.00	111922	7617
885.00	192755	9489	885.00	182589	9413	885.00	173158	9313	885.00	154725	9044
890.00	242905	10526	890.00	232637	10505	890.00	223112	10485	890.00	204295	10404
895.00	298060	11509	895.00	287778	11506	895.00	278217	11499	895.00	259309	11480
900.00	358714	12716	900.00	348432	12716	900.00	338850	12711	900.00	319911	12705
903.40	**403553**	**13623**	**903.40**	**393271**	**13623**	**903.40**	**383682**	**13621**	**903.40**	**364735**	**13619**
904.00	411809	13833	904.00	401527	13833	904.00	391938	13833	904.00	372991	13833
905.00	425757	14068	905.00	415475	14068	905.00	405886	14068	905.00	386939	14068
906.00	439958	14333	906.00	429676	14333	906.00	420087	14333	906.00	401140	14333
907.00	454426	14609	907.00	444144	14609	907.00	434555	14609	907.00	415608	14609
907.40	460292	14719	907.40	450010	14719	907.40	440421	14719	907.40	421474	14719
908.00	469170	14875	908.00	458888	14875	908.00	449299	14875	908.00	430352	14875
909.00	484172	15125	909.00	473890	15125	909.00	464301	15125	909.00	445354	15125
910.00	499414	15362	910.00	489132	15362	910.00	479543	15362	910.00	460596	15362
911.00	514900	15609	911.00	504618	15609	911.00	495029	15609	911.00	476082	15609
912.00	530631	15851	912.00	520349	15851	912.00	510760	15851	912.00	491813	15851
913.00	546599	16086	913.00	536317	16086	913.00	526728	16086	913.00	507781	16086
914.00	562803	16320	914.00	552521	16320	914.00	542932	16320	914.00	523985	16320
915.00	579238	16549	915.00	568956	16549	915.00	559367	16549	915.00	540420	16549
916.00	595909	16800	916.00	585627	16800	916.00	576038	16800	916.00	557091	16800
917.00	612835	17055	917.00	602553	17055	917.00	592964	17055	917.00	574017	17055
918.00	630024	17320	918.00	619742	17320	918.00	610153	17320	918.00	591206	17320
919.00	647474	17578	919.00	637192	17578	919.00	627603	17578	919.00	608656	17578
920.00	665177	17830	920.00	654895	17830	920.00	645306	17830	920.00	626359	17830
921.00	683138	18092	921.00	672856	18092	921.00	663267	18092	921.00	644320	18092
922.00	701362	18358	922.00	691080	18358	922.00	681491	18358	922.00	662544	18358
923.00	719865	18650	923.00	709583	18650	923.00	699994	18650	923.00	681047	18650
924.00	738664	18951	924.00	728382	18951	924.00	718793	18951	924.00	699846	18951
925.00	757774	19272	925.00	747492	19272	925.00	737903	19272	925.00	718956	19272
926.00	777204	19584	926.00	766922	19584	926.00	757333	19584	926.00	738386	19584
927.00	796946	19903	927.00	786664	19903	927.00	777075	19903	927.00	758128	19903
928.00	817018	20239	928.00	806736	20239	928.00	797147	20239	928.00	778200	20239
929.00	837420	20565	929.00	827138	20565	929.00	817549	20565	929.00	798602	20565

HEC-ResSim had errors when the reservoir storage dropped to zero. The Tuttle Creek reservoir storage routinely dropped to zero during the 2124 FWOP scenario. To prevent these errors, the inactive zone was set to elevation 1062 feet. This prevents ResSim from releasing water below this level; although, small drops below inactive will occur due to evaporation. Also, a scripted rule was implemented for the conservation zone. This rule calculates the flow that can be sustained by the remaining storage and sets that as the maximum release. The logic in the script is designed to leave 100 cfs in the multi-purpose pool as a buffer. The rule is show in Figure 3-1. This rule helped to smooth the pool elevation and releases in the multi-purpose pool resulting in a more reasonable simulation; although, the reservoir still dropped to inactive pool a few times in the period of record.

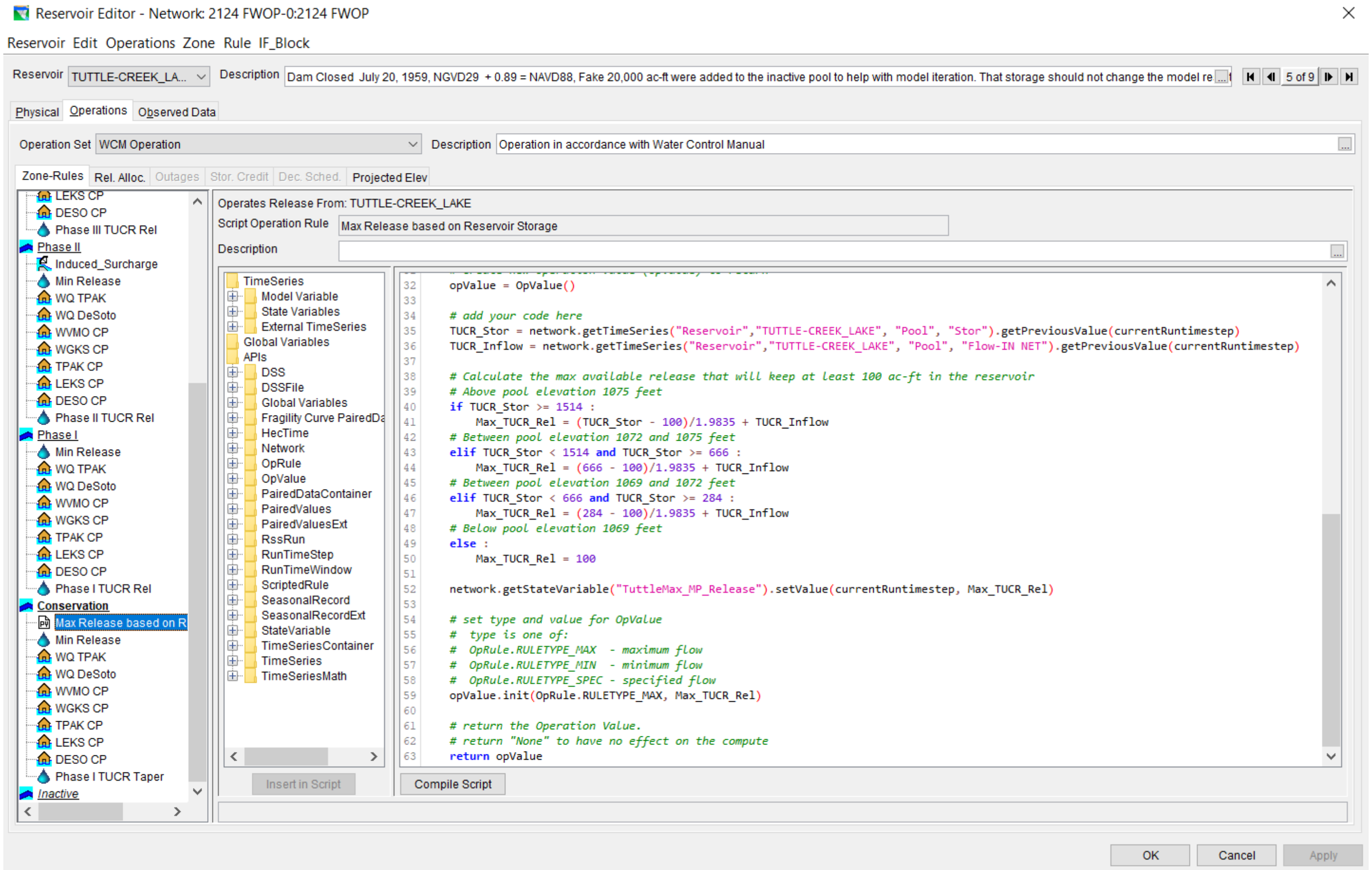


Figure 3-1. Tuttle Creek scripted rule used in the 2124 FWOP scenarios.

Perry pool elevation also dropped to zero storage in a drought period in the 2124 FWOP scenarios; however, no ResSim errors occurred. To further smooth the releases out of Perry, an if-statement was setup to provide a maximum release that can be utilized when inflows are low and the pool elevation drops below a threshold. The if-statement sets the maximum release to 200 cfs when the inflows are less than 200 cfs and the pool elevation is at 872 feet or below and further restricts the maximum release to 50 cfs when inflows are less than 200 cfs and the pool elevation is at 867 feet or below. A screen shot of the Perry if-statement is shown in Figure 3-2.

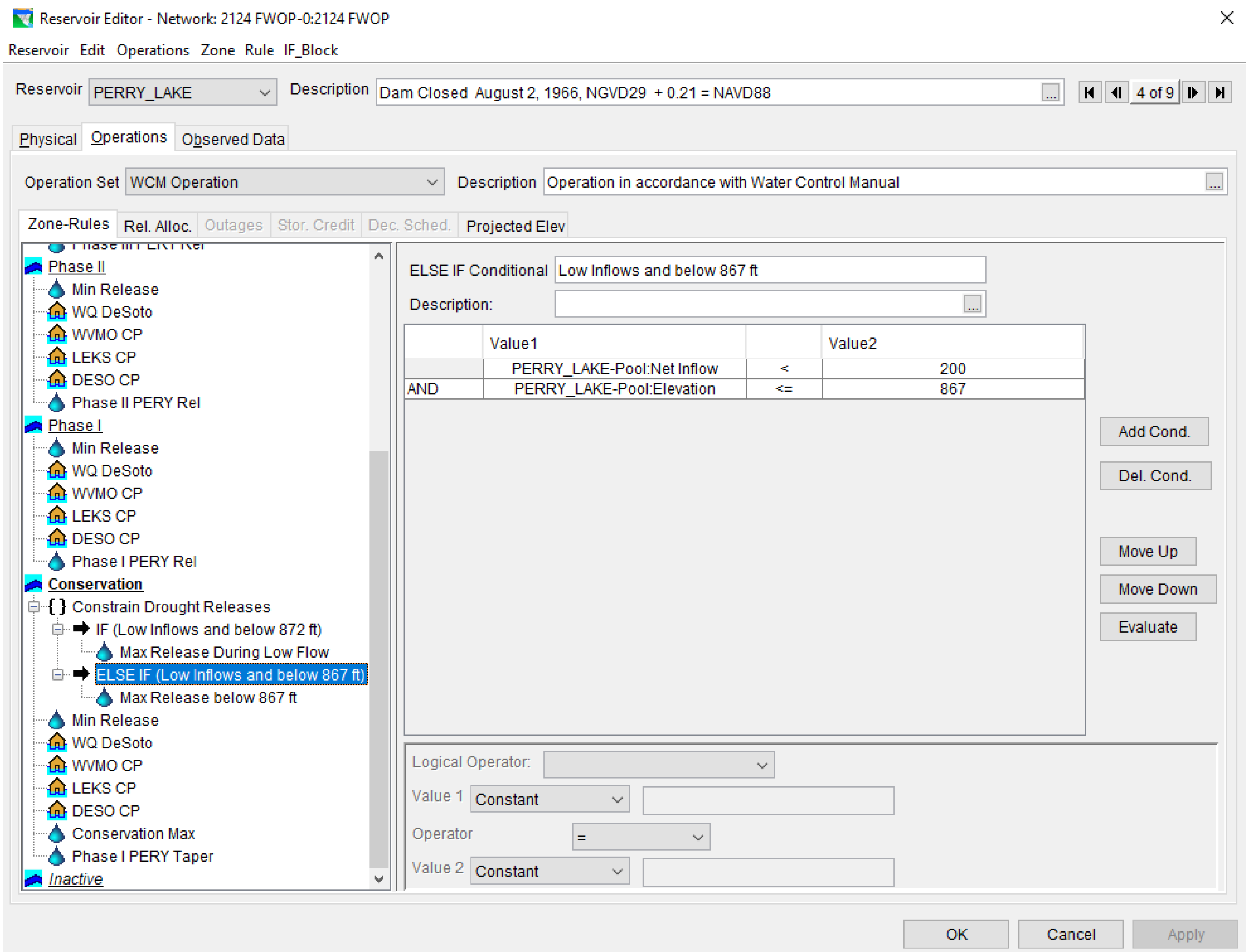


Figure 3-2. Perry if-statement used in the 2124 FWOP scenarios.

4 Model Results

4.1 Reservoir Statistics

Each reservoir pool elevations and outflows were evaluated for six different data sets: observed (from first fill through November 2021), existing conditions (1920 to 2019), 2024 FWOP (2024 to 2123), 2049 FWOP (2024 to 2123), 2074 FWOP (2024 to 2123), and 2124 FWOP (2024 to 2123). A statistical analysis was conducted on each data set and a family of curves were produced to quantify the difference between each scenario. Impacts of navigation were also evaluated for Milford, Tuttle Creek, and Perry.

Observed and modeled existing condition data was included in the analysis of FWOP data to provide a reference of change in the future condition. For detailed discussion on the comparison of observed and modeled existing conditions see Section 4 of the existing conditions documentation “KRRFSS_ResSim_Documentation.docx”

4.1.1 Kanopolis

Kanopolis observed data was from first fill of July 1948 through November 2021. The Kanopolis family of curves are shown in Figure 4-1 to Figure 4-18. Navigation did not impact Kanopolis and the navigation FWOP scenarios were identical to the non-navigation. The median modeled pool elevation tends to mostly be around or a few feet above the top of the multi-purpose pool since that was used as the guide curve in HEC-ResSim. Median observed pool elevation is more variable with some pool raises and drawdowns as part of the routine operations. All the model scenarios have high pool elevations in 95th percentile data set that compare reasonably with the observed. The model is a little lower than observed. This may indicate that the model was more aggressive with releases when the real time operations are often constrained due to chances of rainfall or concerns in the downstream channel.

Average elevation time series were compared for each scenario. The observed data has lower lows and higher highs than the modeled pool elevations. The lower pool elevations in the observed data set are from non-routine maintenance drawdowns and non-routine water supply usage that were not modeled. Multipurpose pool was also lower in the past. The higher pool elevations in the observed data set come from the water level management plan that keeps the lake about four feet into the flood pool during much of the year.

The existing conditions and 2024 FWOP scenarios are very similar as the sediment conditions do not change dramatically between these two scenarios. However, as more sediment accumulates with each additional FWOP scenario the average pool elevation also increases. The 2124 FWOP has slightly higher pool elevations because of reduced storage in the multi-purpose pool.

The modeled outflow data matches the observed data generally well, especially the average daily flows. There are a couple exceptions. For the 95-percentile category, the observed data was much more variable than the modeled in the warm months. This is likely due to situationally specific decisions made by reservoir managers that are not considered in the model.

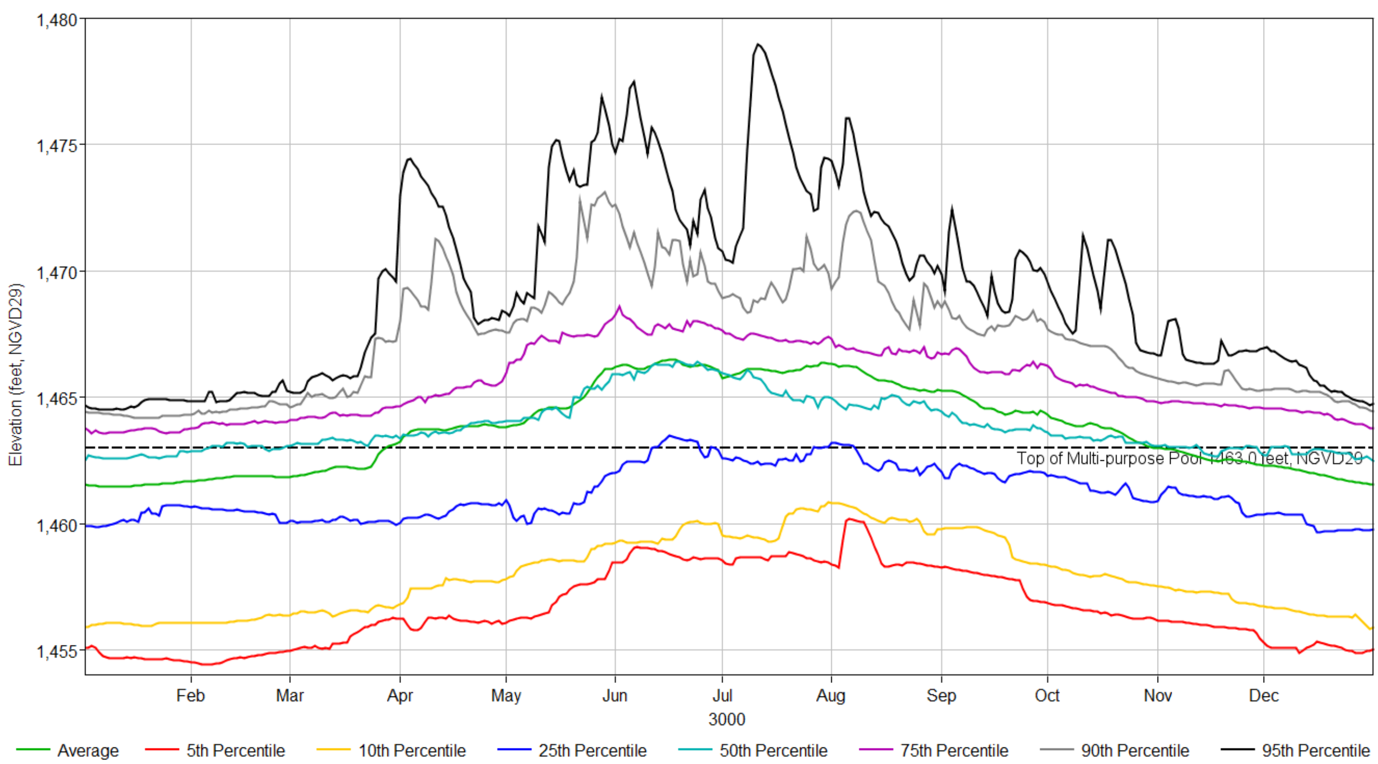


Figure 4-1. Kanopolis pool elevation statistics for the observed data from first fill Jul 1948 to Dec 2021.

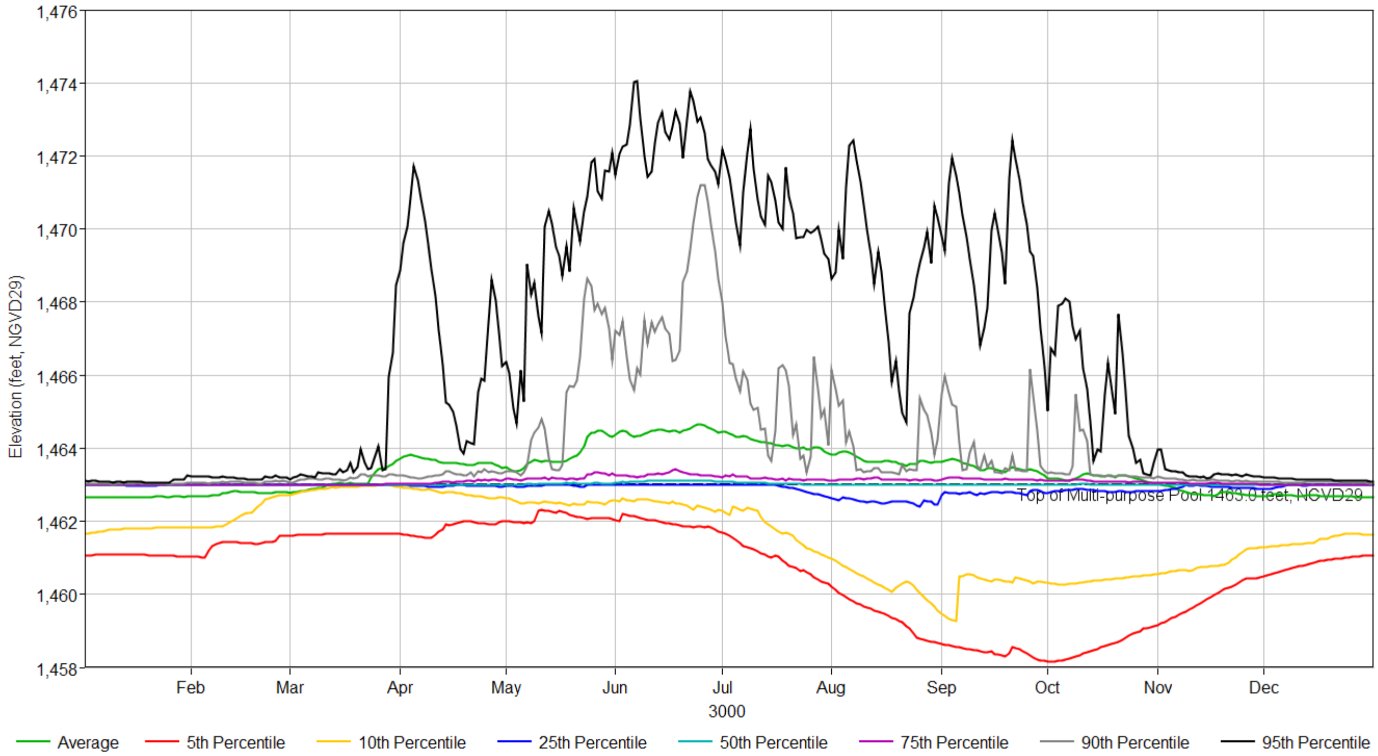


Figure 4-2. Kanopolis pool elevation statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

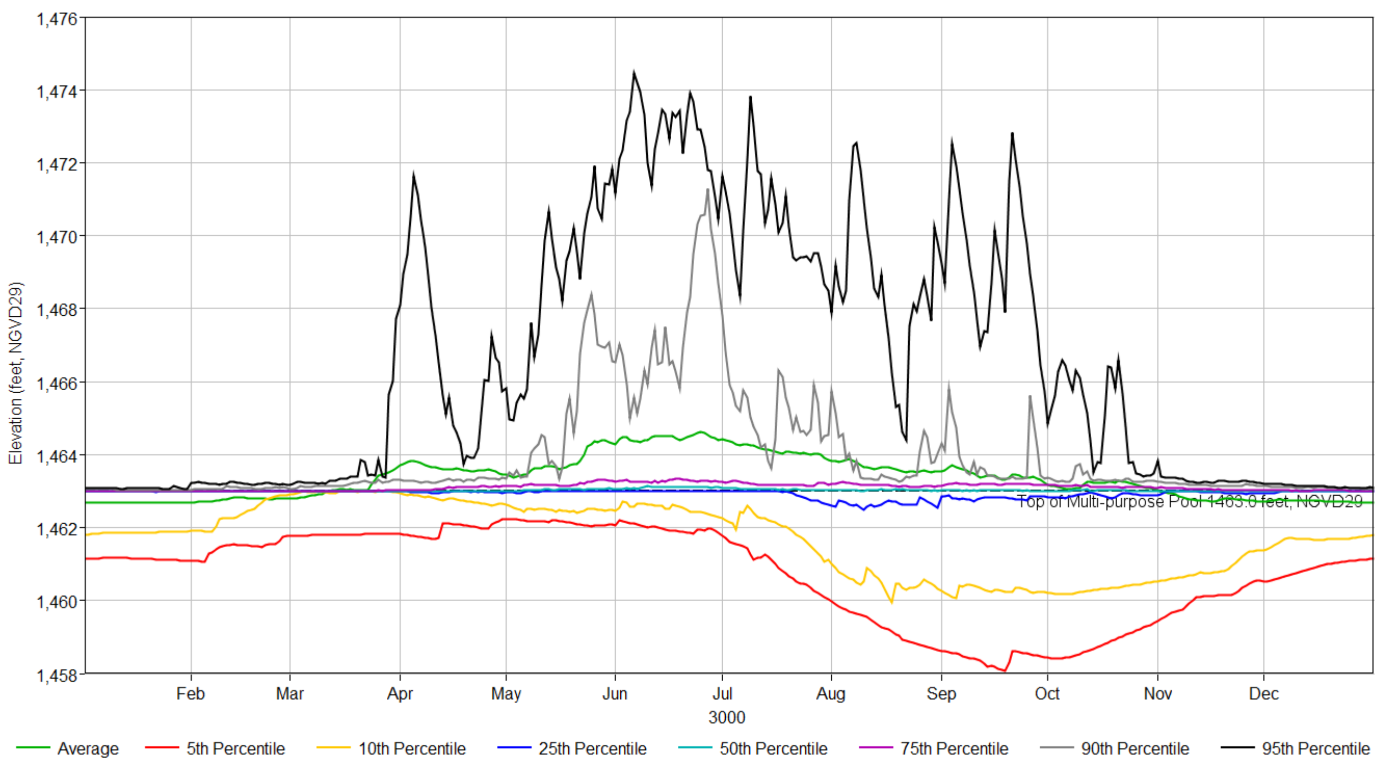


Figure 4-3. Kanopolis pool elevation statistics for the 100-year FWOP at 2024 sediment conditions.

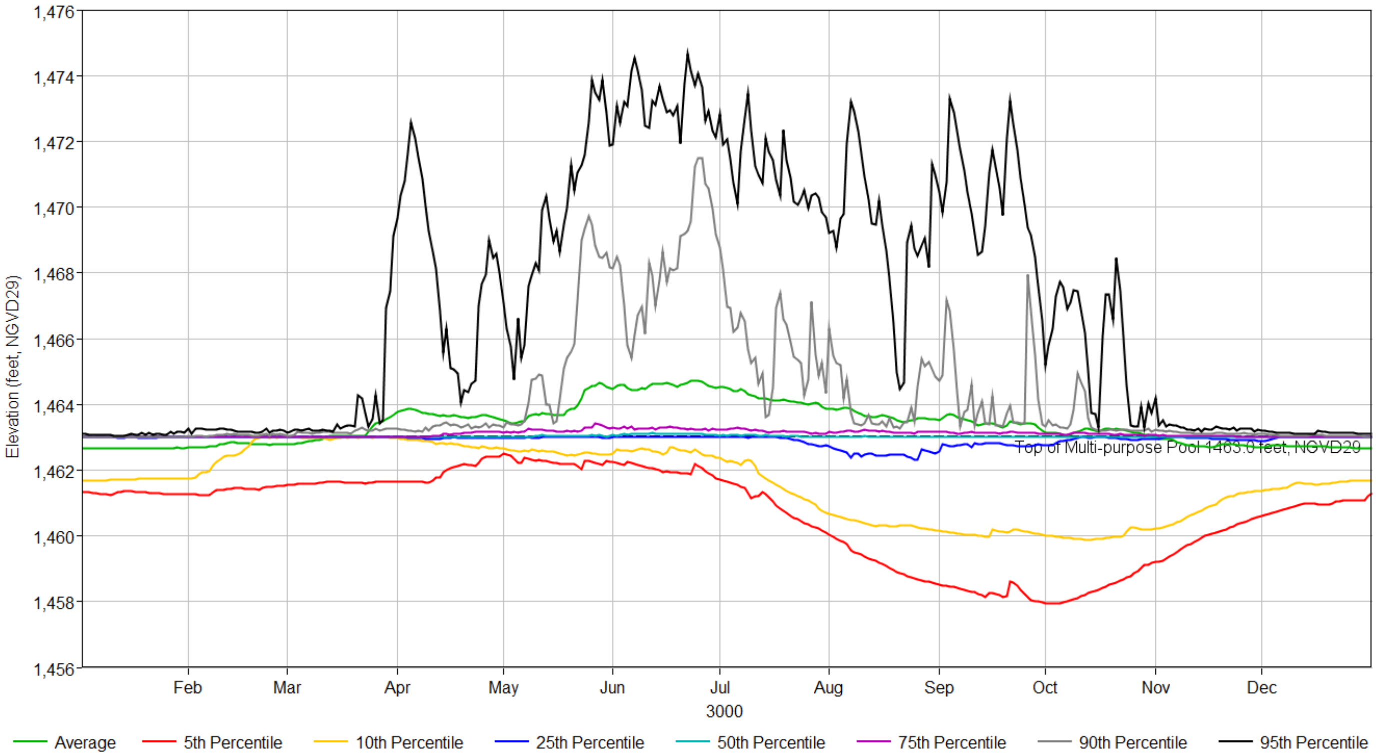


Figure 4-4. Kanopolis pool elevation statistics for the 100-year FWOP at 2049 sediment conditions.

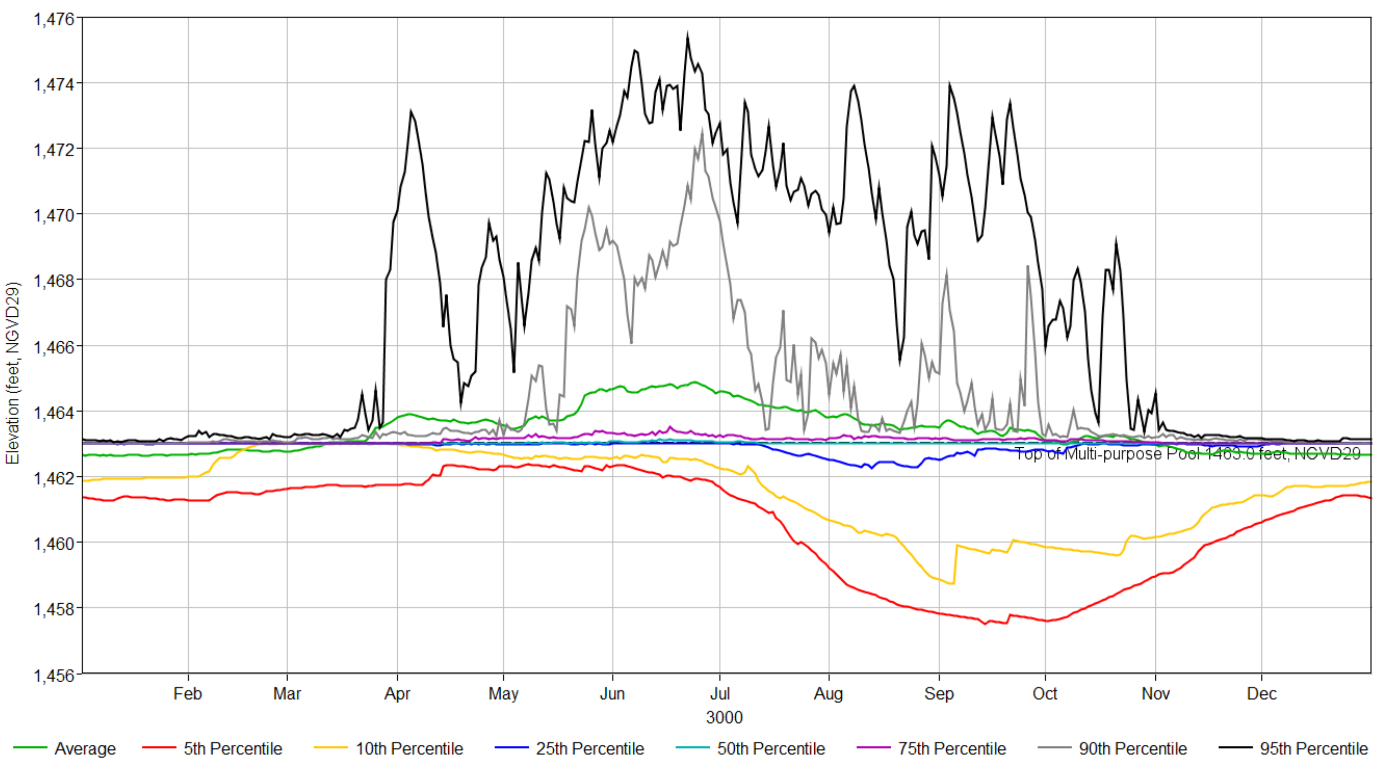


Figure 4-5. Kanopolis pool elevation statistics for the 100-year FWOP at 2074 sediment conditions.

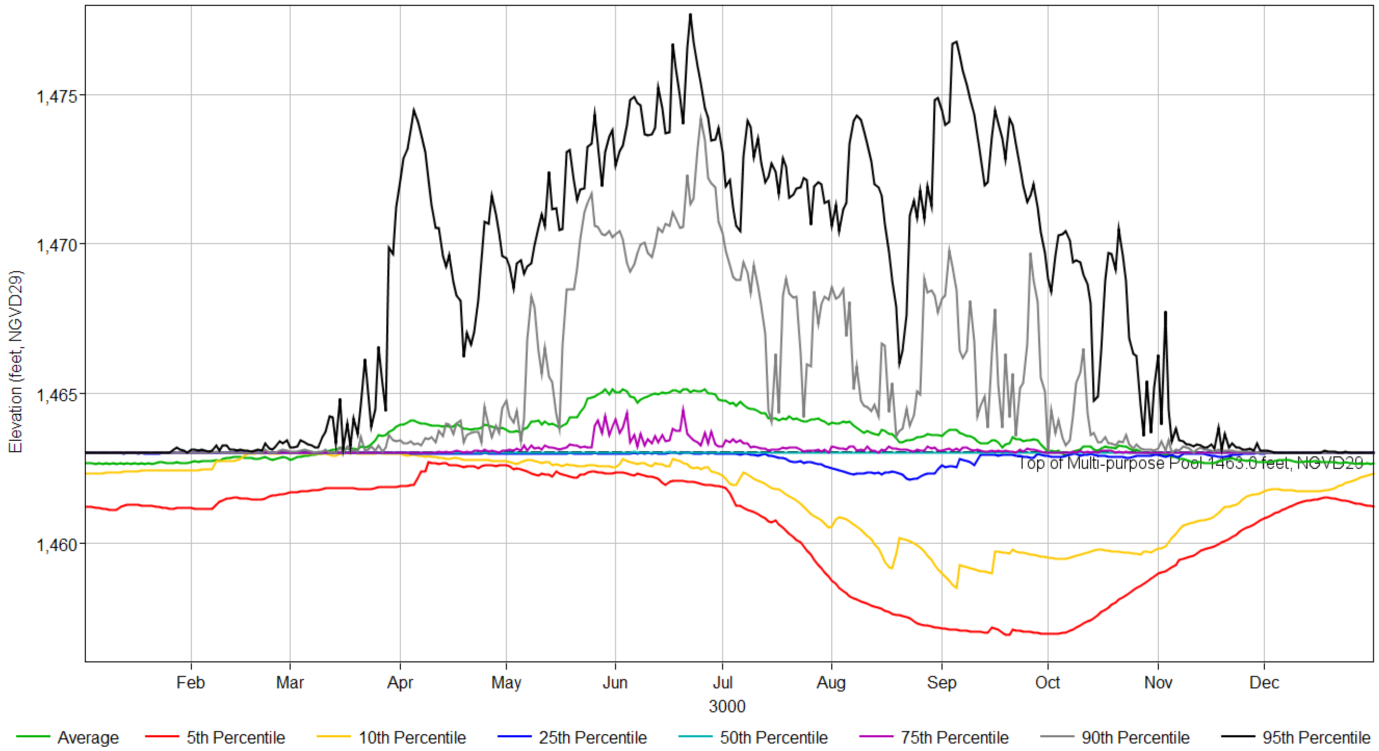


Figure 4-6. Kanopolis pool elevation statistics for the 100-year FWOP at 2124 sediment conditions.

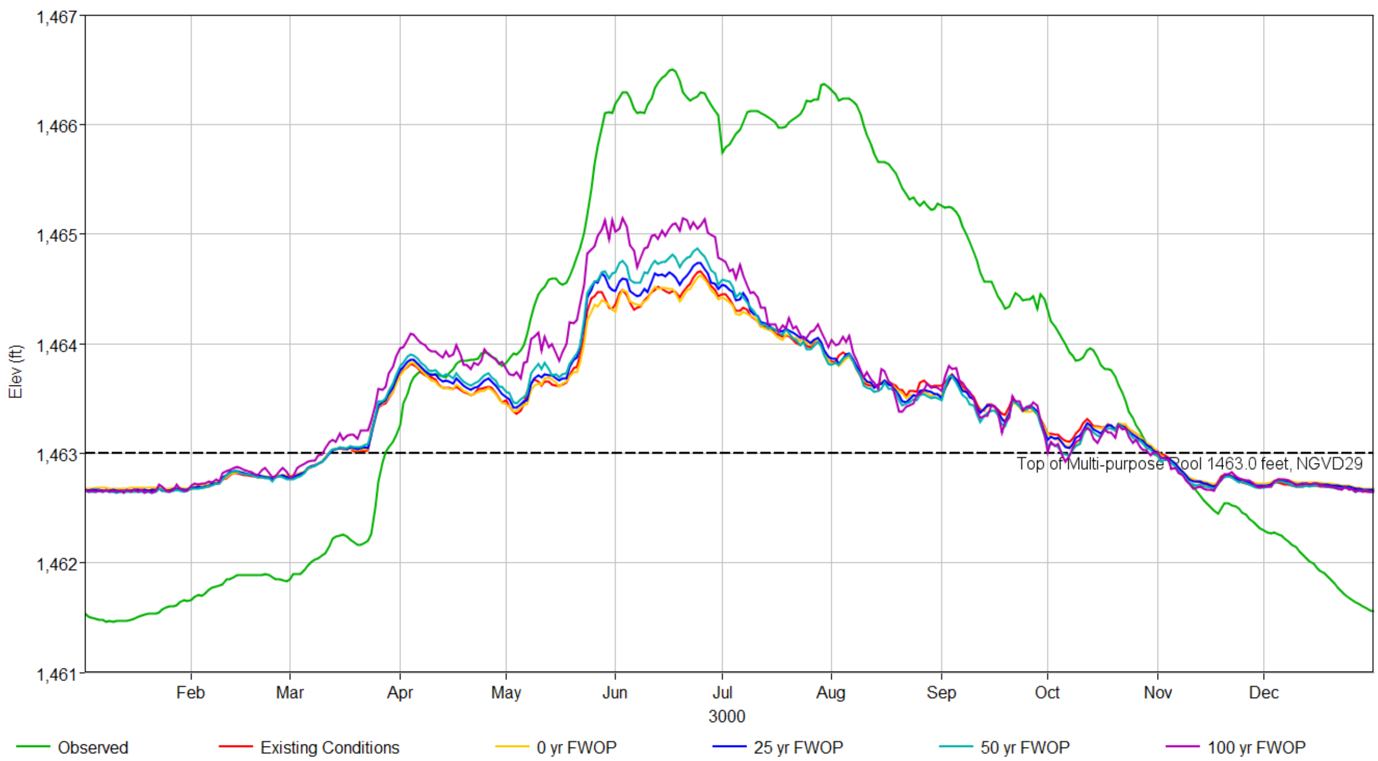


Figure 4-7. Daily average Kanopolis pool elevation for each set of data.

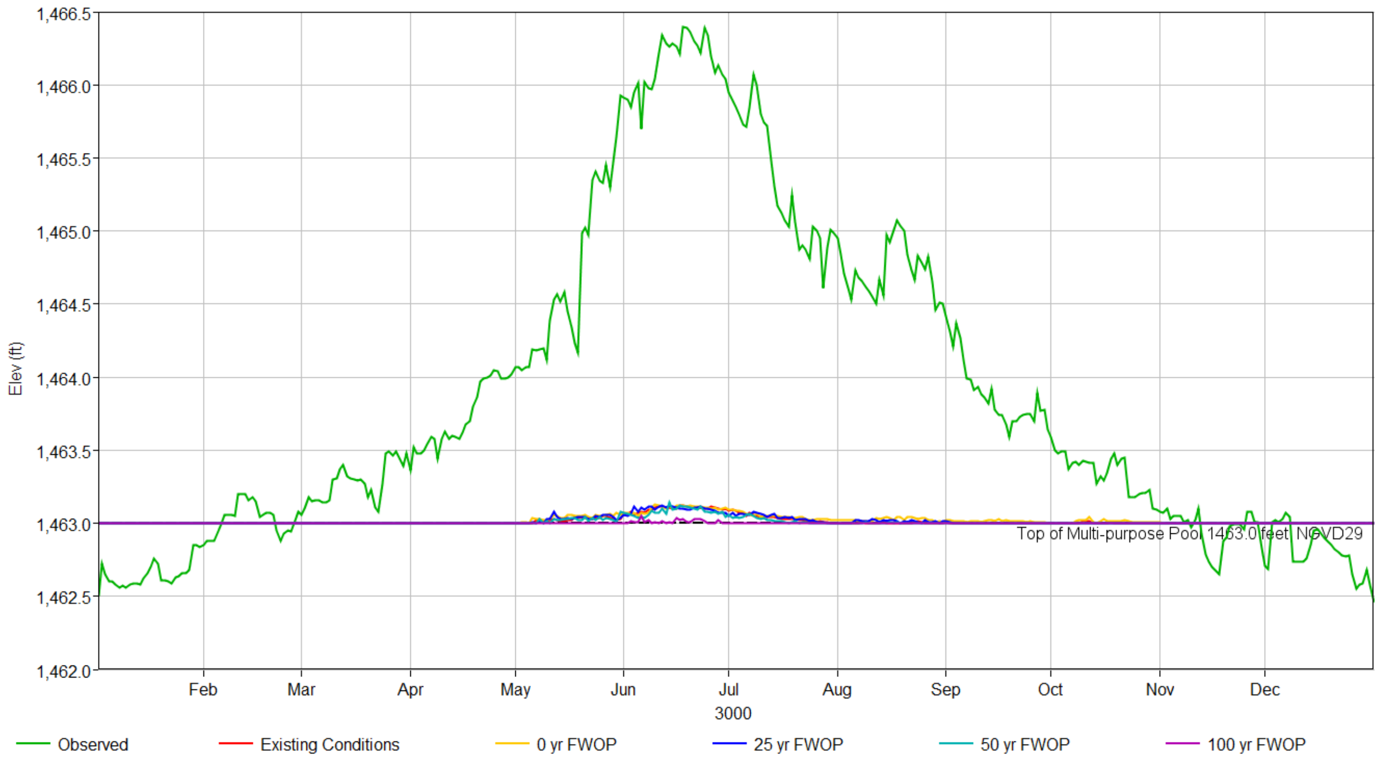


Figure 4-8. Daily median (50th Percentile) Kanopolis pool elevation for each set of data.

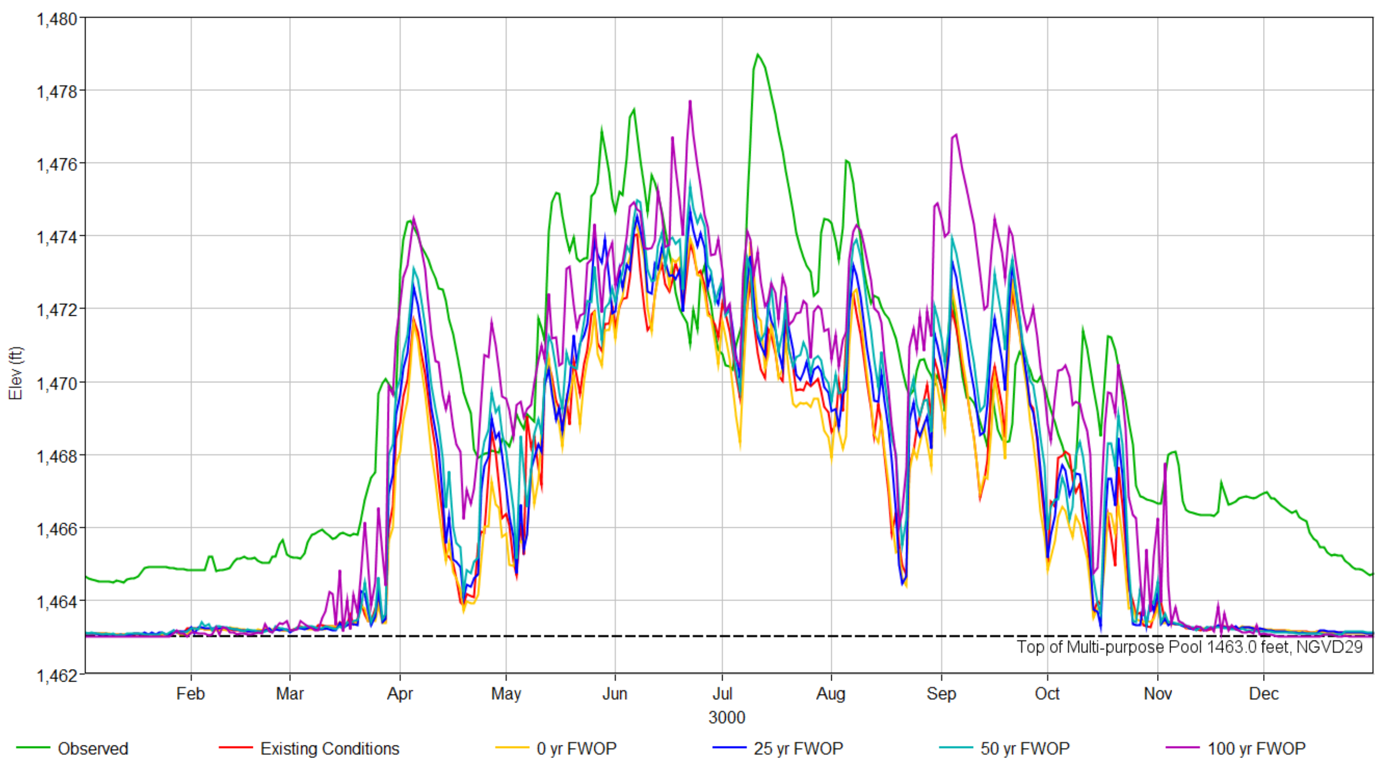


Figure 4-9. Daily 95th Percentile Kanopolis pool elevation for each set of data.

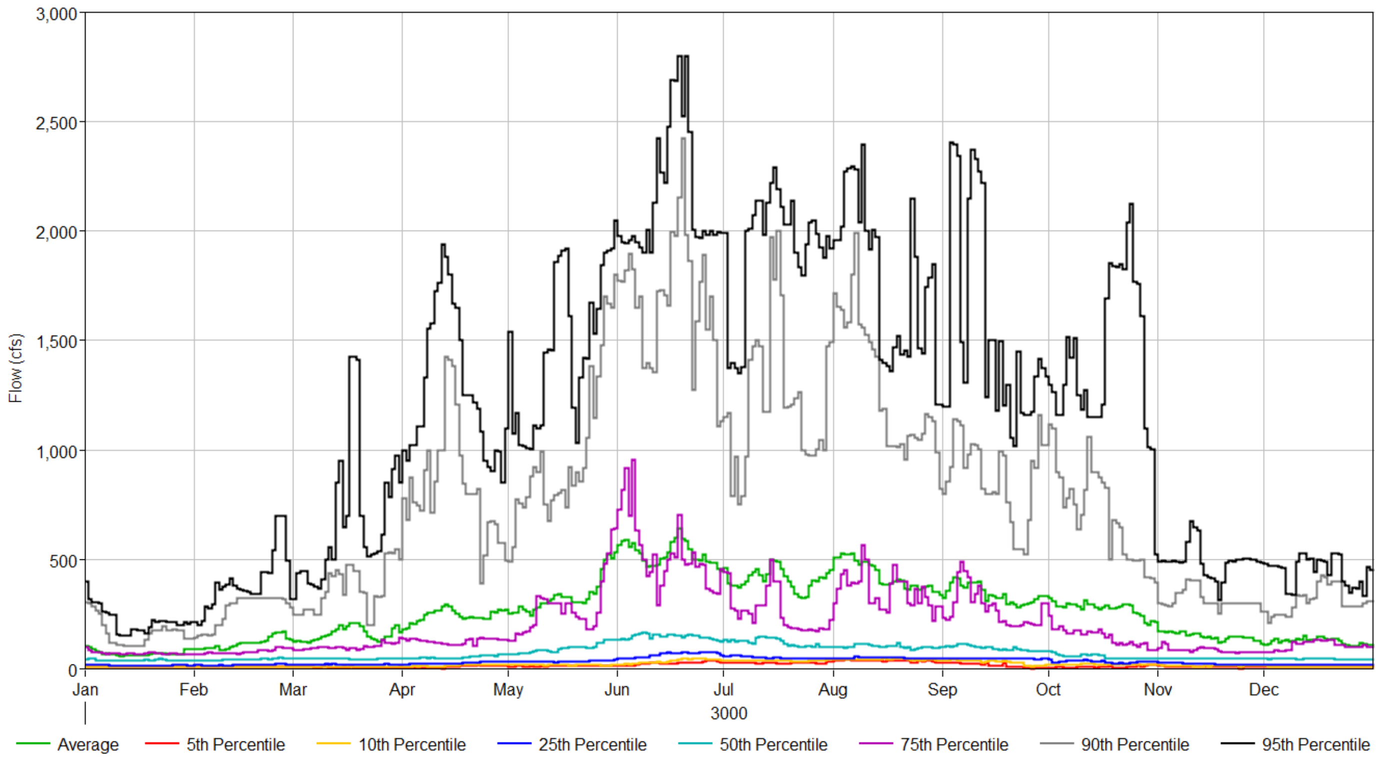


Figure 4-10. Kanopolis outflow statistics for the observed data from first fill Jul 1948 to Dec 2021.

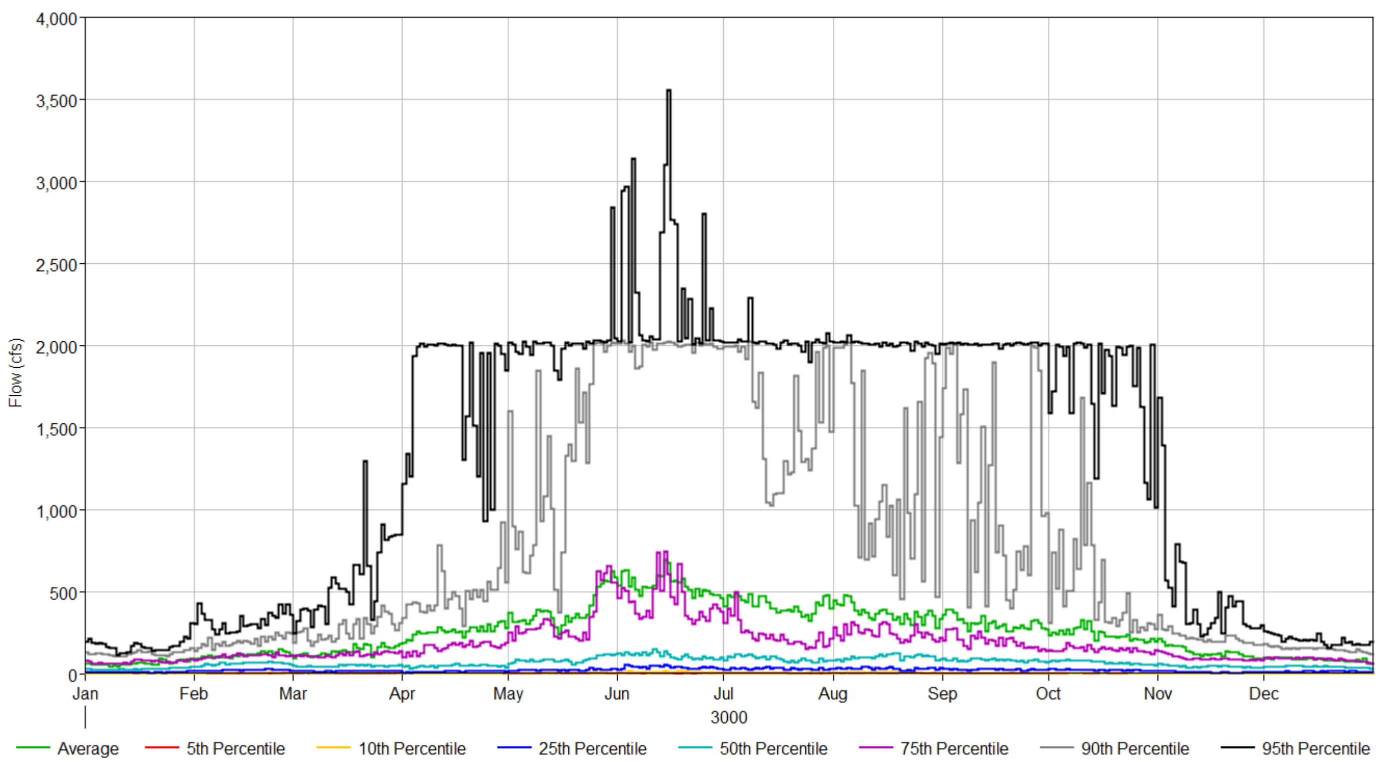


Figure 4-11. Kanopolis outflow statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

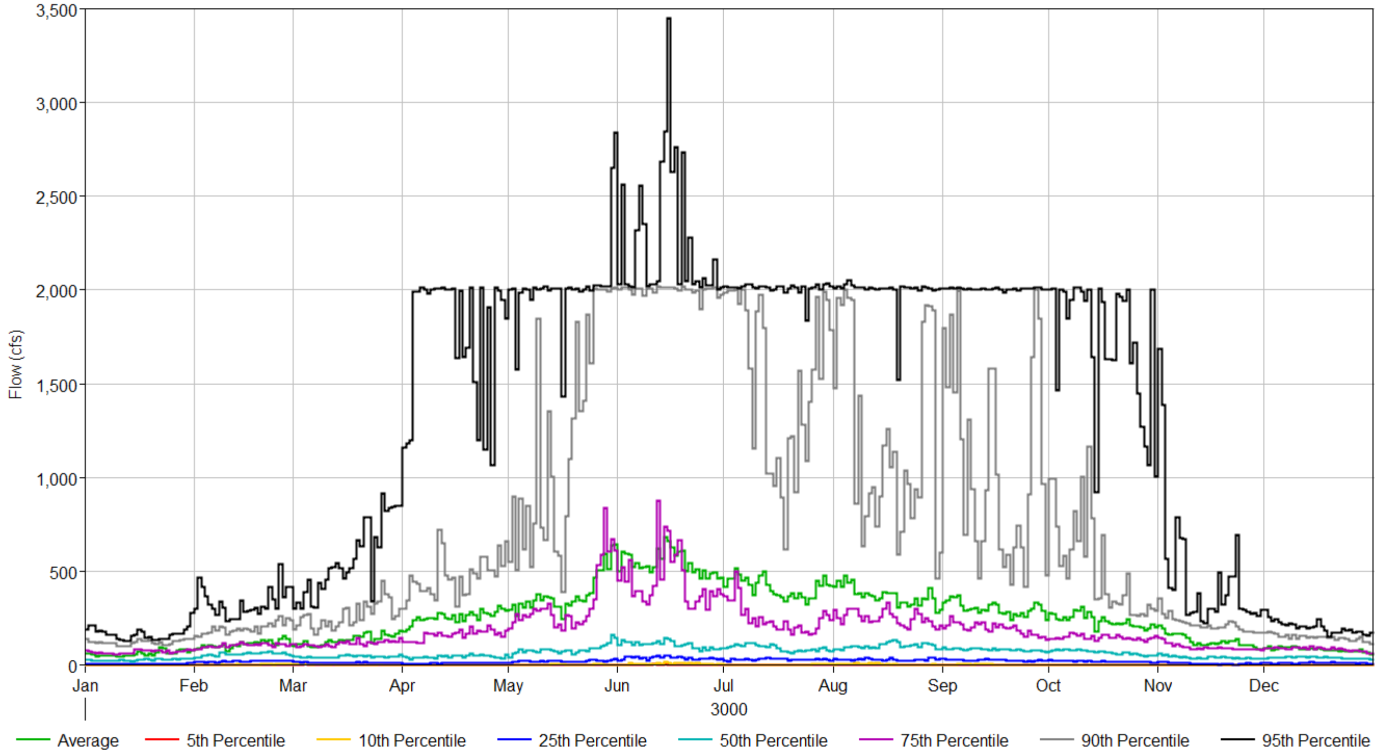


Figure 4-12. Kanopolis outflow statistics for the 100-year FWOP at 2024 sediment conditions.

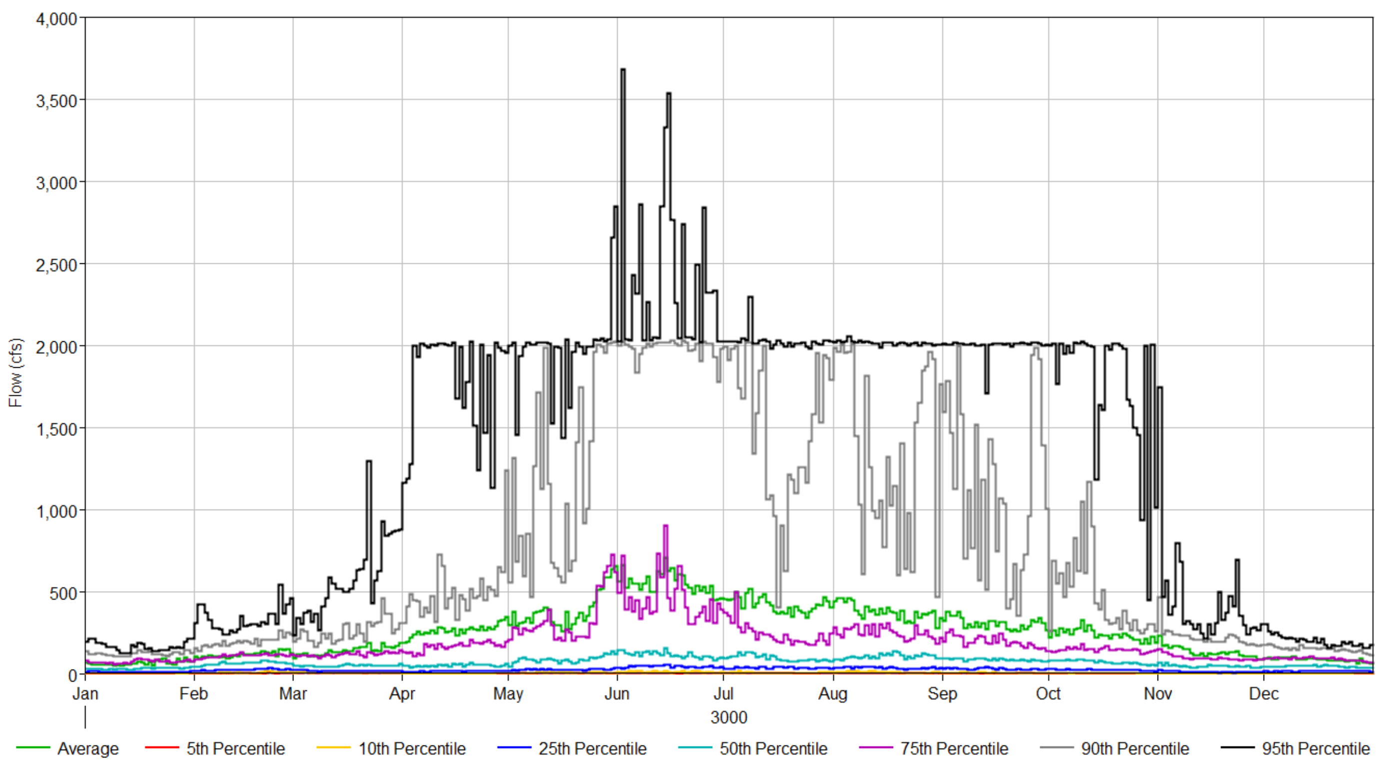


Figure 4-13. Kanopolis outflow statistics for the 100-year FWOP at 2049 sediment conditions.

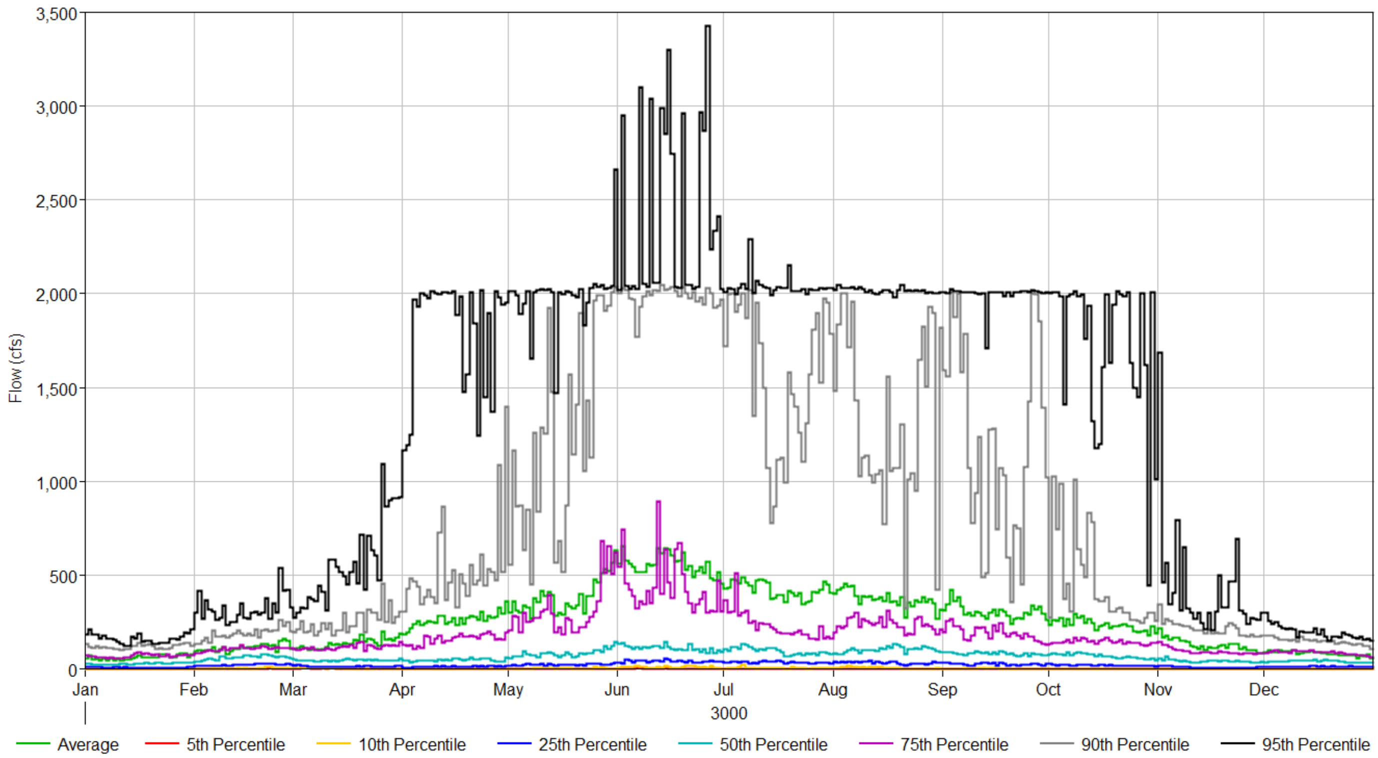


Figure 4-14. Kanopolis outflow statistics for the 100-year FWOP at 2074 sediment conditions.

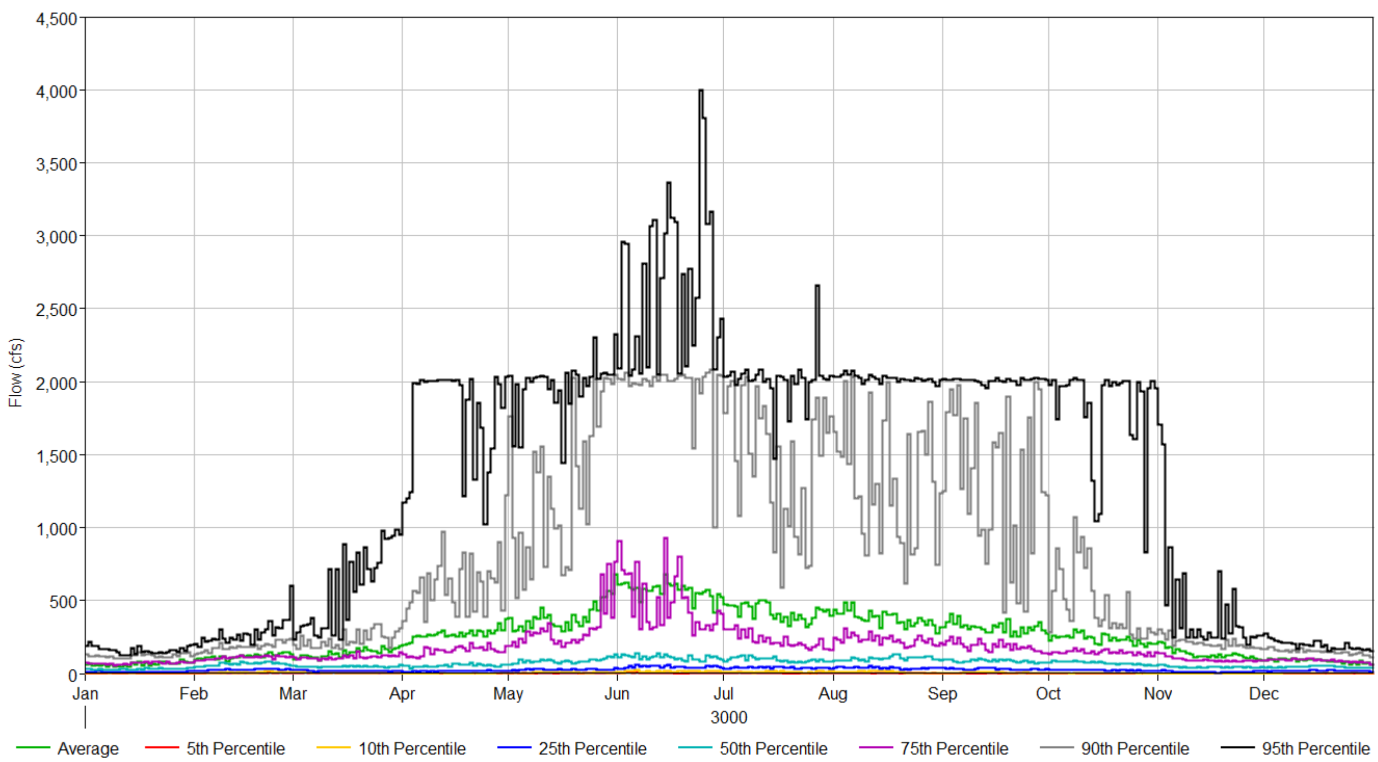


Figure 4-15. Kanopolis outflow statistics for the 100-year FWOP at 2124 sediment conditions.

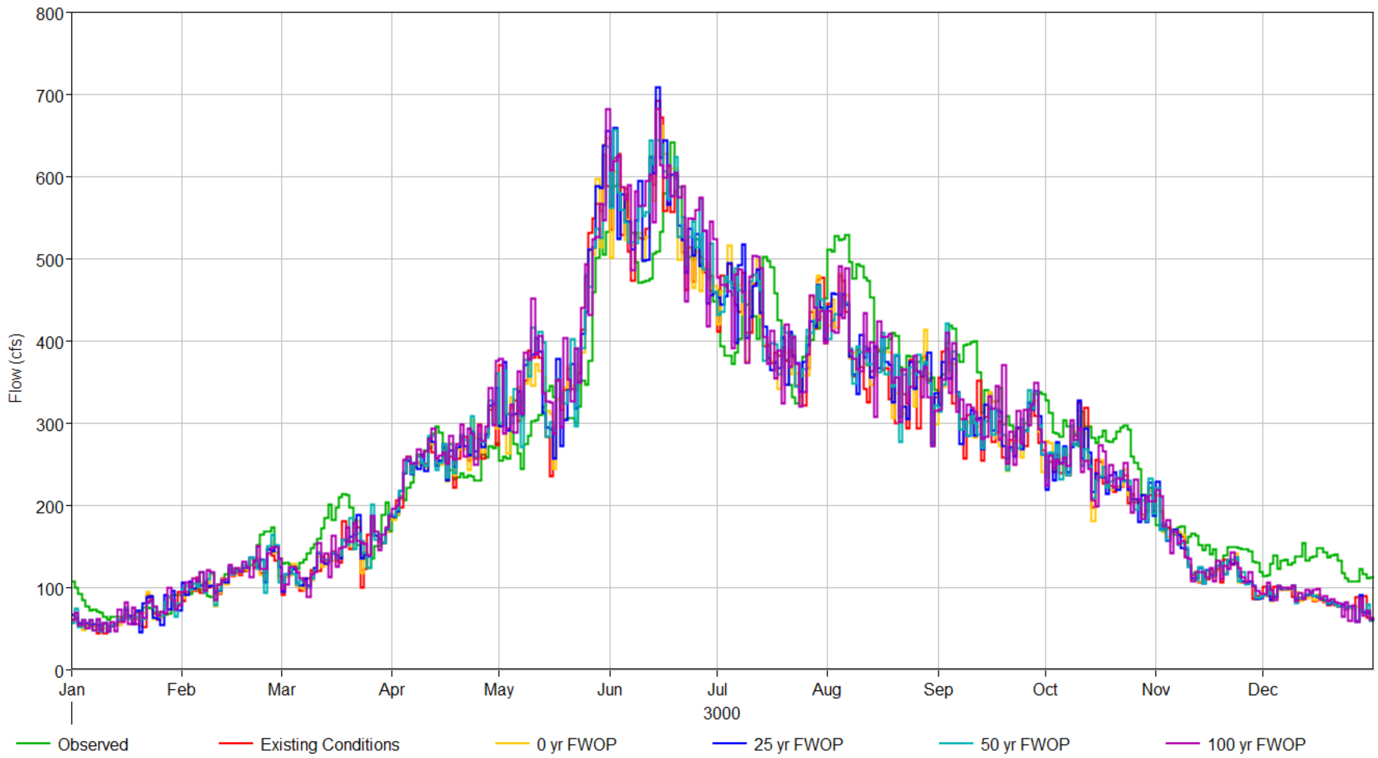


Figure 4-16. Daily average Kanopolis outflow for each set of data.

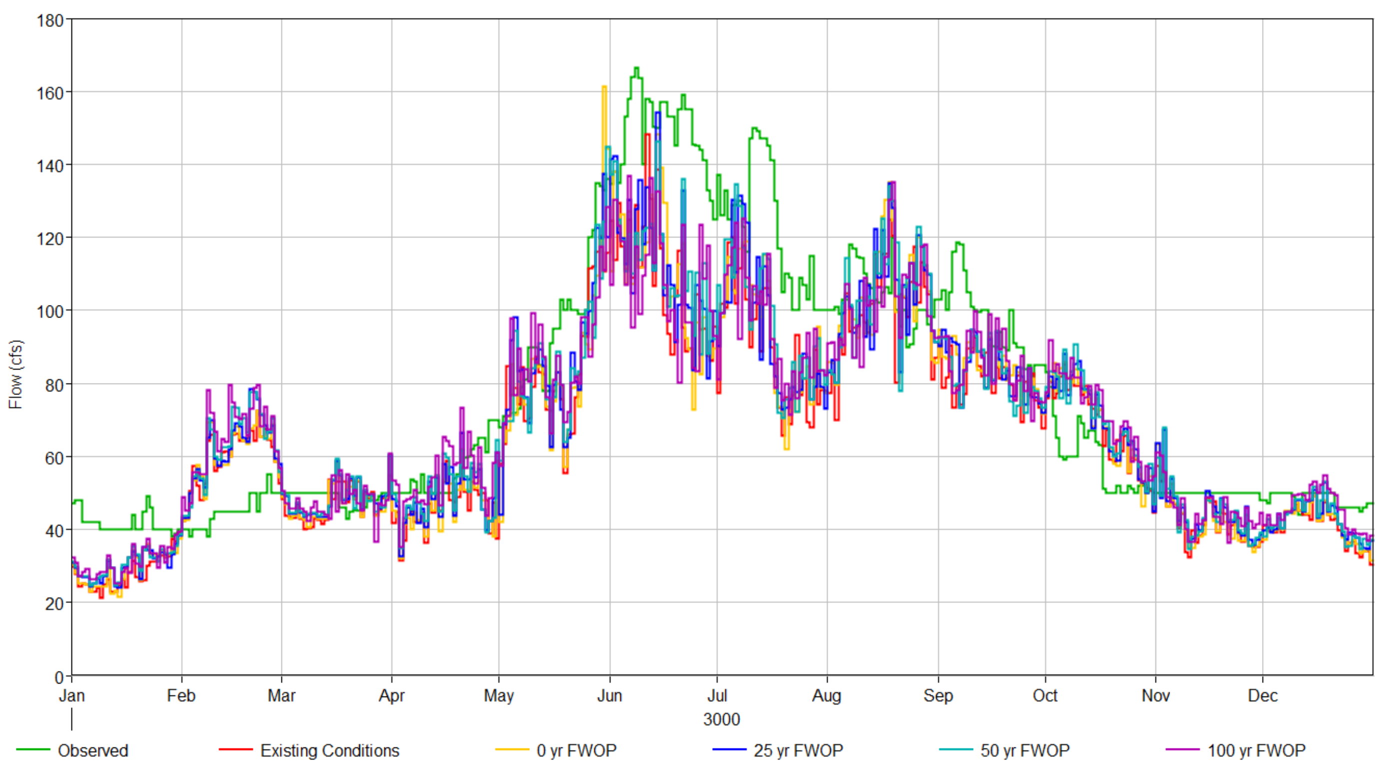


Figure 4-17. Daily median (50th Percentile) Kanopolis flow for each set of data.

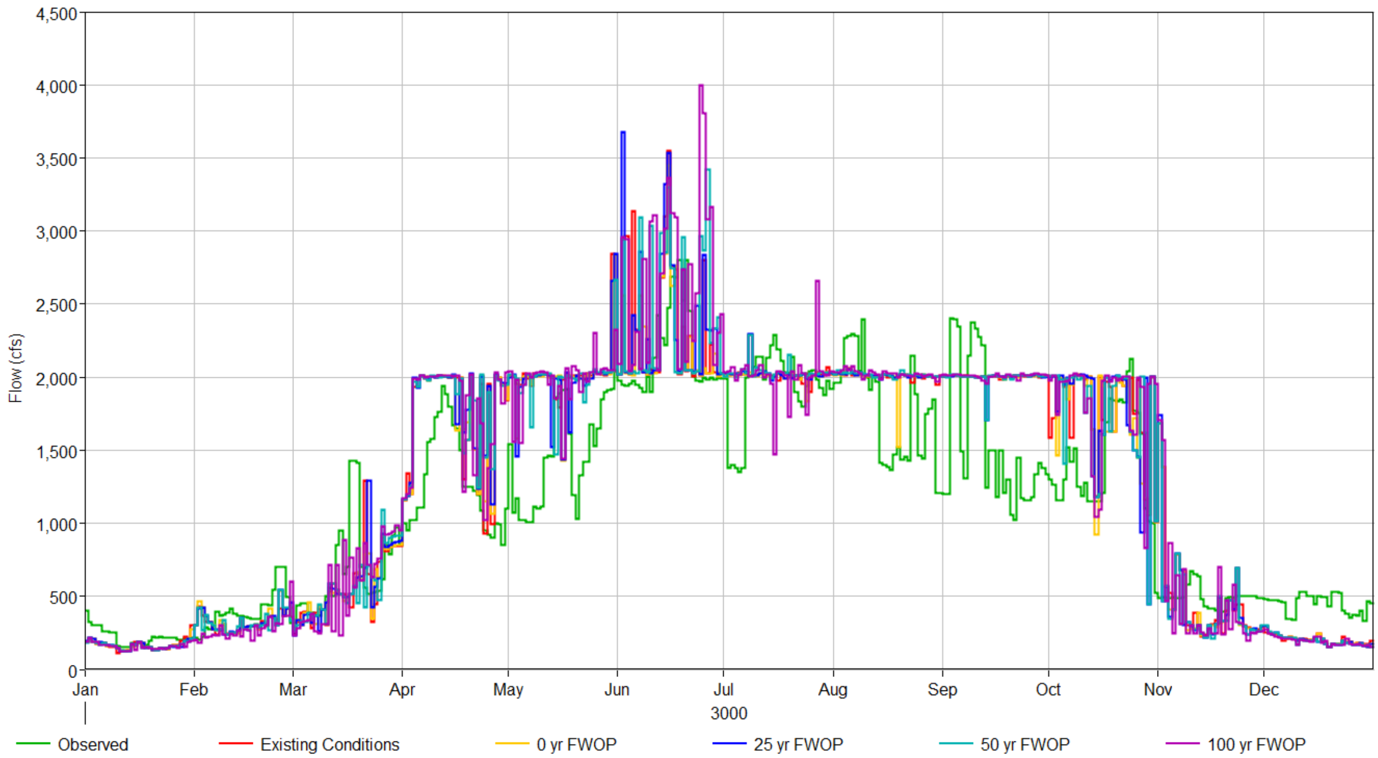


Figure 4-18. Daily 95th Percentile Kanopolis flow for each set of data.

The pool elevation duration is shown in Figure 4-19. It shows increased frequency in the lower portions of the flood control pool and deeper drops into the multi-purpose pool as the storage diminishes due to sedimentation.

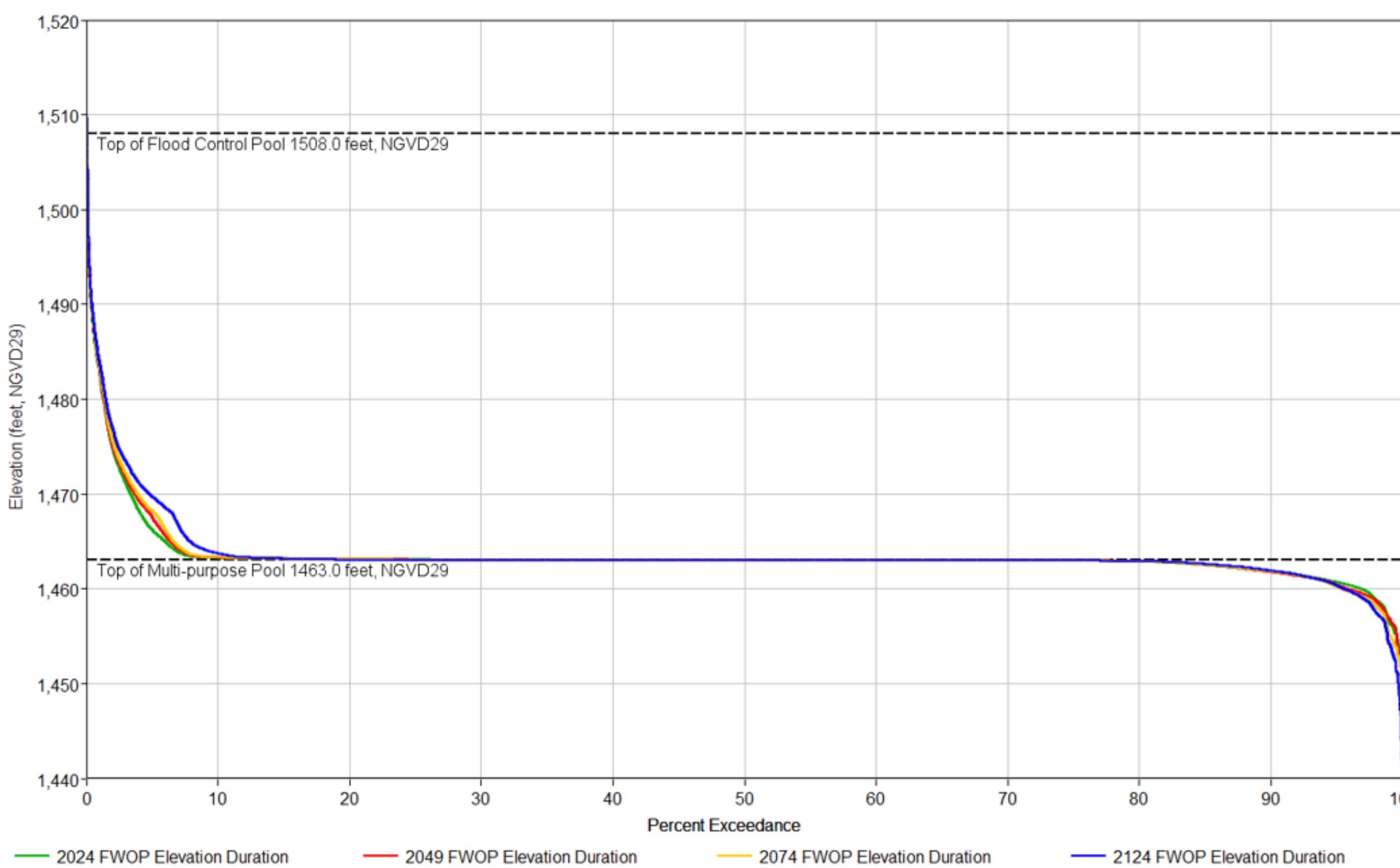


Figure 4-19. Kanopolis pool elevation duration for the four non-navigation FWOP scenarios.

4.1.2 Wilson

Wilson observed data is from first fill of March 1973 through November 2021. The Wilson family of curves are shown in Figure 4-20 to Figure 4-37. Navigation did not impact Wilson and the navigation FWOP scenarios were identical to the non-navigation. The average and median modeled elevations are all below the top of multipurpose pool which is reflective of the frequent drought conditions observed there. Observed pool elevations are mostly higher than the average, median and 95-percential for every model scenario. This may indicate that the model was more aggressive with releases when the real time operations are often constrained due to chances of rainfall or concerns in the downstream channel.

Only the median December/January elevations of the 2124 FWOP scenario match the observed. This may reflect differences between how the reservoir was operated during some large flood years and the Res Sim simulated operations. Or estimated evaporation may be causing the differences.

The 2024 FWOP and 2049 FWOP scenarios are very similar as the sediment conditions do not change dramatically in this timeframe. However, as more sediment accumulates with each additional FWOP scenario the average pool elevation also increases.

The modeled outflow data matches the observed data generally well, especially the average and median daily flows. An exception is the 95-percentile category, for which the observed data was more variable and generally lower than the modeled in the summer months. This is likely due to situationally specific decisions made by reservoir managers that aren't considered in the model.

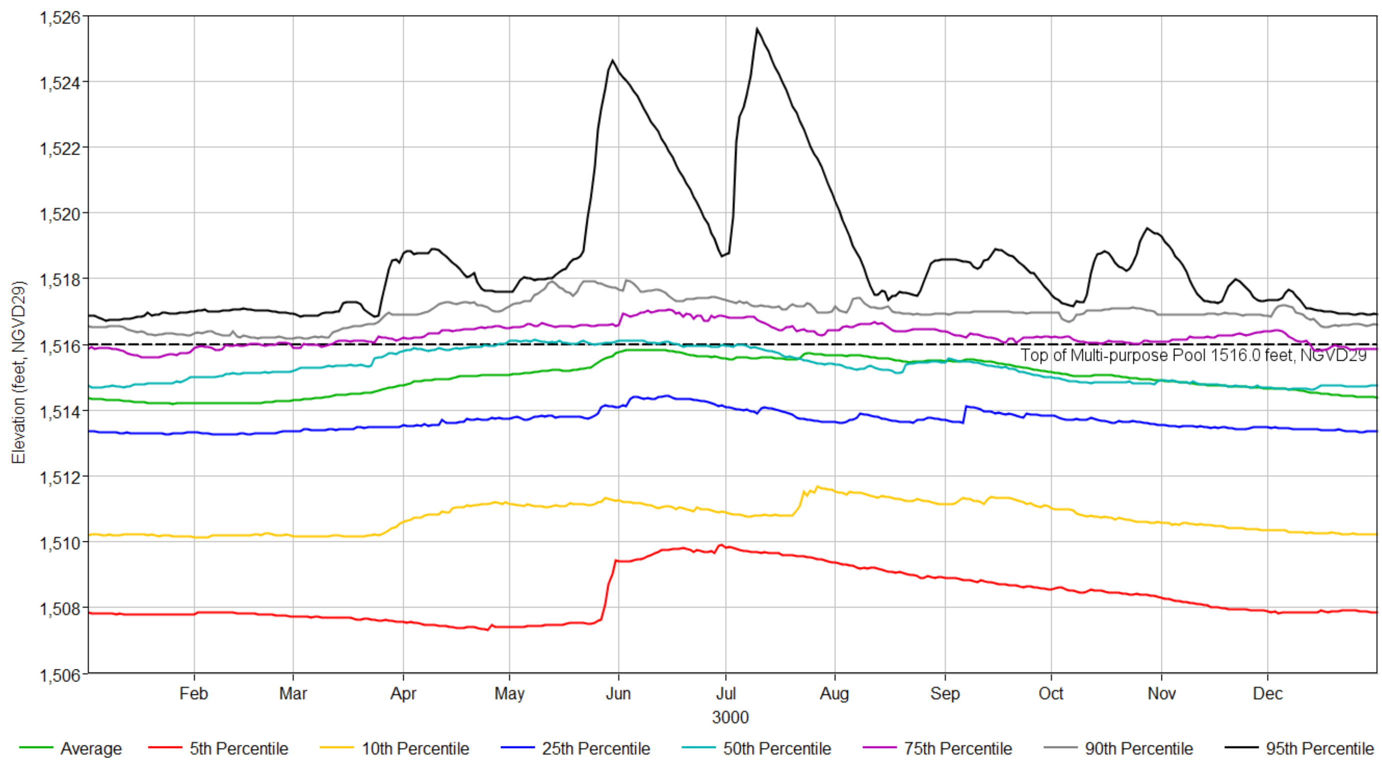


Figure 4-20. Wilson pool elevation statistics for the observed data from first fill Mar 1973 to Dec 2021.

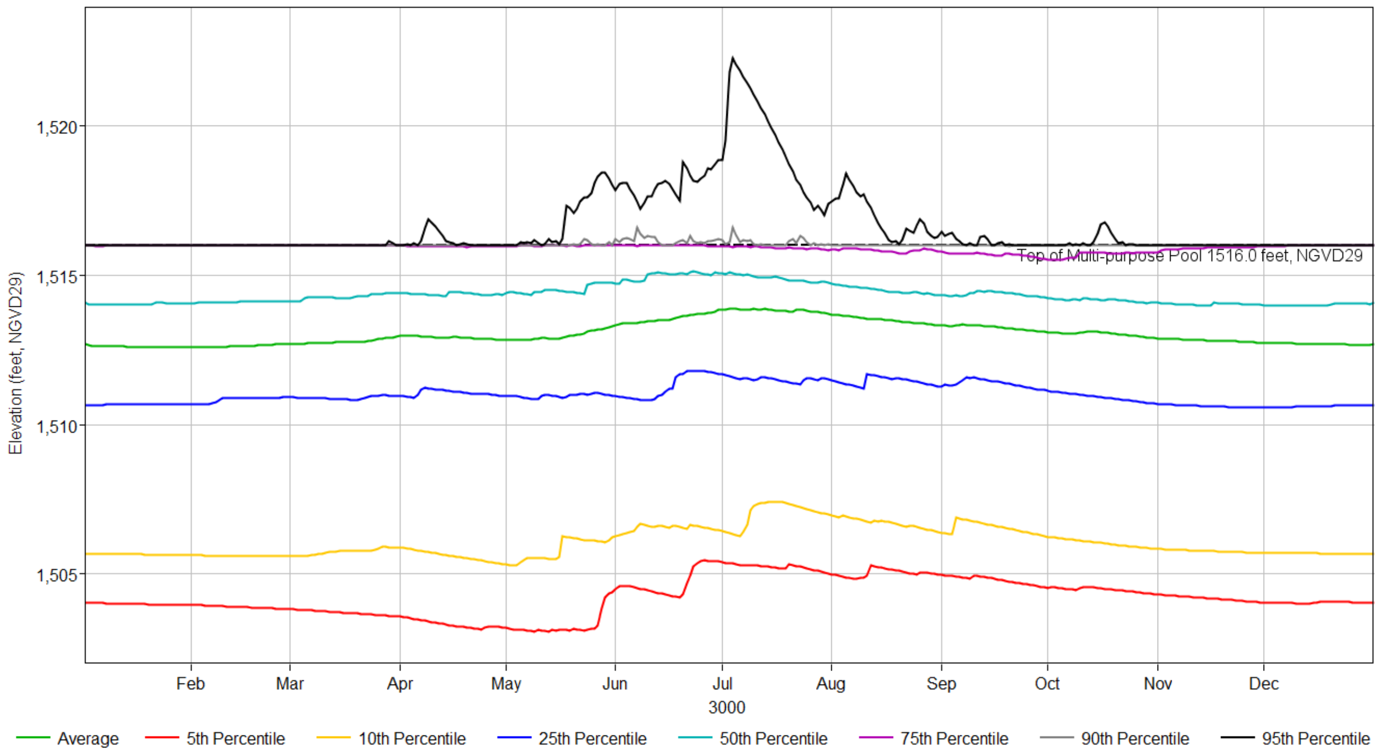


Figure 4-21. Wilson pool elevation statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

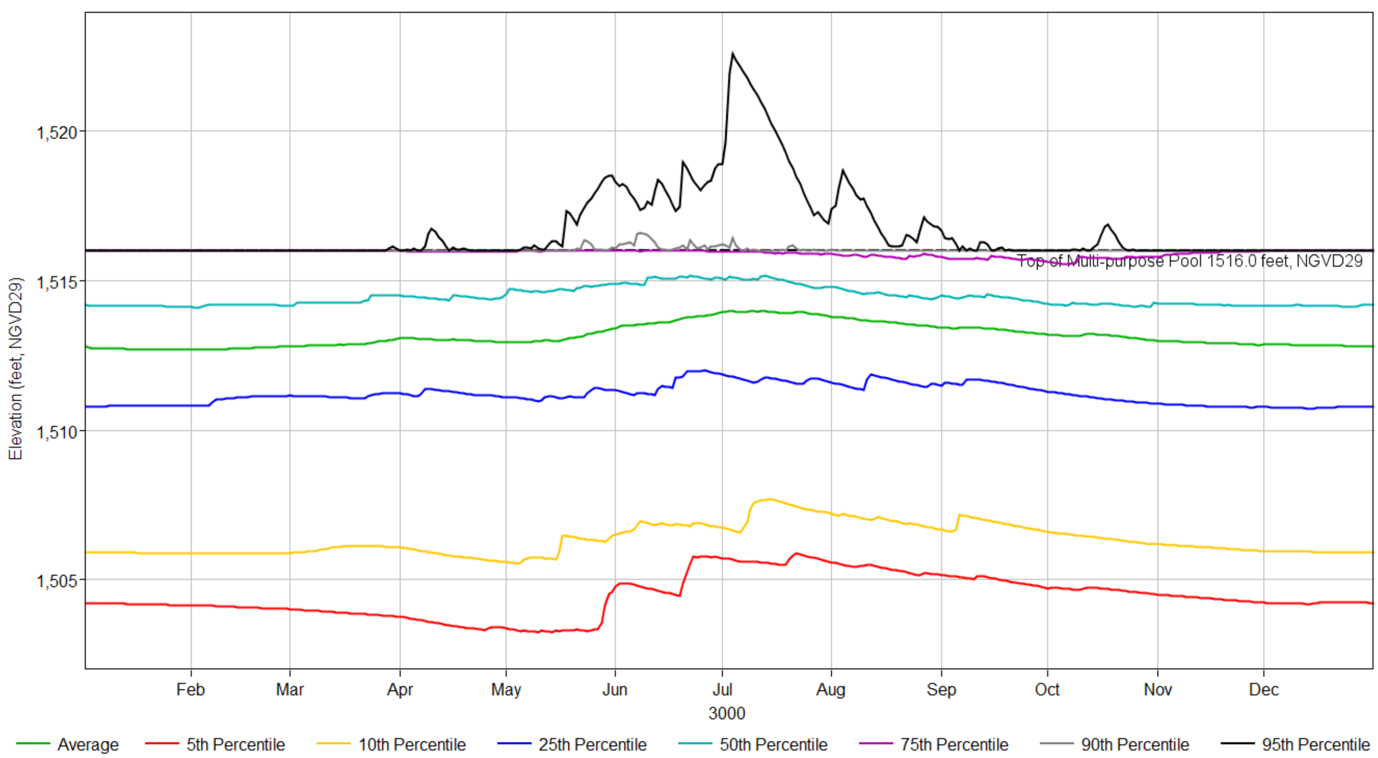


Figure 4-22. Wilson pool elevation statistics for the 100-year FWOP at 2024 sediment conditions.

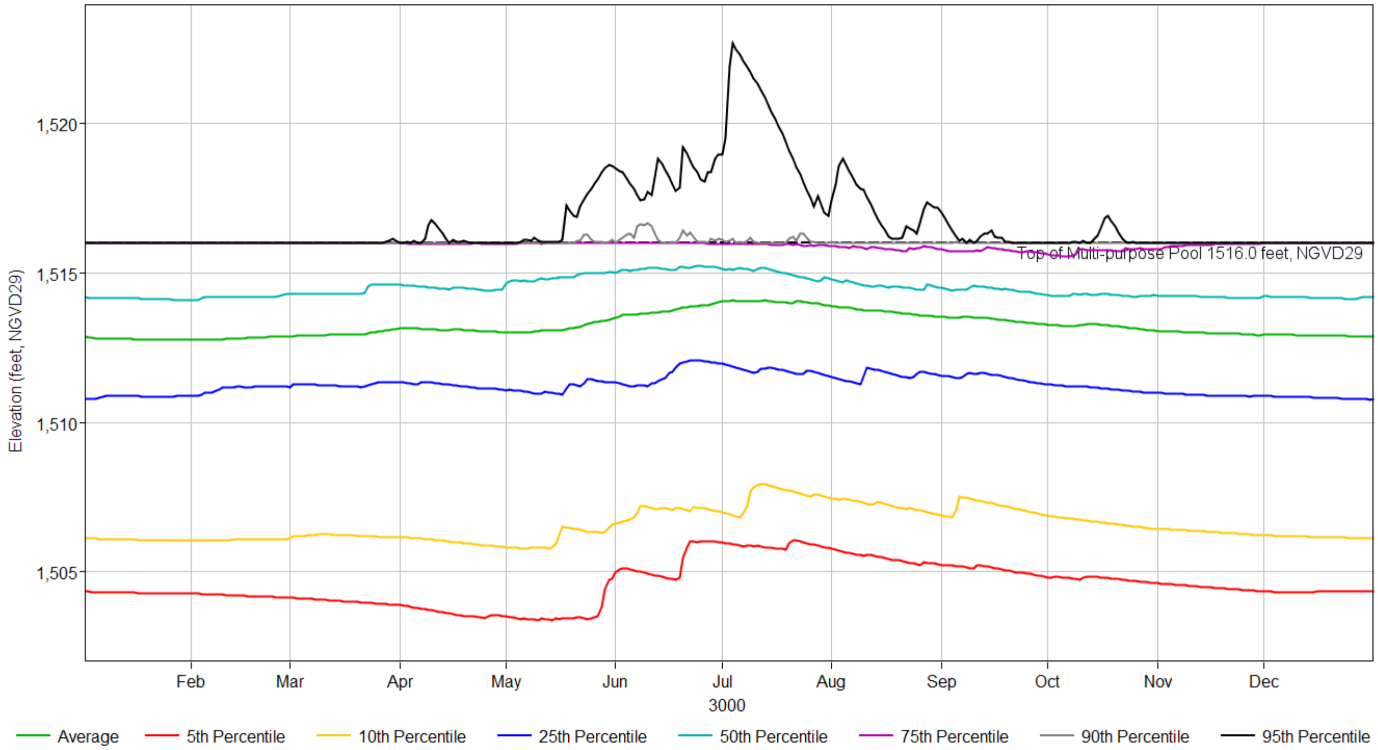


Figure 4-23. Wilson pool elevation statistics for the 100-year FWOP at 2049 sediment conditions.

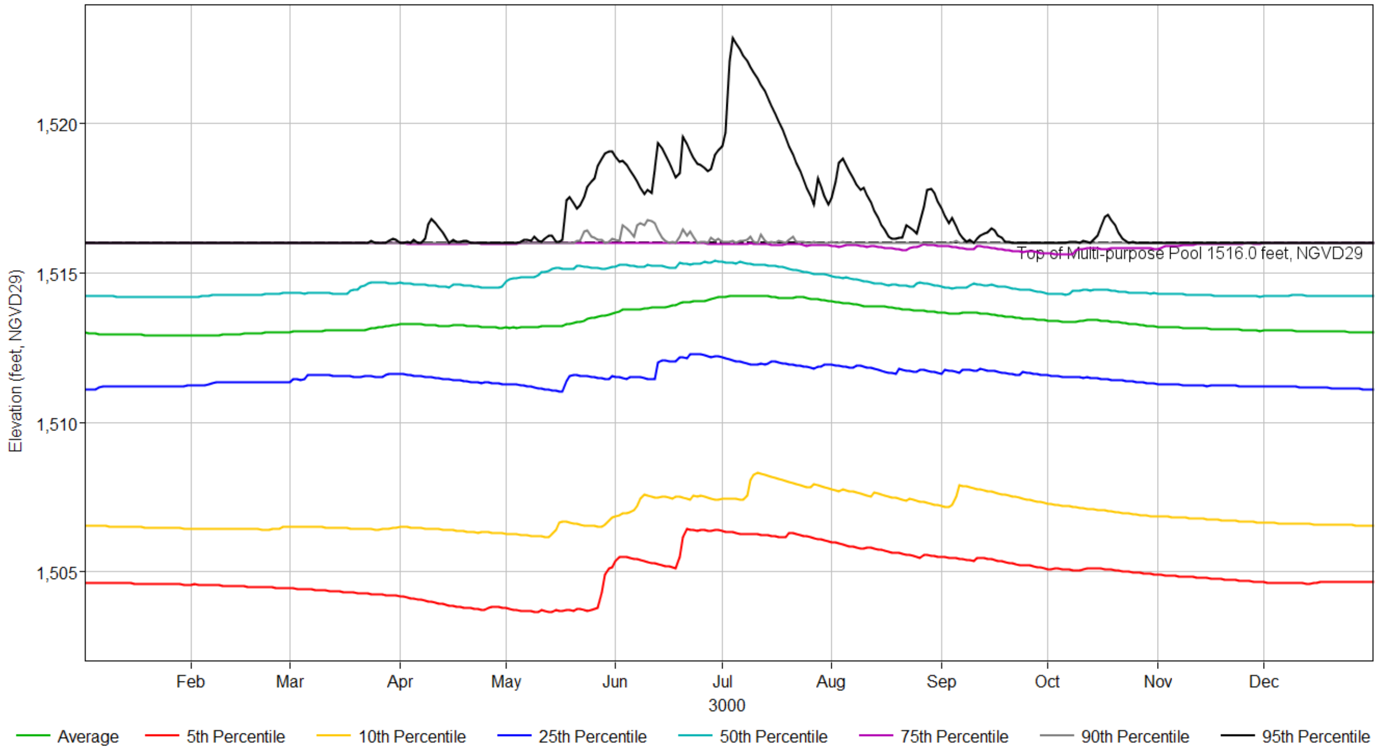


Figure 4-24. Wilson pool elevation statistics for the 100-year FWOP at 2074 sediment conditions.

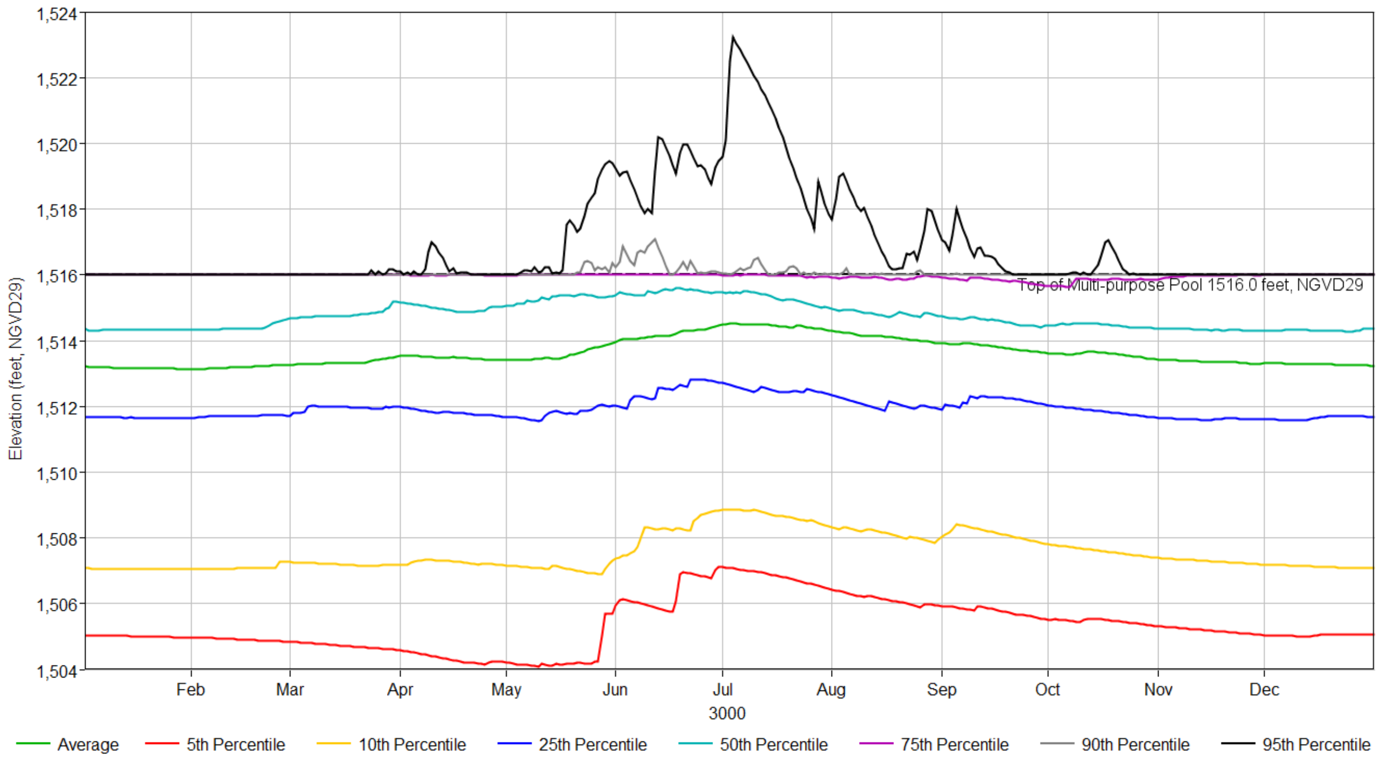


Figure 4-25. Wilson pool elevation statistics for the 100-year FWOP at 2124 sediment conditions.

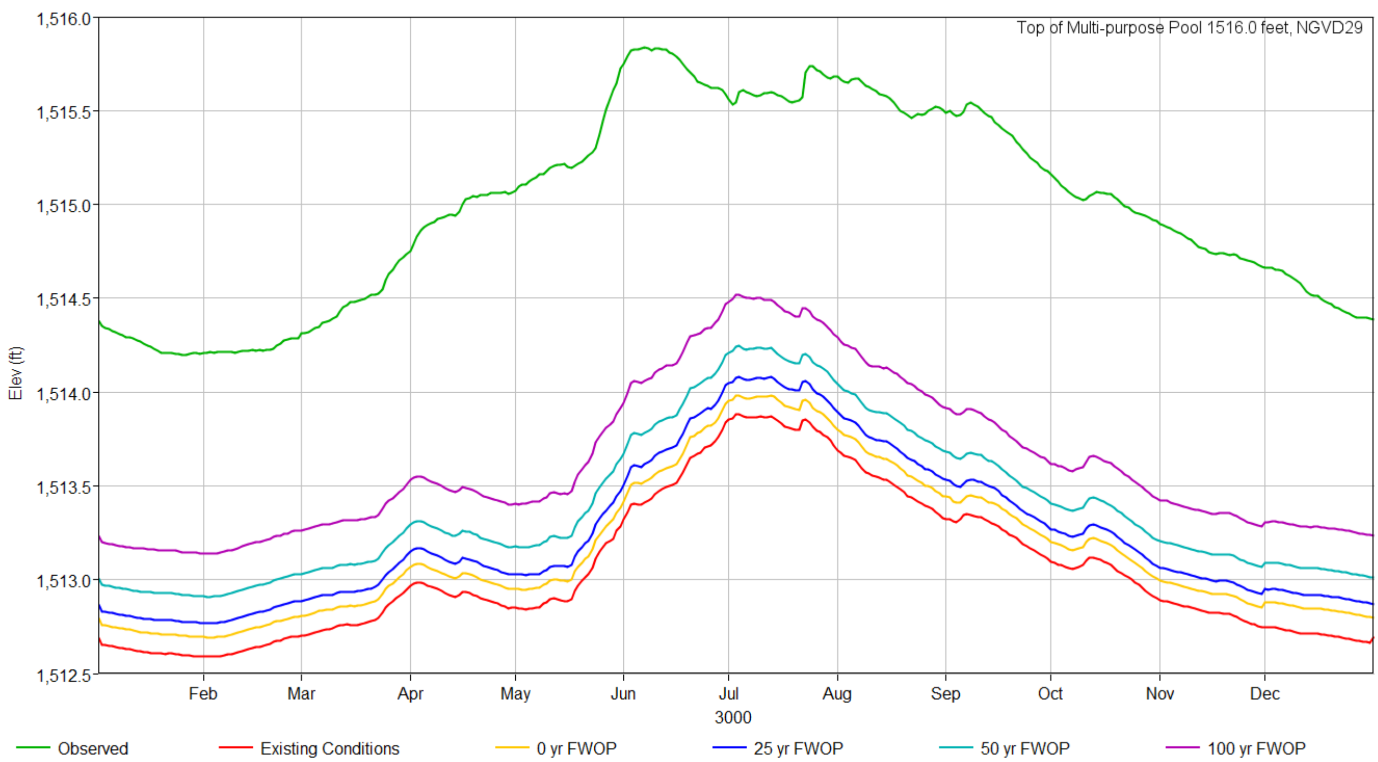


Figure 4-26. Daily average Wilson pool elevation for each set of data.

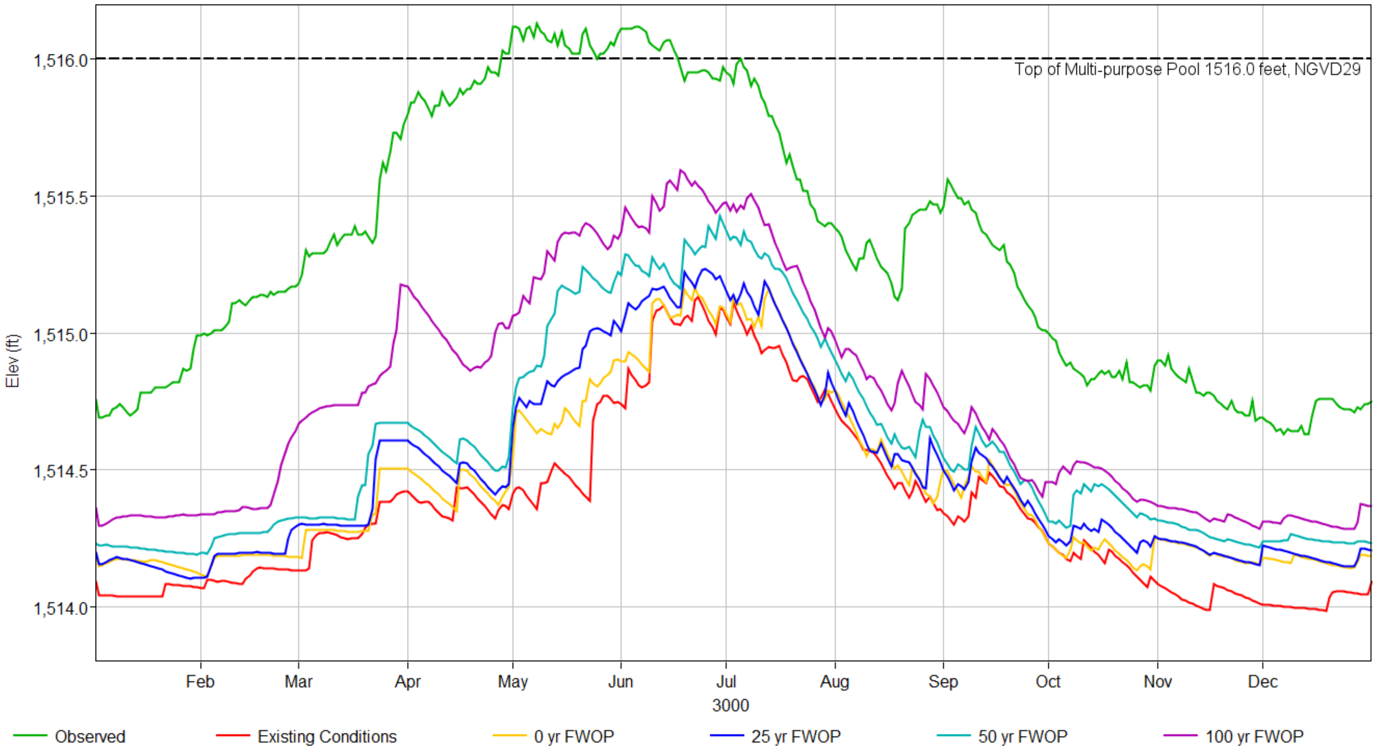


Figure 4-27. Daily median (50th Percentile) Wilson pool elevation for each set of data.

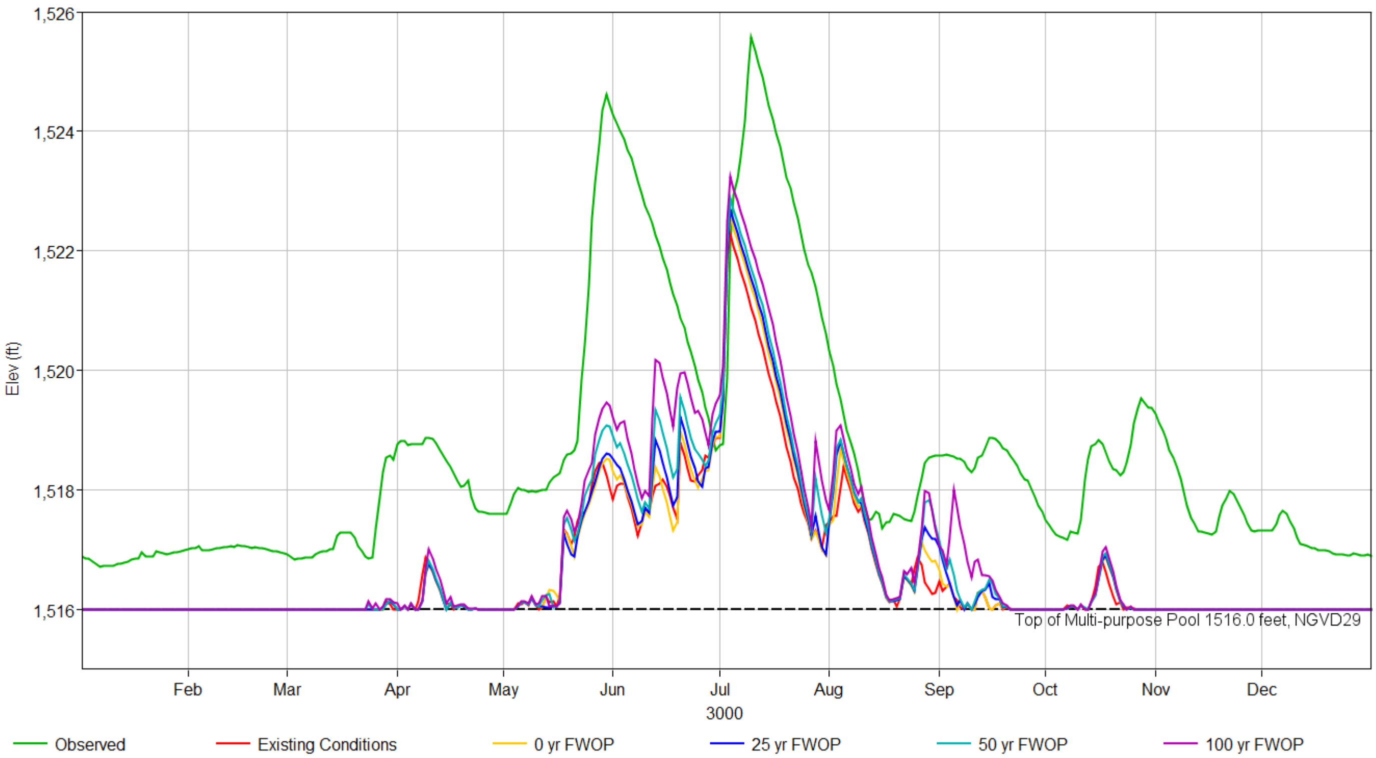


Figure 4-28. Daily 95th Percentile Wilson pool elevation for each set of data.

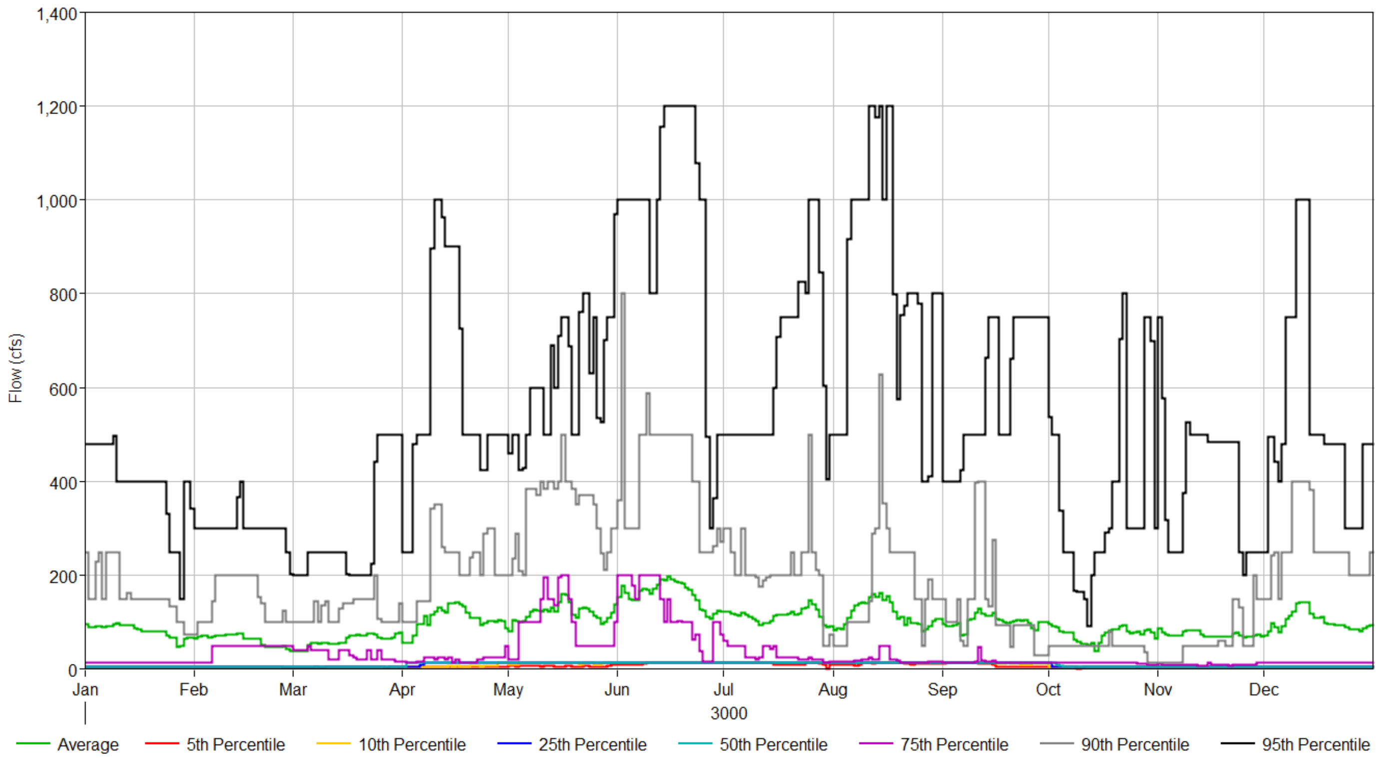


Figure 4-29. Wilson outflow statistics for the observed data from first fill Sep 1963 to Dec 2021.

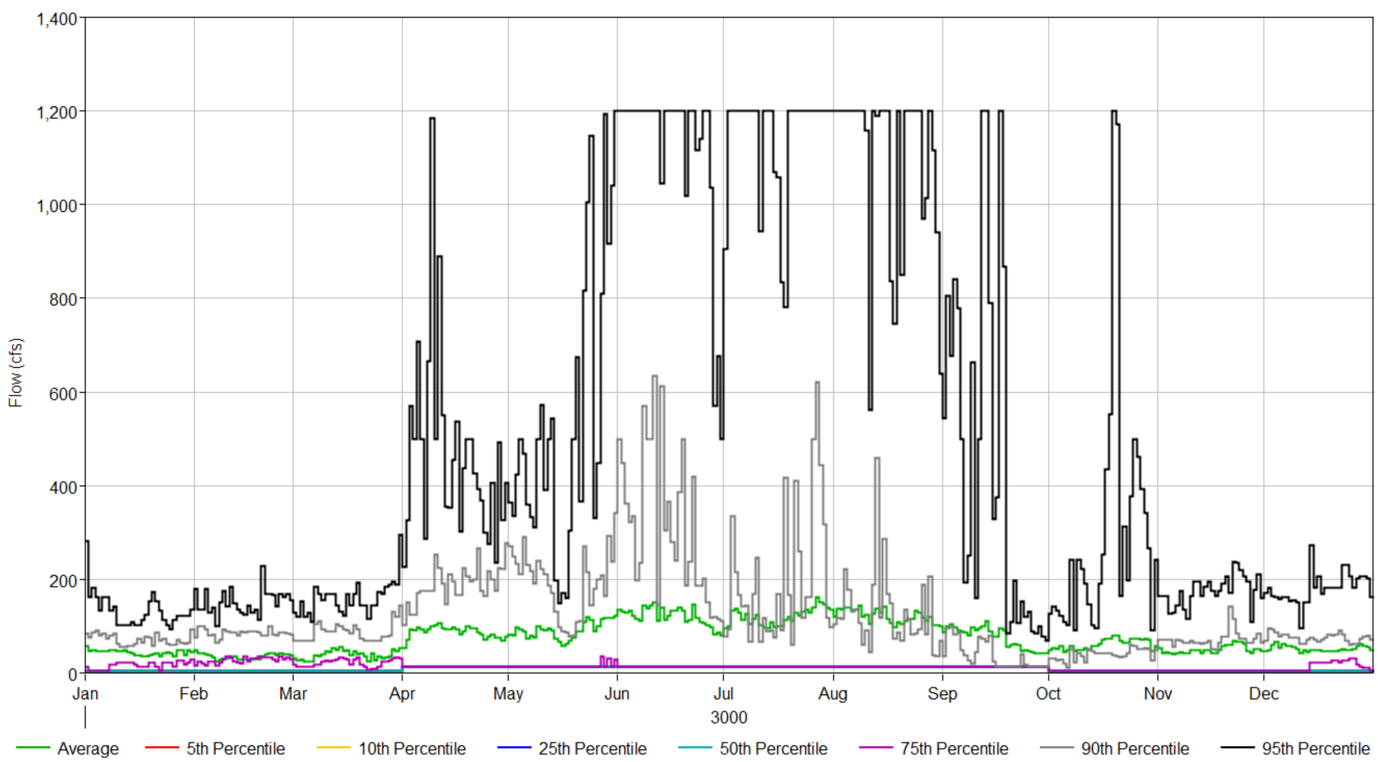


Figure 4-30. Wilson outflow statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

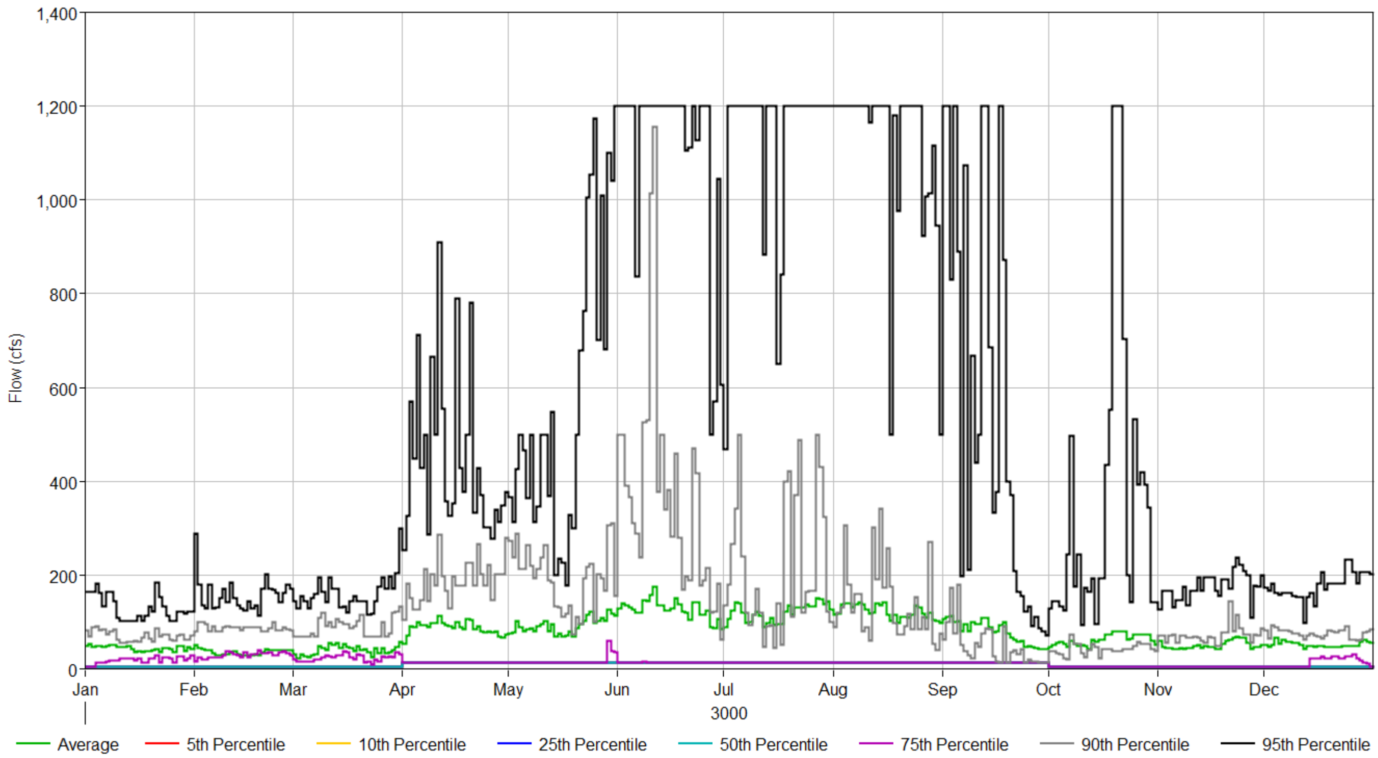


Figure 4-31. Wilson outflow statistics for the 100-year FWOP at 2024 sediment conditions.

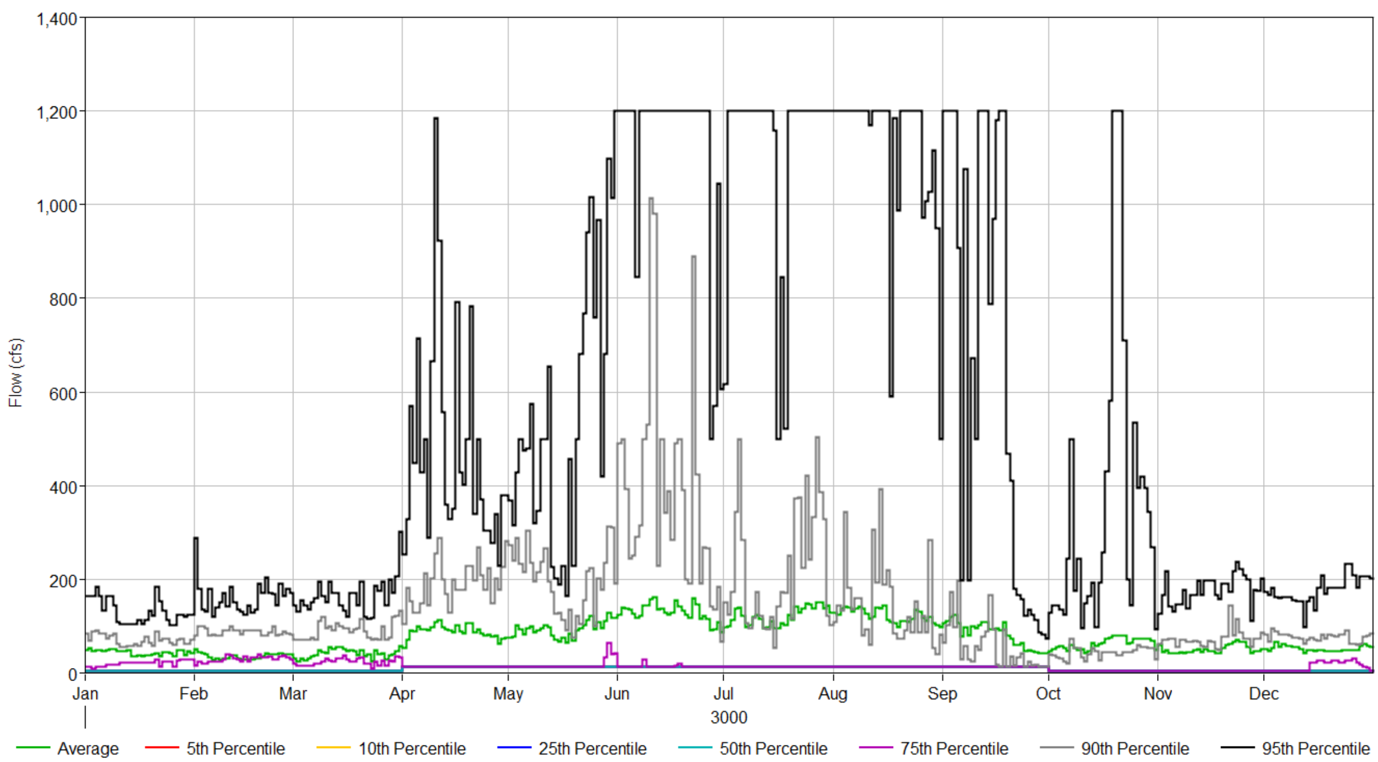


Figure 4-32. Wilson outflow statistics for the 100-year FWOP at 2049 sediment conditions.

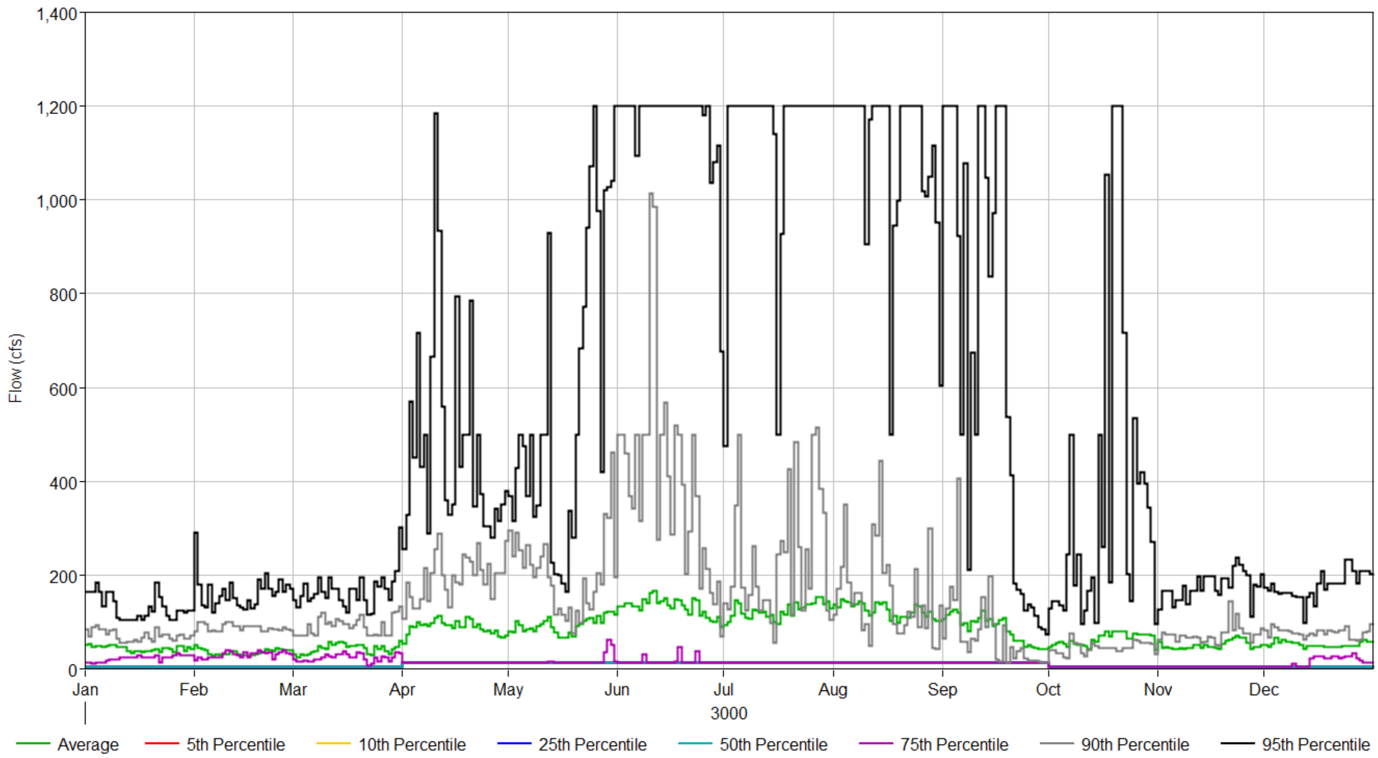


Figure 4-33. Wilson outflow statistics for the 100-year FWOP at 2074 sediment conditions.

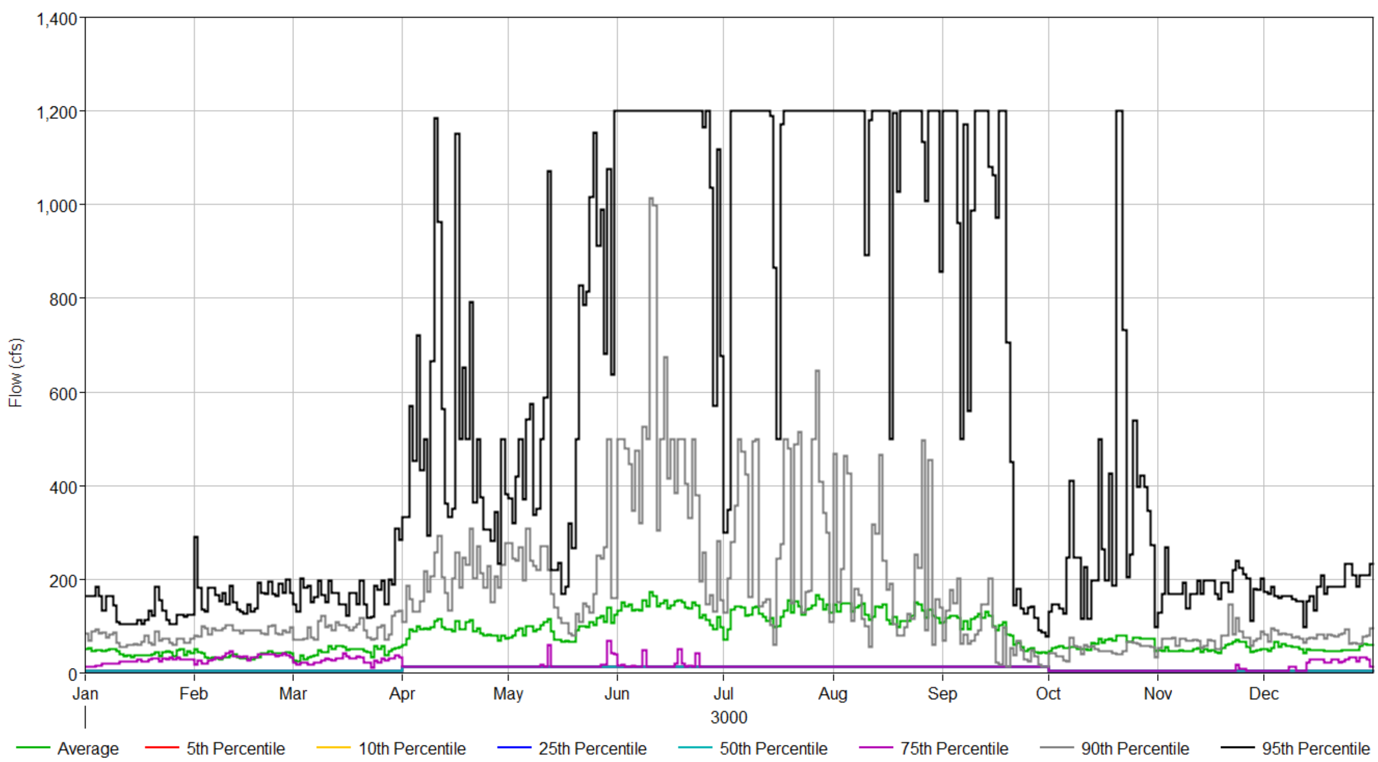


Figure 4-34. Wilson outflow statistics for the 100-year FWOP at 2124 sediment conditions.

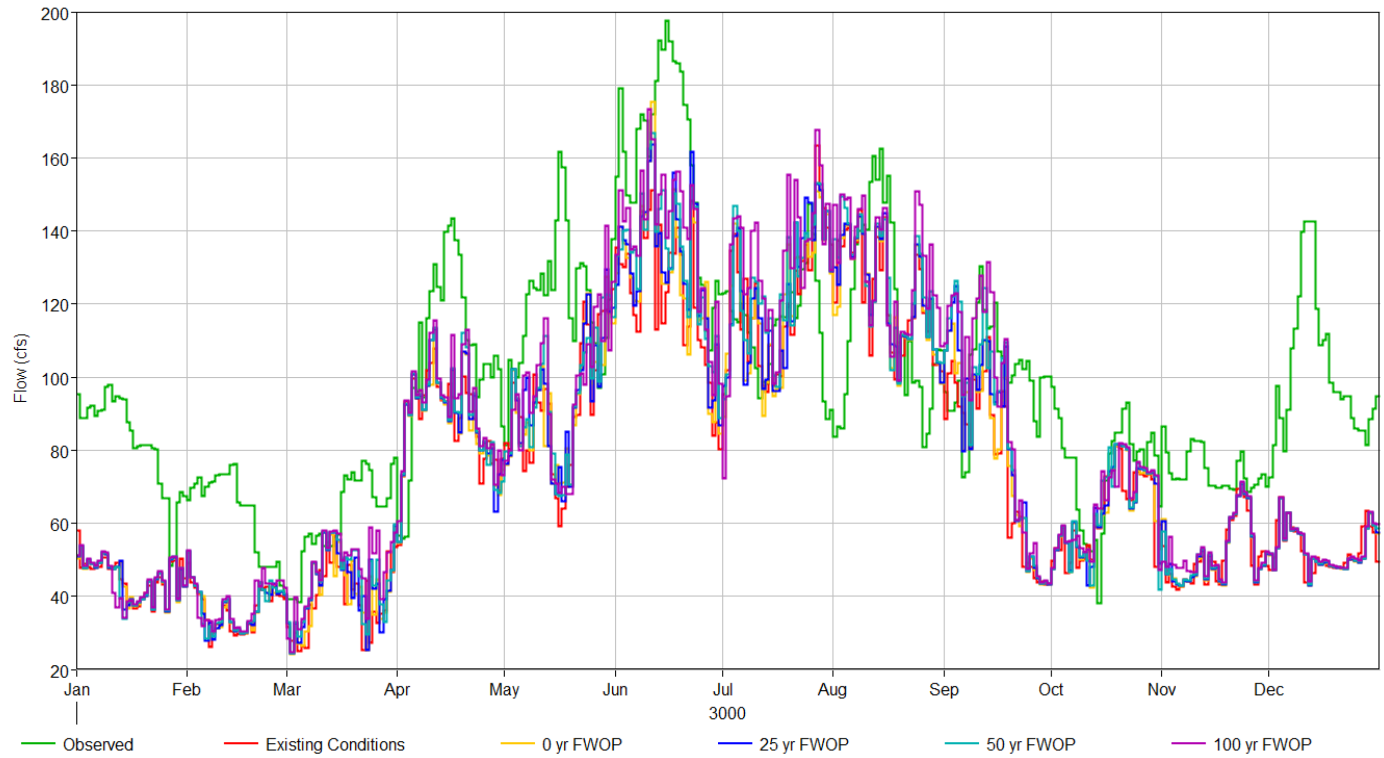


Figure 4-35. Daily average Wilson outflow for each set of data.

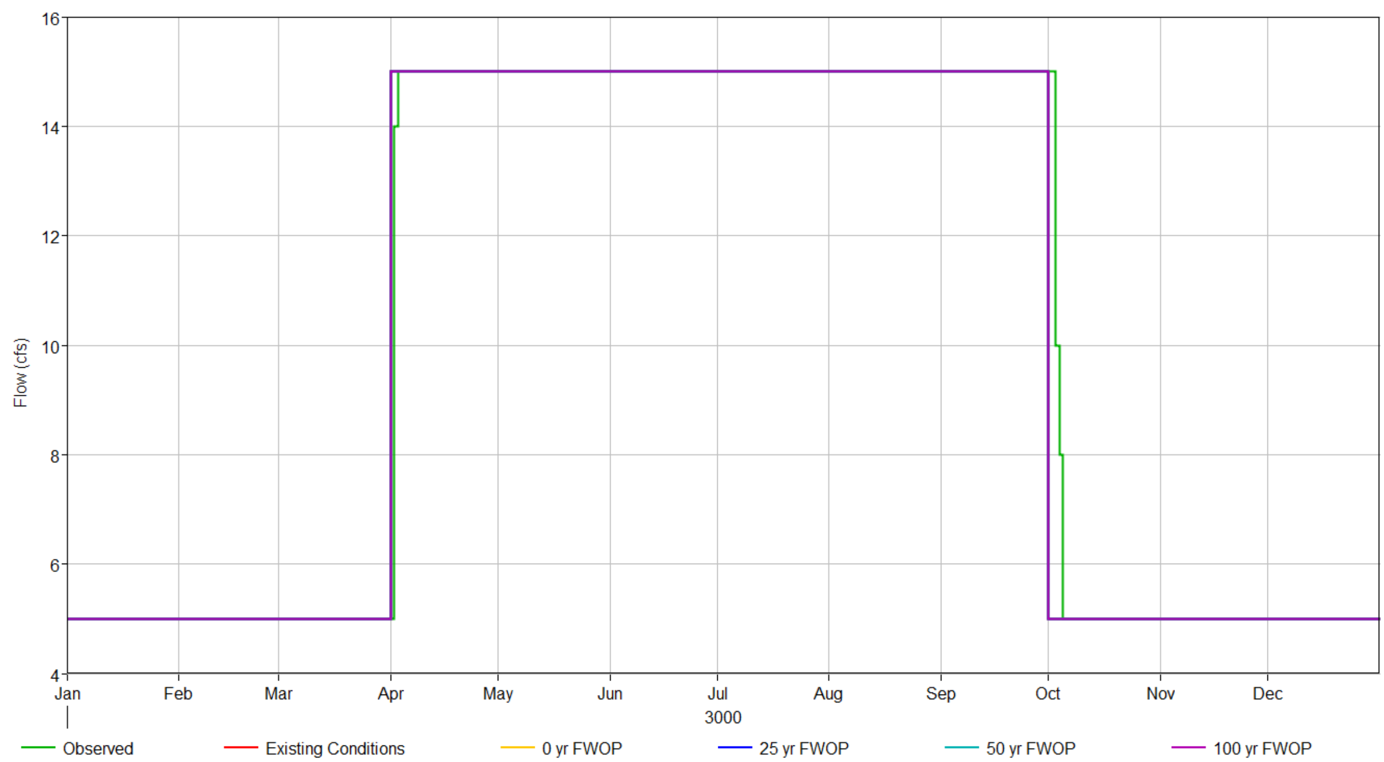


Figure 4-36. Daily median (50th Percentile) Wilson flow for each set of data.

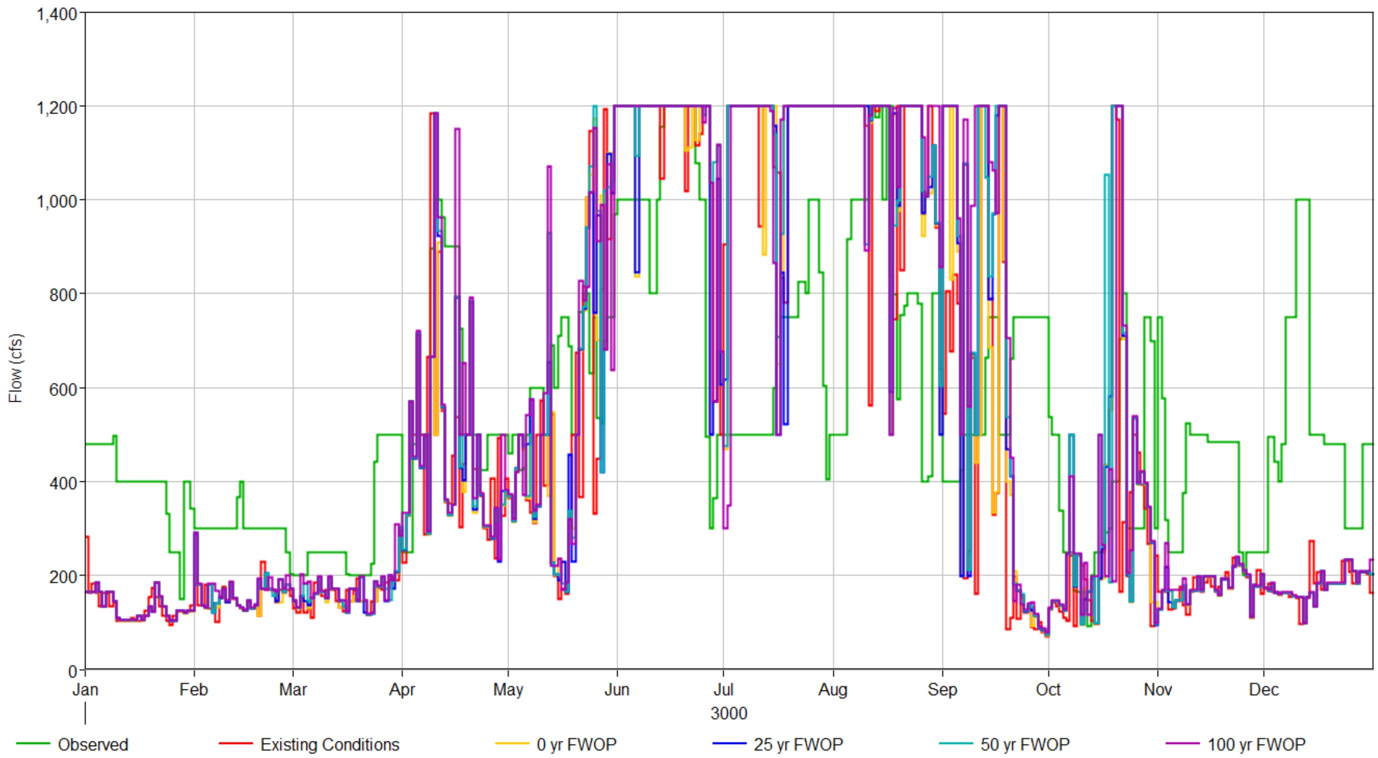


Figure 4-37. Daily 95th Percentile Wilson flow for each set of data.

The pool elevation duration is shown in Figure 4-38. It shows that the Wilson pool elevation does not drop as far into the multi-purpose pool in the later FWOP scenarios. This is probably because of reduced evaporation from smaller pool areas. Evaporation is a large driver of pool elevation in Wilson.

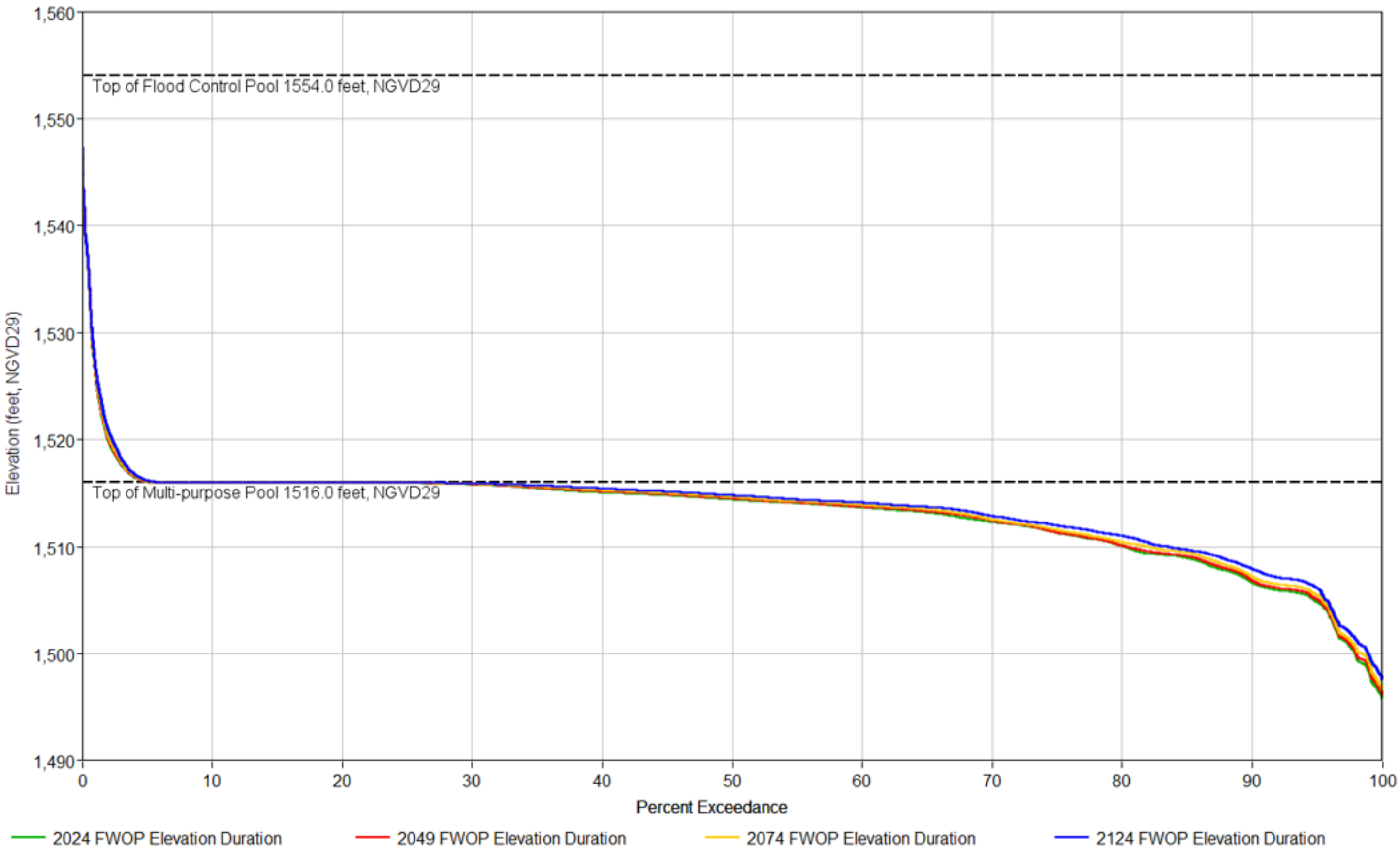


Figure 4-38. Wilson pool elevation duration for the four non-navigation FWOP scenarios.

4.1.3 Waconda

Waconda observed data is from first fill of May 1973 through November 2021. The Waconda family of curves are shown in Figure 4-39 to Figure 4-56. Navigation did not impact Waconda and the navigation FWOP scenarios were identical to the non-navigation. The median modeled pool elevation is near or a little below multi-purpose pool since that was used as the guide curve in HEC-ResSim. Median observed pool elevation is more variable with some pool raises and drawdowns as part of the routine operations. All the model scenarios 95th percentile pool elevations compare reasonably with the observed.

Average elevation time series were compared for each scenario. The observed data has a wider range and is consistently lower than the modeled pool elevations. The US Bureau of Reclamation (USBR) draws the reservoir down one foot in the winter, which was not accounted for in the model. Low flow releases are variable and discretionary, so they were difficult to capture in the model. As sediment accumulates with each additional FWOP scenario, the average modeled pool elevation increases slightly.

There are some significant differences between modeled and observed outflow data. The modeled average daily data contains a large flow spike in July that is from the modeled 1951 surcharge event. This event was before the observed data started. In the same data set, the observed releases are higher in the winter months due to seasonal drawdowns. The median outflow data varies some between model scenarios, with slightly increasing releases for each subsequent FWOP scenario. The median modeled outflow is a consistent low flow value for most of the second half of the year, while the observed doesn’t dip down until around October to a slightly larger low flow. Except for winter months, the 95th percentile observed data was more variable than the modeled.

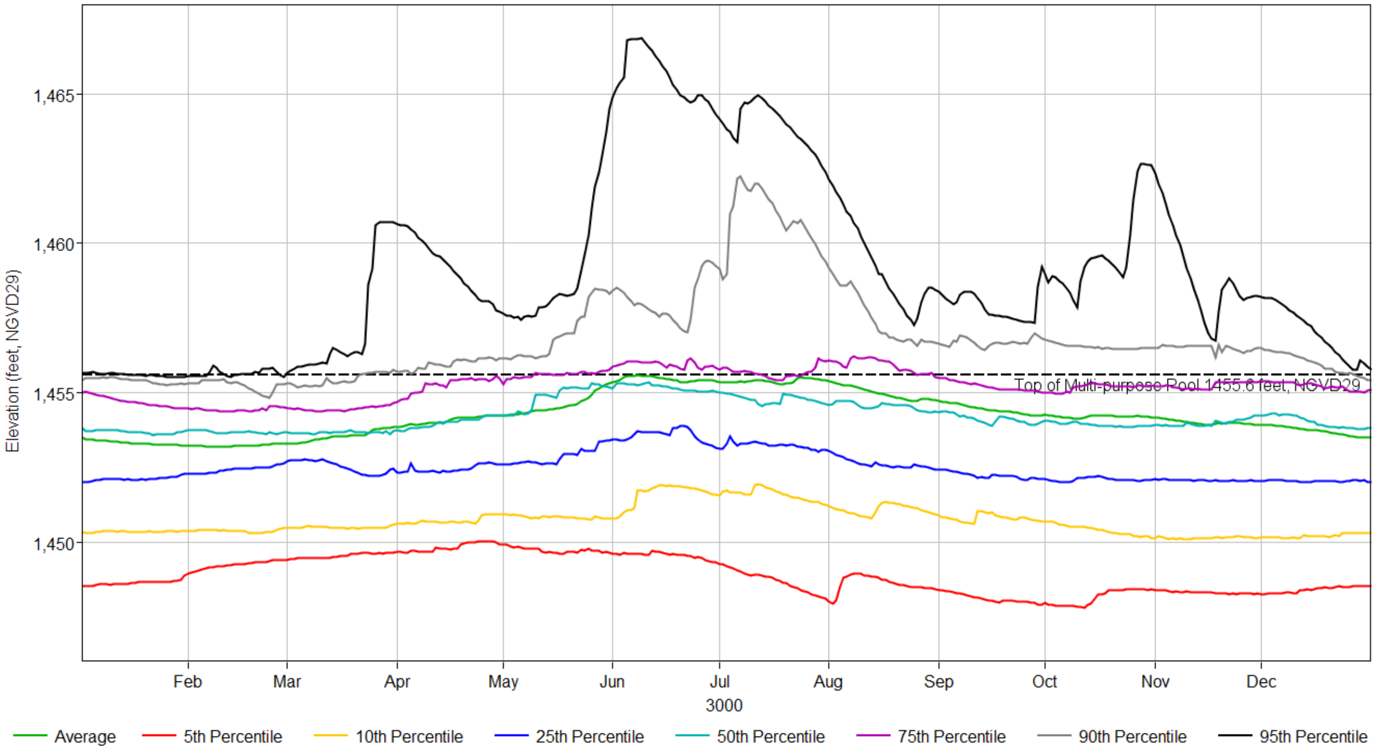


Figure 4-39. Waconda pool elevation statistics for the observed data from first fill May 1973 to Dec 2021.

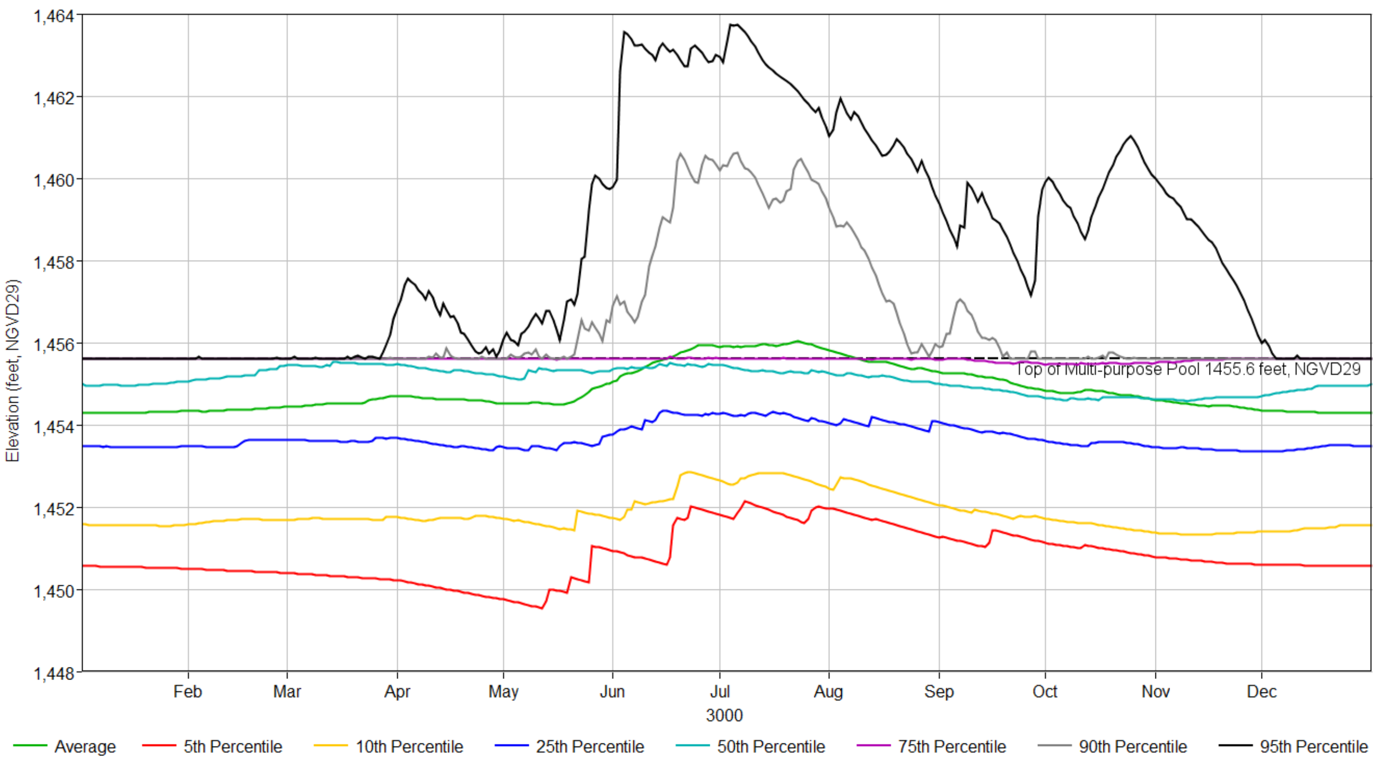


Figure 4-40. Waconda pool elevation statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

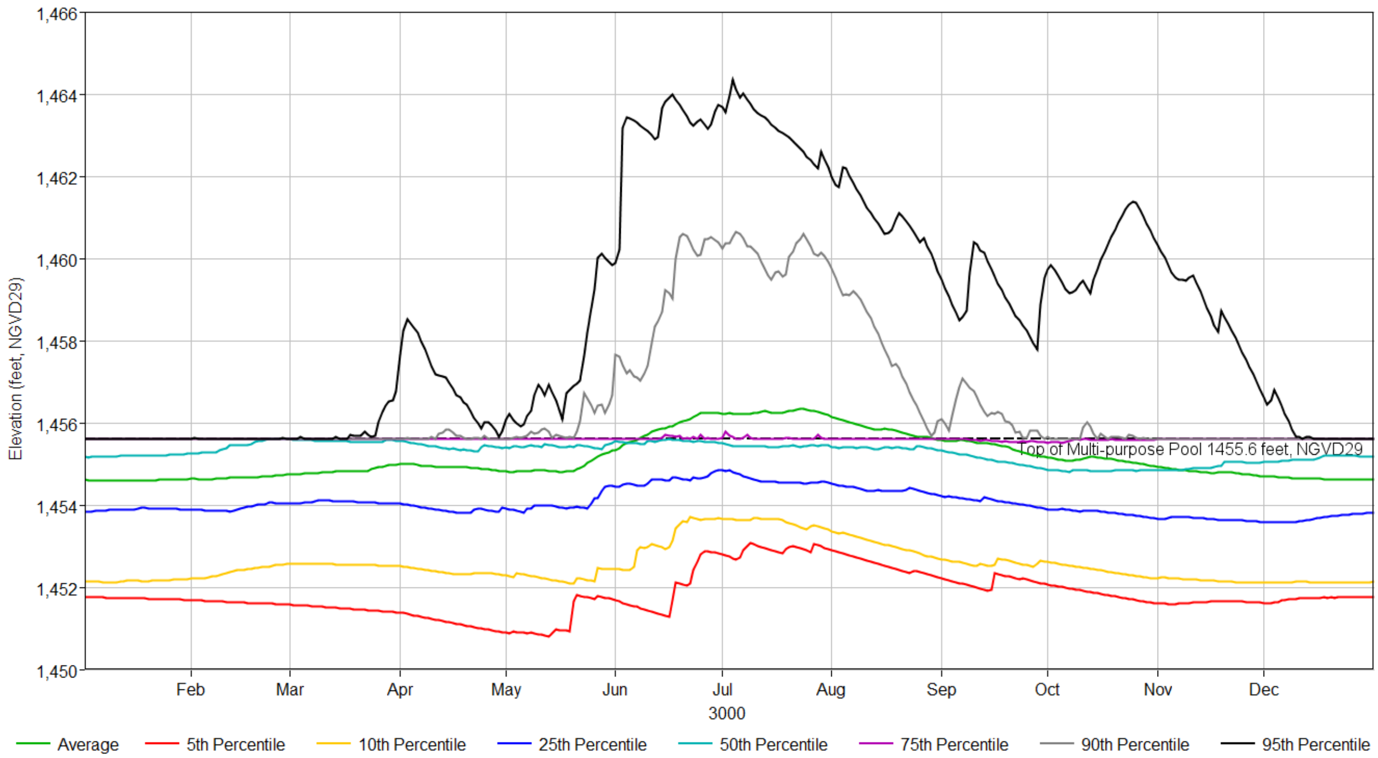


Figure 4-41. Waconda pool elevation statistics for the 100-year FWOP at 2024 sediment conditions.

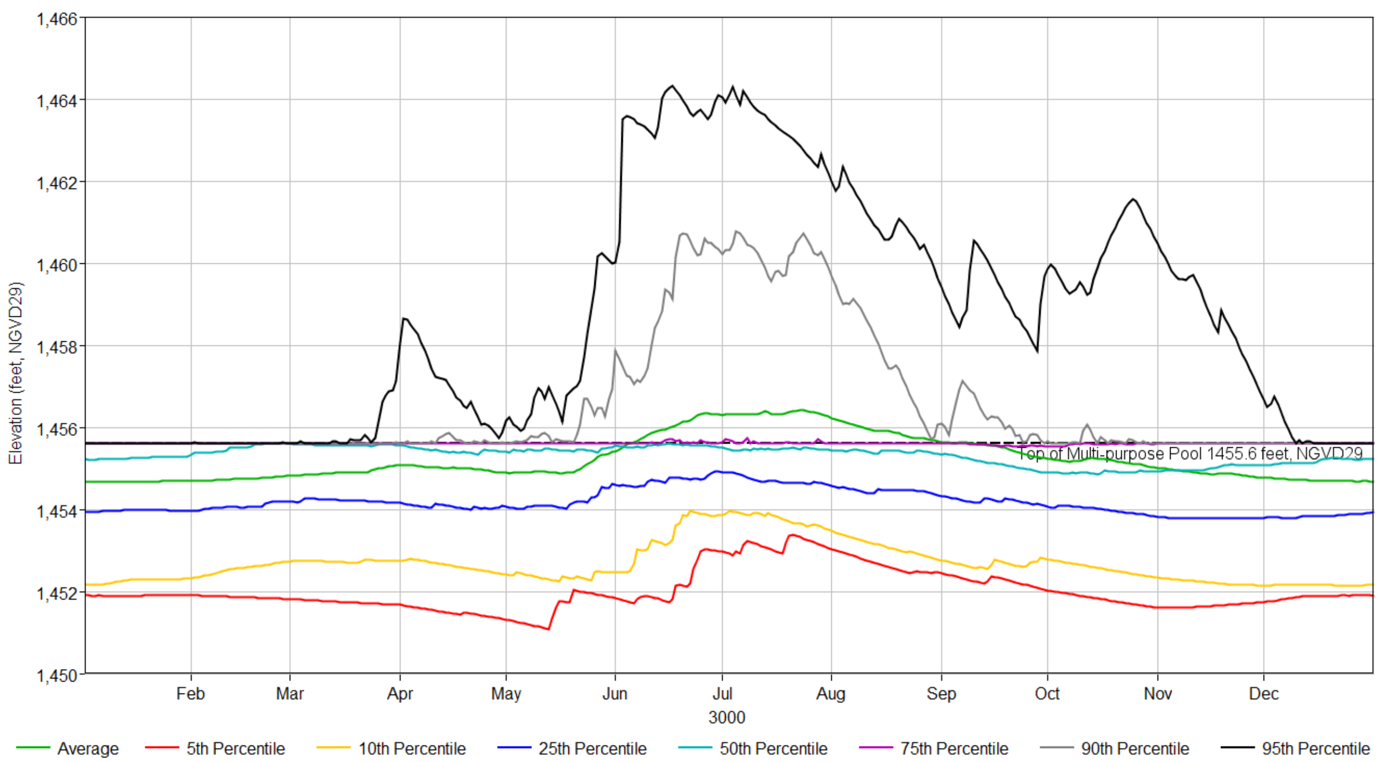


Figure 4-42. Waconda pool elevation statistics for the 100-year FWOP at 2049 sediment conditions.

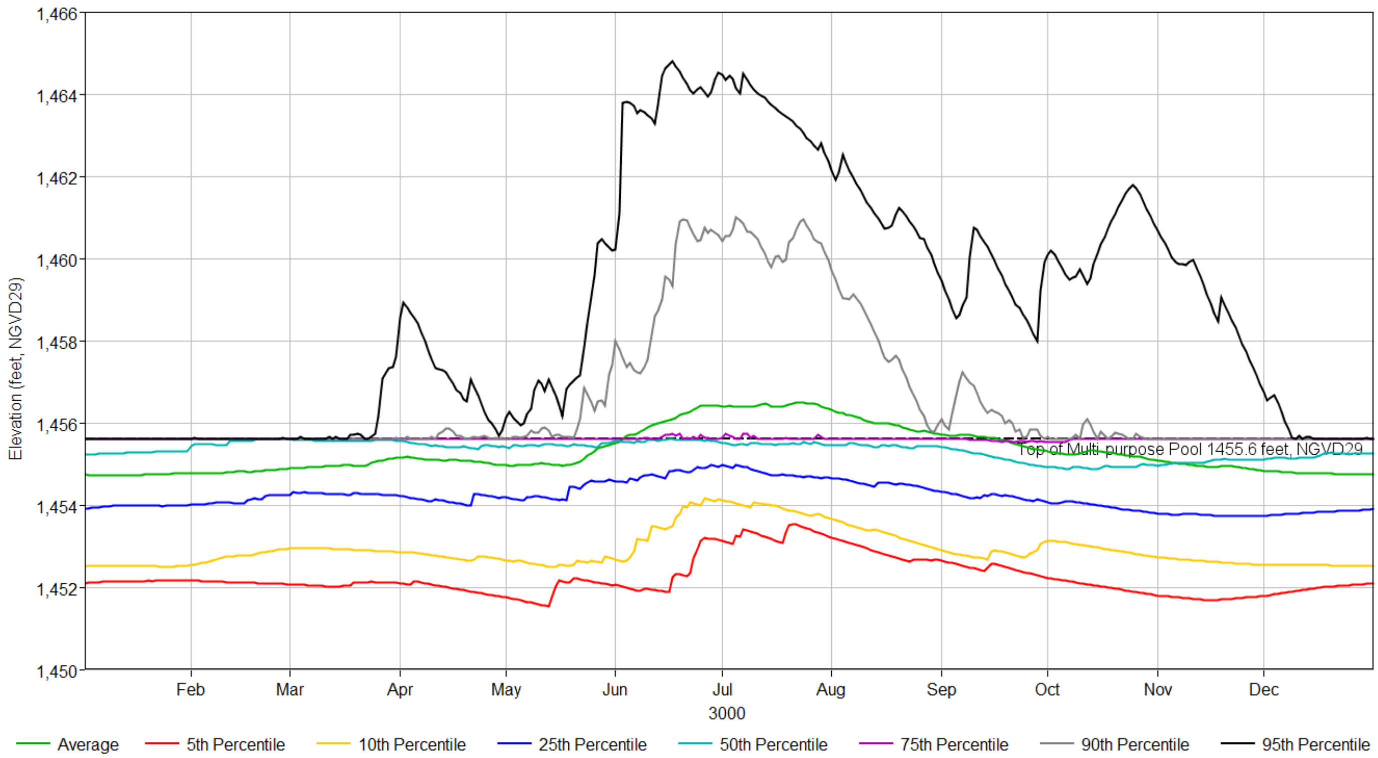


Figure 4-43. Waconda pool elevation statistics for the 100-year FWOP at 2074 sediment conditions.

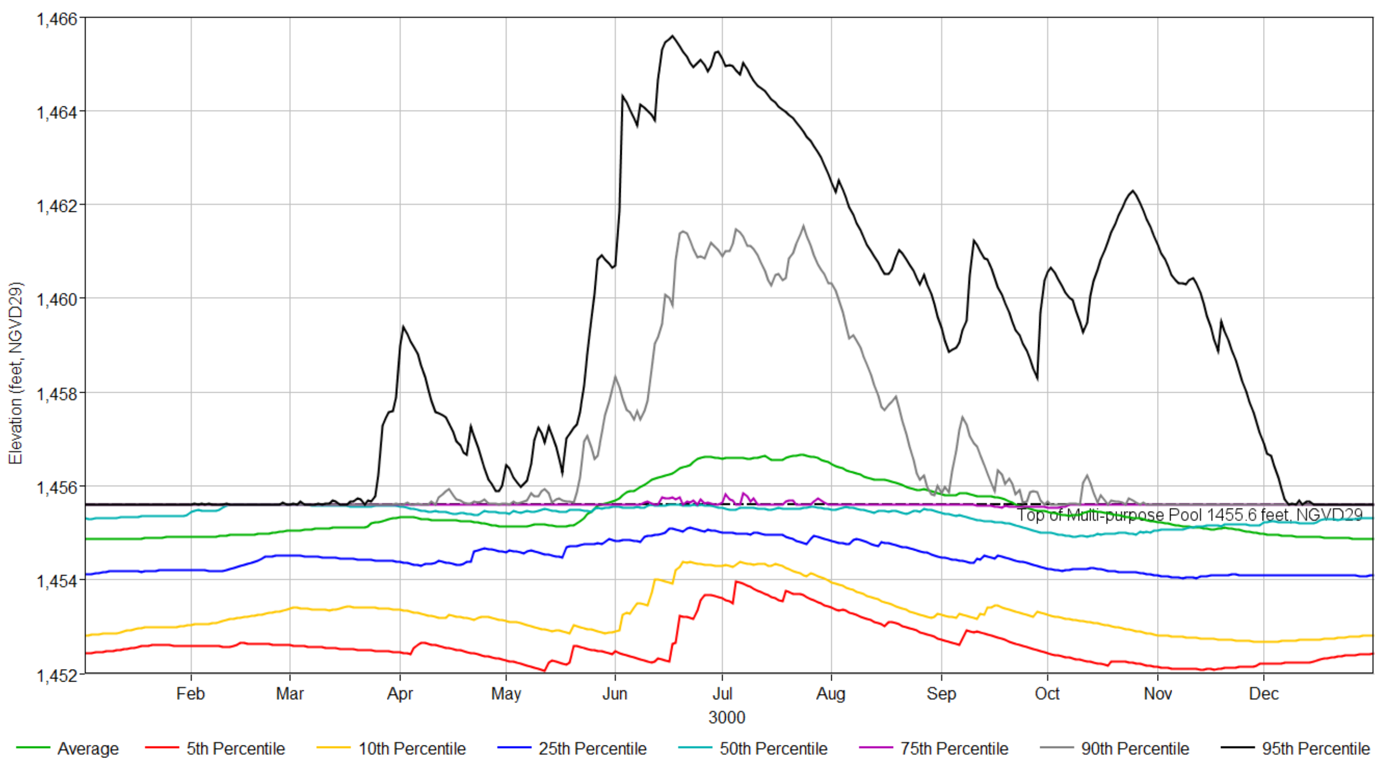


Figure 4-44. Waconda pool elevation statistics for the 100-year FWOP at 2124 sediment conditions.

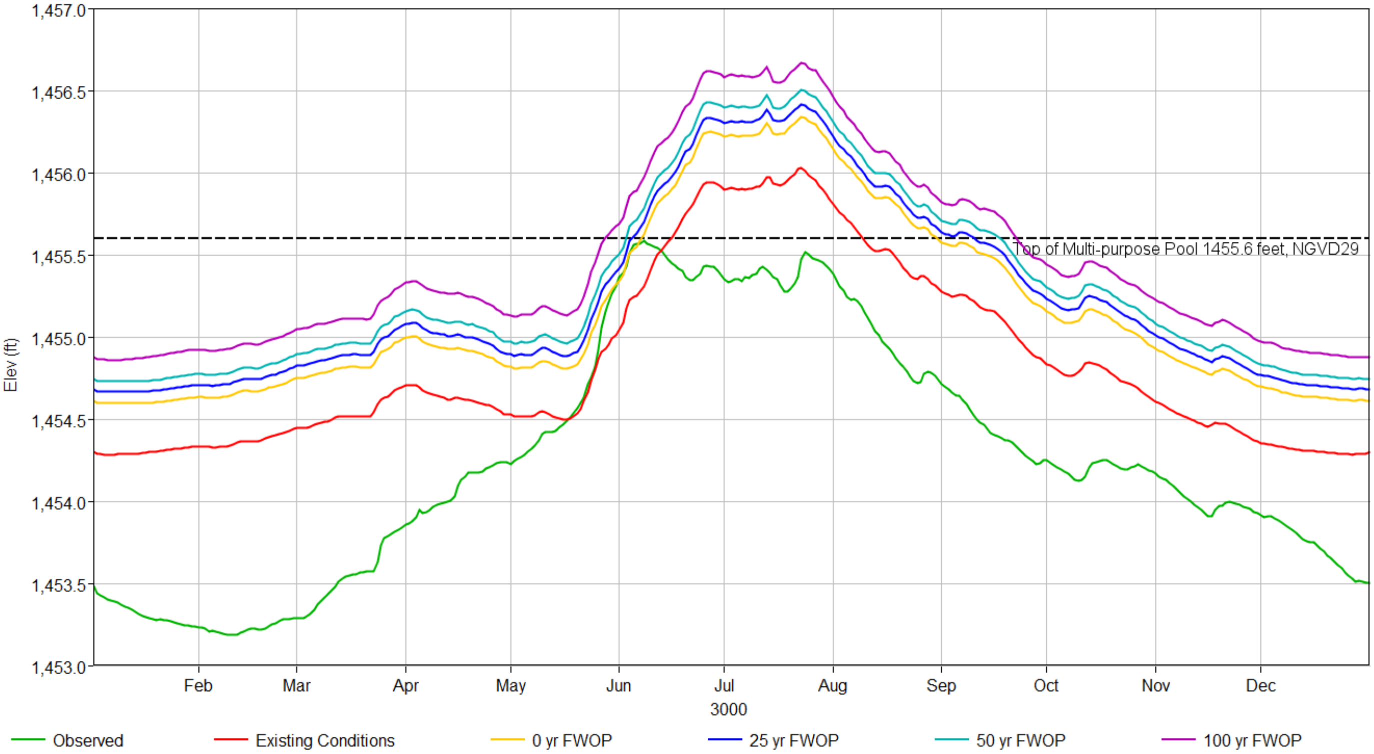


Figure 4-45. Daily average Waconda pool elevation for each set of data.

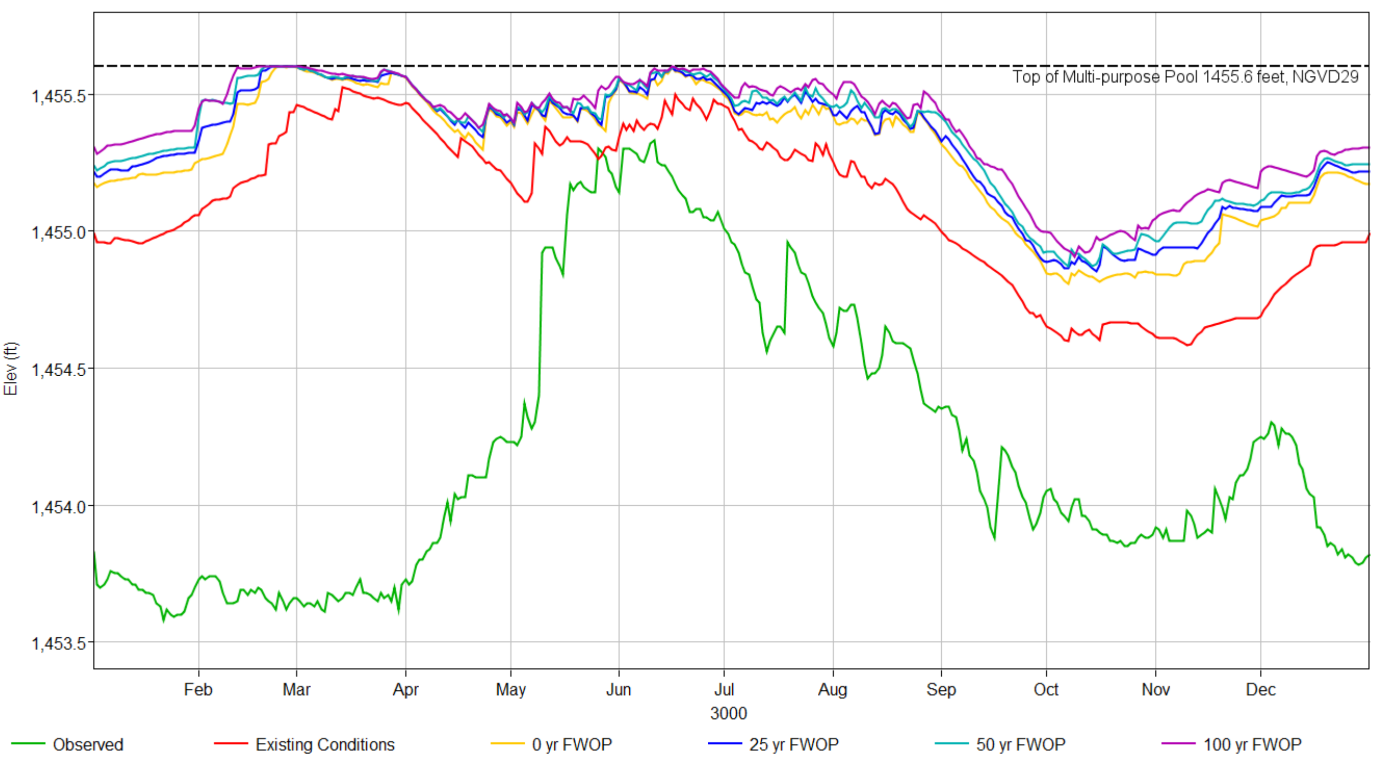


Figure 4-46. Daily median (50th Percentile) Waconda pool elevation for each set of data.

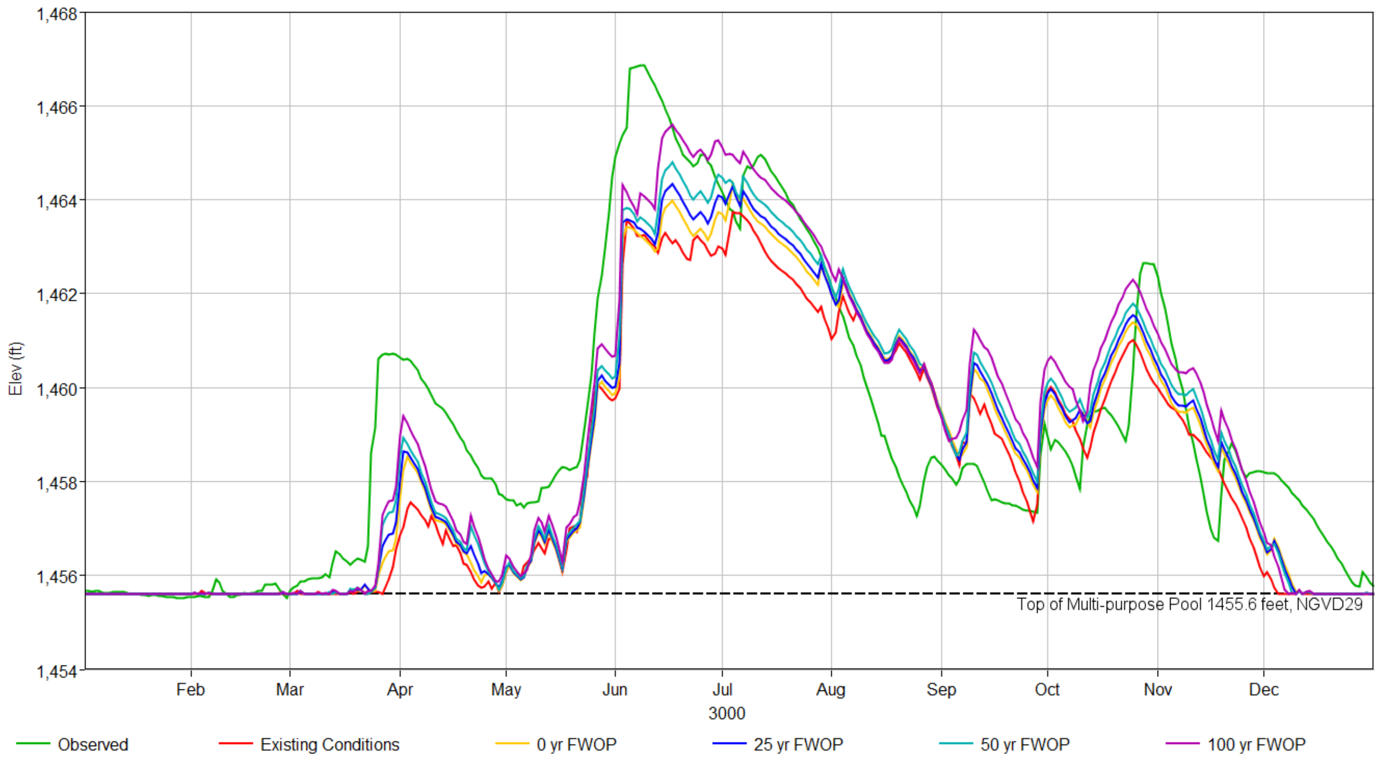


Figure 4-47. Daily 95th Percentile Waconda pool elevation for each set of data.

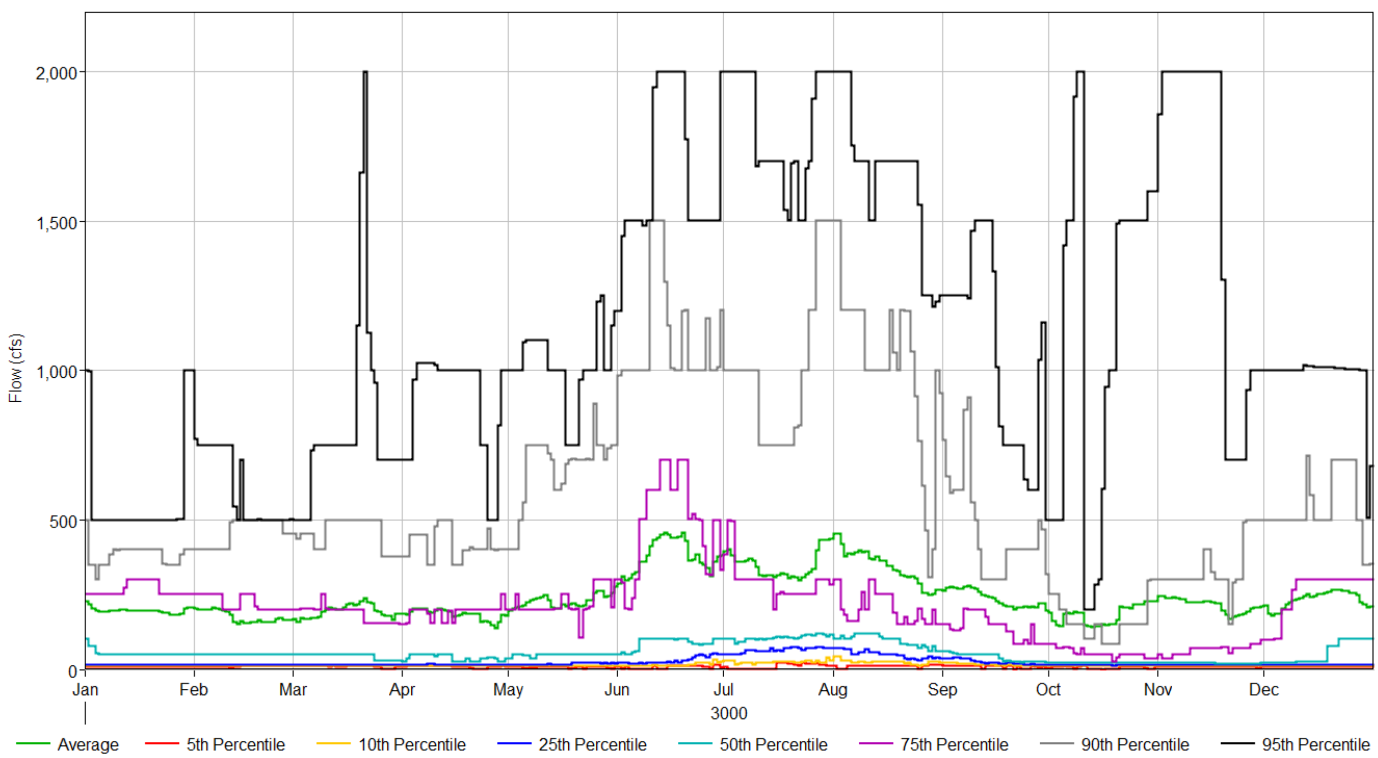


Figure 4-48. Waconda outflow statistics for the observed data from first fill Oct 1967 to Dec 2021.

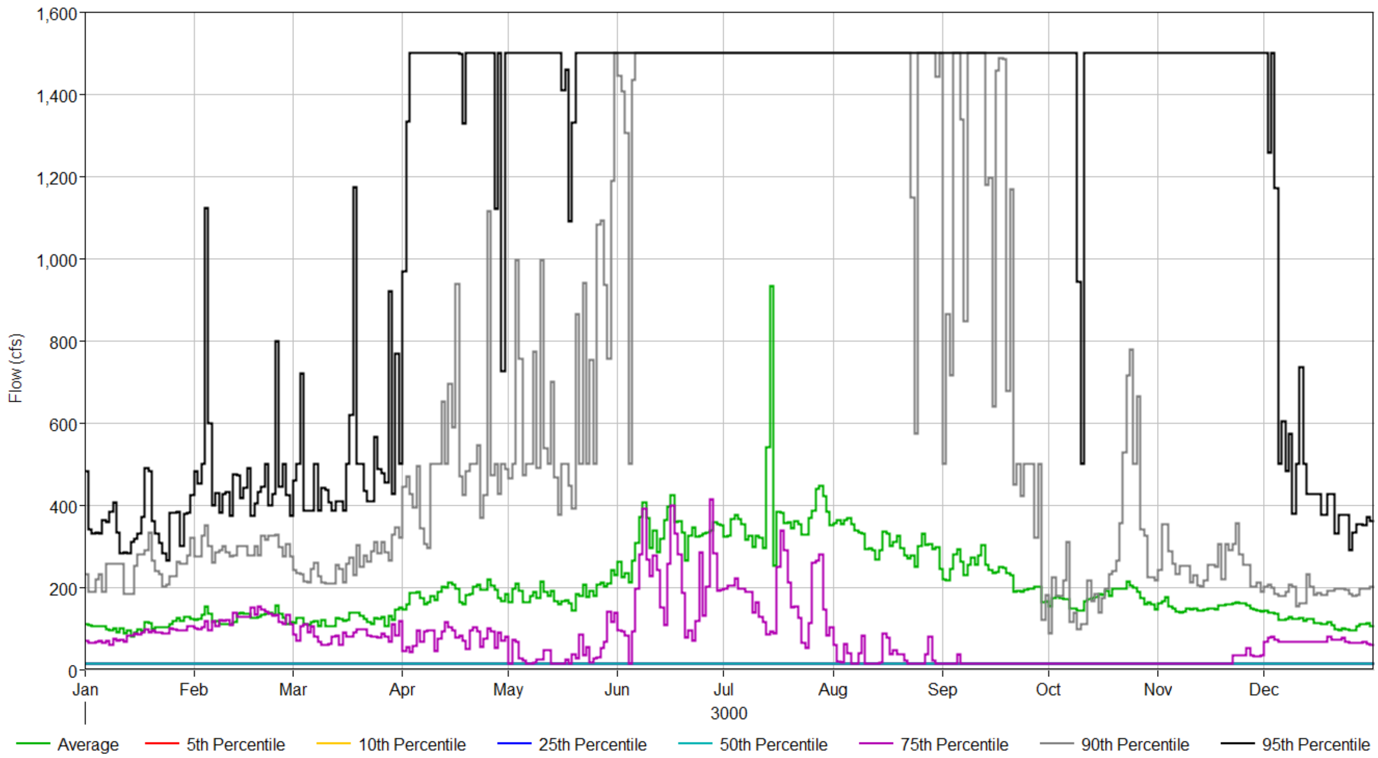


Figure 4-49. Waconda outflow statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

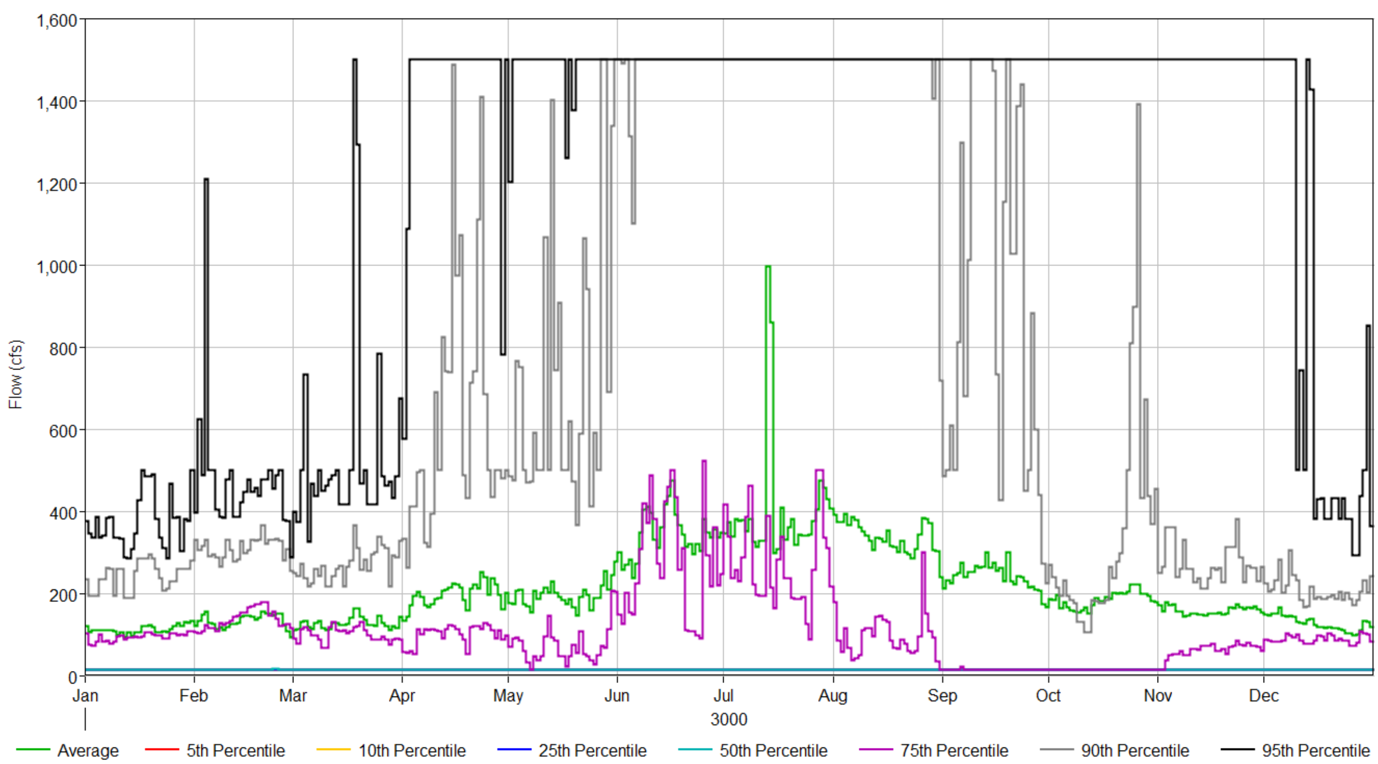


Figure 4-50. Waconda outflow statistics for the 100-year FWOP at 2024 sediment conditions.

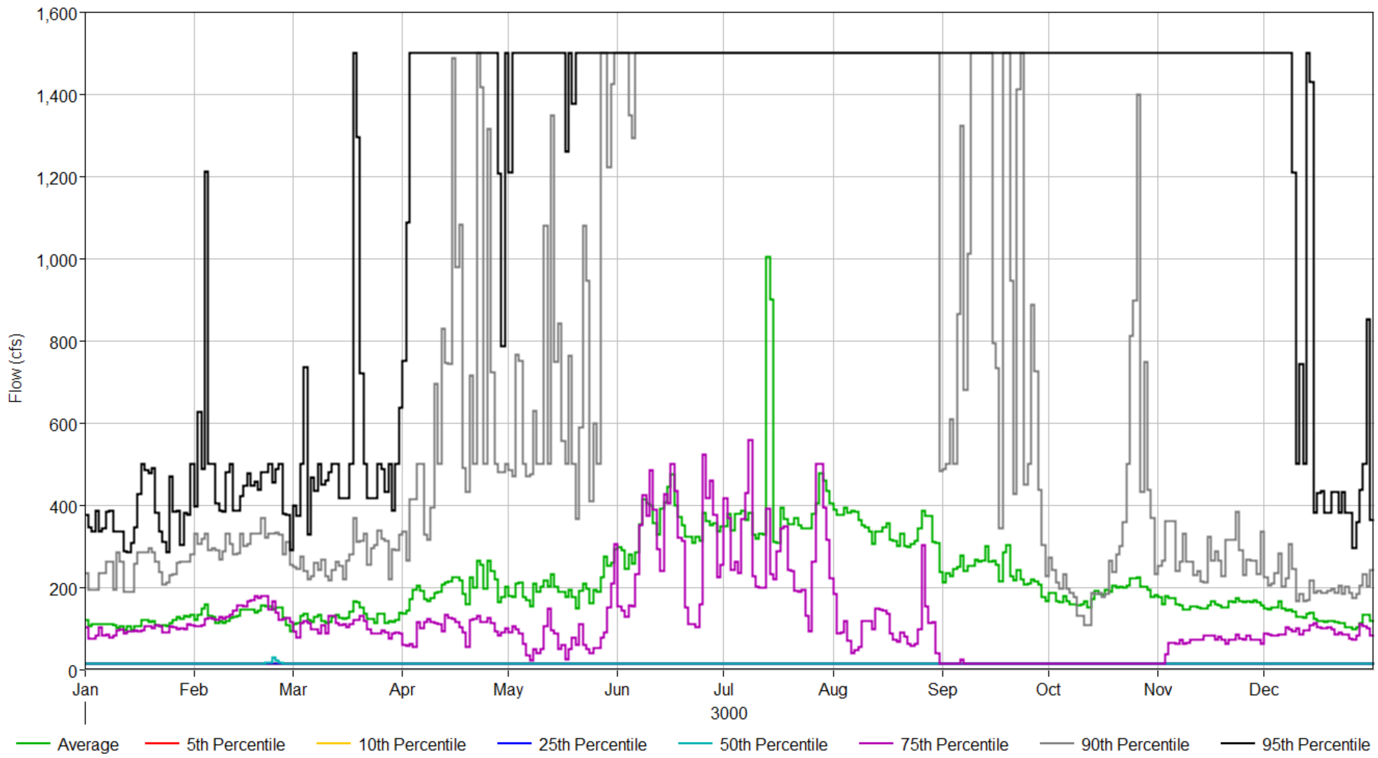


Figure 4-51. Waconda outflow statistics for the 100-year FWOP at 2049 sediment conditions.

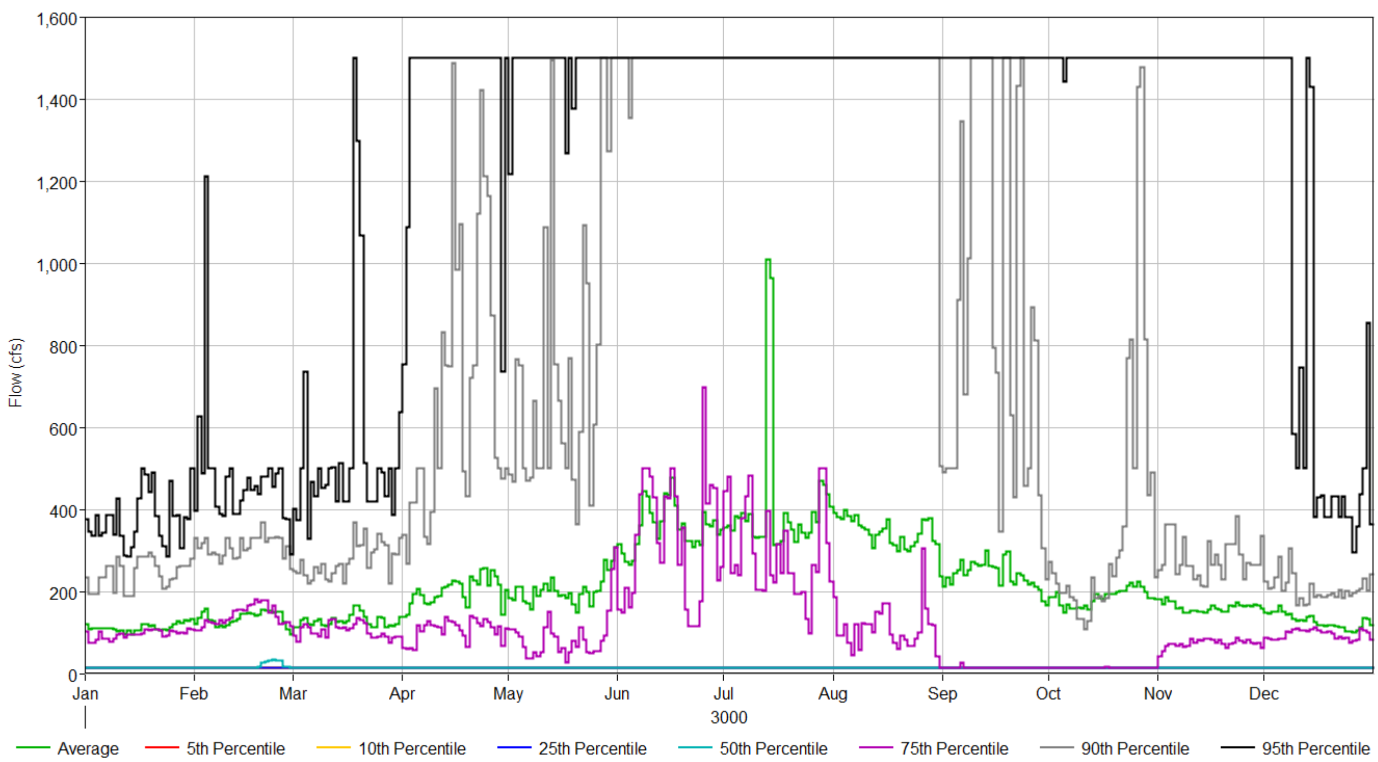


Figure 4-52. Waconda outflow statistics for the 100-year FWOP at 2074 sediment conditions.

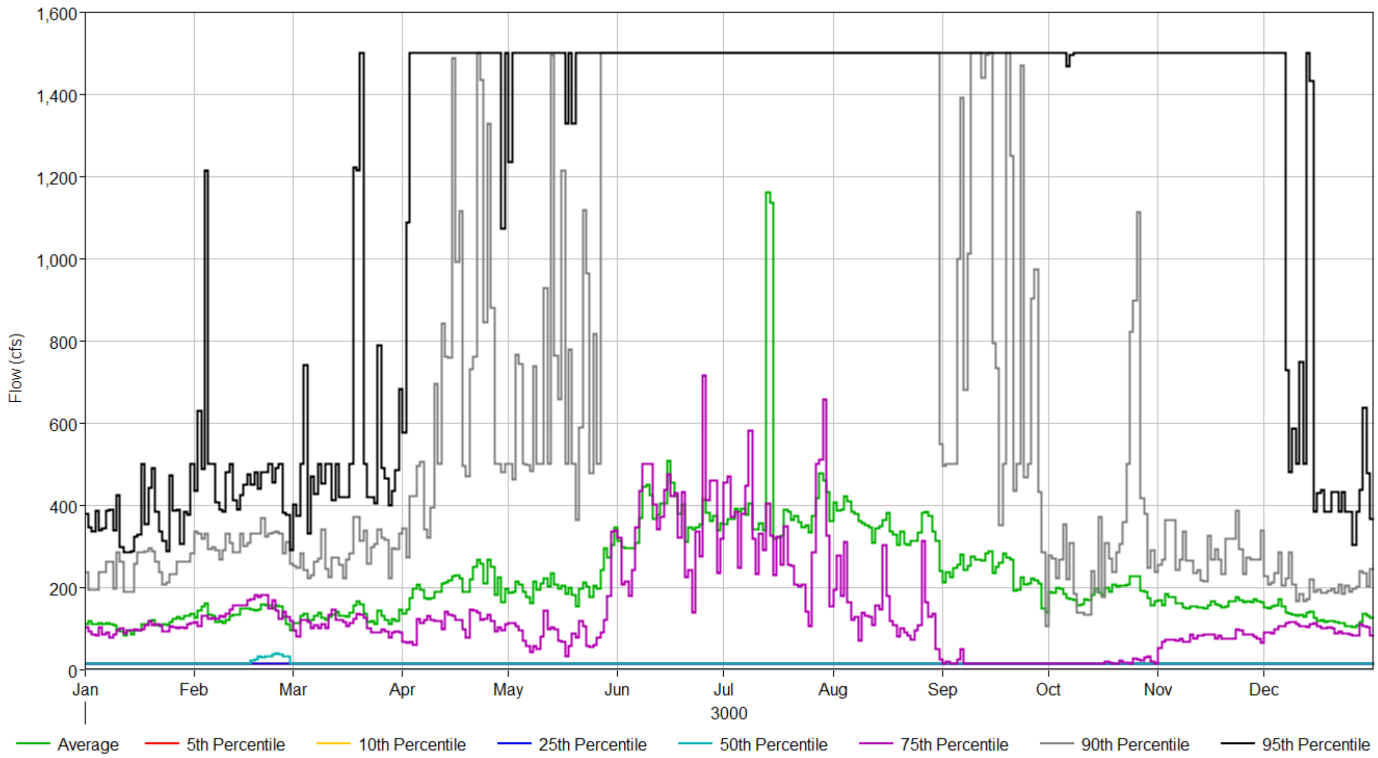


Figure 4-53. Waconda outflow statistics for the 100-year FWOP at 2124 sediment conditions.

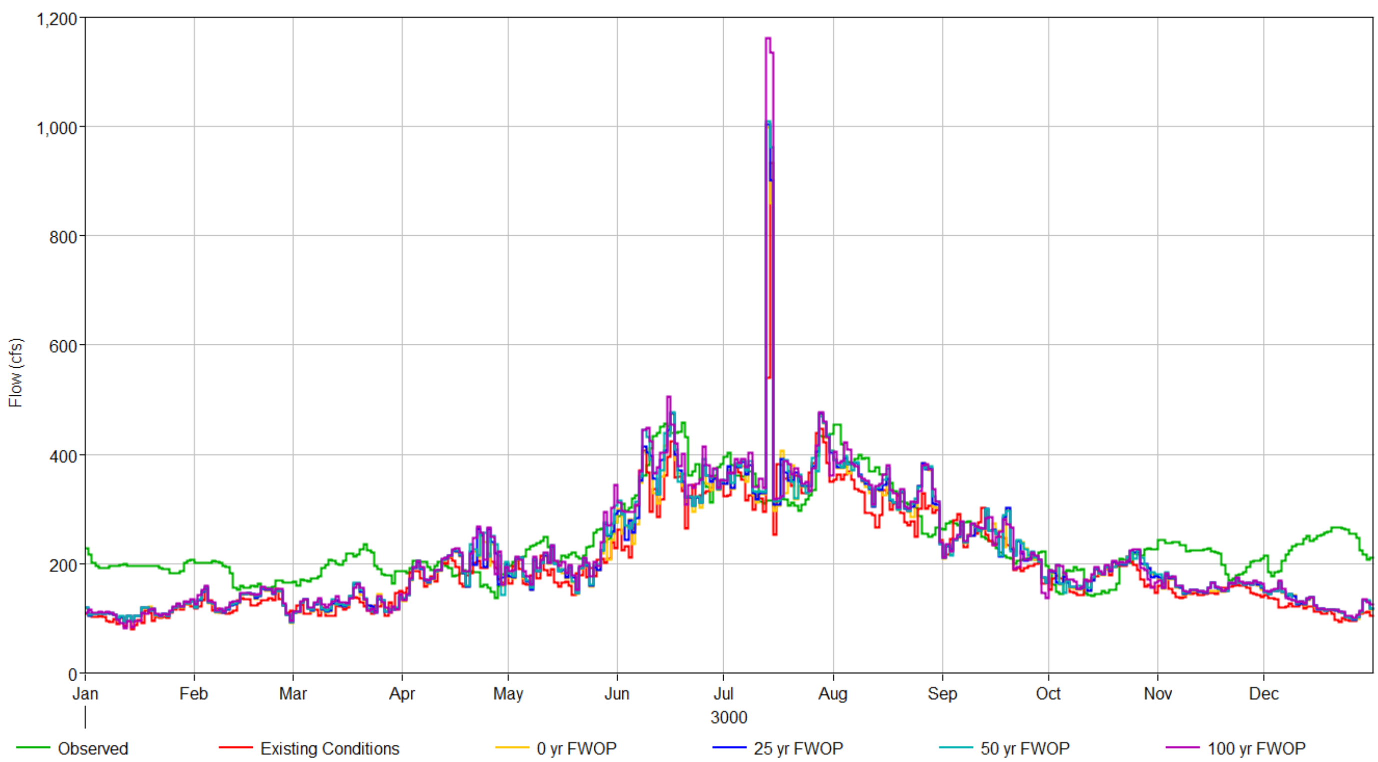


Figure 4-54. Daily average Waconda outflow for each set of data.

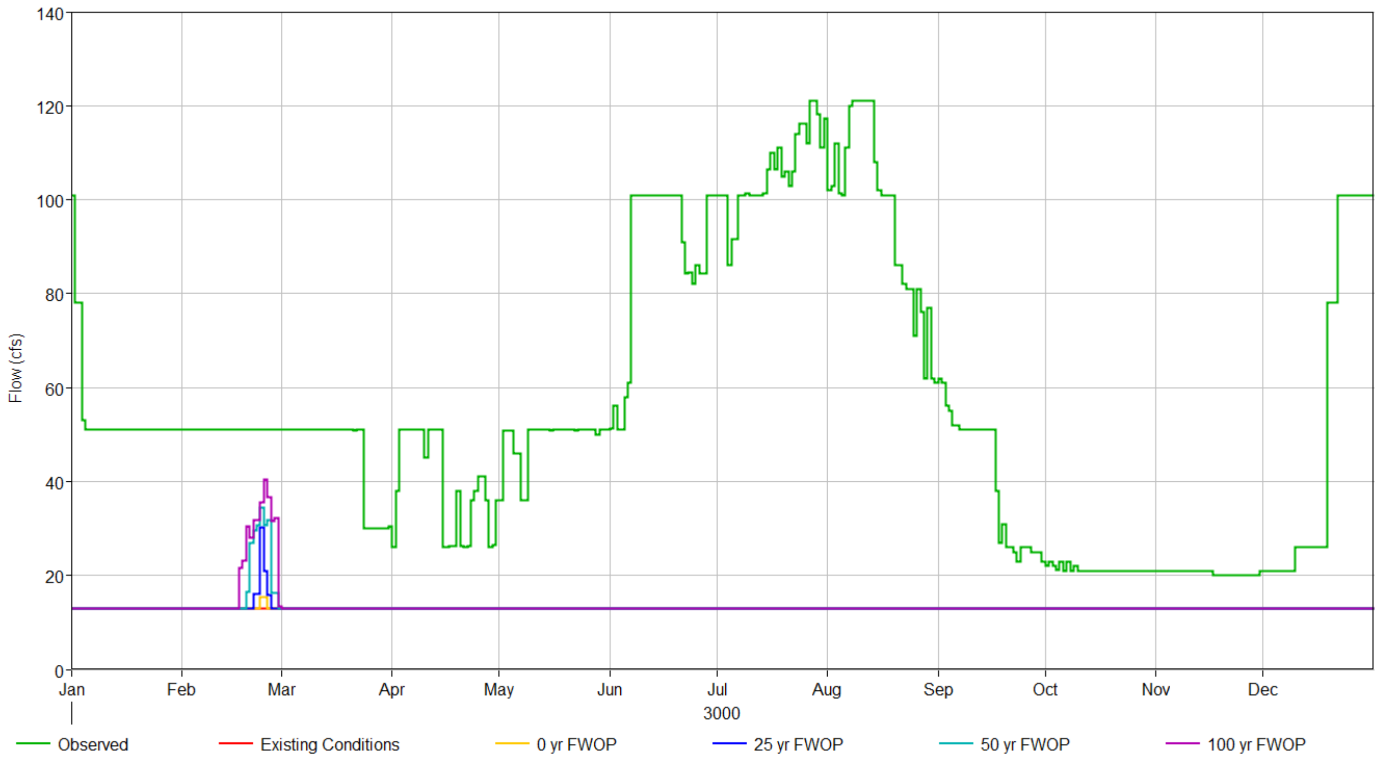


Figure 4-55. Daily median (50th Percentile) Waconda flow for each set of data.

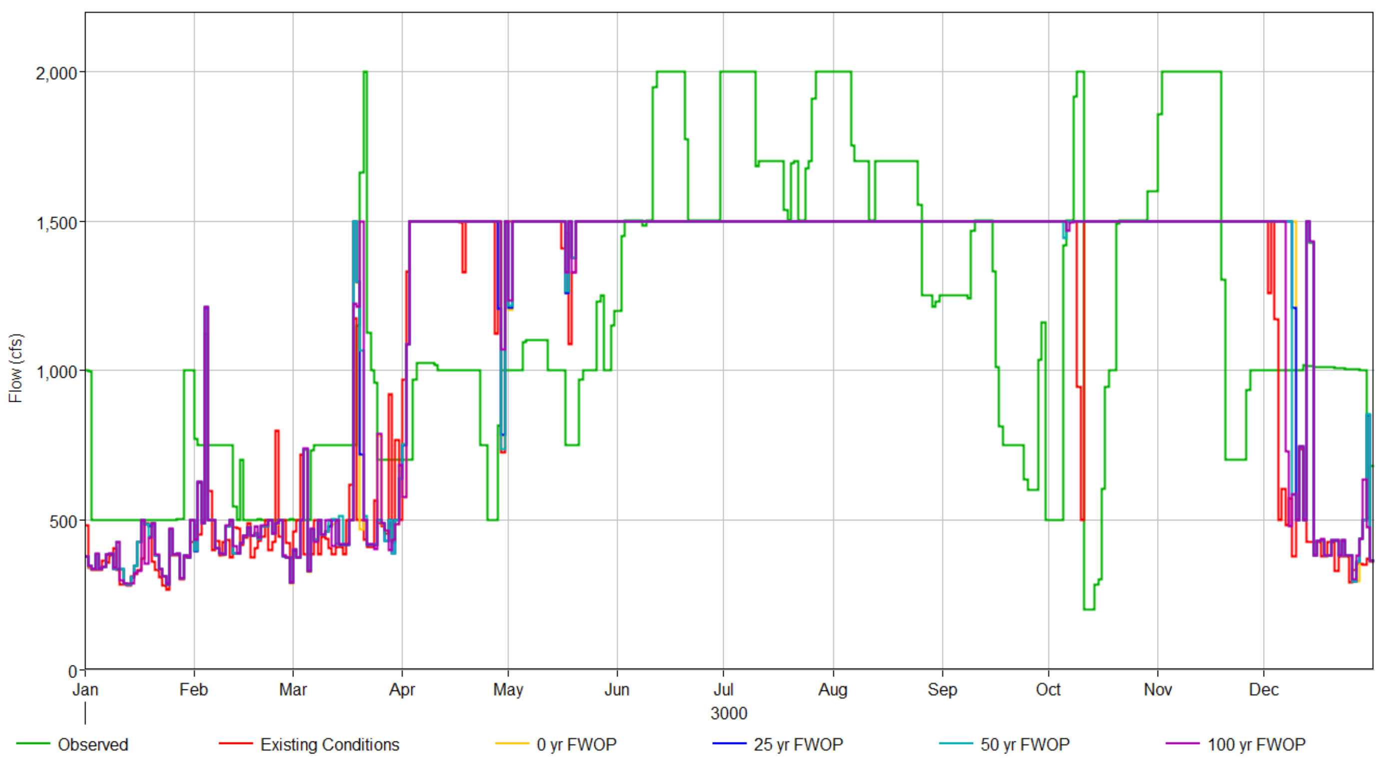


Figure 4-56. Daily 95th Percentile Waconda flow for each set of data.

The pool elevation duration is shown in Figure 4-57. It shows that the Waconda pool elevation does not drop as far into the multi-purpose pool in the later FWOP scenarios. This is probably because of reduced evaporation from smaller pool areas. Evaporation is a large driver of pool elevation in Waconda.

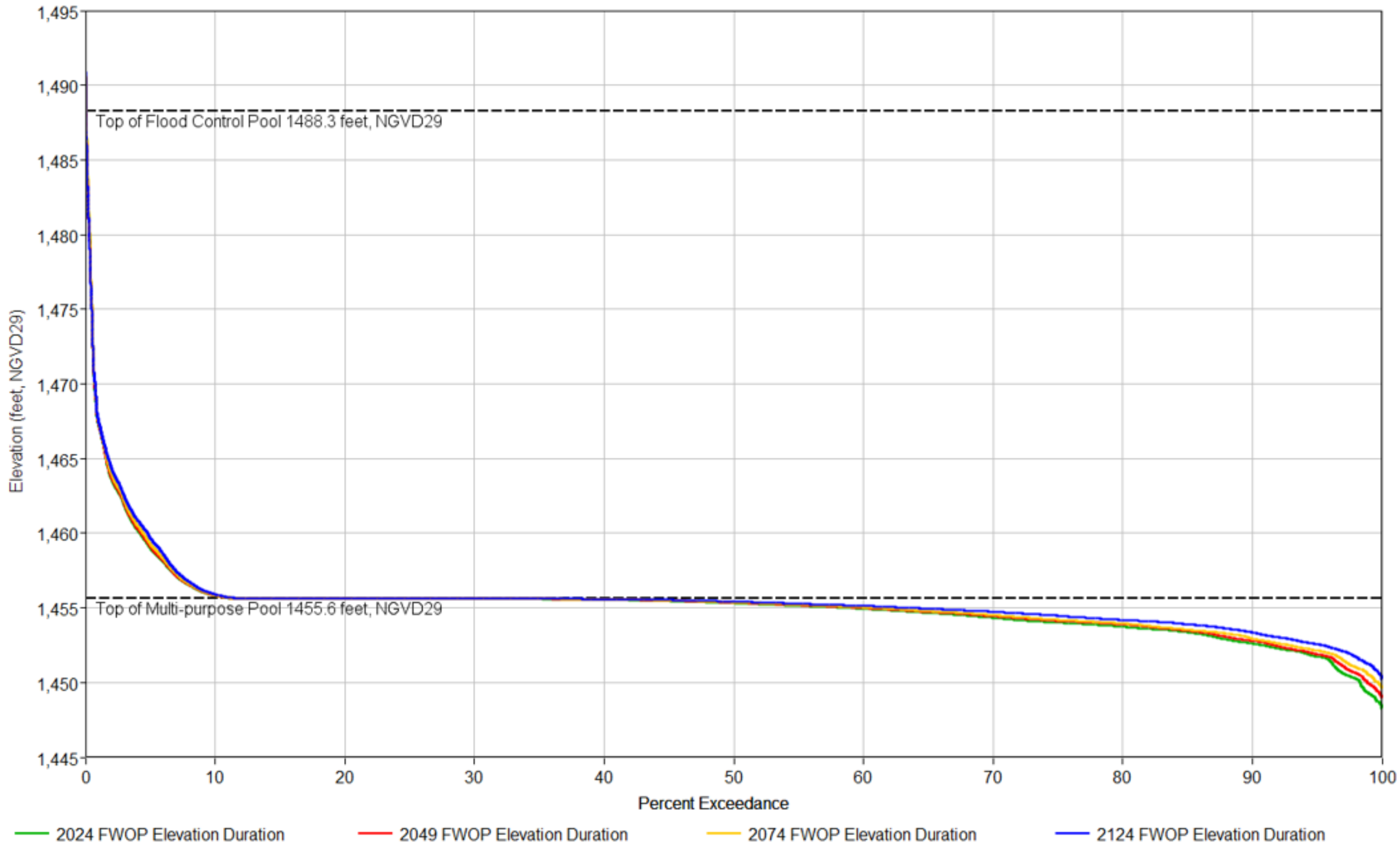


Figure 4-57. Waconda pool elevation duration for the four non-navigation FWOP scenarios.

4.1.4 Milford

Milford observed data is from first fill of July 1967 through November 2021. The Milford families of curves are shown in Figure 4-58 to Figure 4-75. The median modeled pool elevation stays near the top of the multi-purpose pool since that was used as the guide curve in HEC-ResSim. Median observed pool elevation is more variable with some pool raises and drawdowns as part of the routine operations. All the model scenarios have high pool elevations in 95th percentile data set that are well above the observed from March to December due to variations in real-time operation versus the perfect foresight of modeled operations. Some years required constrained releases in flood control operations for the Missouri River at Waverly. The observed data set does not have the extended high pool elevation because deviations were utilized in the real-time operations.

Average elevation time series were compared for each scenario with observed reasonably matching modeled. Milford does not loose significant storage over the 100-years of the FWOP. However, with each subsequent FWOP scenario, the average modeled pool elevation decreases as Milford releases more to meet the water quality targets. Tuttle Creek storage diminishes in each subsequent FWOP scenario, and it is less able to support water quality flows putting a greater burden on Milford.

There are some notable differences between modeled and observed outflow data. The average daily data matches well except for the summer months, when the observed is lower. For the median daily flow comparison, the modeled outflow is generally higher in the cold months and lower in the warm months than the modeled, except for a high observed peak in December when the winter drawdown occurs. The daily 95th percentile outflow generally matches, but the modeled is higher in the warm months, and has a large peak above observed in December. These differences could be due historical operational decisions based on uncertainty about rain, concerns in the downstream channel, or other factors previously noted. Each FWOP scenario has similar outflow trends.

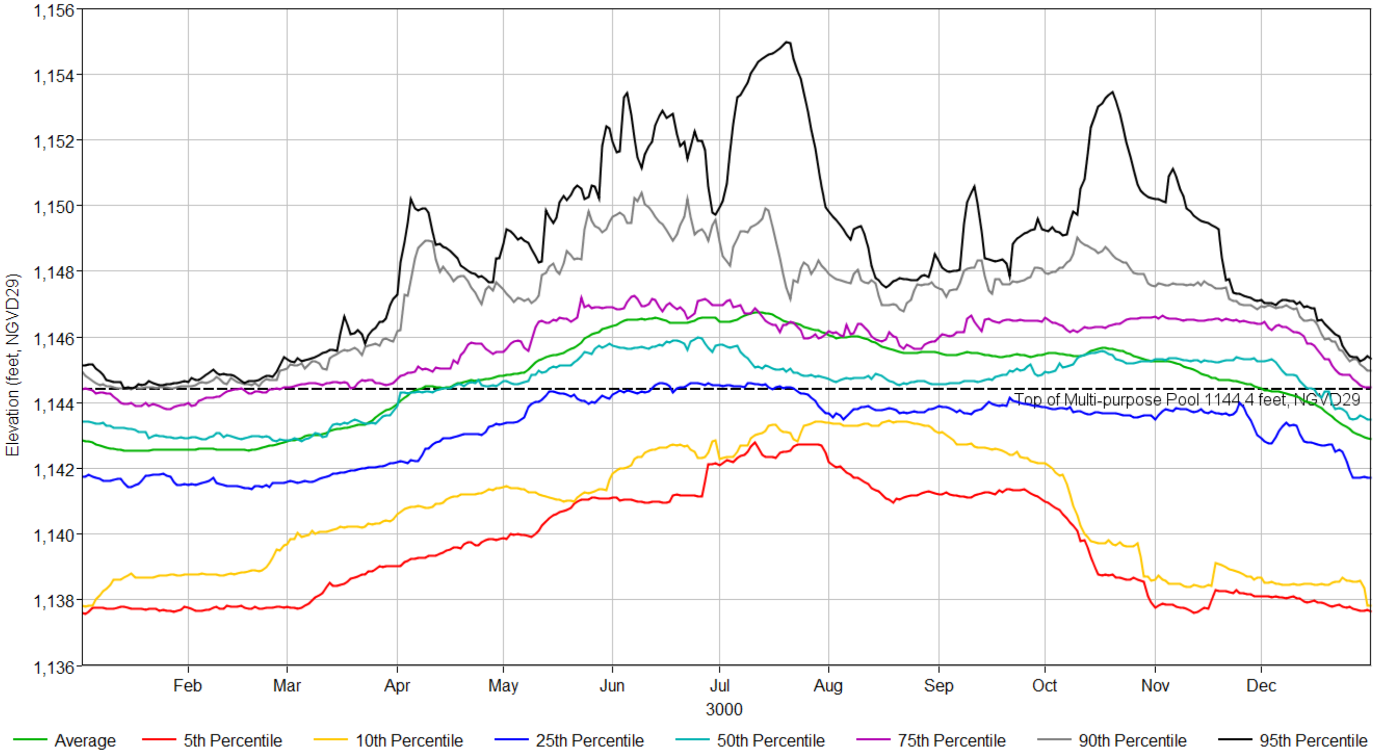


Figure 4-58. Milford pool elevation statistics for the observed data from first fill Jul 1967 to Dec 2021.

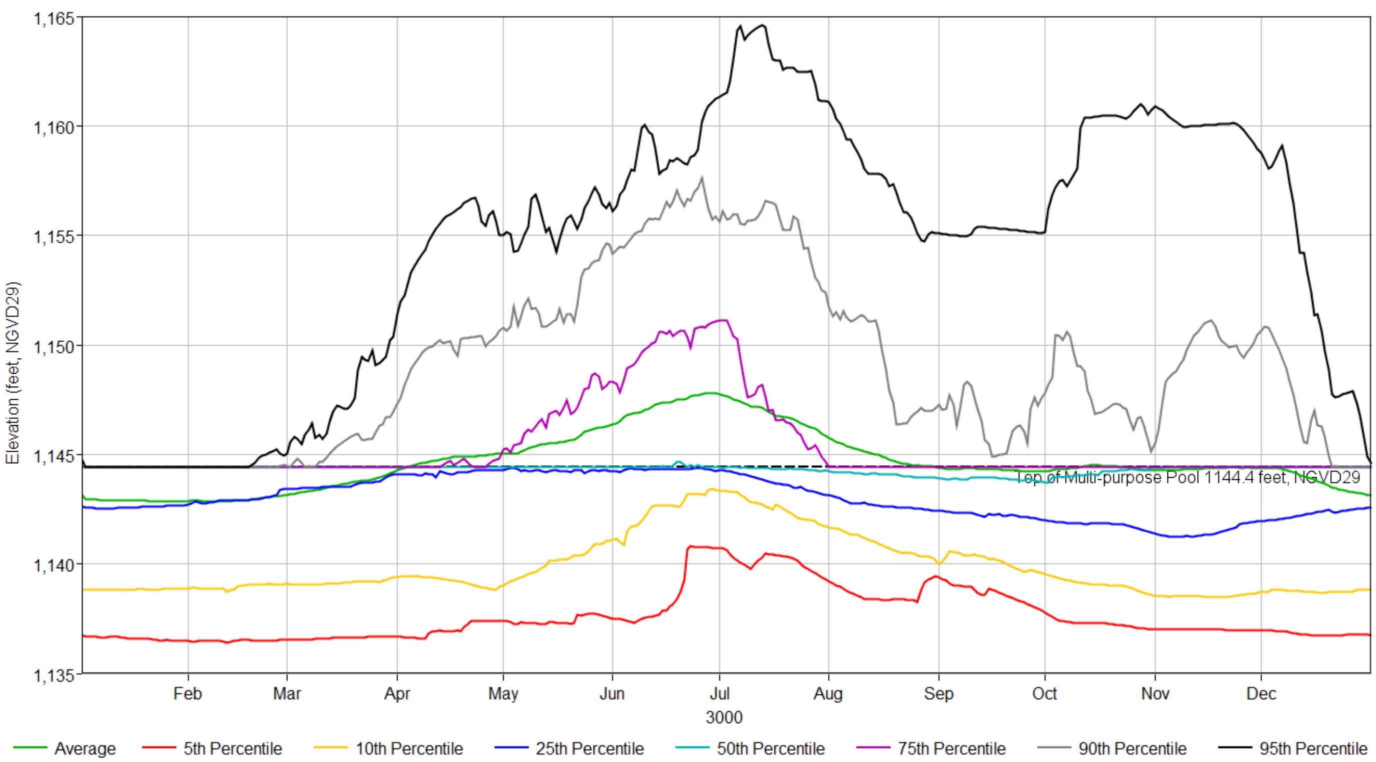


Figure 4-59. Milford pool elevation statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

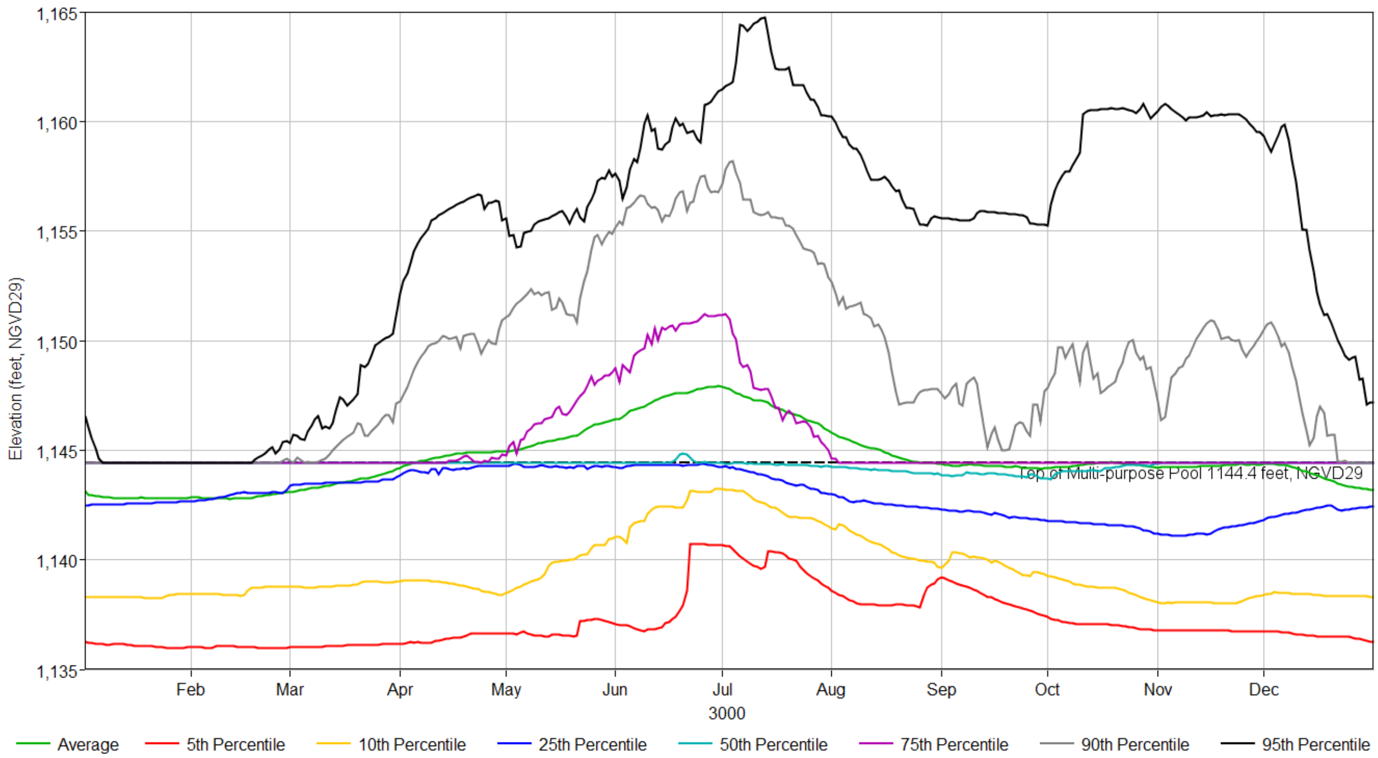


Figure 4-60. Milford pool elevation statistics for the 100-year FWOP at 2024 sediment conditions.

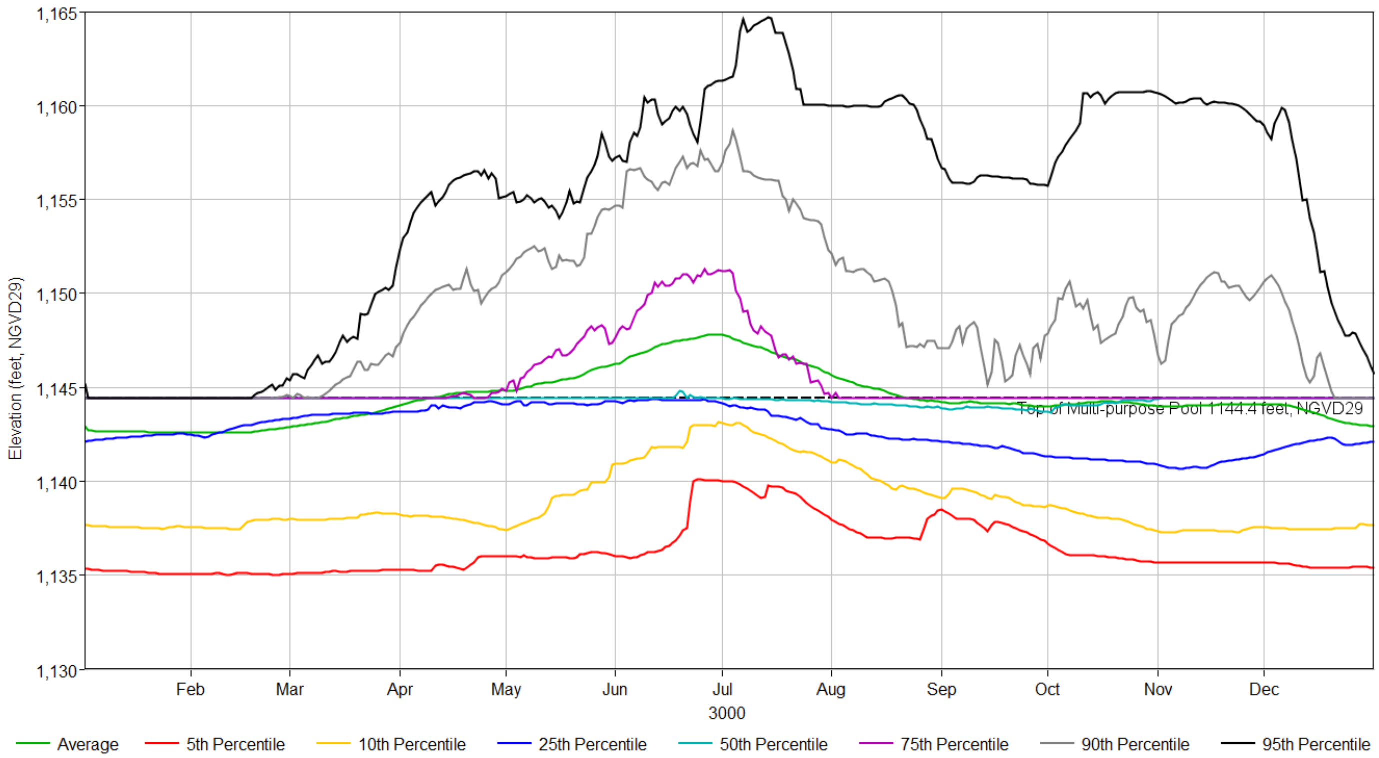


Figure 4-61. Milford pool elevation statistics for the 100-year FWOP at 2049 sediment conditions.

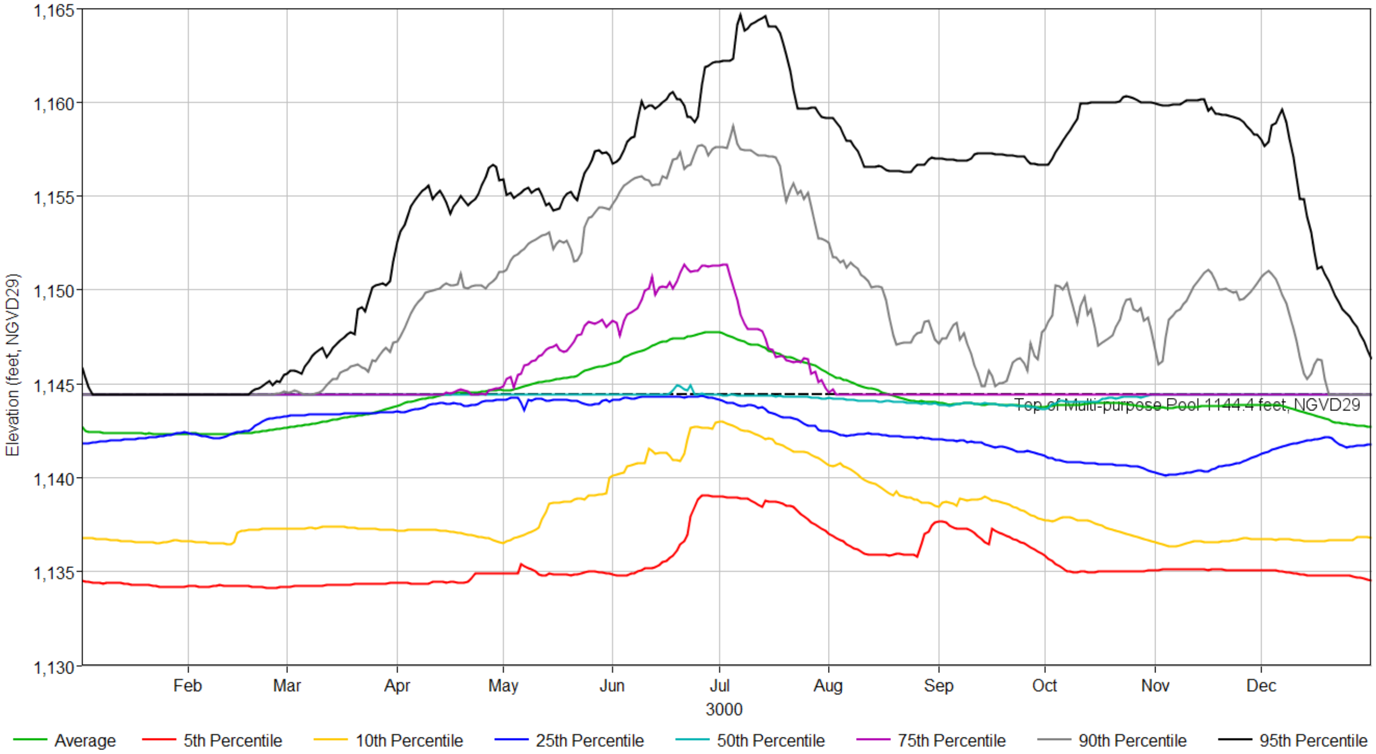


Figure 4-62. Milford pool elevation statistics for the 100-year FWOP at 2074 sediment conditions.

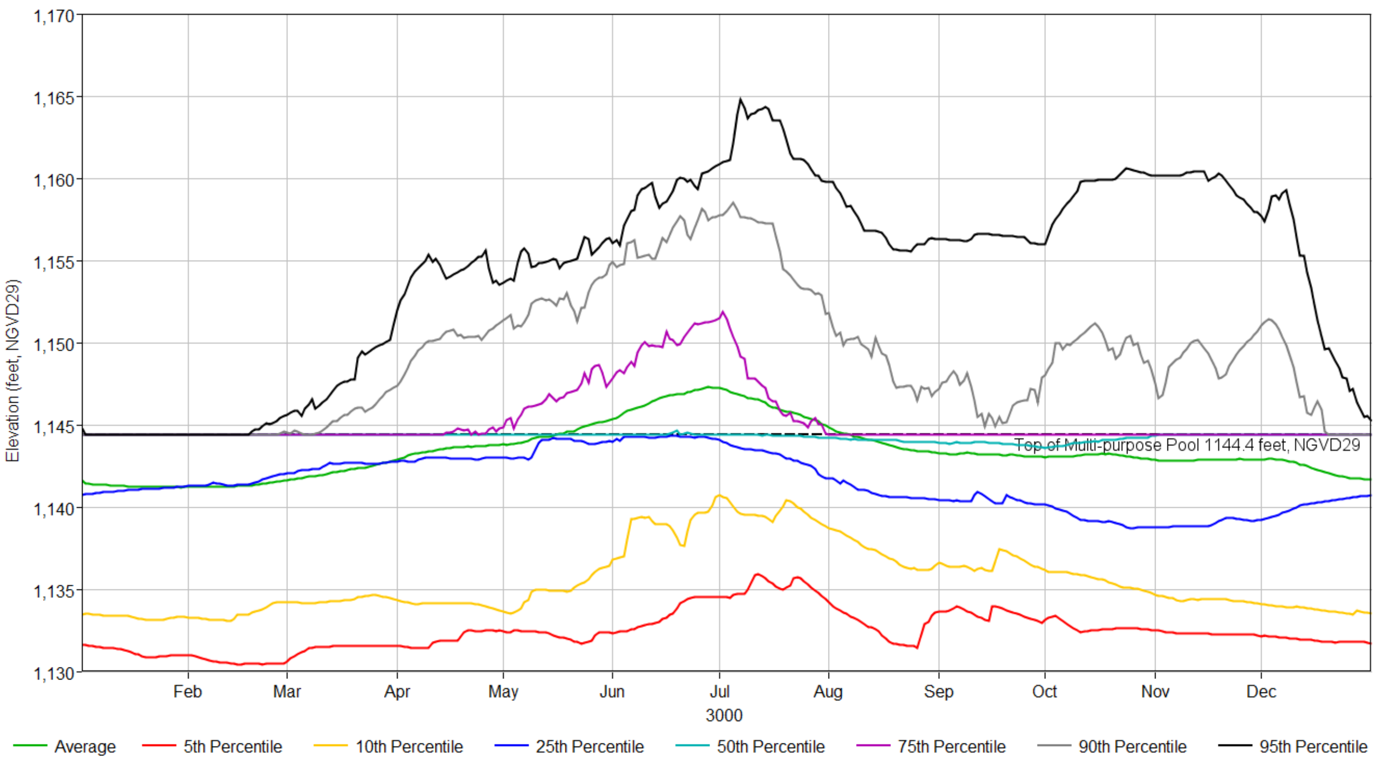


Figure 4-63. Milford pool elevation statistics for the 100-year FWOP at 2124 sediment conditions.

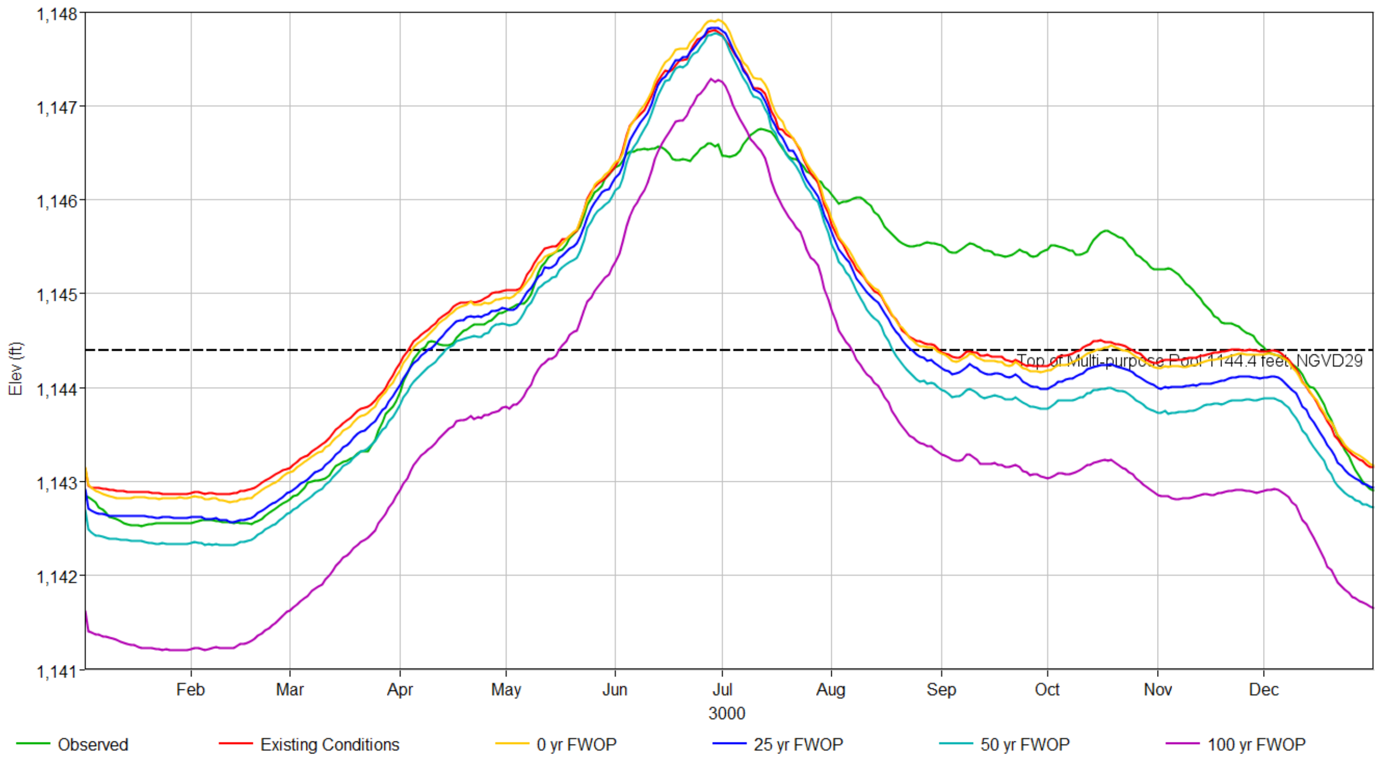


Figure 4-64. Daily average Milford pool elevation for each set of data.

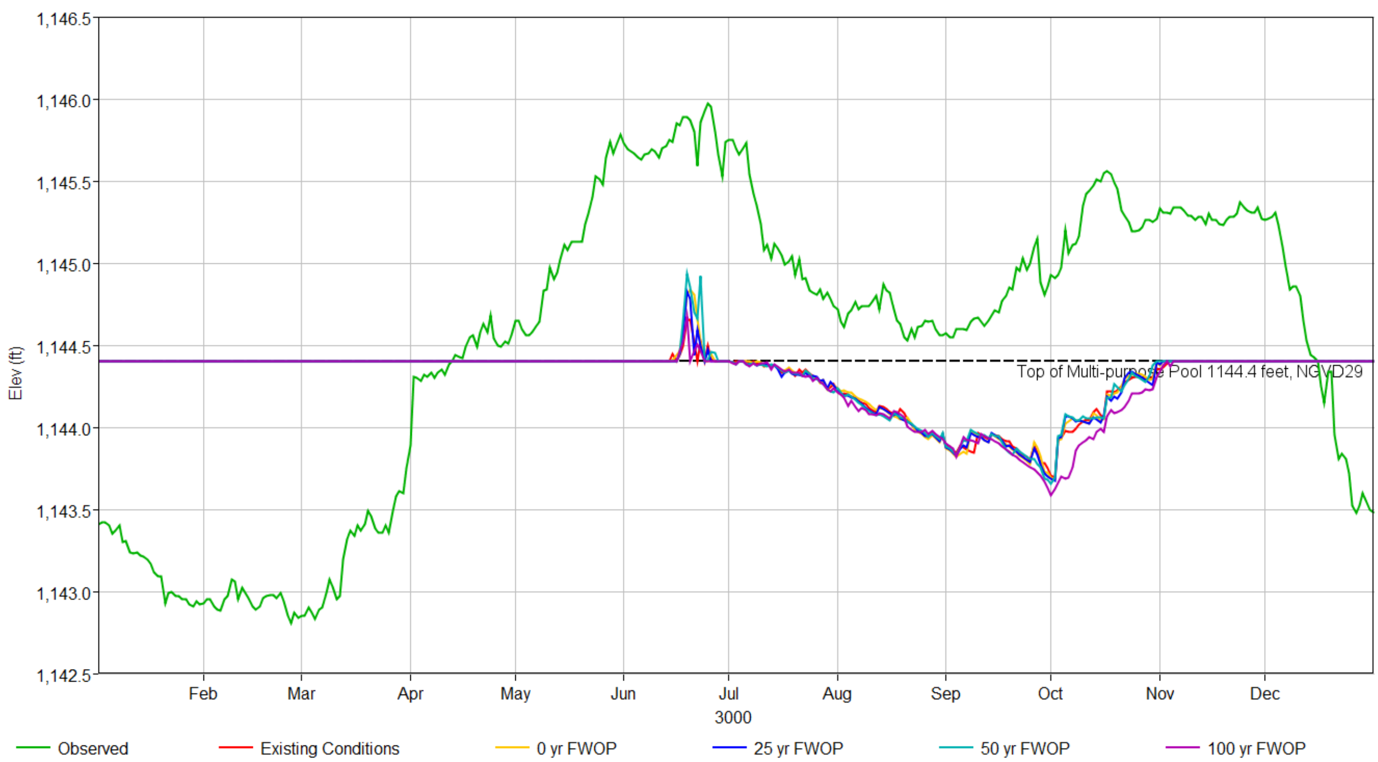


Figure 4-65. Daily median (50th Percentile) Milford pool elevation for each set of data.

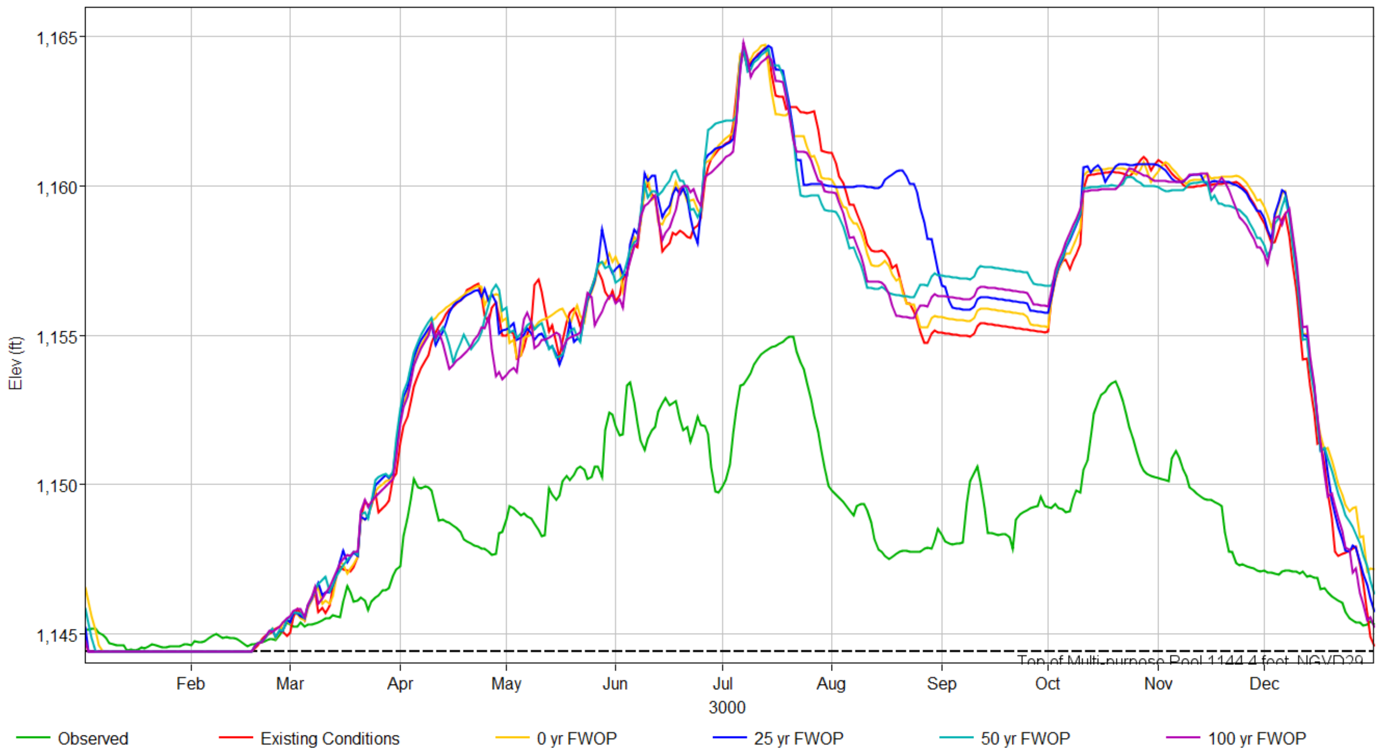


Figure 4-66. Daily 95th Percentile Milford pool elevation for each set of data.

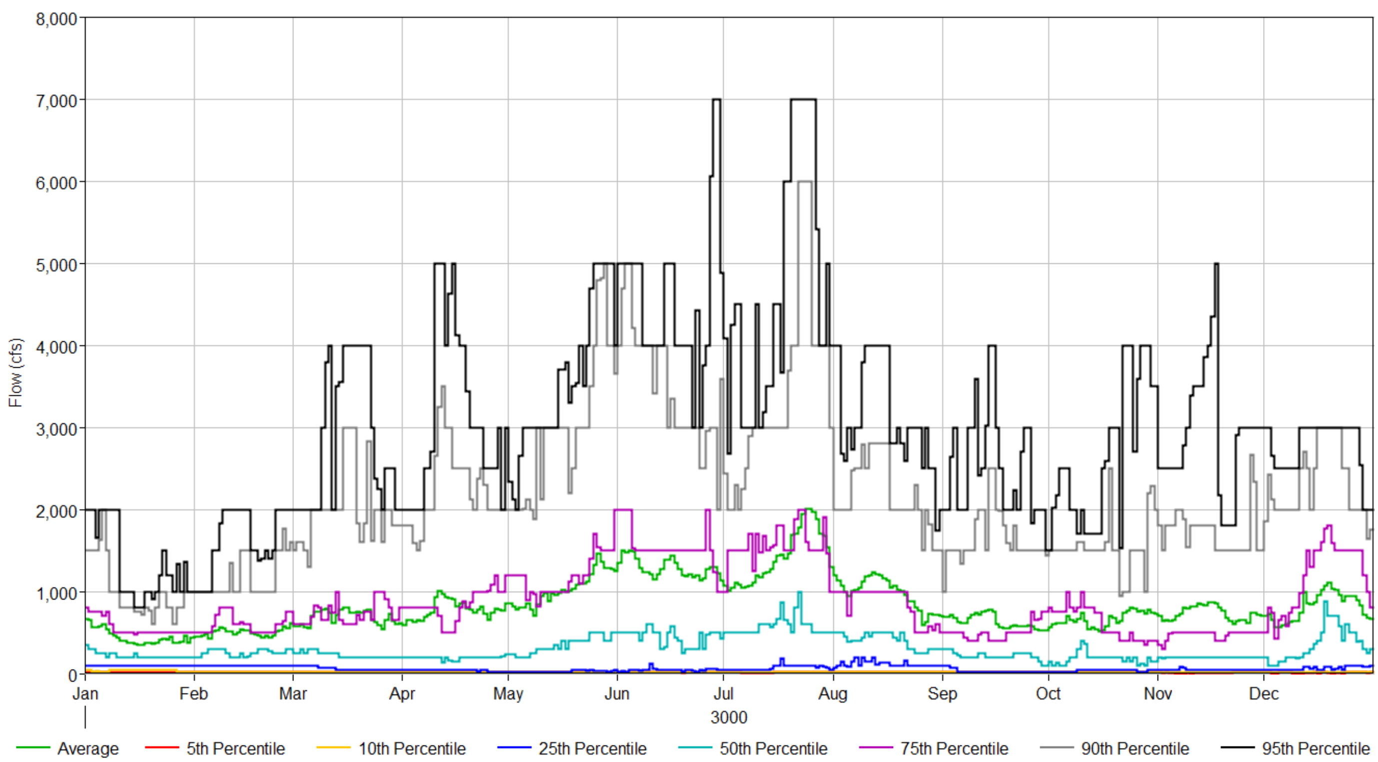


Figure 4-67. Milford outflow statistics for the observed data from first fill Aug 1964 to Dec 2021.

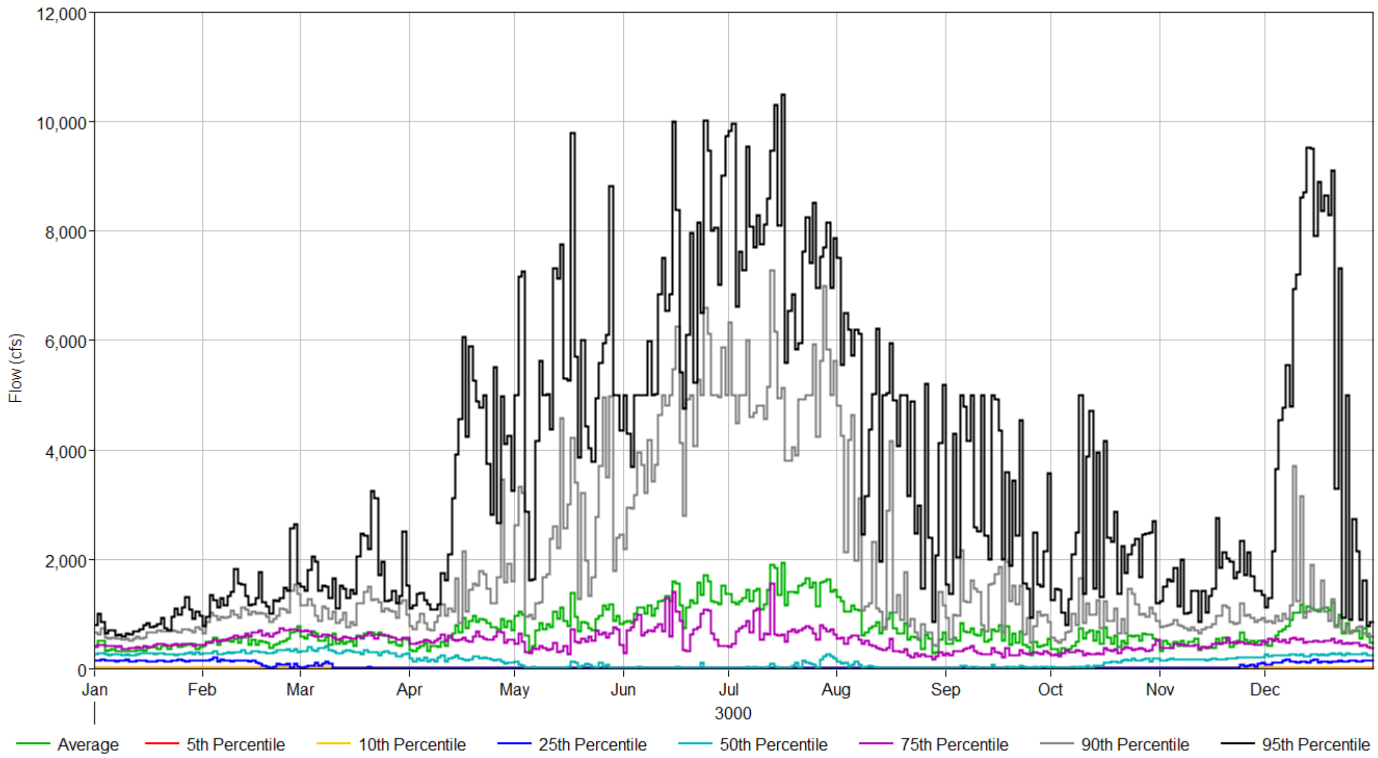


Figure 4-68. Milford outflow statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

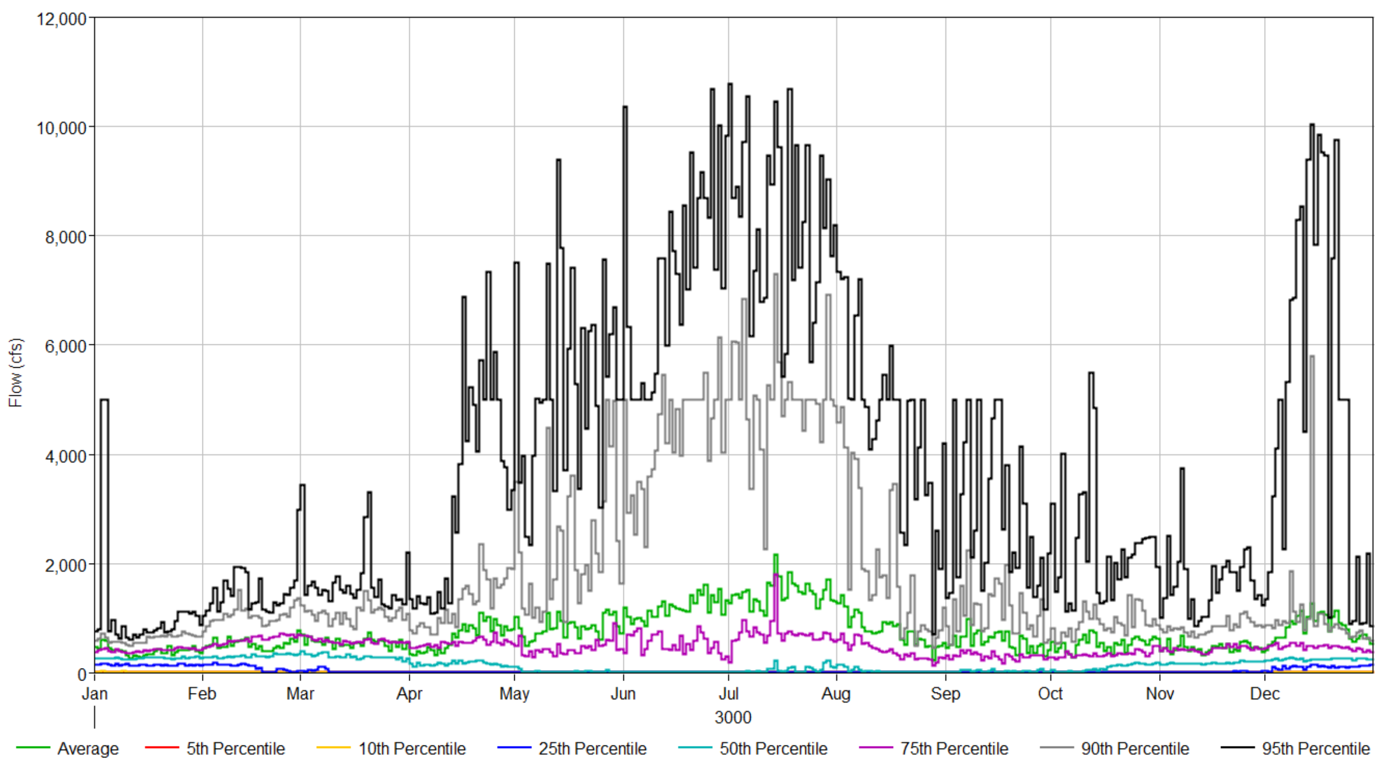


Figure 4-69. Milford outflow statistics for the 100-year FWOP at 2024 sediment conditions.

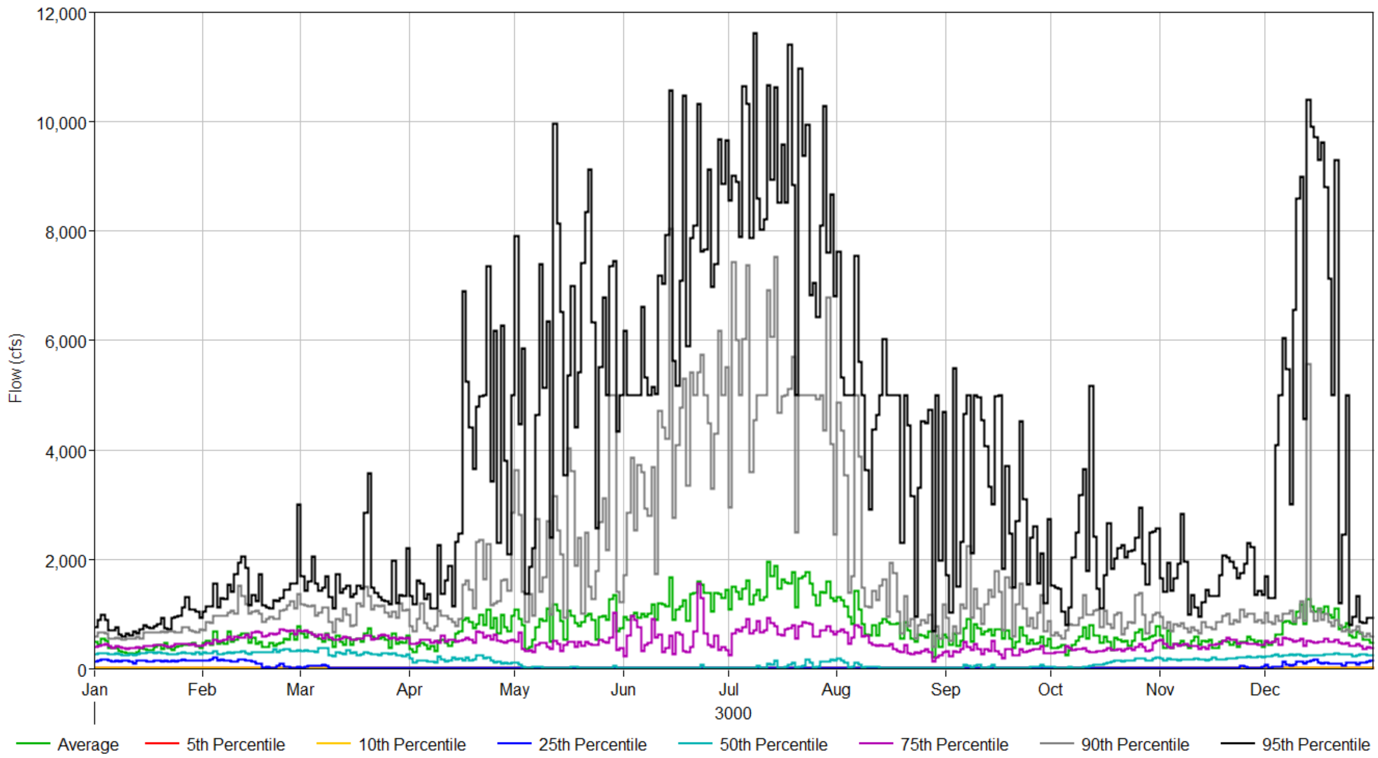


Figure 4-70. Milford outflow statistics for the 100-year FWOP at 2049 sediment conditions.

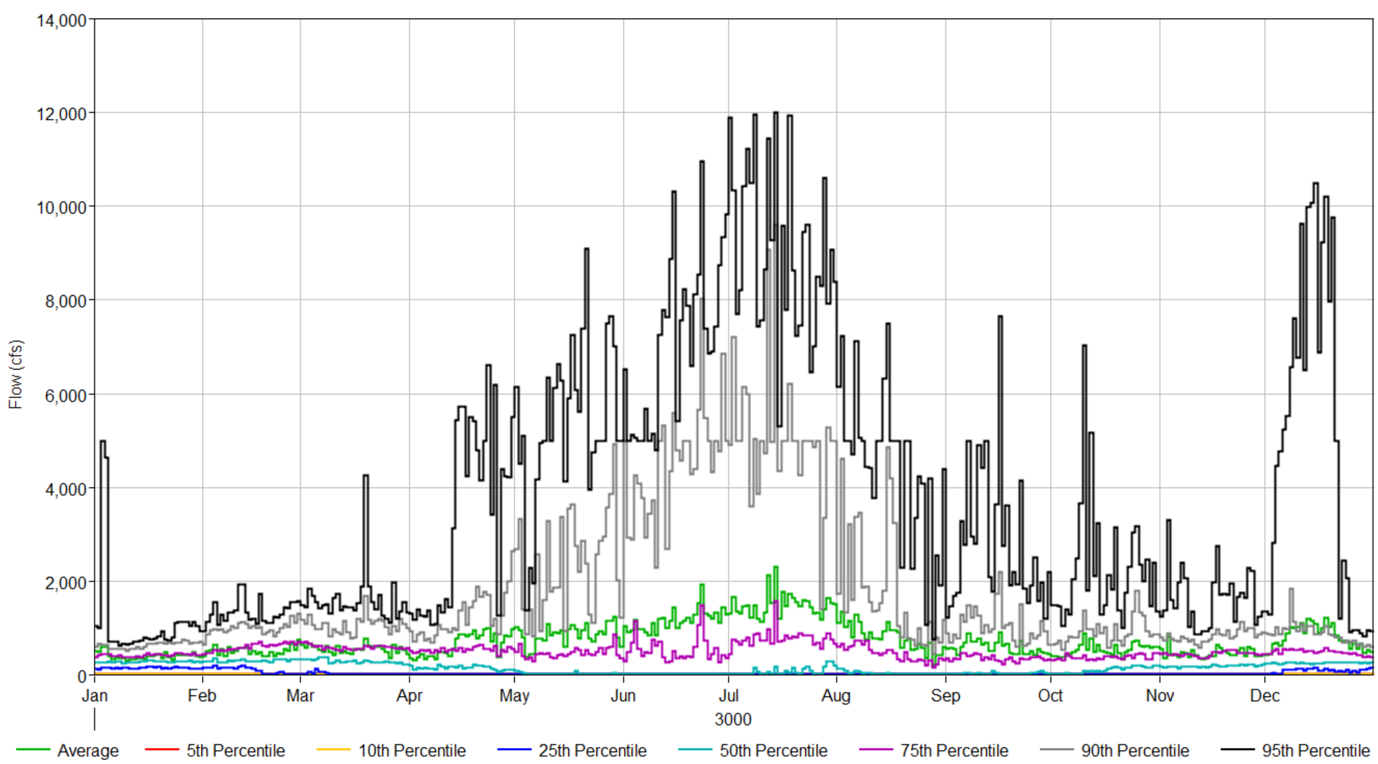


Figure 4-71. Milford outflow statistics for the 100-year FWOP at 2074 sediment conditions.

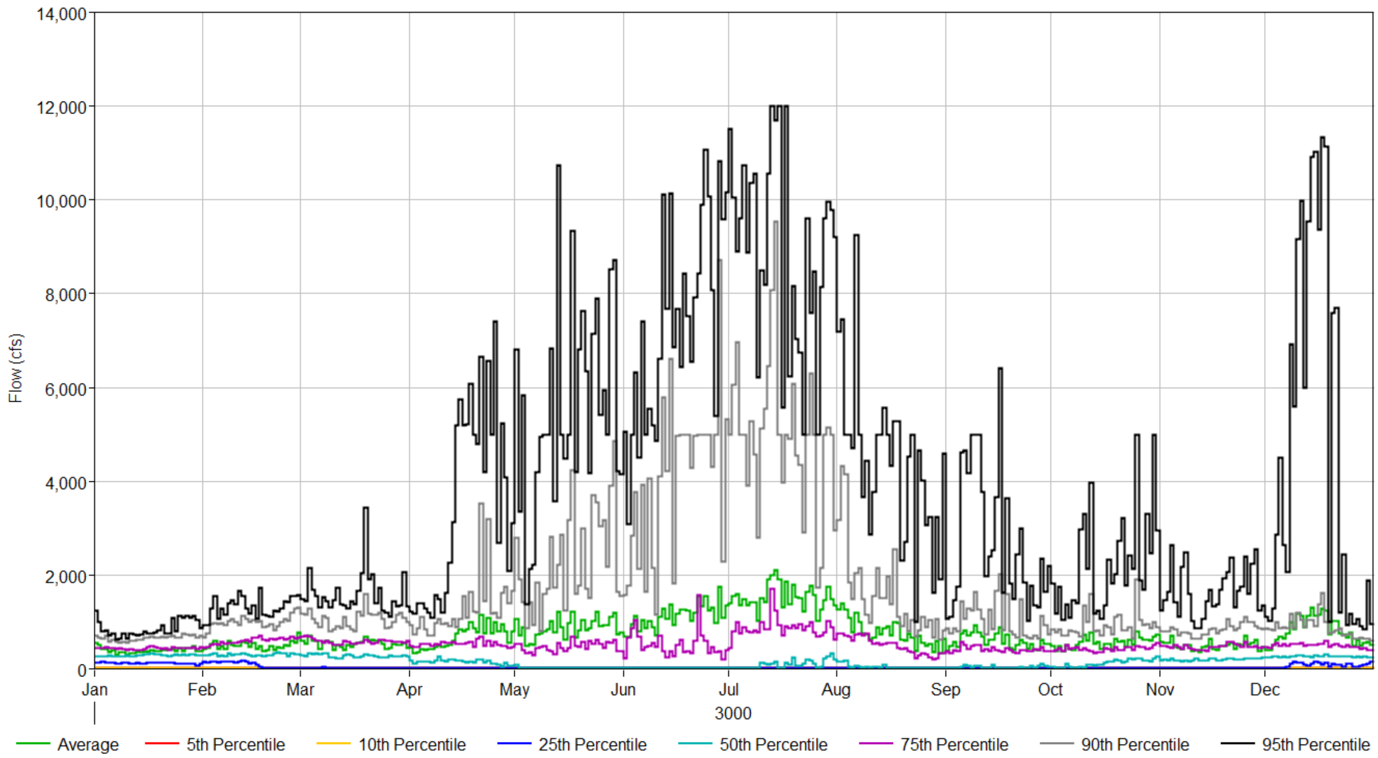


Figure 4-72. Milford outflow statistics for the 100-year FWOP at 2124 sediment conditions.

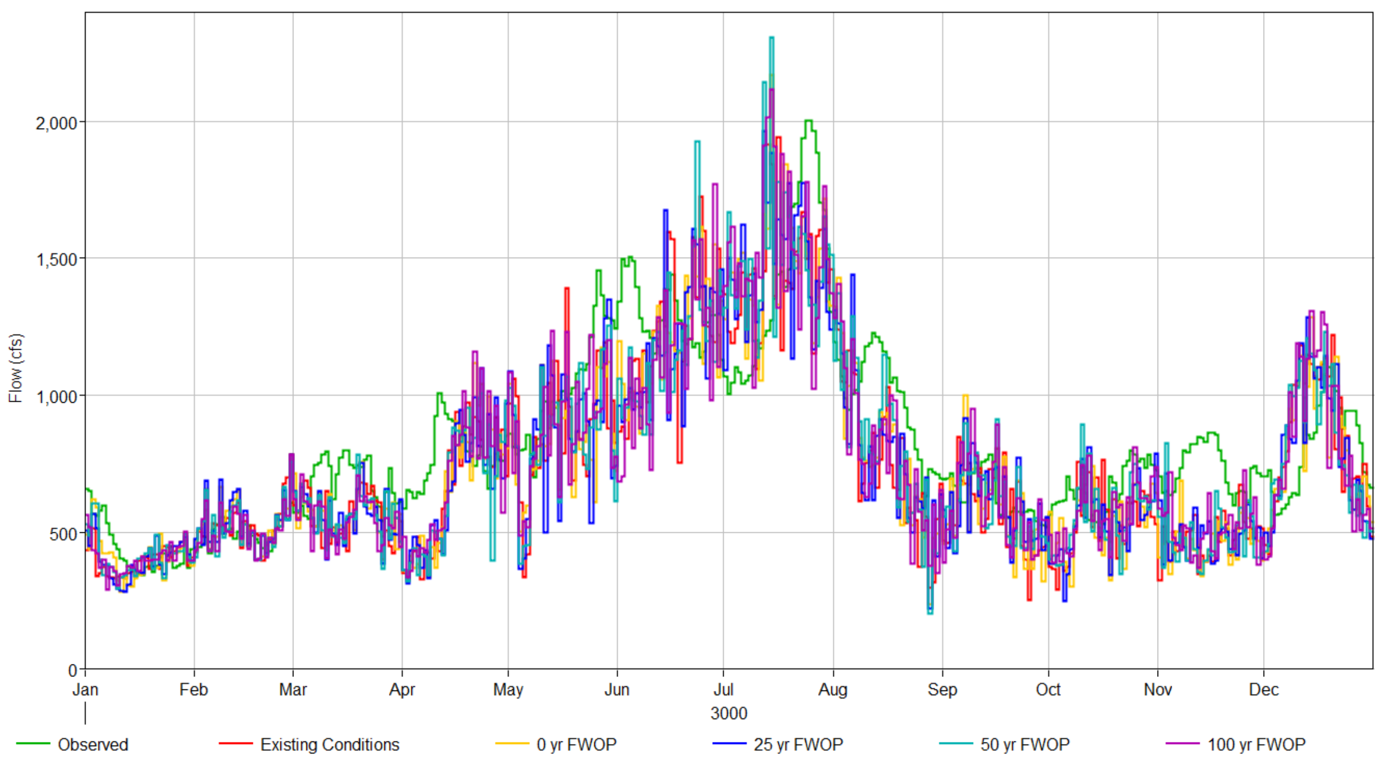


Figure 4-73. Daily average Milford outflow for each set of data.

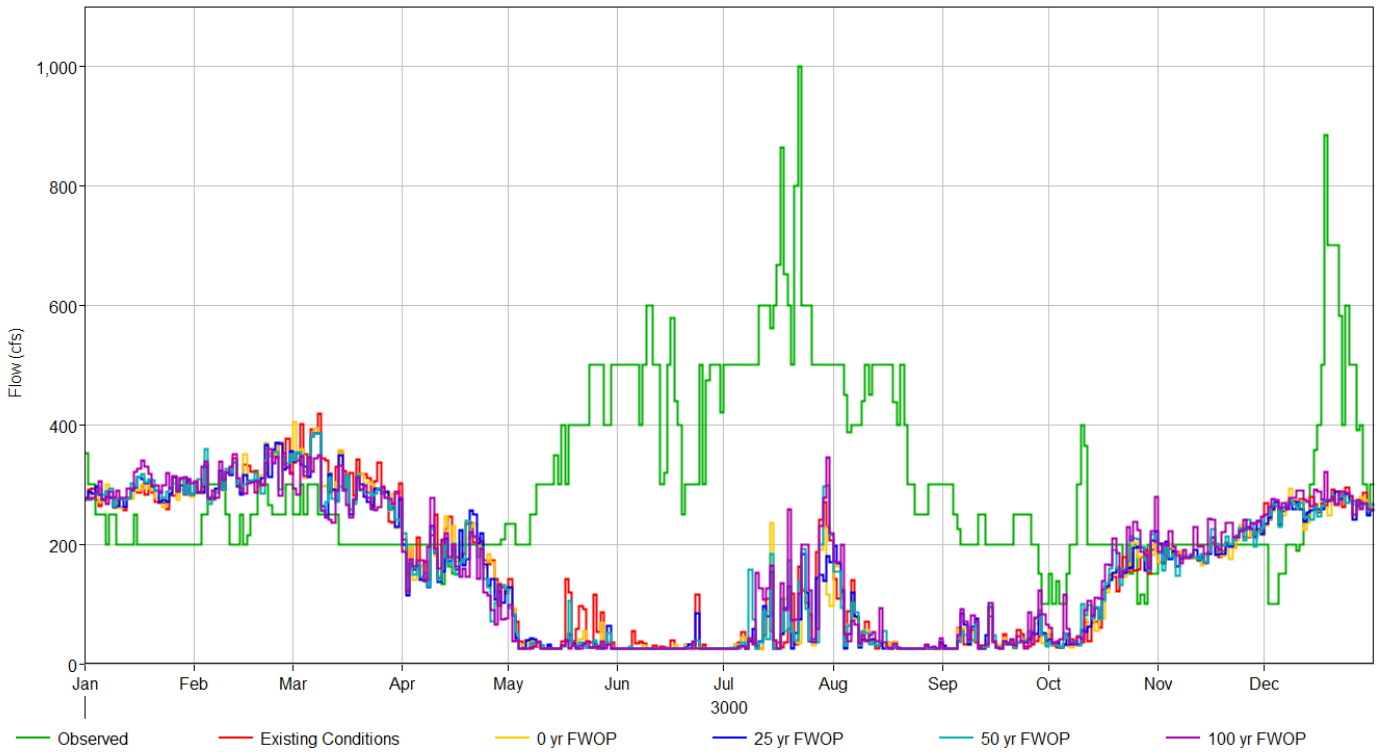


Figure 4-74. Daily median (50th Percentile) Milford flow for each set of data.

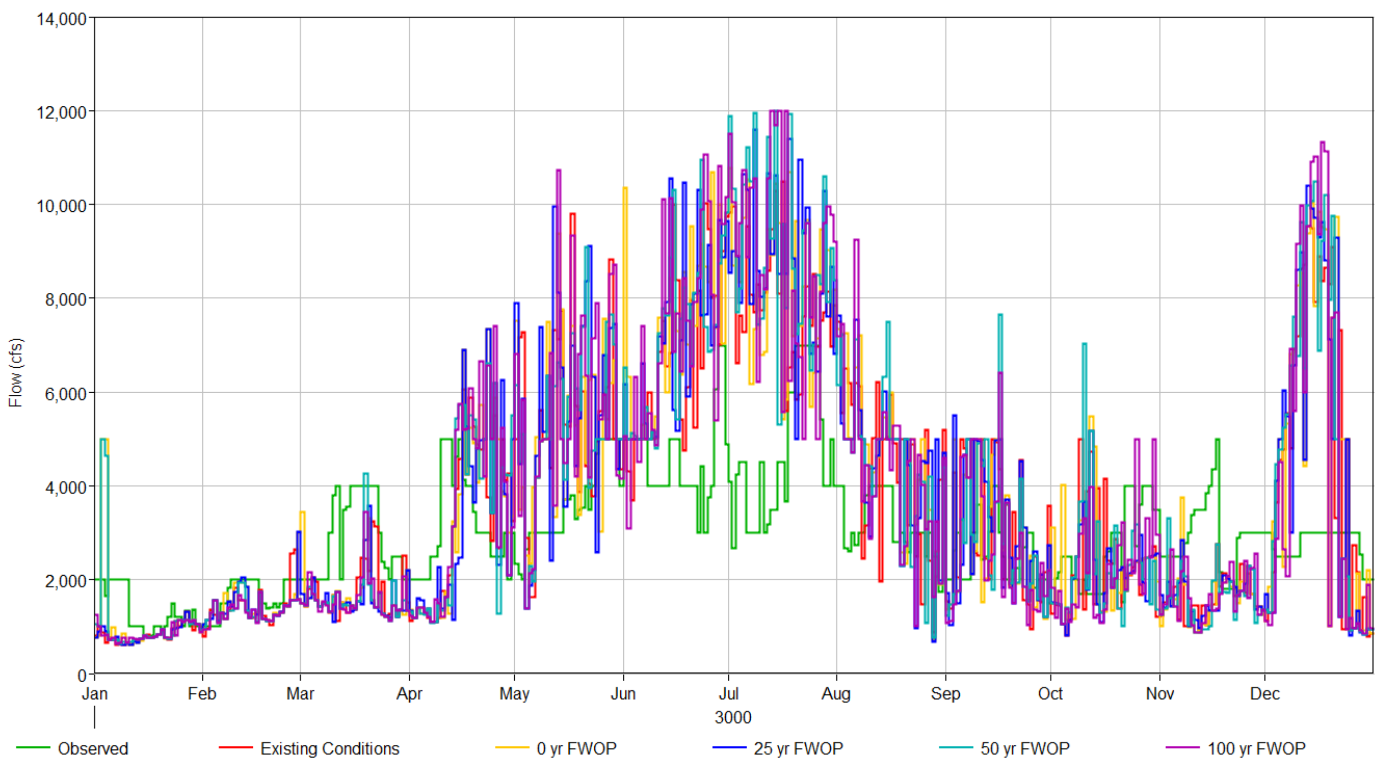


Figure 4-75. Daily 95th Percentile Milford flow for each set of data.

The pool elevation duration is shown in Figure 4-76. It shows small decreases in frequency in the lower portions of the flood control pool and deeper drops into the multi-purpose pool as the storage diminishes due to sedimentation.

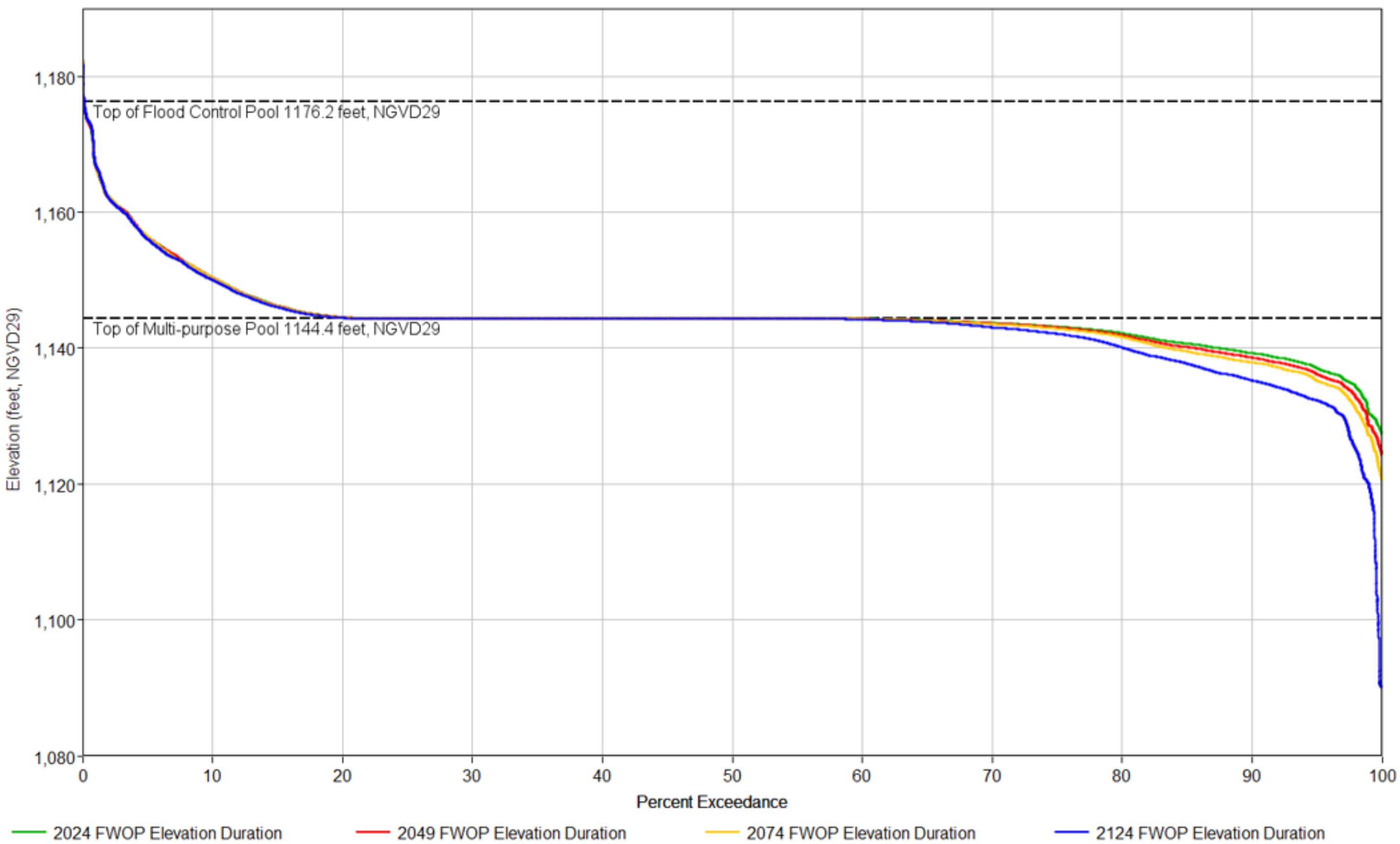


Figure 4-76. Milford pool elevation duration for the four non-navigation FWOP scenarios.

Navigation flow support is provided from Milford in the 2024 FWOP navigation scenario. This results in increased frequency of pool elevations below the multi-purpose pool. High pool elevations are unchanged. Figure 4-77 shows the pool duration plot for 2024 FWOP scenarios with and without navigation. Figure 4-78 to Figure 4-80 show the rest of the FWOP Milford pool elevation duration plots. In these scenarios, Milford does not provide navigation support flows, but some small impacts are assessed because of Tuttle Creek providing the navigation support flows which then requires Milford to give additional releases to support water quality. By 2124, there is very little impact as Milford is already supporting most of the water quality releases.

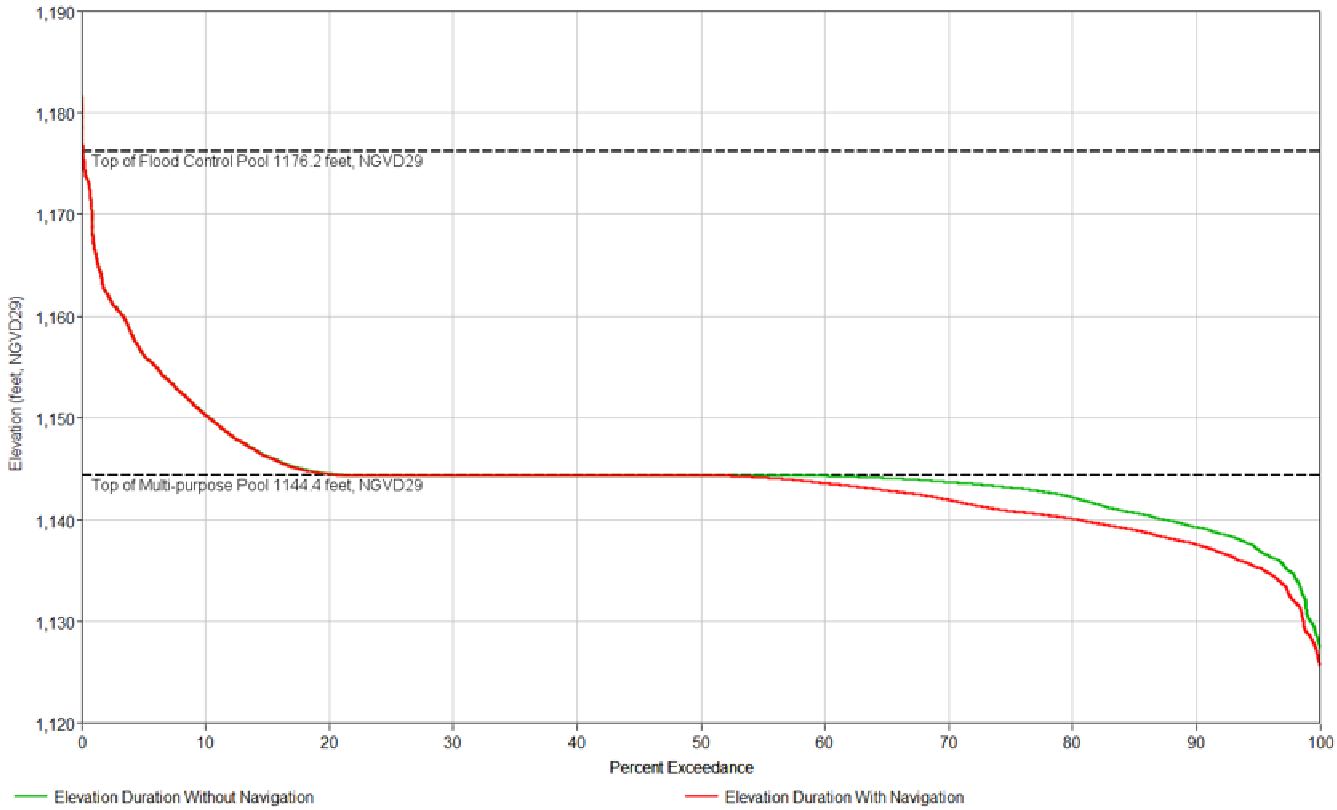


Figure 4-77. Milford 2024 FWOP pool elevation duration with and without navigation.

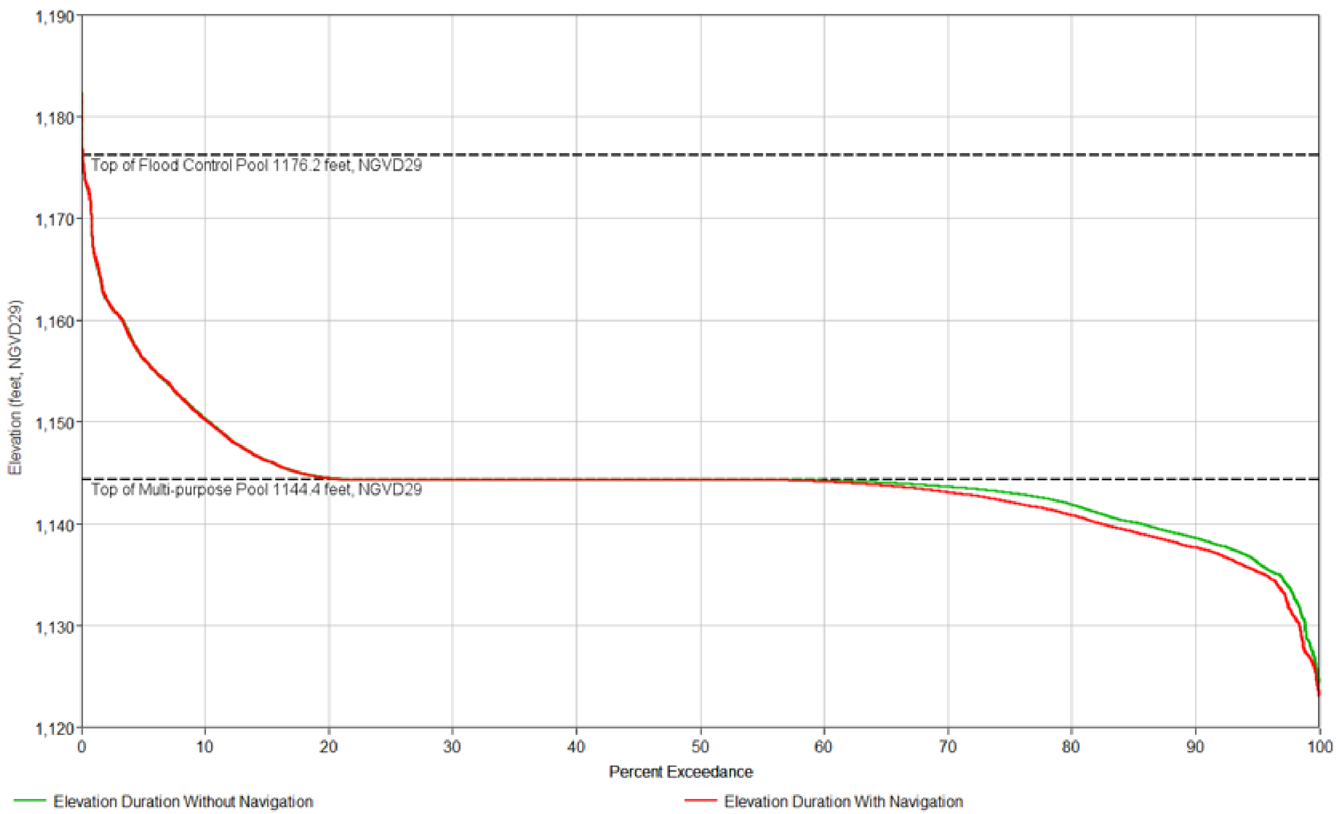


Figure 4-78. Milford 2049 FWOP pool elevation duration with and without navigation.

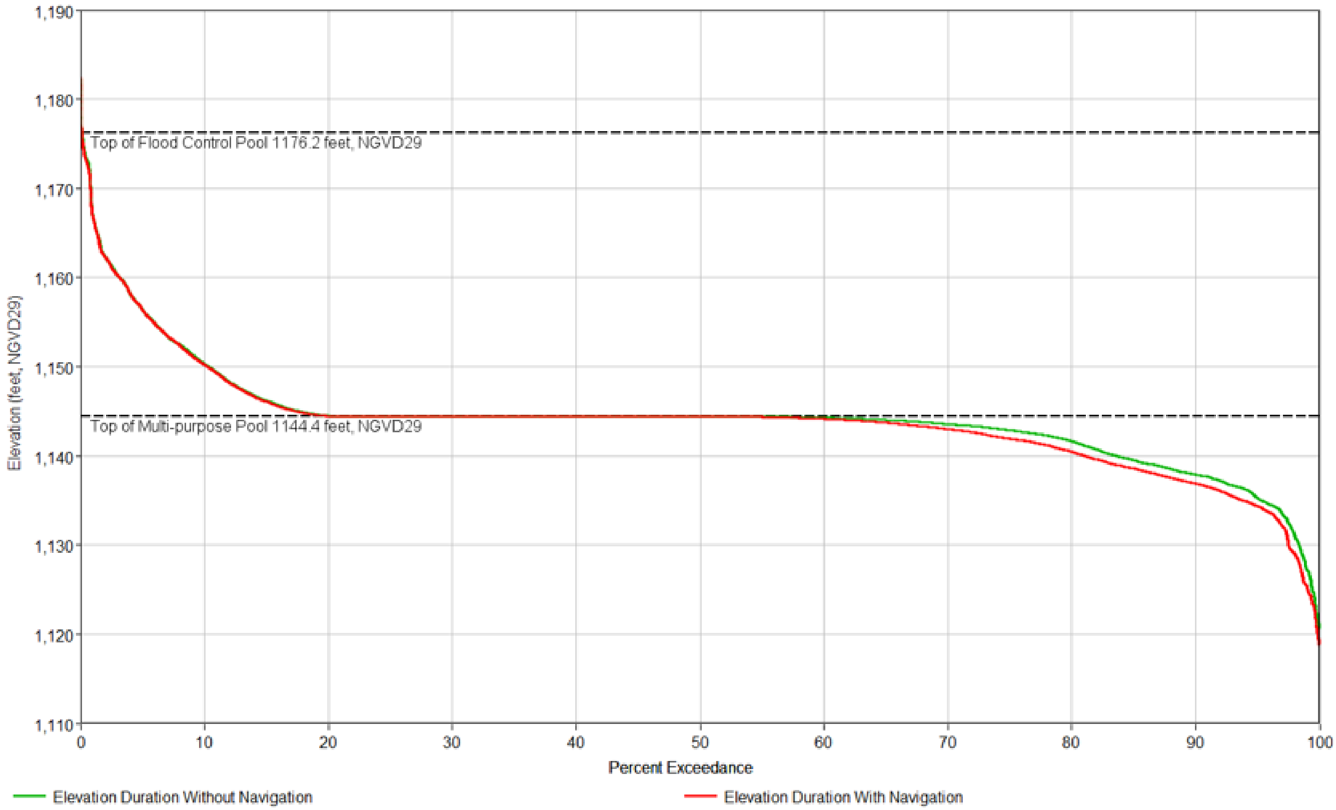


Figure 4-79. Milford 2074 FWOP pool elevation duration with and without navigation.

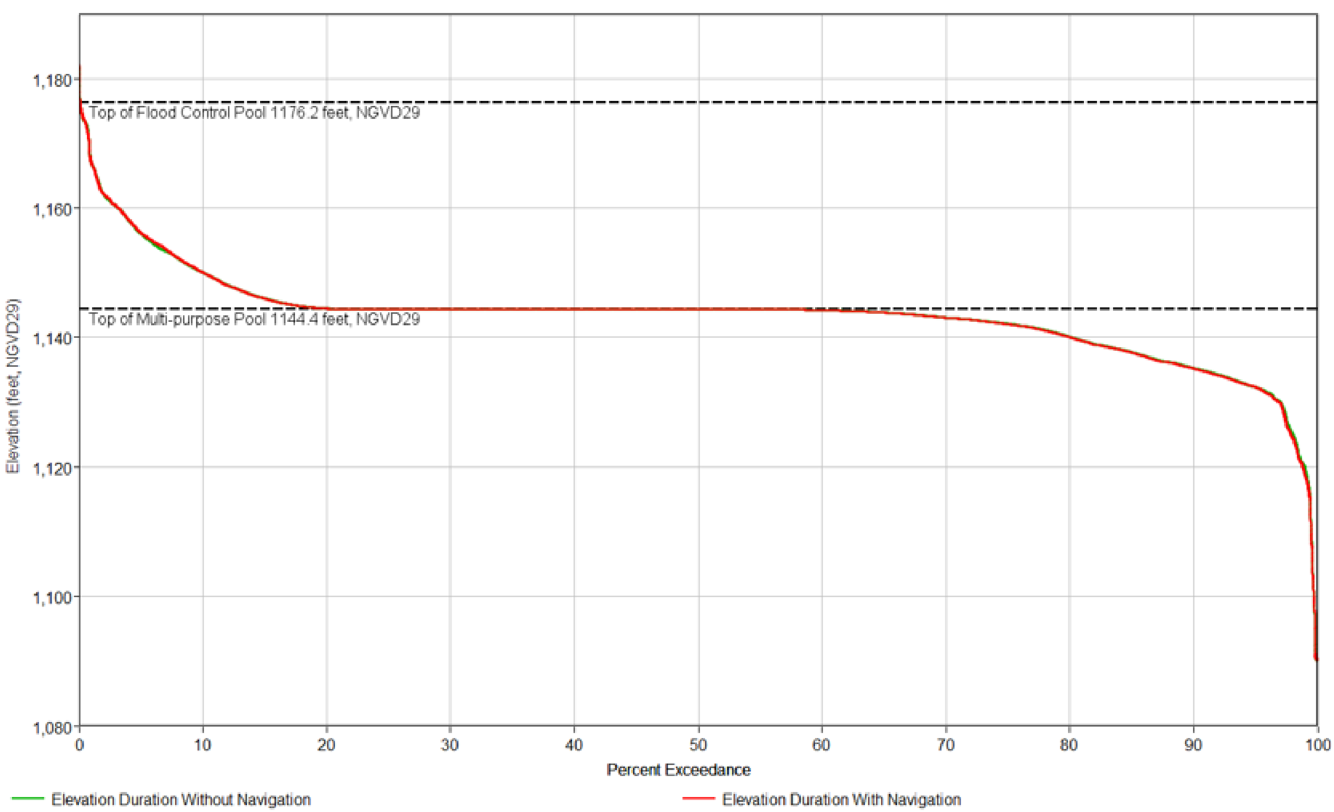


Figure 4-80. Milford 2124 FWOP pool elevation duration with and without navigation.

4.1.5 Tuttle Creek

Tuttle Creek observed data is from first fill of April 1963 through November 2021. The Tuttle Creek family of curves are shown in Figure 4-81 to Figure 4-98. The median modeled pool elevation tends to be near the top of the multi-purpose pool since that was used as the guide curve in HEC-ResSim but is much higher in the summer months especially for the later FWOP scenarios. Median observed pool elevation is more variable with some pool raises and drawdowns as part of the routine operations. All the model scenarios have high pool elevations in 95th percentile data set as some years required constrained releases in flood control operations for the Missouri River at Waverly. The observed data set does not have the extended high pool elevation because deviations were utilized in the real-time operations.

Average time series were compared for each scenario. The observed data is consistently lower than the modeled pool elevations. This may be because deviations were utilized in some large flood years to lower the pool elevation. Also, seasonal drawdowns that are part of the water level management plan take place over the winter. The existing conditions and 2024 FWOP scenarios are very similar as the sediment conditions do not change dramatically between these two scenarios. However, as more sediment accumulates with each additional FWOP the average pool elevation also increases. The 2124 FWOP has more variability in the data set because of the multi-purpose pool being near full of sediment. This results in quick drops in the pool when low-flow water quality releases need to be made and quick rises in the pool as inflows are received. The 2124 FWOP scenario also has lower pool elevations over the winter because what multi-purpose storage is available is often used for water quality releases.

The modeled outflow data matches the observed data generally well, especially the average daily flows and 95th percentile flows. But for the median percentile category, the observed data was significantly higher during the warm months. This may be due to historical deviations from the water management plan or other factors previously noted.

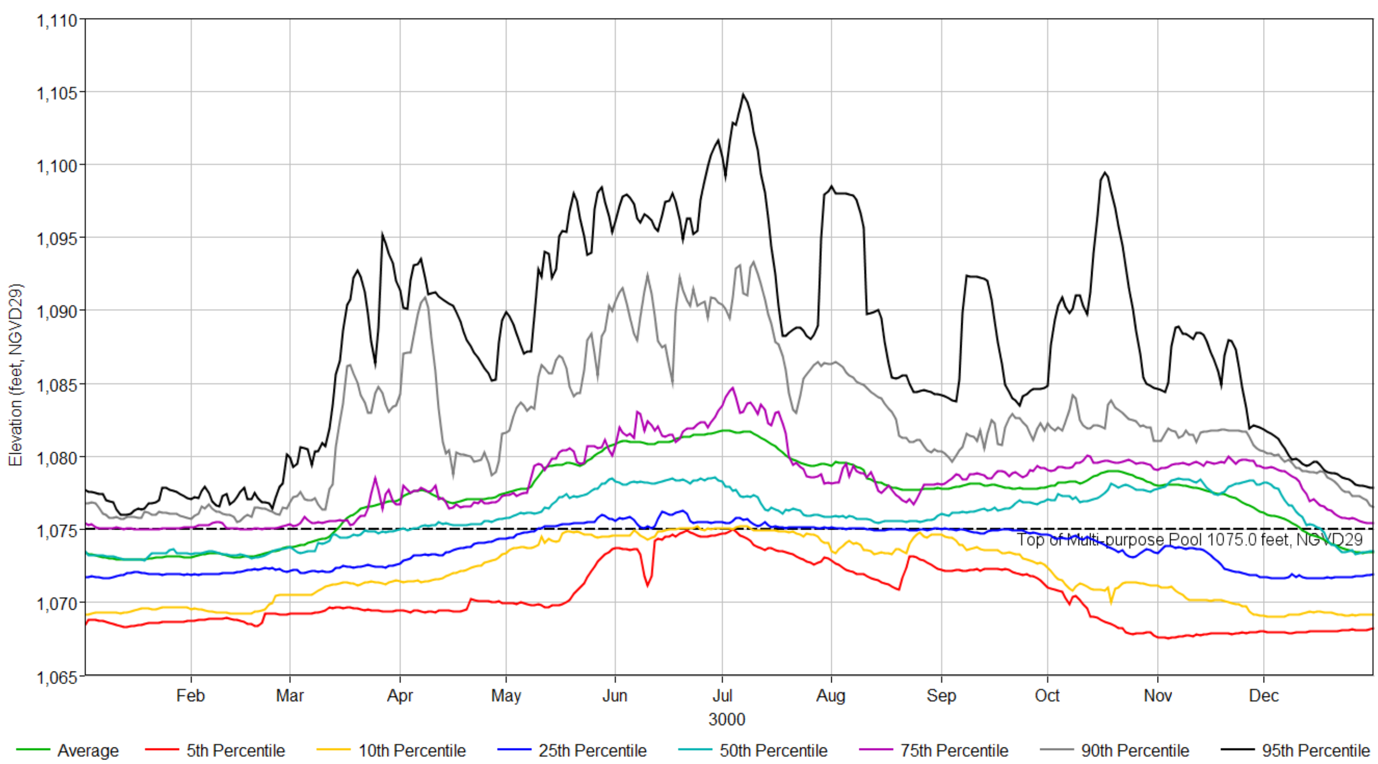


Figure 4-81. Tuttle Creek pool elevation statistics for the observed data from first fill April 1963 to Dec 2021.

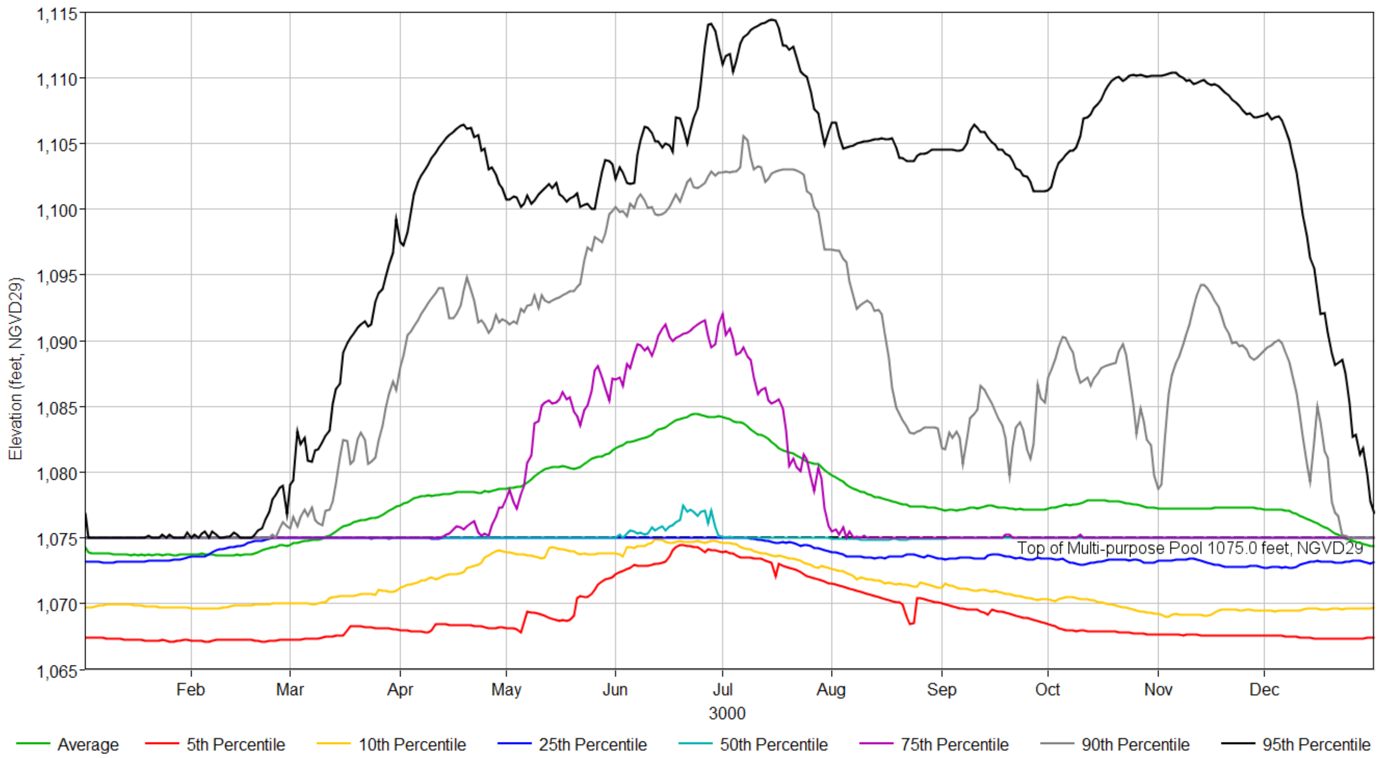


Figure 4-82. Tuttle Creek pool elevation statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

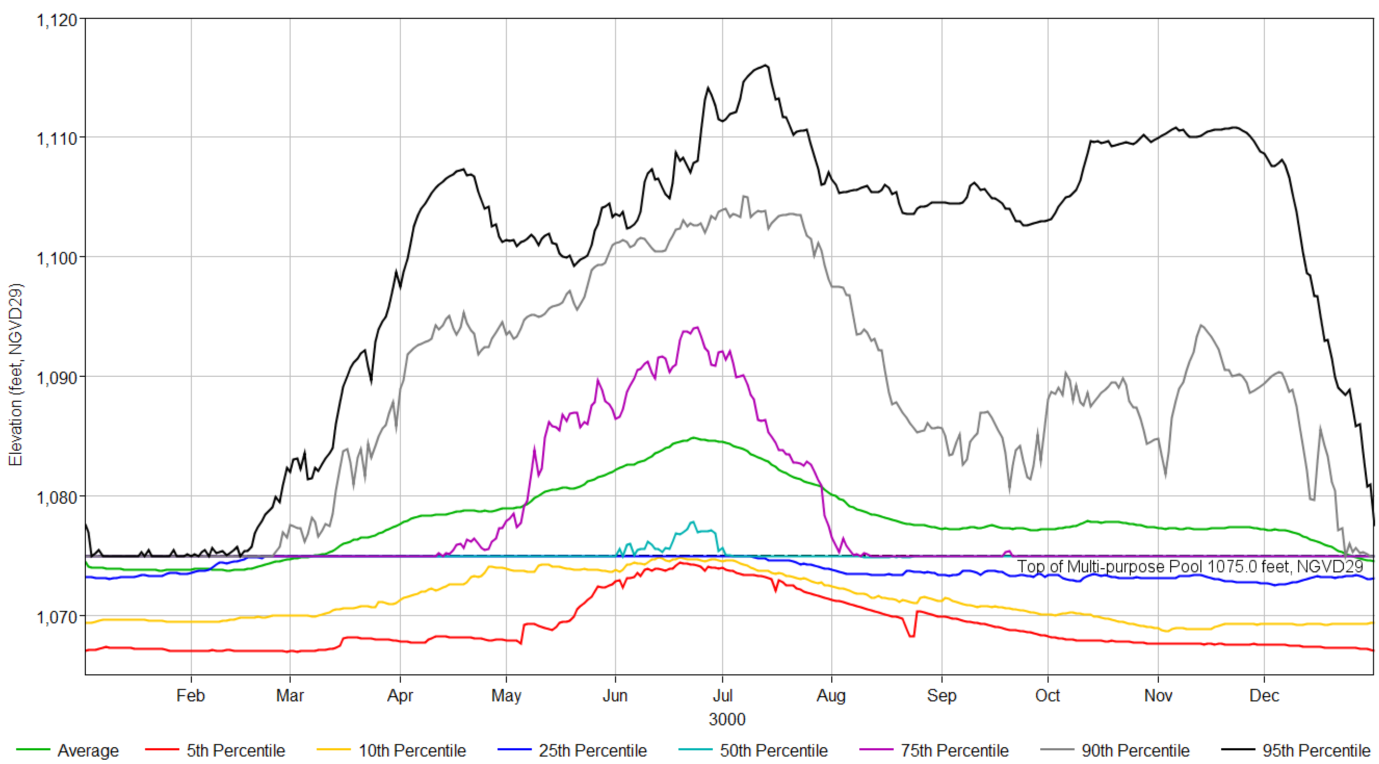


Figure 4-83. Tuttle Creek pool elevation statistics for the 100-year FWOP at 2024 sediment conditions.

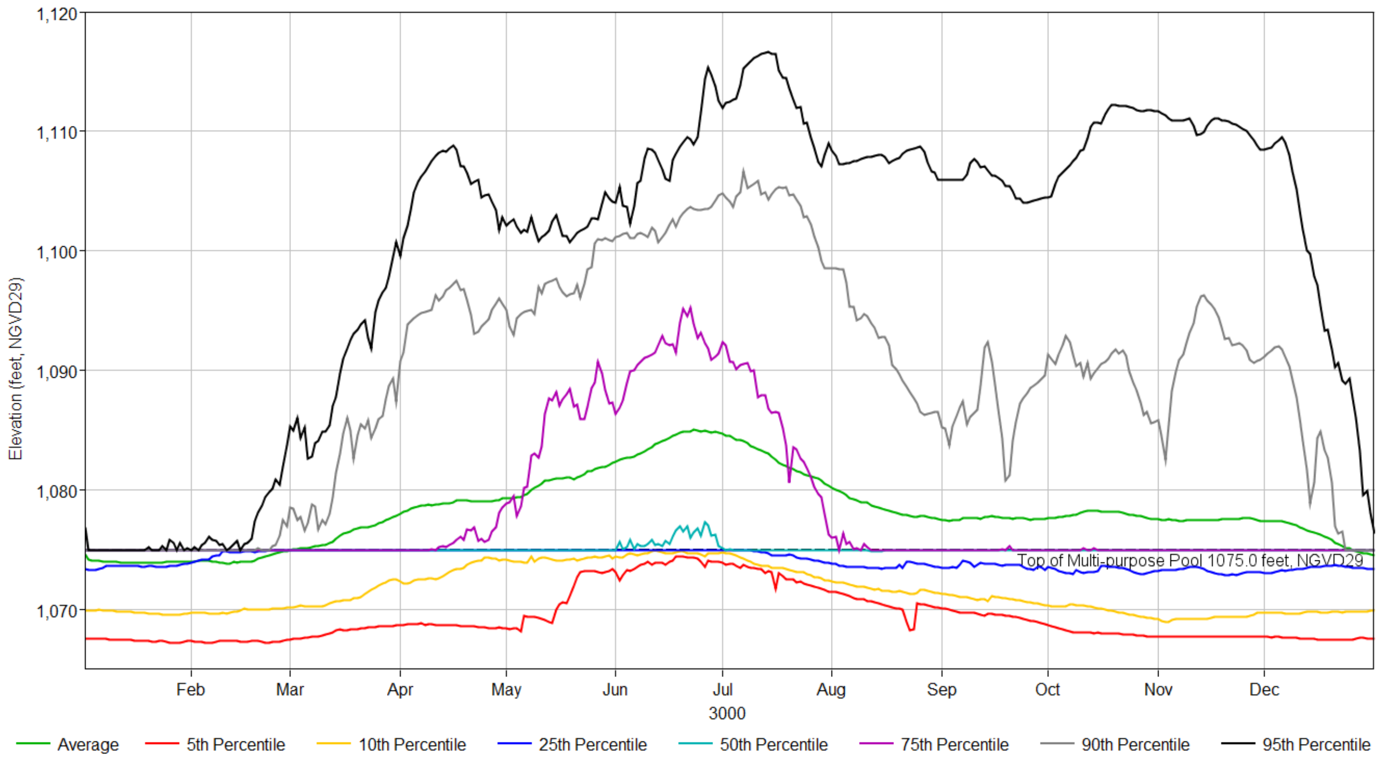


Figure 4-84. Tuttle Creek pool elevation statistics for the 100-year FWOP at 2049 sediment conditions.

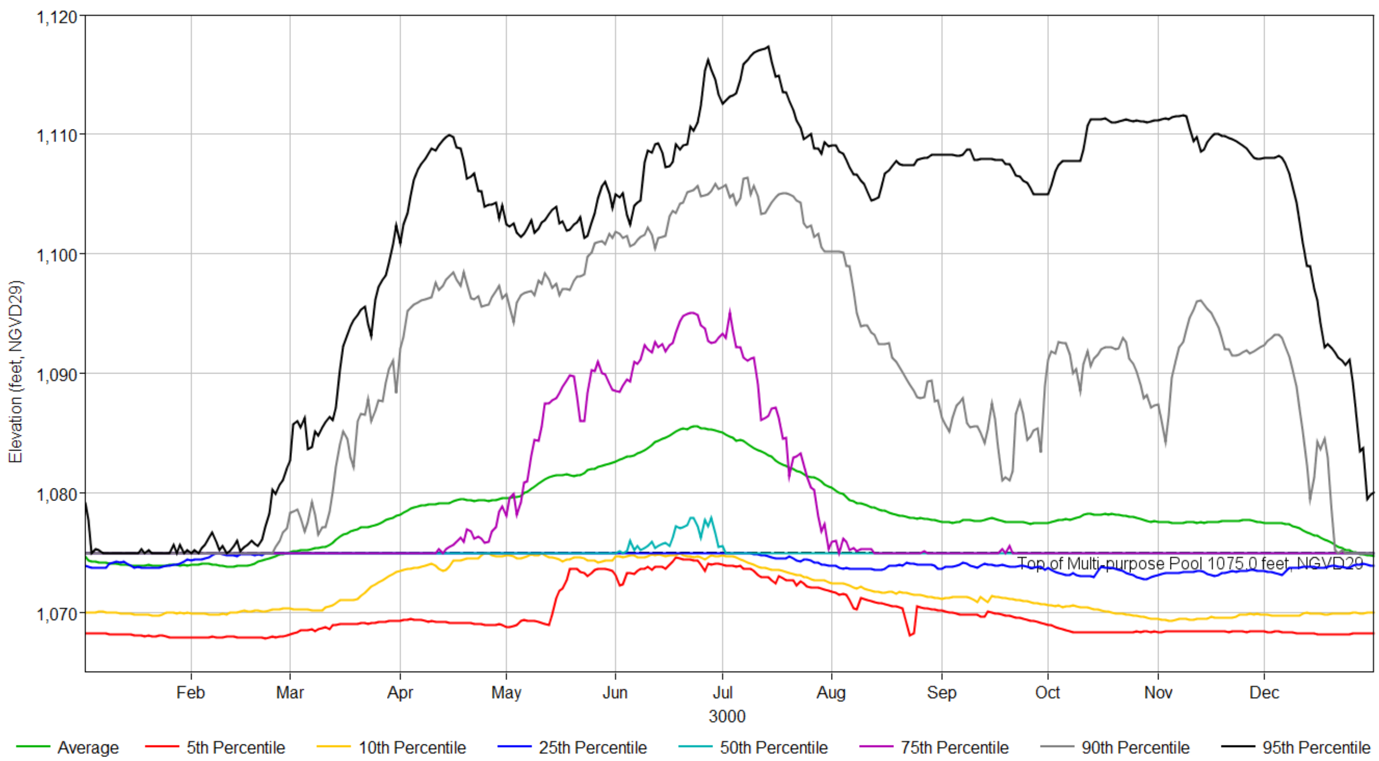


Figure 4-85. Tuttle Creek pool elevation statistics for the 100-year FWOP at 2074 sediment conditions.

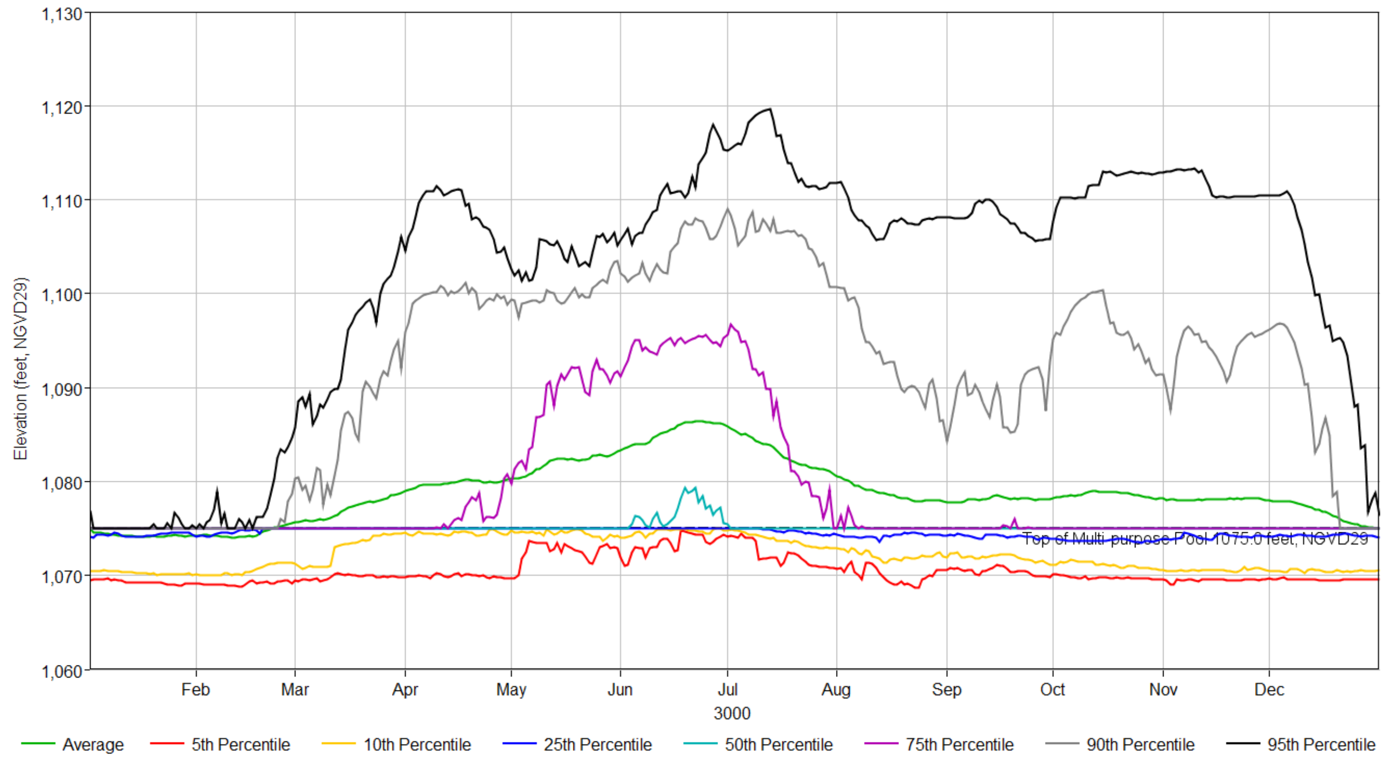


Figure 4-86. Tuttle Creek pool elevation statistics for the 100-year FWOP at 2124 sediment conditions.

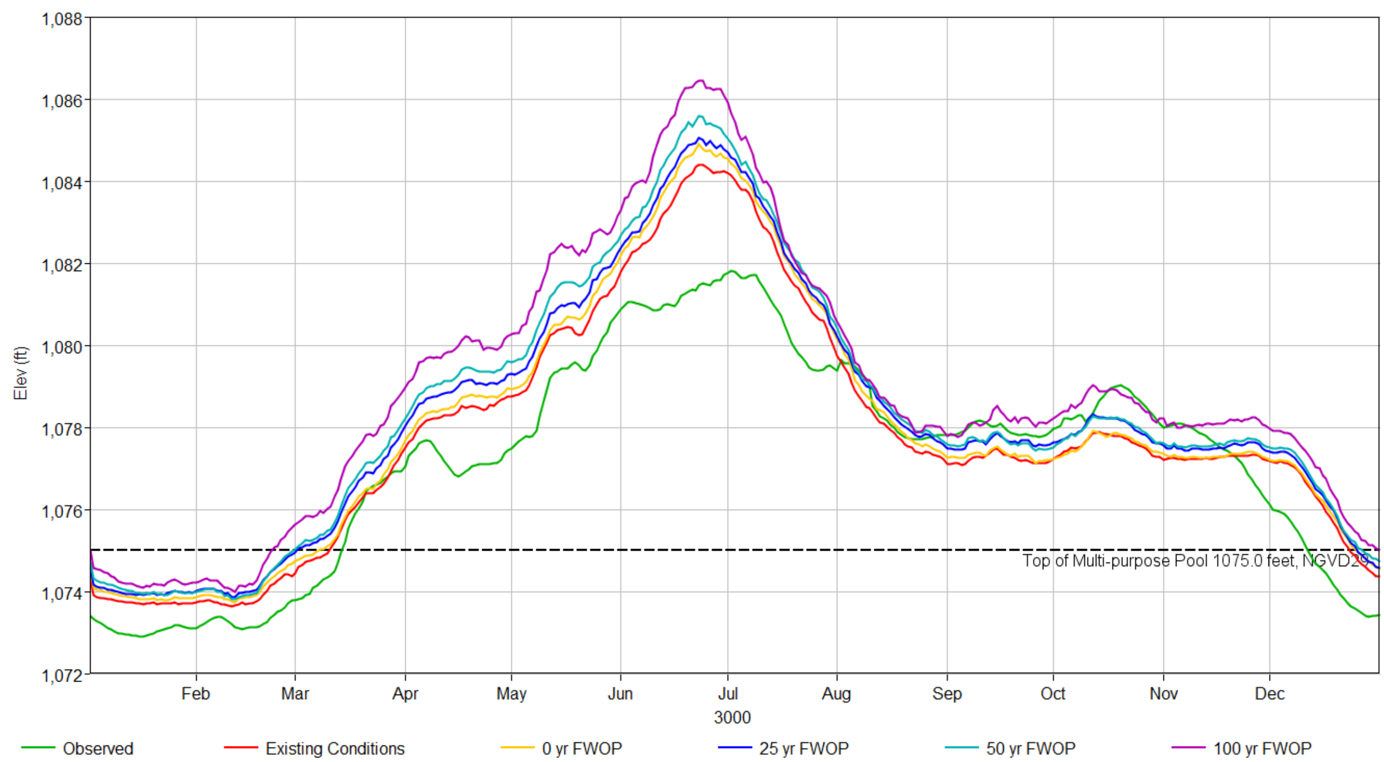


Figure 4-87. Daily average Tuttle Creek pool elevation for each set of data.

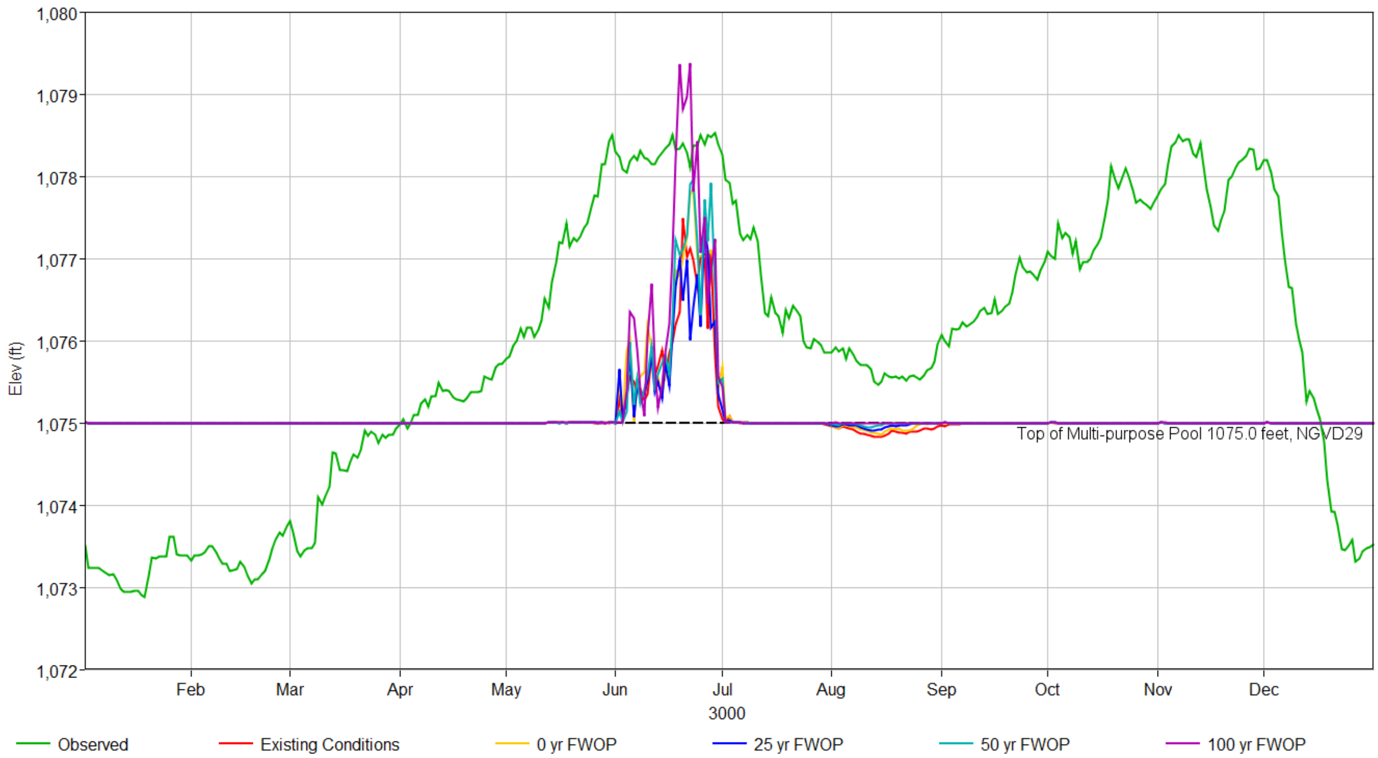


Figure 4-88. Daily median (50th Percentile) Tuttle Creek pool elevation for each set of data.

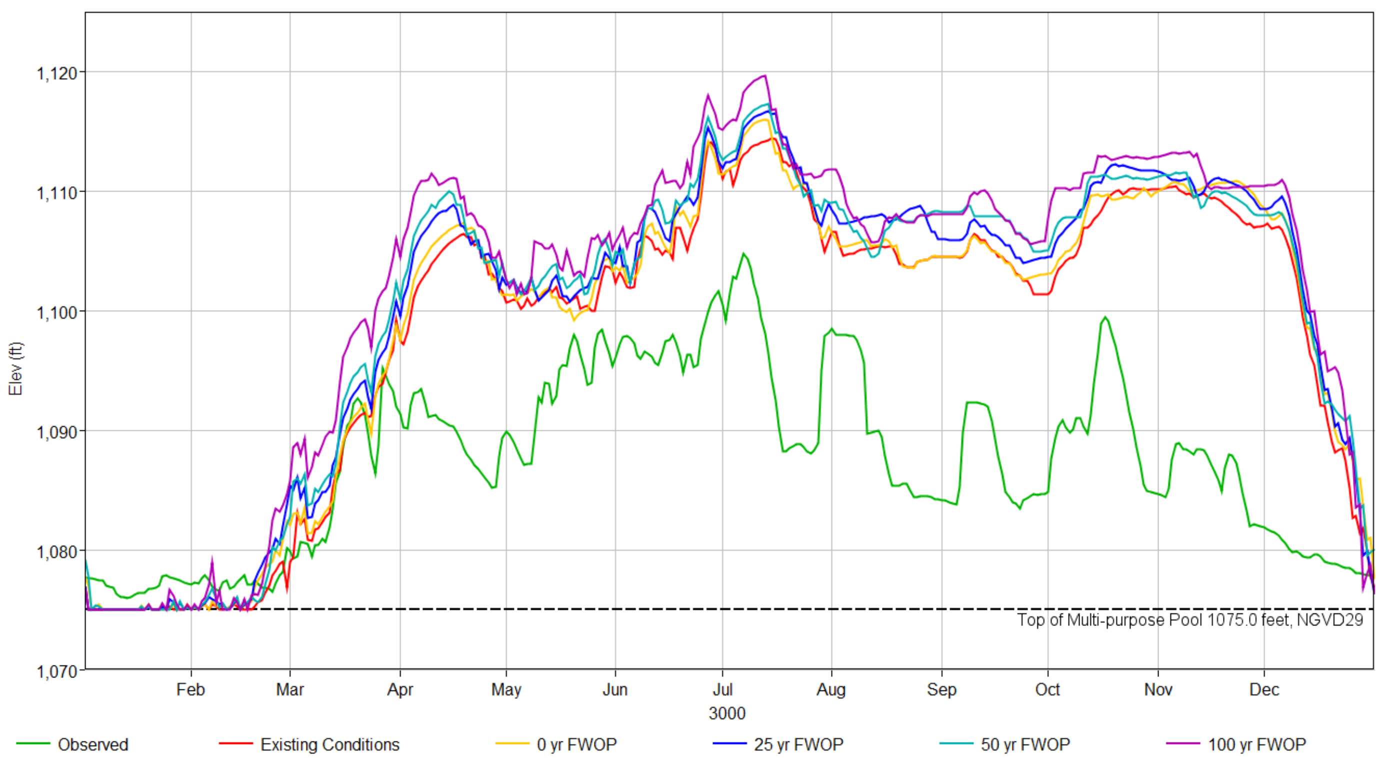


Figure 4-89. Daily 95th Percentile Tuttle Creek pool elevation for each set of data.

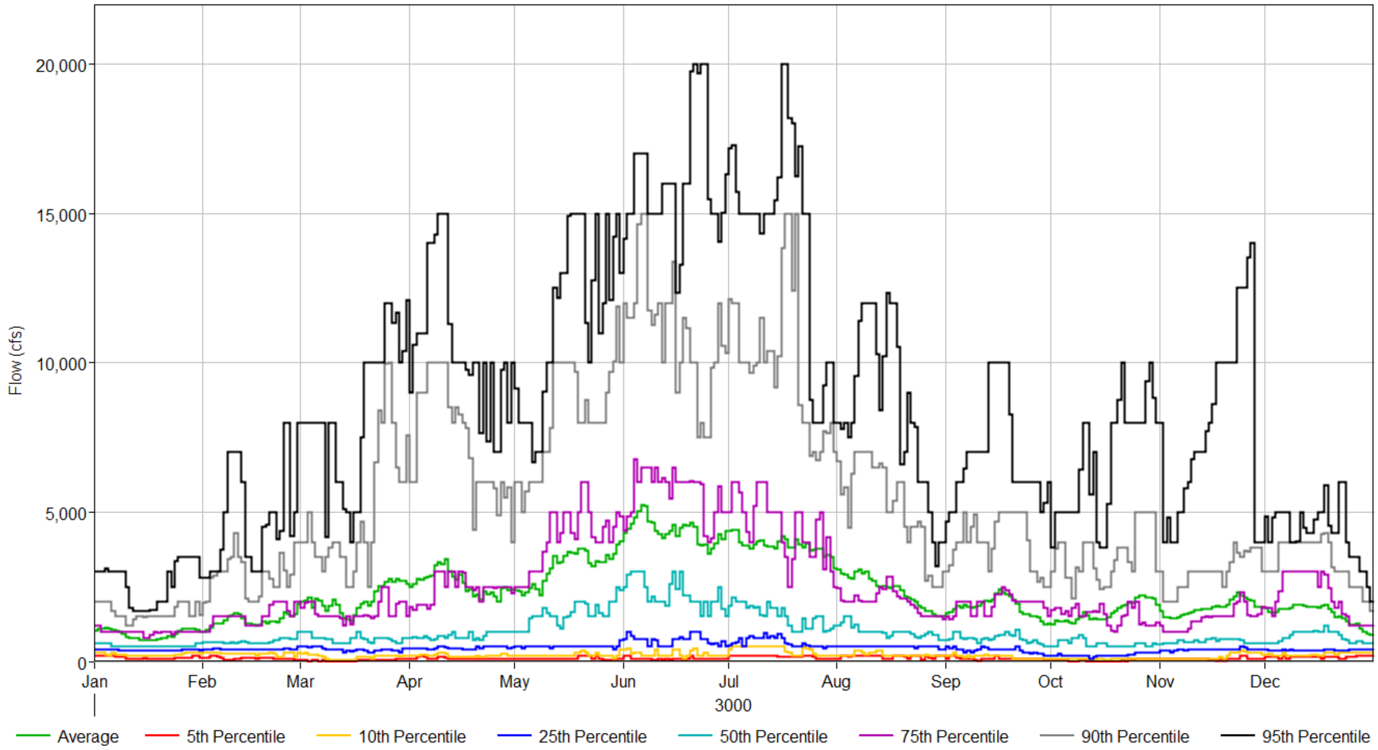


Figure 4-90. Tuttle Creek outflow statistics for the observed data from first fill Jul 1959 to Dec 2021.

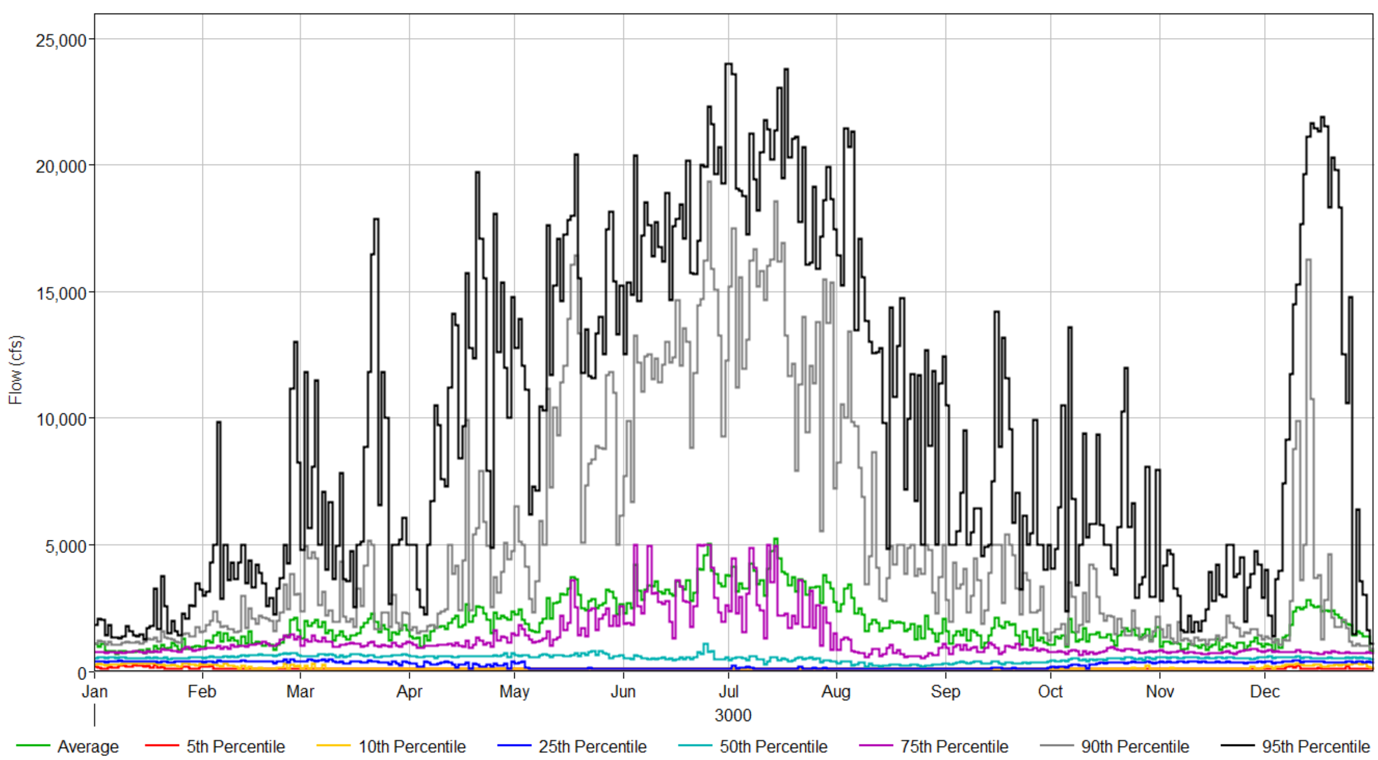


Figure 4-91. Tuttle Creek outflow statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

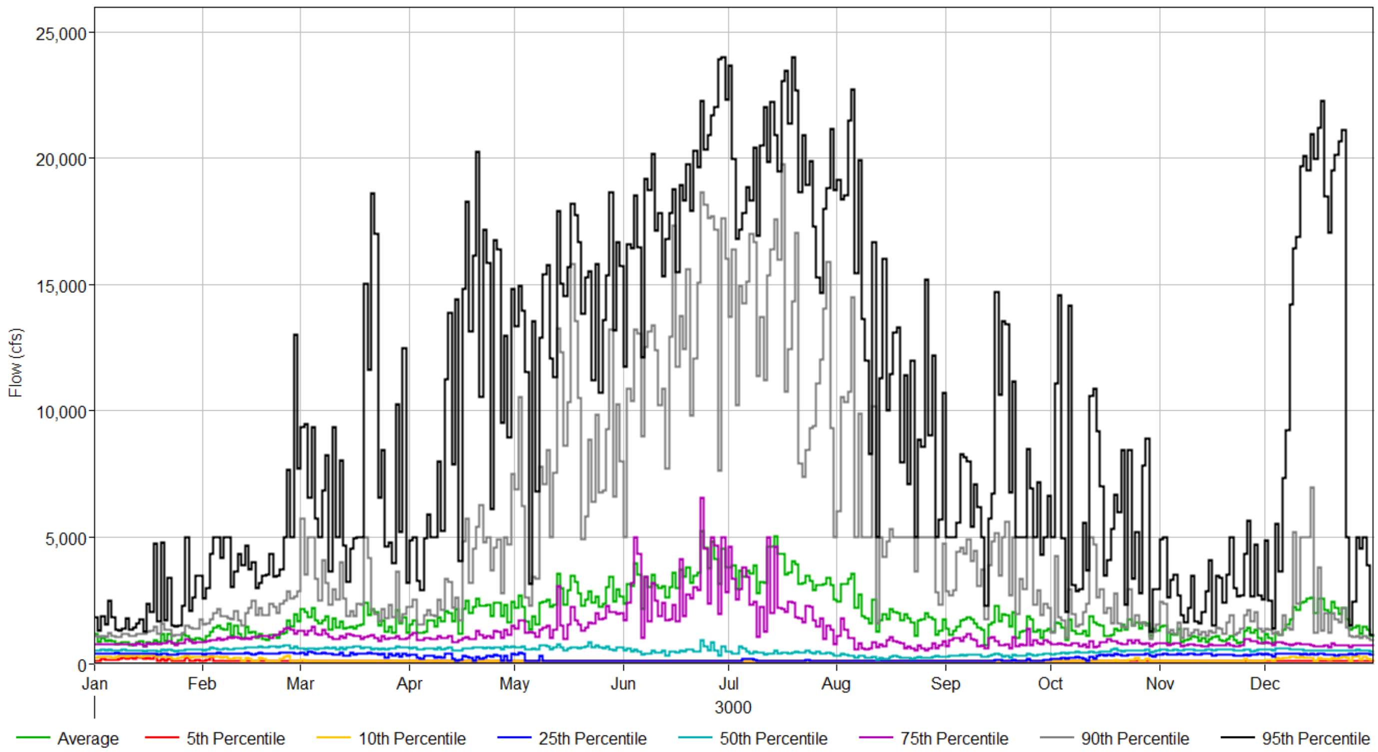


Figure 4-92. Tuttle Creek outflow statistics for the 100-year FWOP at 2024 sediment conditions.

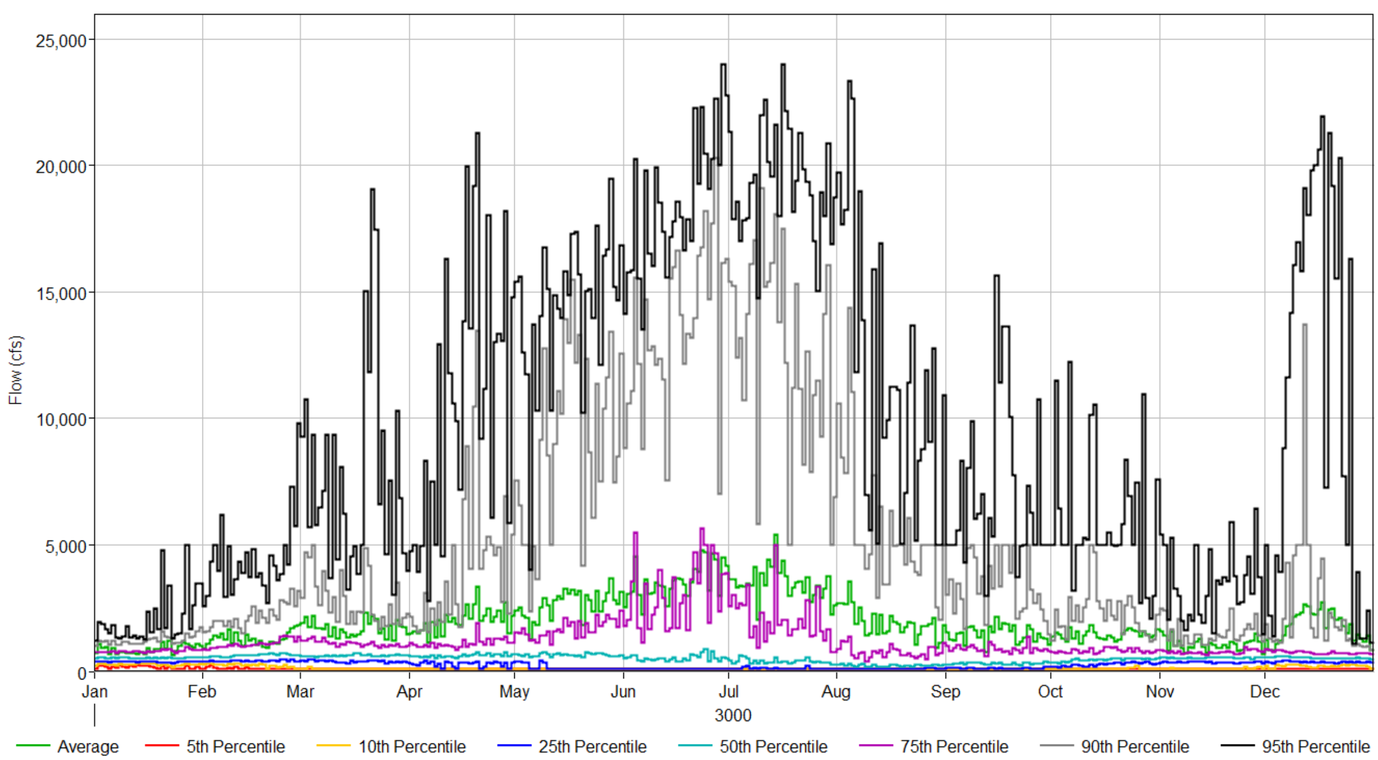


Figure 4-93. Tuttle Creek outflow statistics for the 100-year FWOP at 2049 sediment conditions.

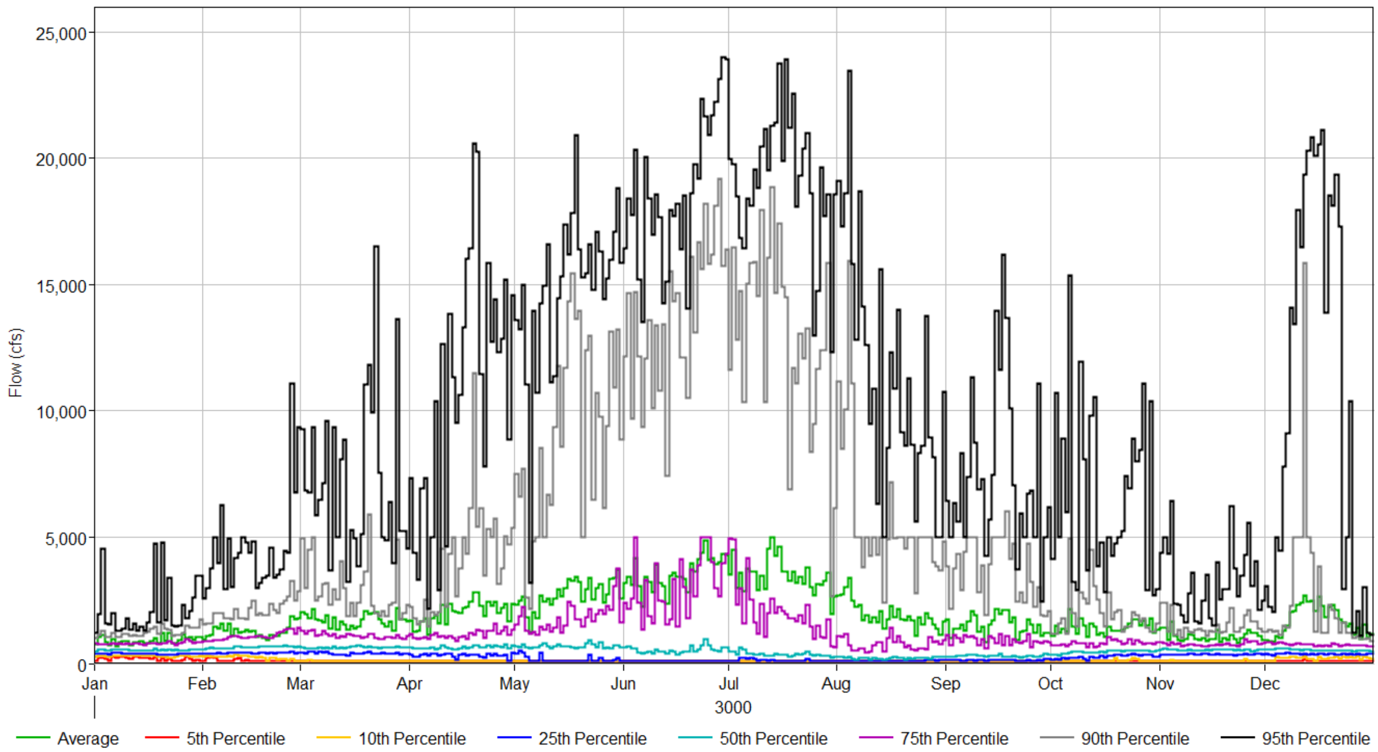


Figure 4-94. Tuttle Creek outflow statistics for the 100-year FWOP at 2074 sediment conditions.

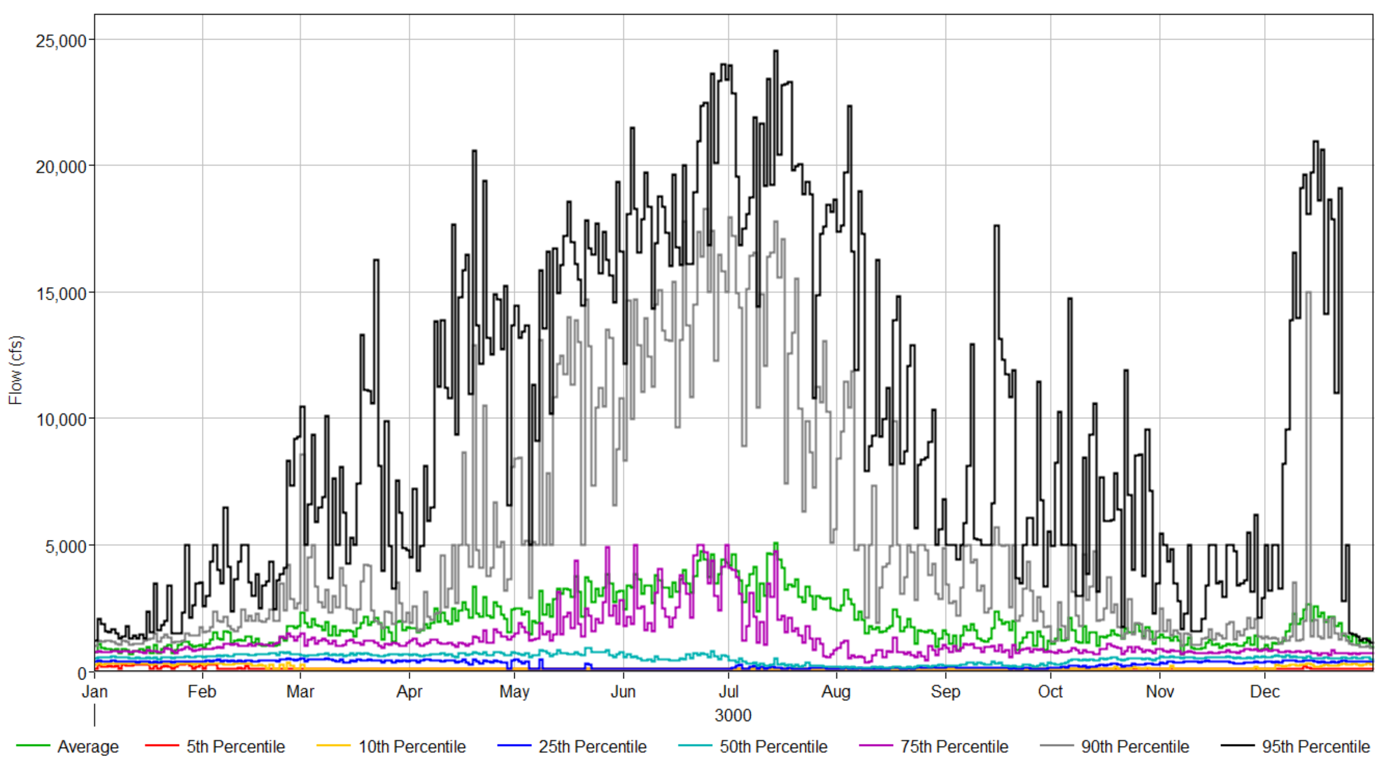


Figure 4-95. Tuttle Creek outflow statistics for the 100-year FWOP at 2124 sediment conditions.

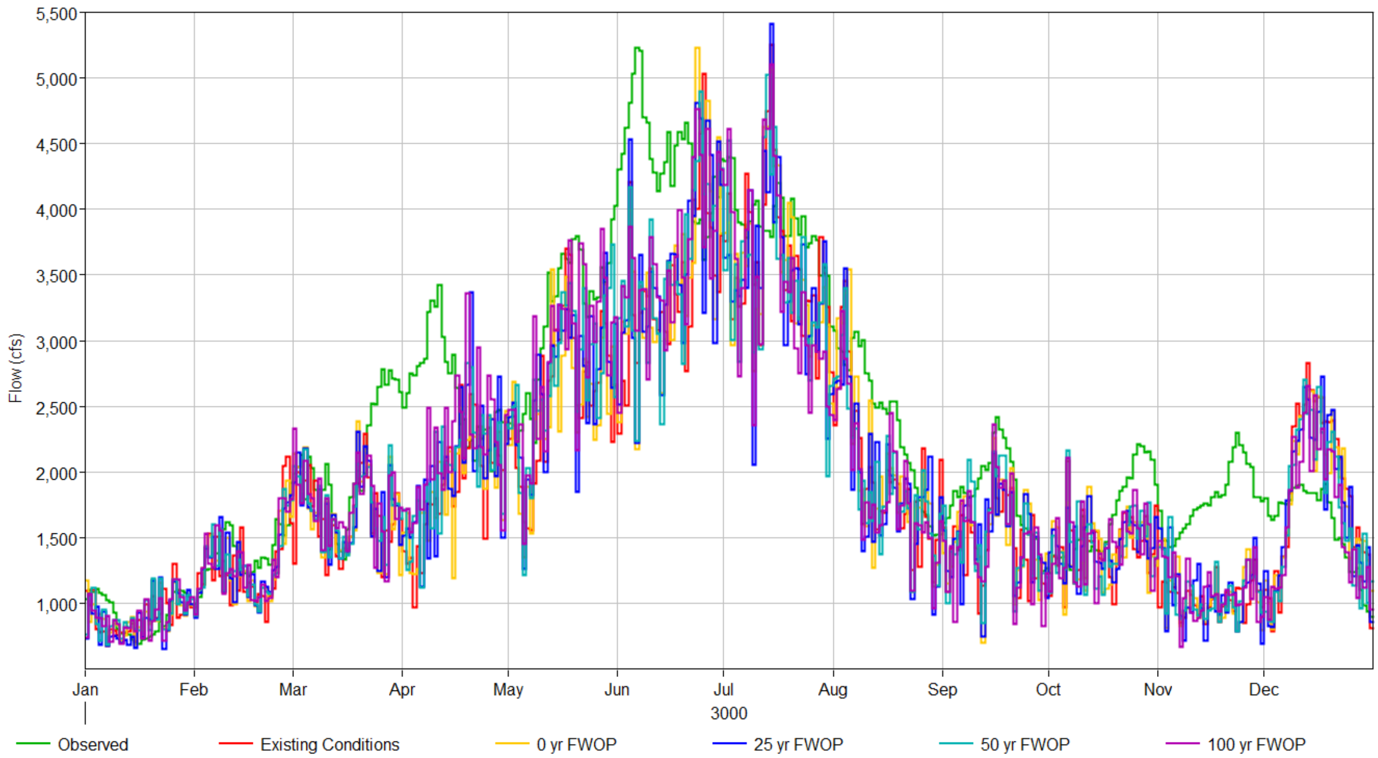


Figure 4-96. Daily average Tuttle Creek outflow for each set of data.

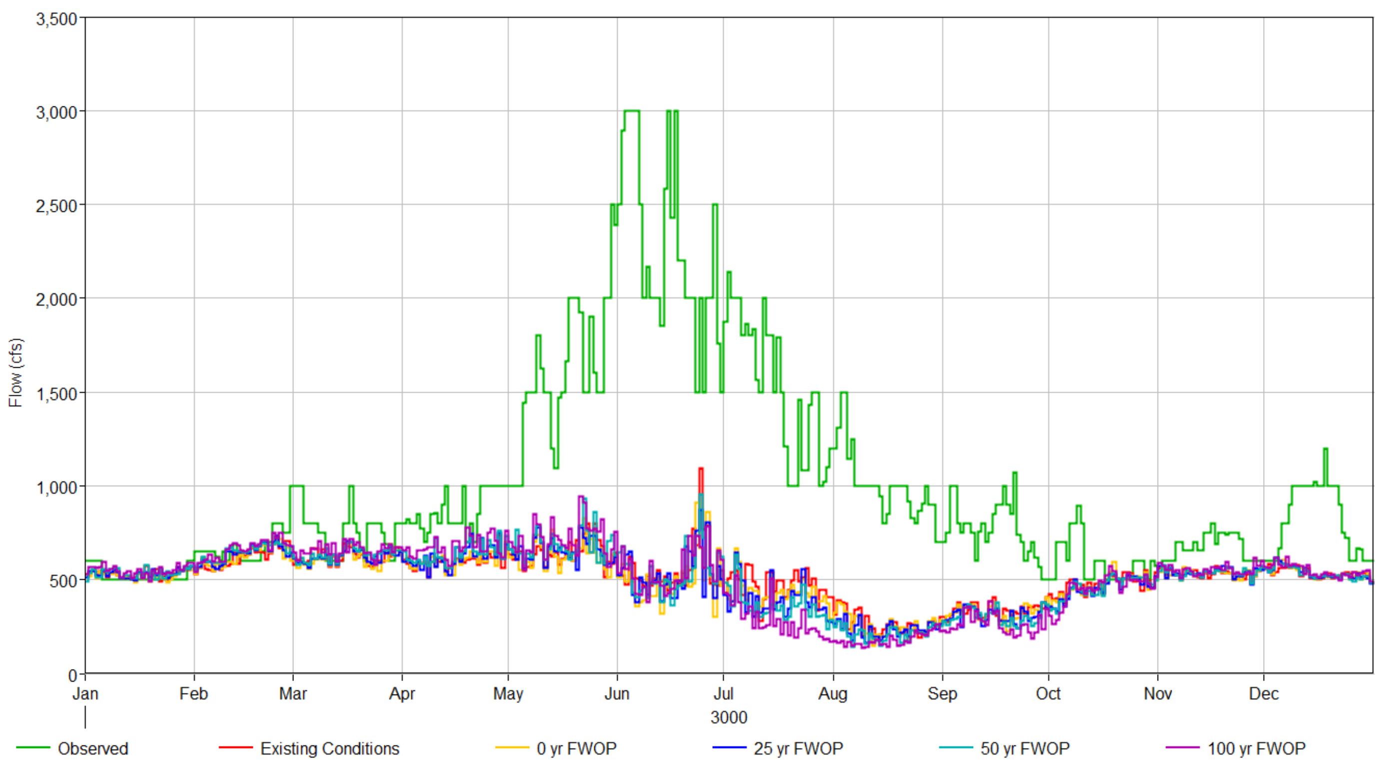


Figure 4-97. Daily median (50th Percentile) Tuttle Creek flow for each set of data.

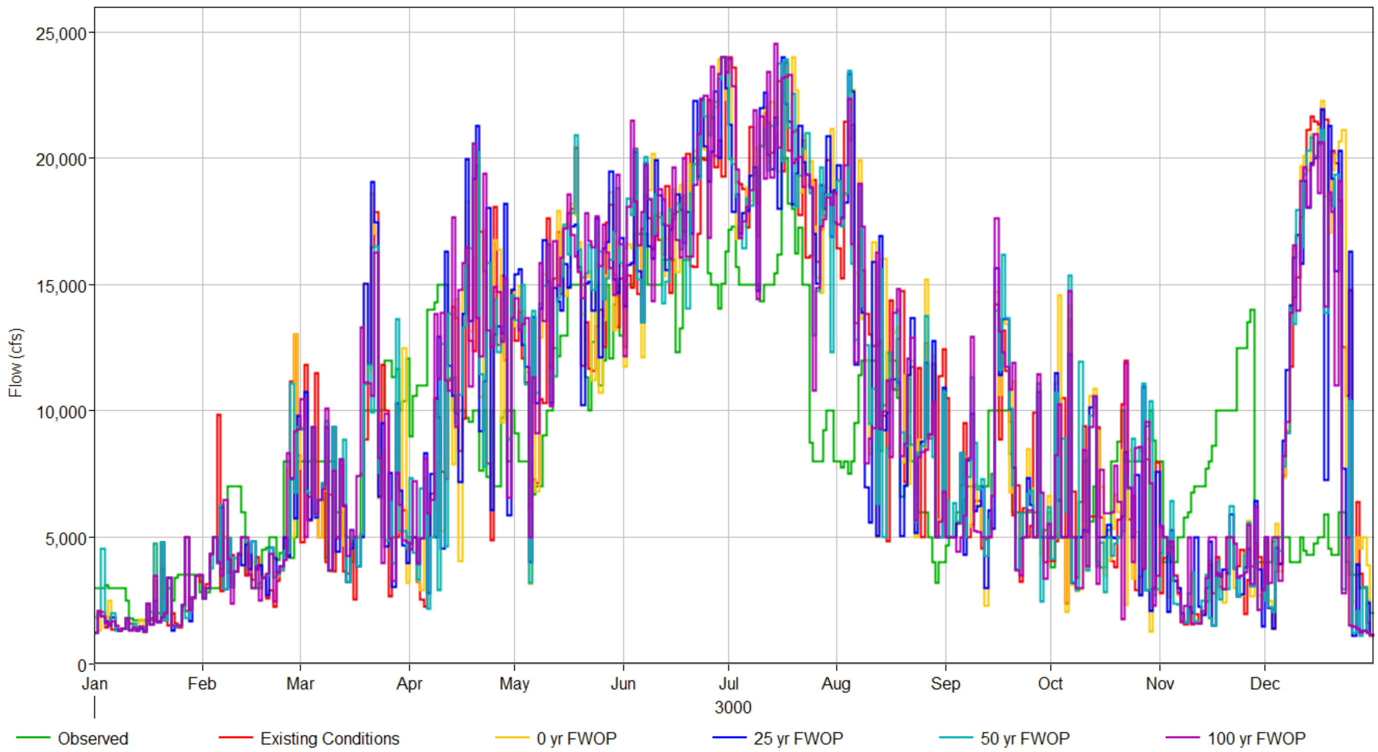


Figure 4-98. Daily 95th Percentile Tuttle Creek flow for each set of data.

The pool elevation duration is shown in Figure 4-99. It shows increased frequency in the flood control pool and lessening drops into the multi-purpose pool as the storage diminishes due to sedimentation.

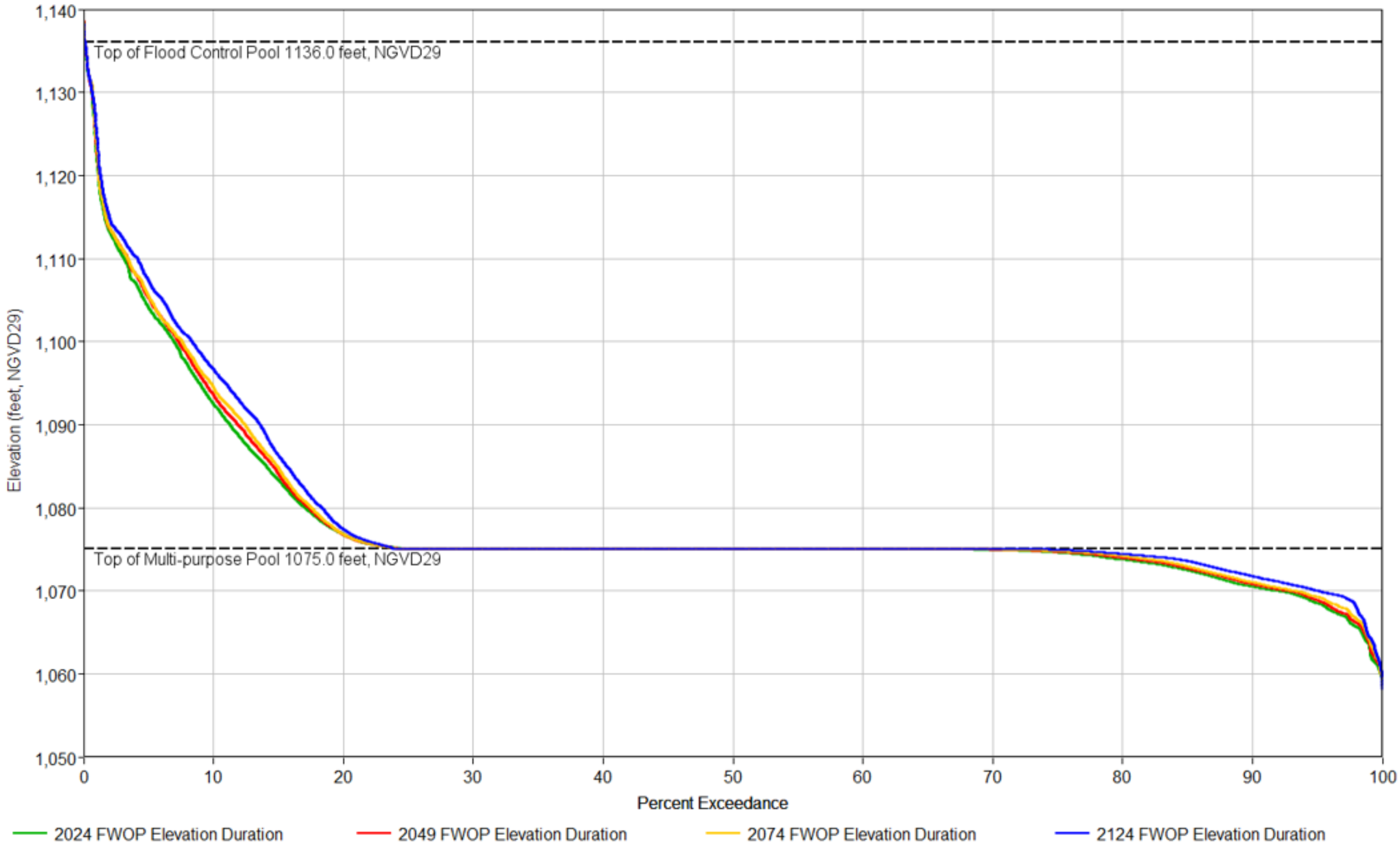


Figure 4-99. Tuttle Creek pool elevation duration for the four non-navigation FWOP scenarios.

Navigation flow support is provided from Tuttle Creek in all four FWOP navigation scenarios. This results in increased frequency of pool elevations below the multi-purpose pool. High pool elevations are unchanged. Figure 4-100 to Figure 4-103 show the pool duration plots for the FWOP scenarios with and without navigation. As the sediment increases the pool does not drop as far into the multi-purpose pool because there is simply not as much depth. The decreasing storage as results in the pool rising into the lower portions of the flood control pool more often.

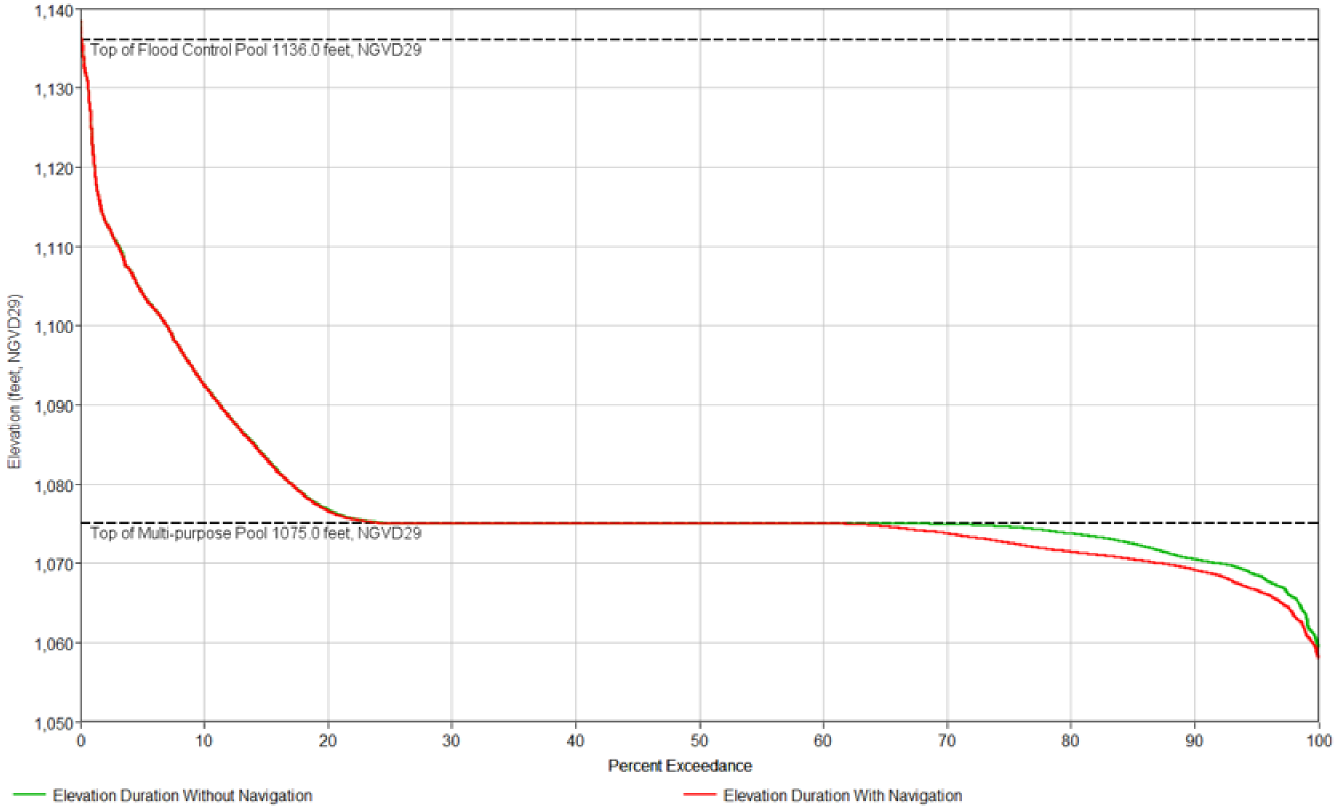


Figure 4-100. Tuttle Creek 2024 FWOP pool elevation duration with and without navigation.

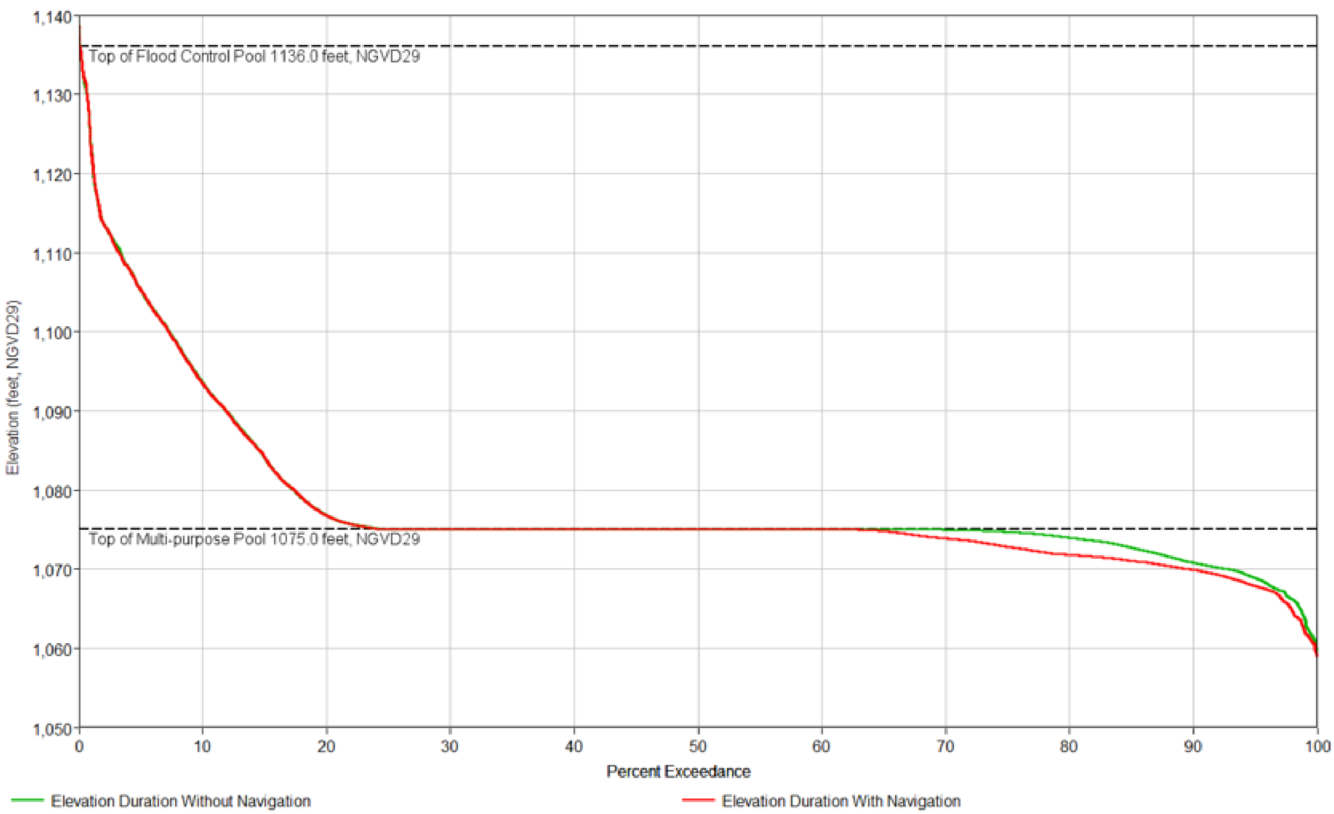


Figure 4-101. Tuttle Creek 2049 FWOP pool elevation duration with and without navigation.

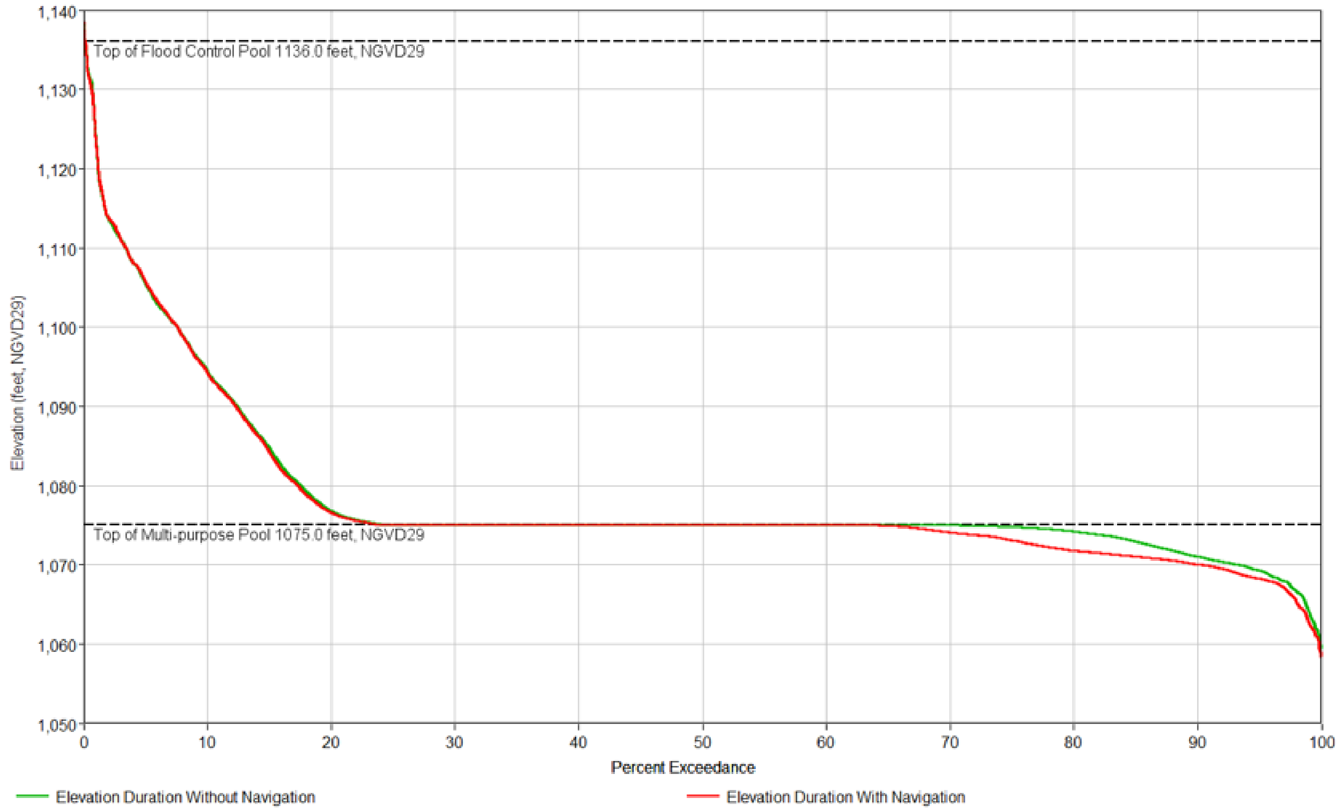


Figure 4-102. Tuttle Creek 2074 FWOP pool elevation duration with and without navigation.

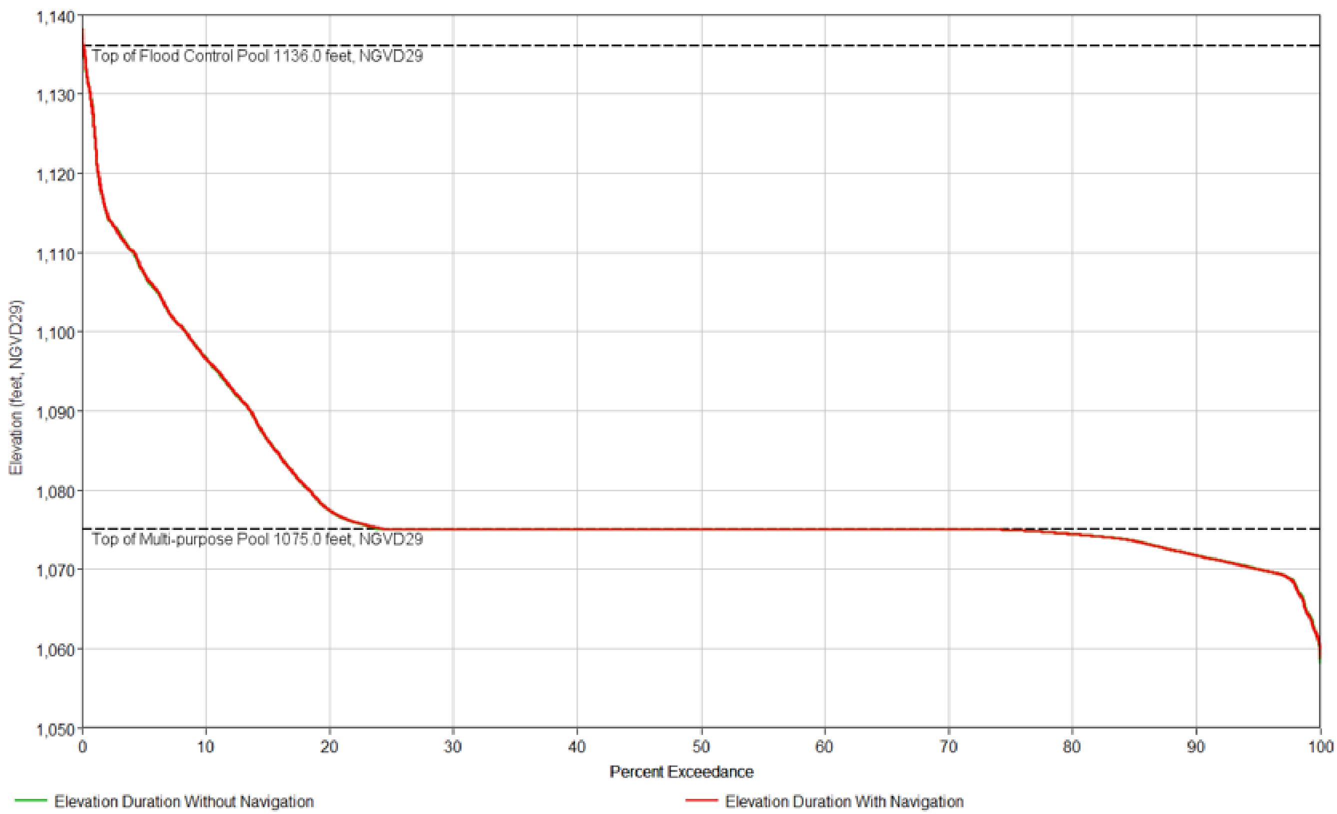


Figure 4-103. Tuttle Creek 2124 FWOP pool elevation duration with and without navigation.

4.1.6 Perry

Perry observed data is from first fill of June 1970 through November 2021. The Perry family of curves are shown in Figure 4-104 to Figure 4-121. The median modeled pool elevation tends to be near the top of the multi-purpose pool since that was used as the guide curve in HEC-ResSim but is slightly higher for in the summer months. Median observed pool elevation is more variable with some pool raises and drawdowns as part of the routine operations. All the model scenarios have high pool elevations in 95th percentile data set as some years required constrained releases in flood control operations for the Missouri River at Waverly. The observed data set does not have as extensive high pool elevations because deviations were utilized in the real-time operations.

Average time series were compared for each scenario. The observed and modeled data mostly matches, but the observed is lower in the summer months. This may be because deviations were utilized in some large flood years to lower the pool elevation. There are not significant differences between the FWOP scenarios, but as sediment increases, the pool elevations tend higher during flood season because of reduced storage in the multi-purpose pool. As sediment increases, slightly lower pool elevations are seen in the drier winter months because the multi-purpose pool drops quicker when making releases for water quality targets.

The modeled outflow data reasonably matches the observed data. The average daily modeled outflow is a bit lower during June. The median modeled data was significantly lower than observed during the summer months and higher during most winter months. The December bump in 95th percentile observed releases and the January drop in median releases likely relate to winter drawdown as part of the water control plan. Outflows from all the FWOP scenarios were similar with no trends for varying flows based on future sediment conditions.

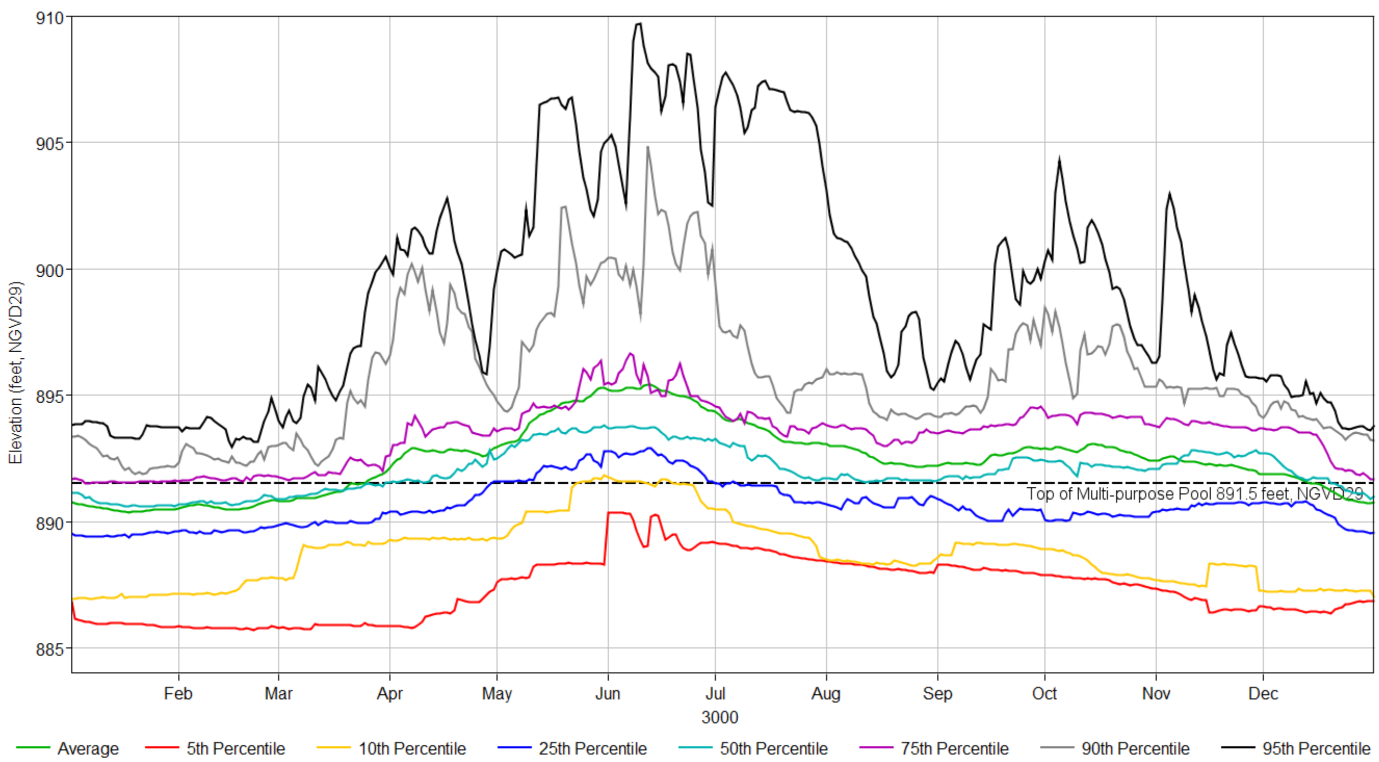


Figure 4-104. Perry pool elevation statistics for the observed data from first fill Jun 1970 to Dec 2021.

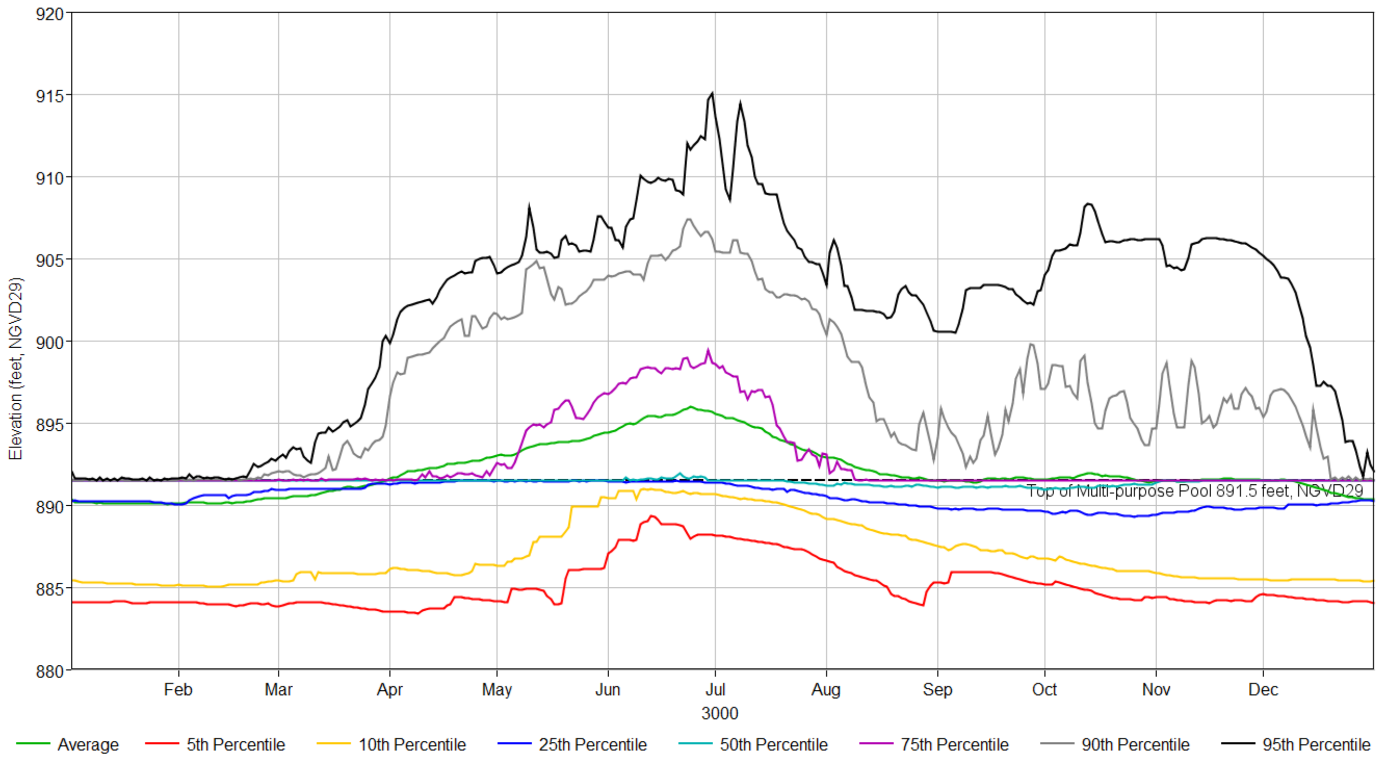


Figure 4-105. Perry pool elevation statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

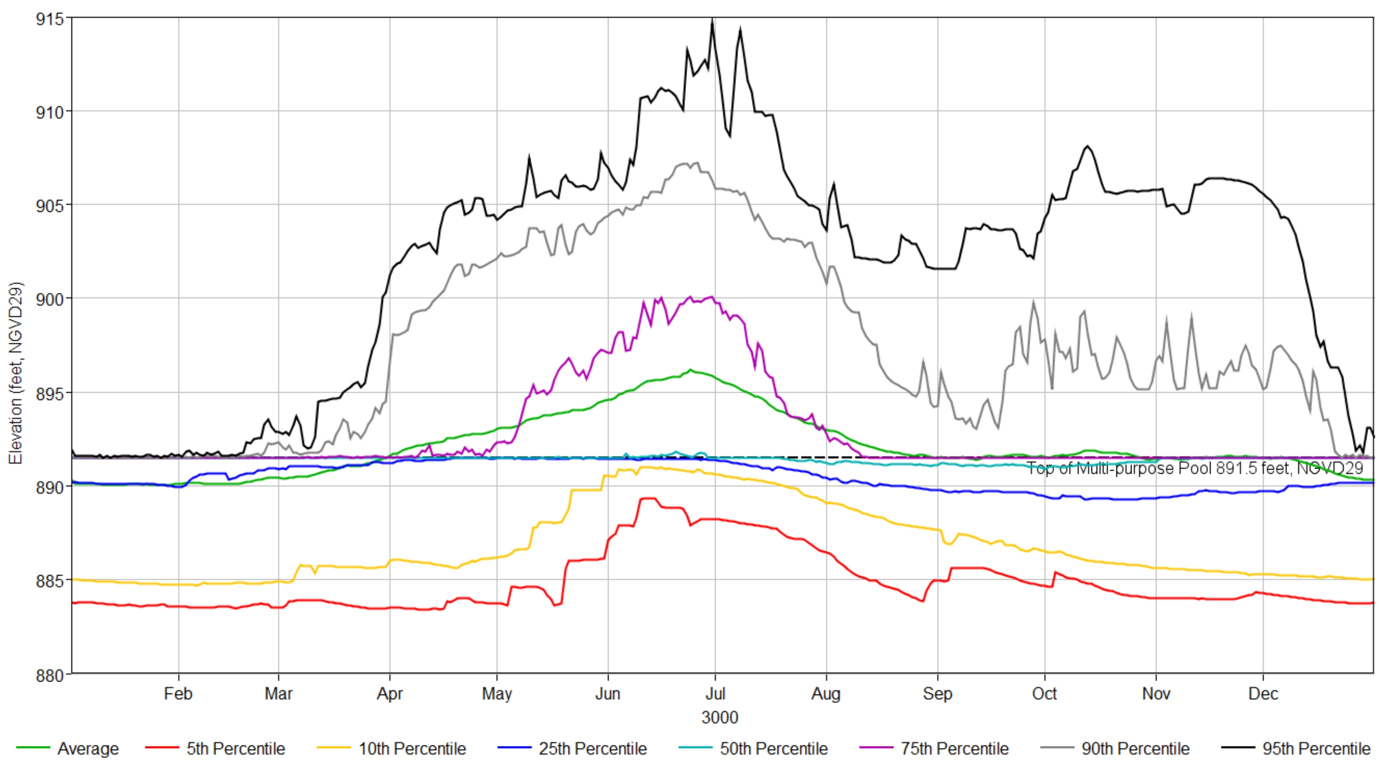


Figure 4-106. Perry pool elevation statistics for the 100-year FWOP at 2024 sediment conditions.

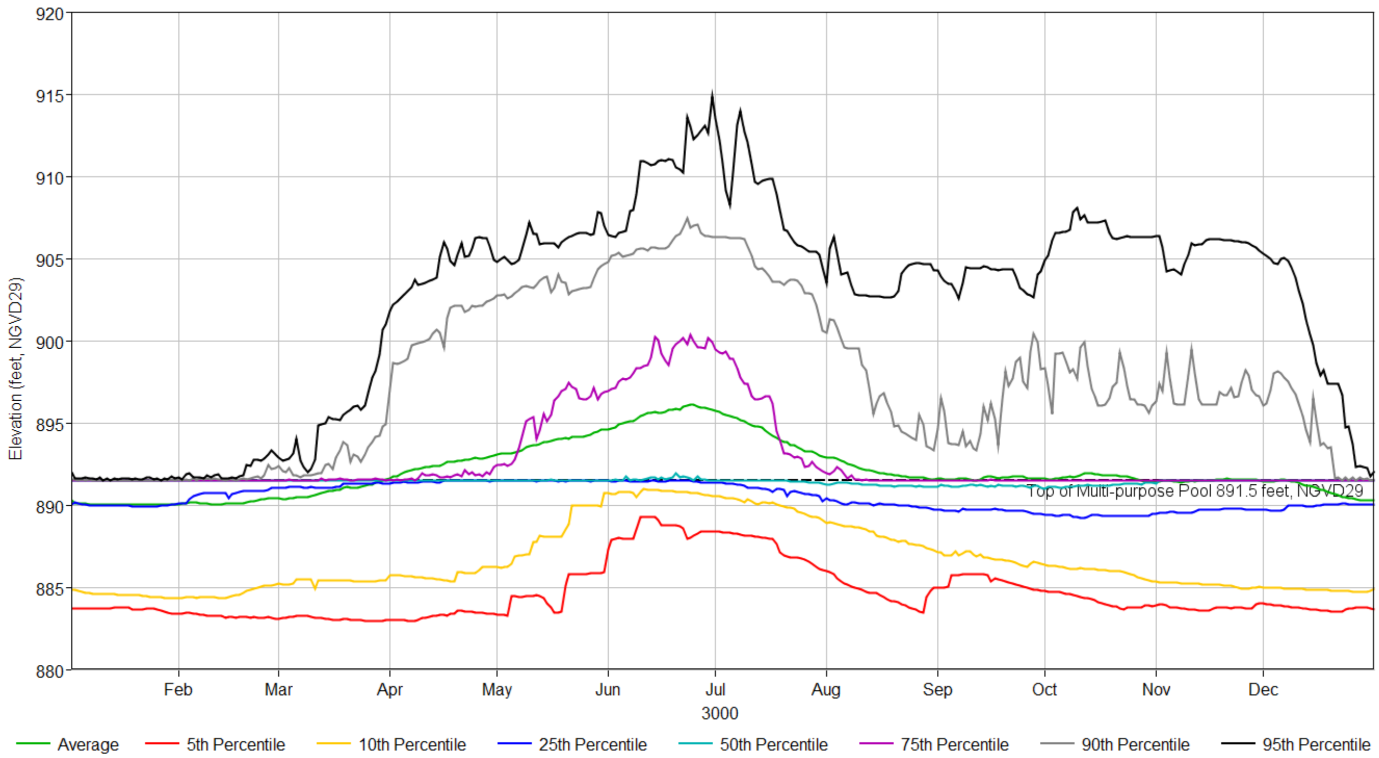


Figure 4-107. Perry pool elevation statistics for the 100-year FWOP at 2049 sediment conditions.

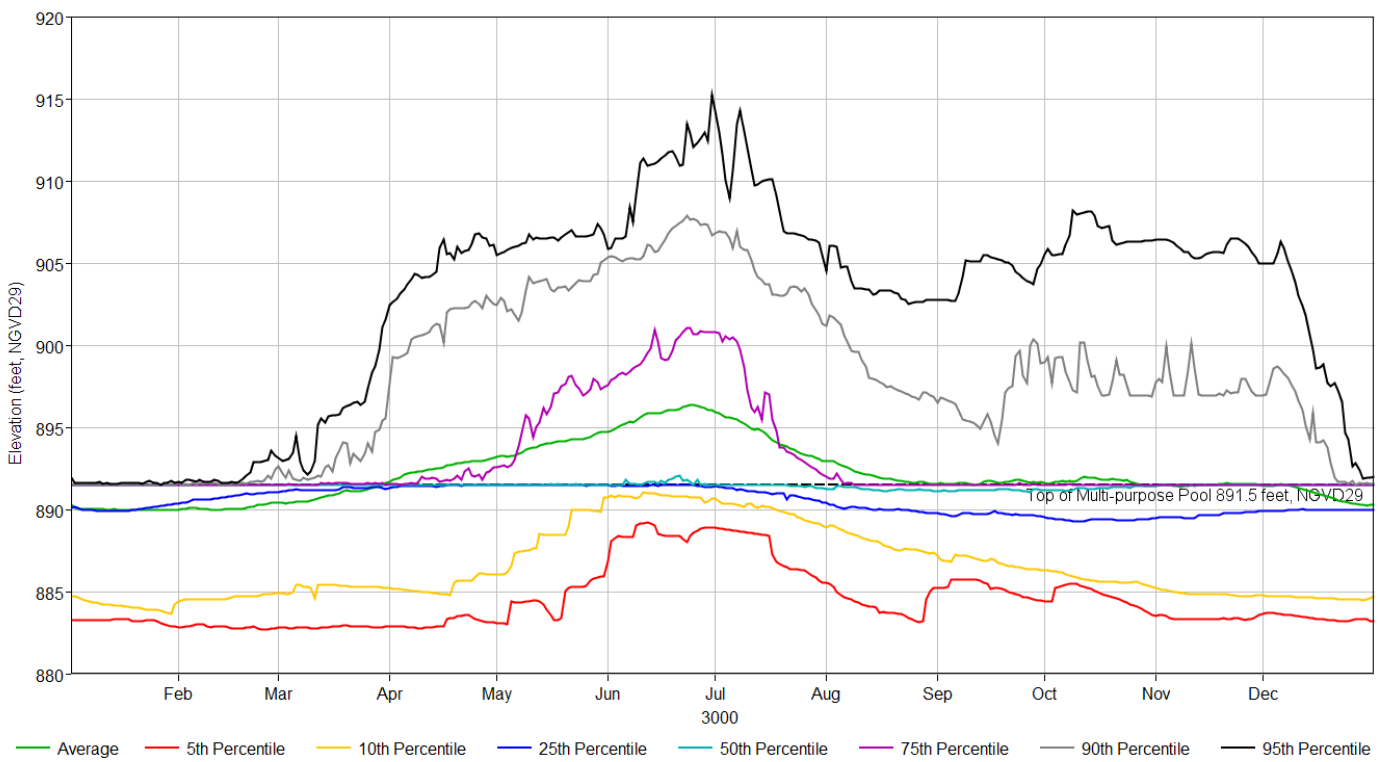


Figure 4-108. Perry pool elevation statistics for the 100-year FWOP at 2074 sediment conditions.

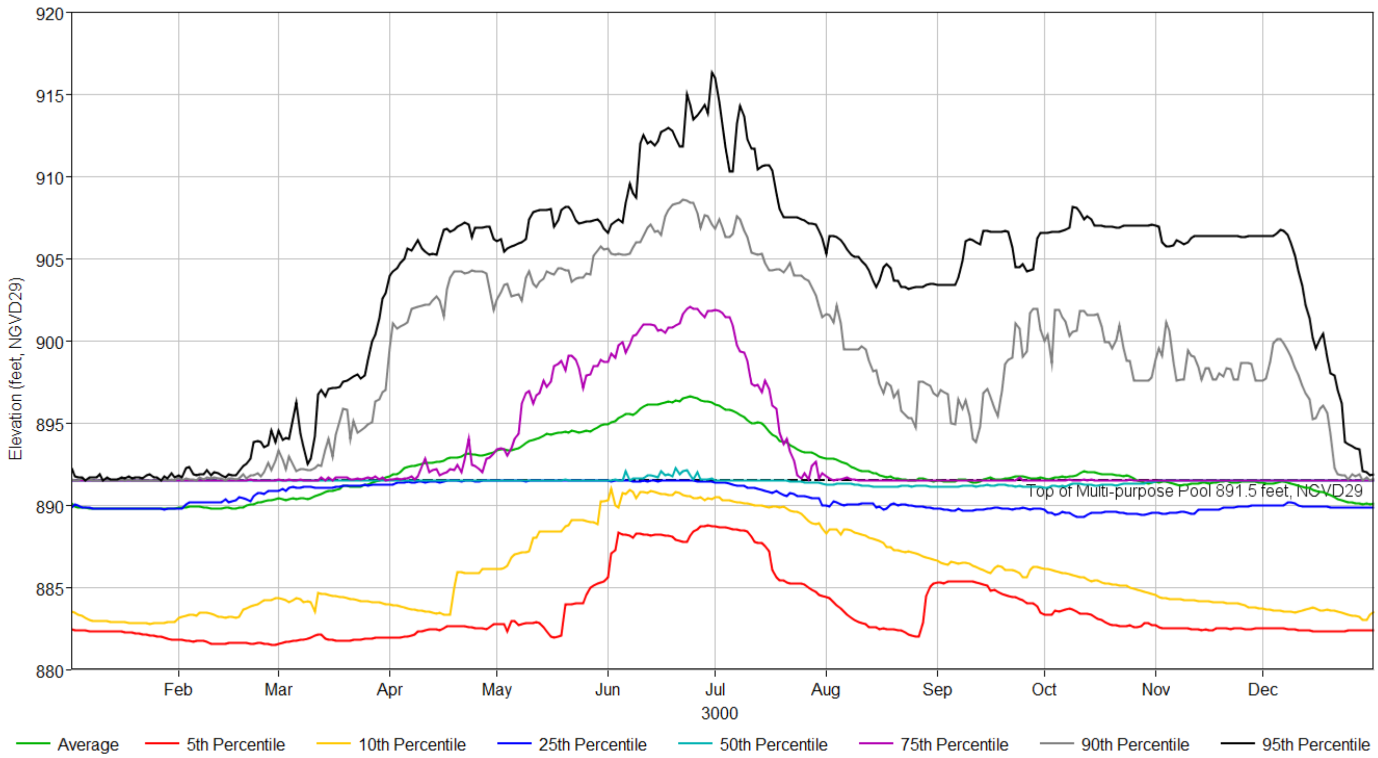


Figure 4-109. Perry pool elevation statistics for the 100-year FWOP at 2124 sediment conditions.

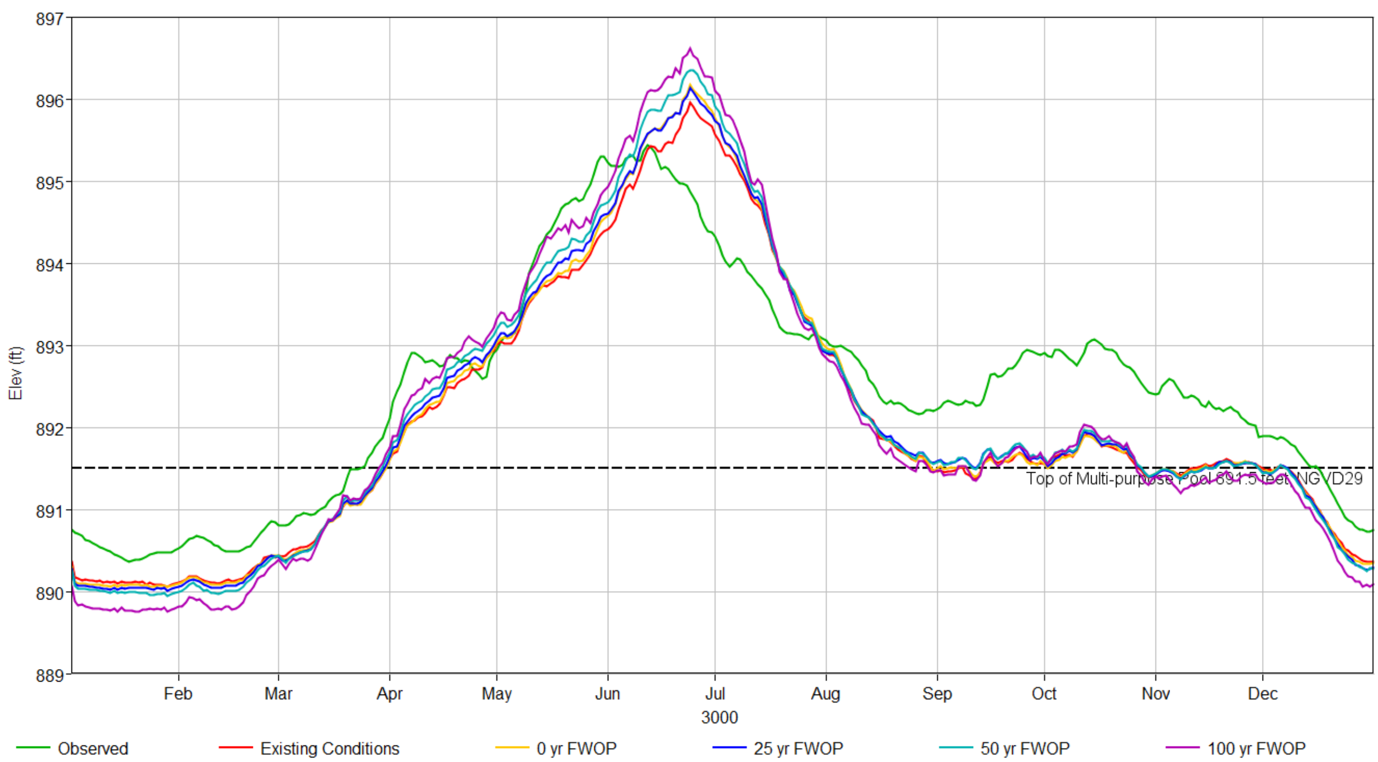


Figure 4-110. Daily average Perry pool elevation for each set of data.

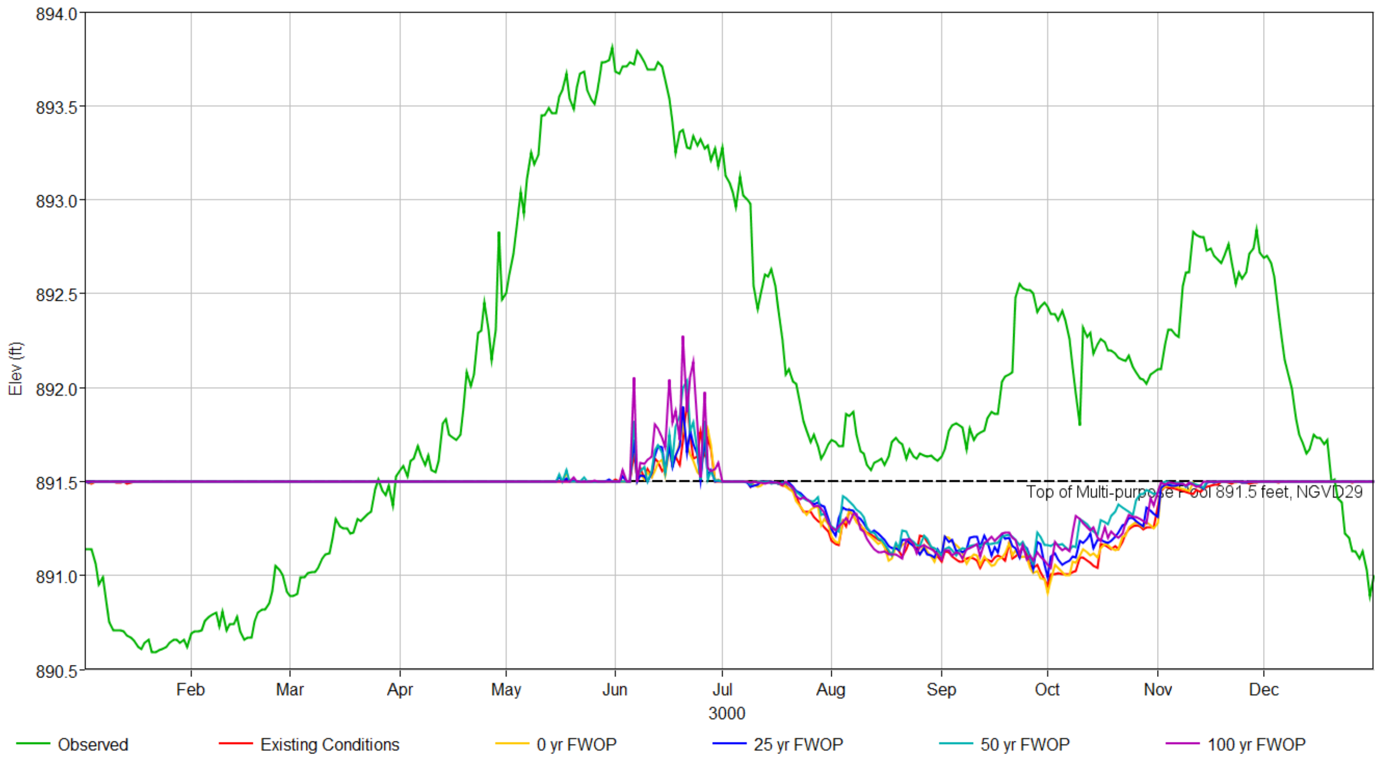


Figure 4-111. Daily median (50th Percentile) Perry pool elevation for each set of data.

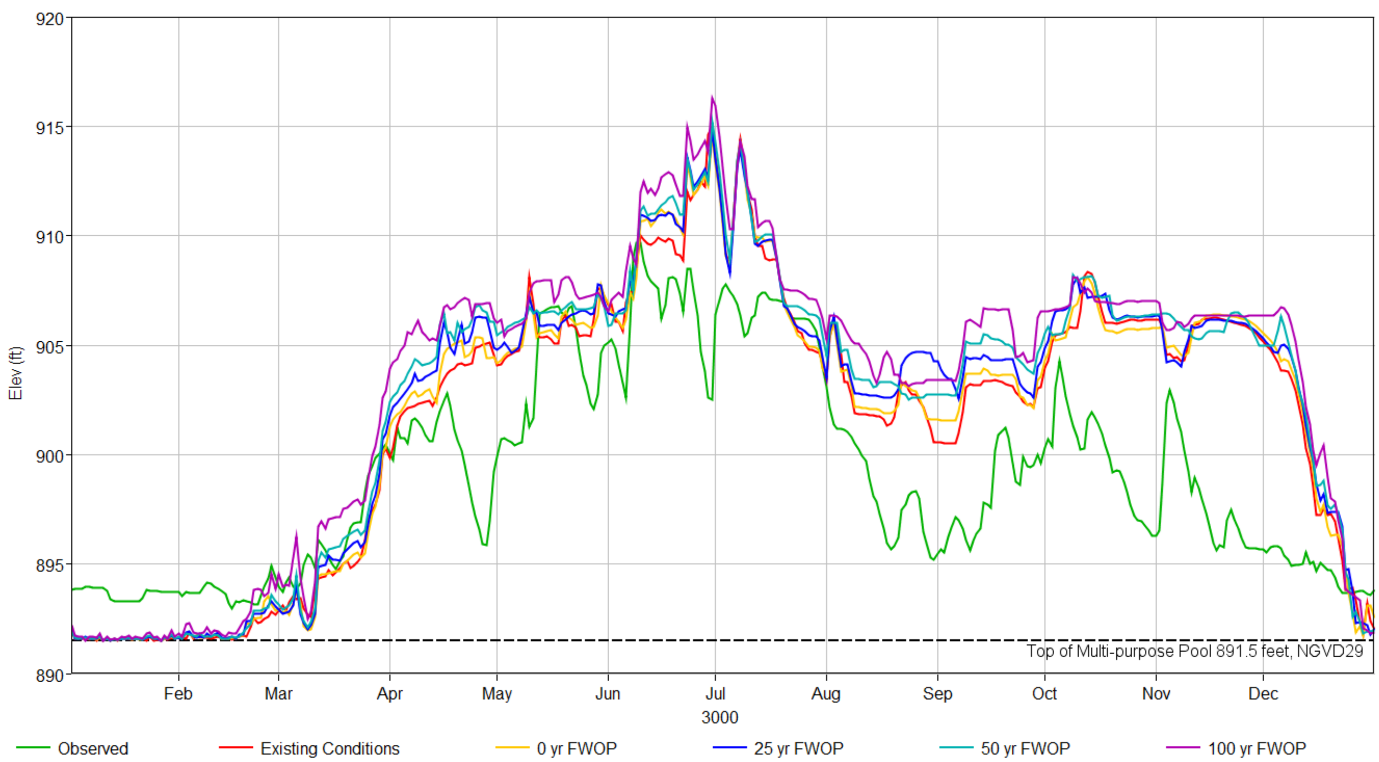


Figure 4-112. Daily 95th Percentile Perry pool elevation for each set of data.

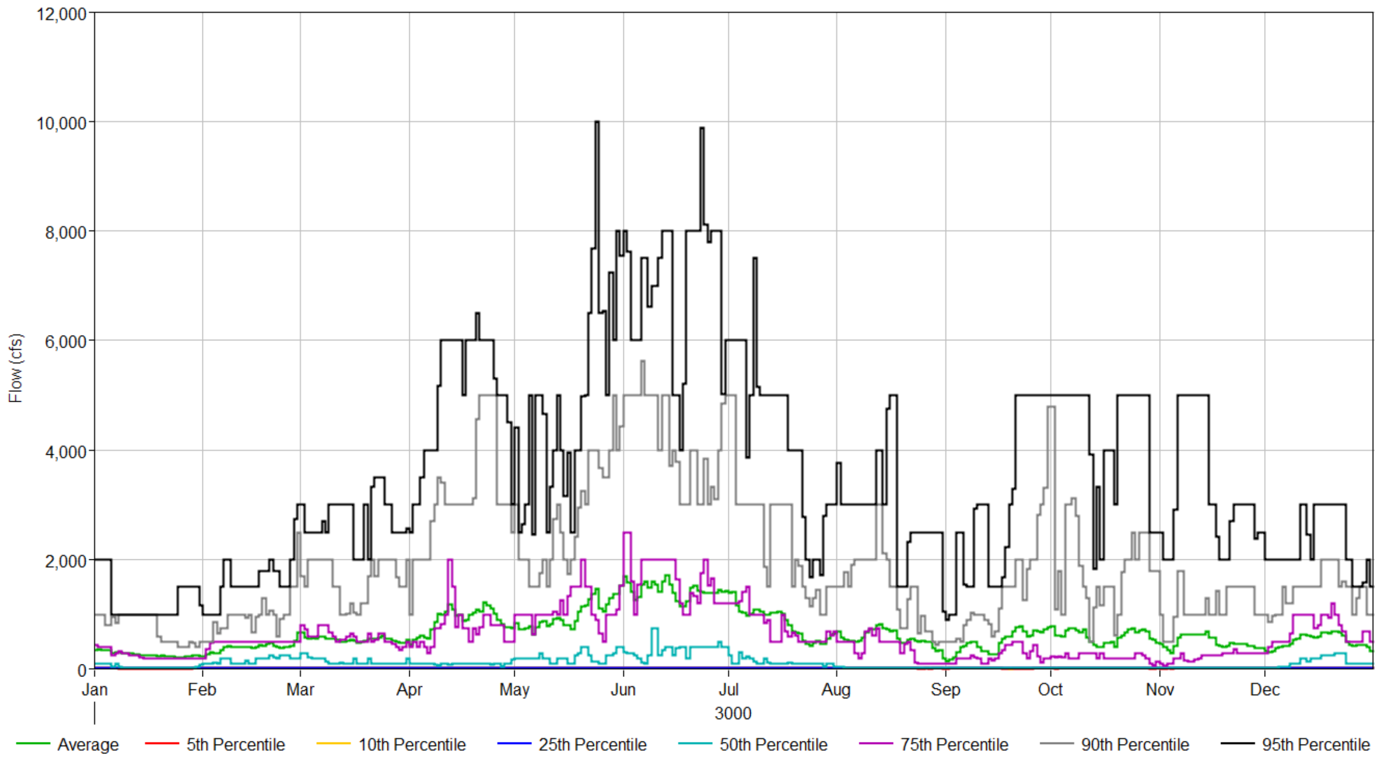


Figure 4-113. Perry outflow statistics for the observed data from the first fill Dec 1977 to Dec 2021.

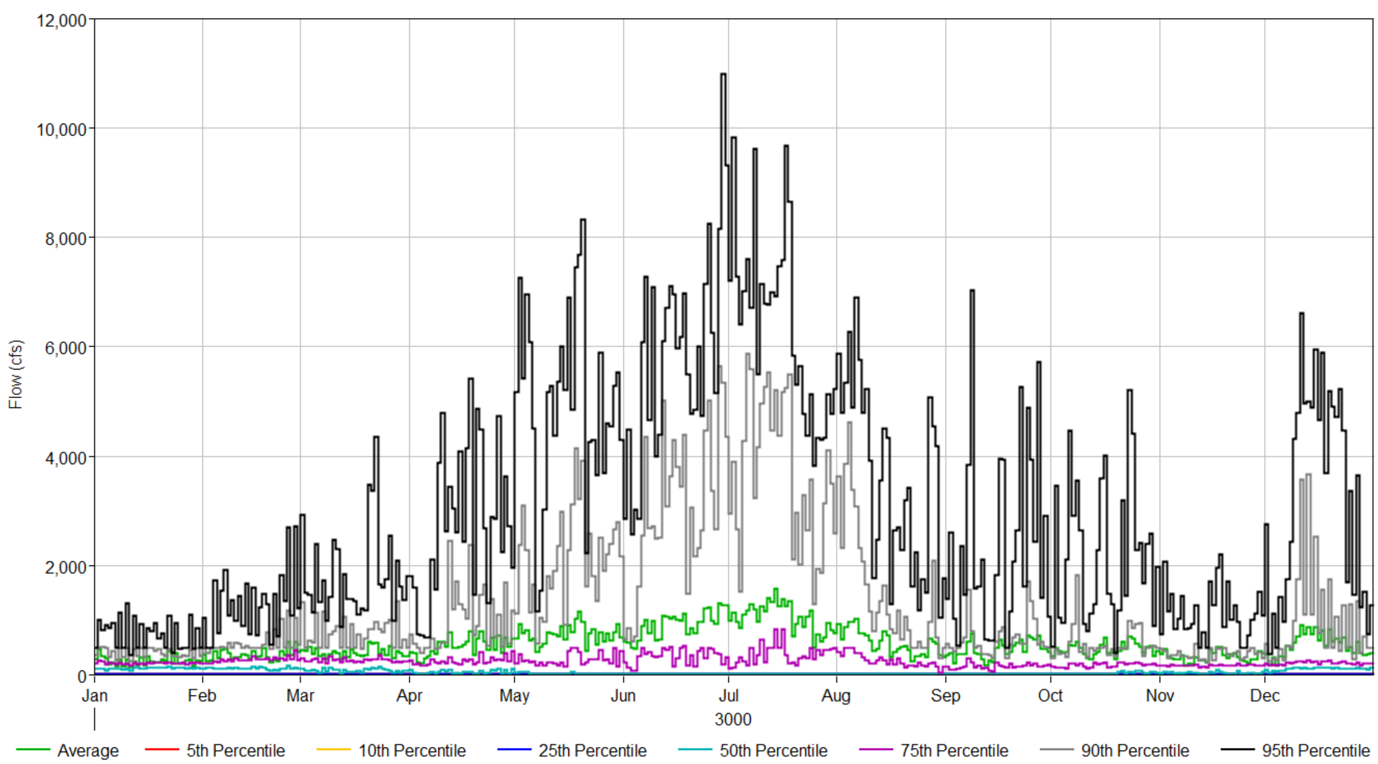


Figure 4-114. Perry outflow statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

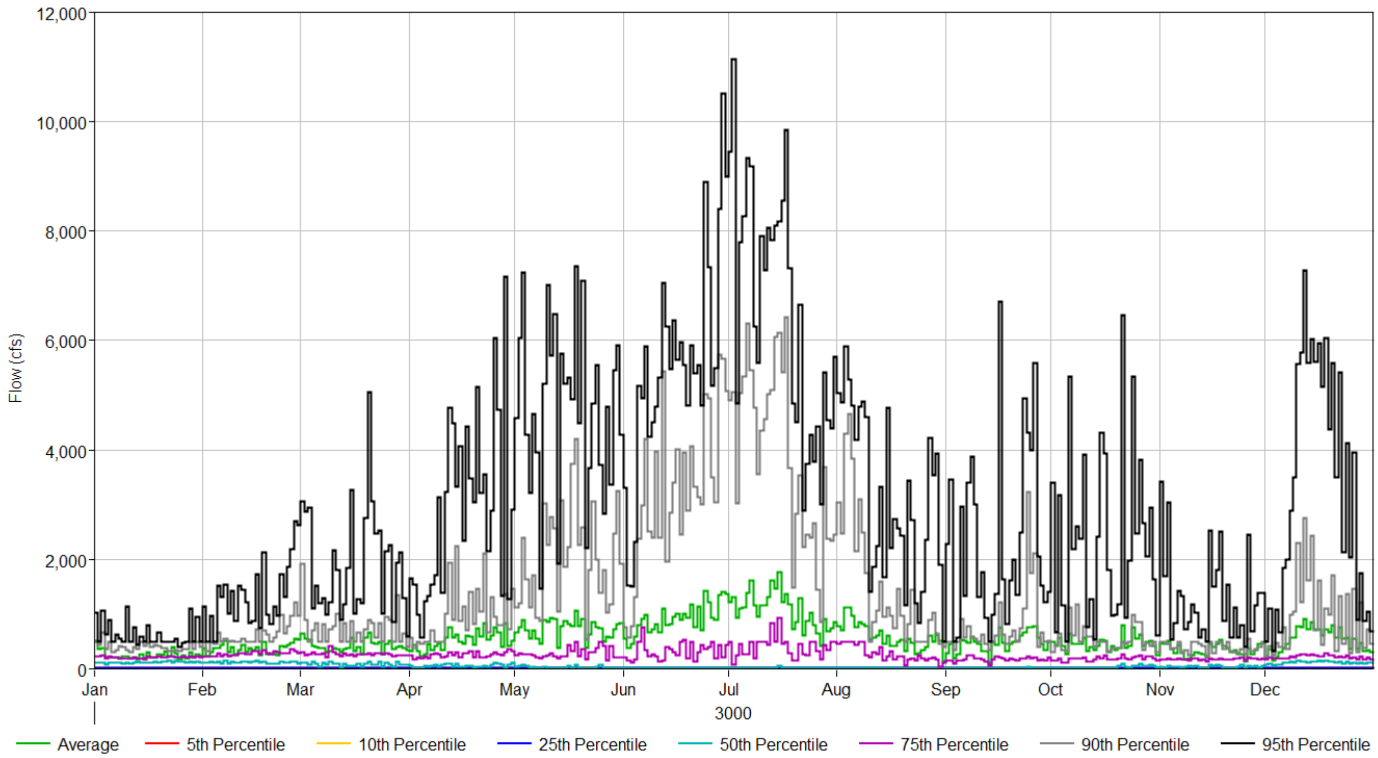


Figure 4-115. Perry outflow statistics for the 100-year FWOP at 2024 sediment conditions.

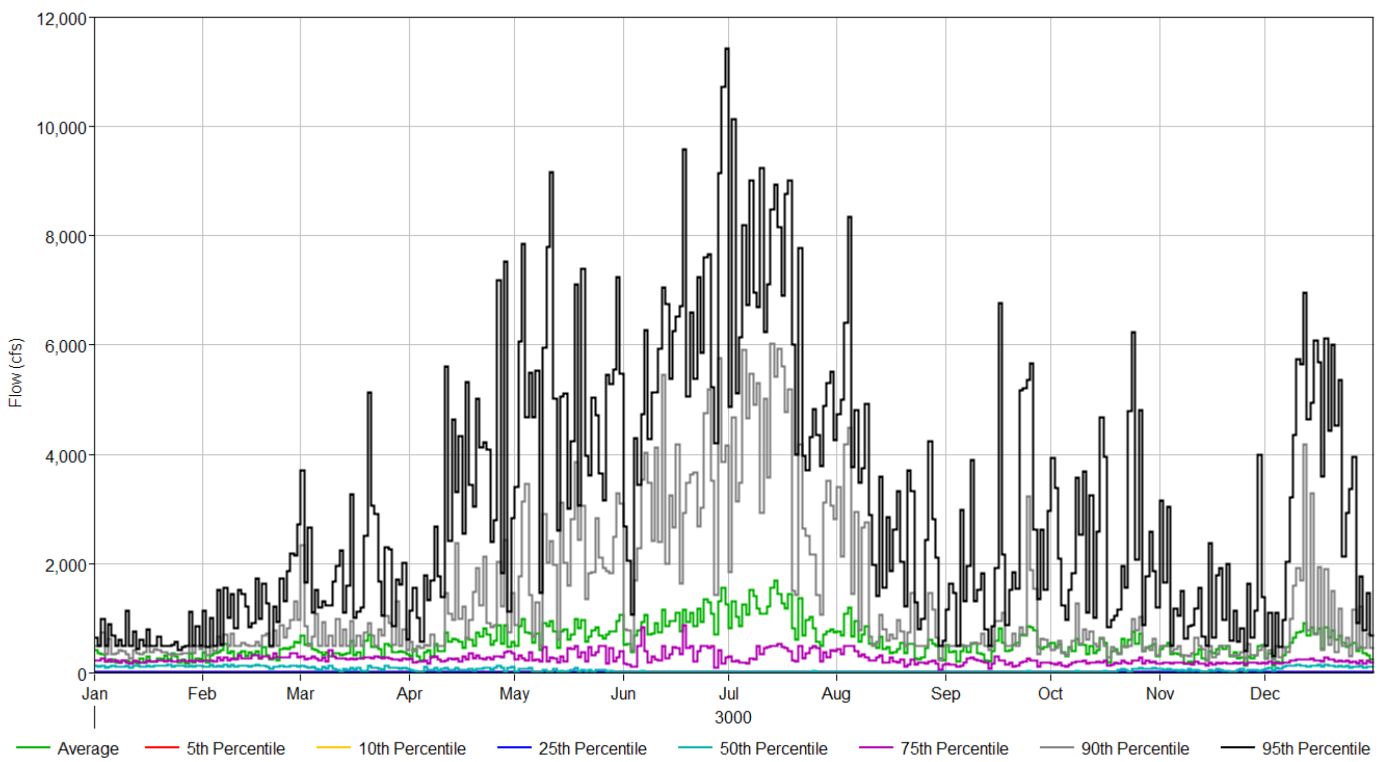


Figure 4-116. Perry outflow statistics for the 100-year FWOP at 2049 sediment conditions.

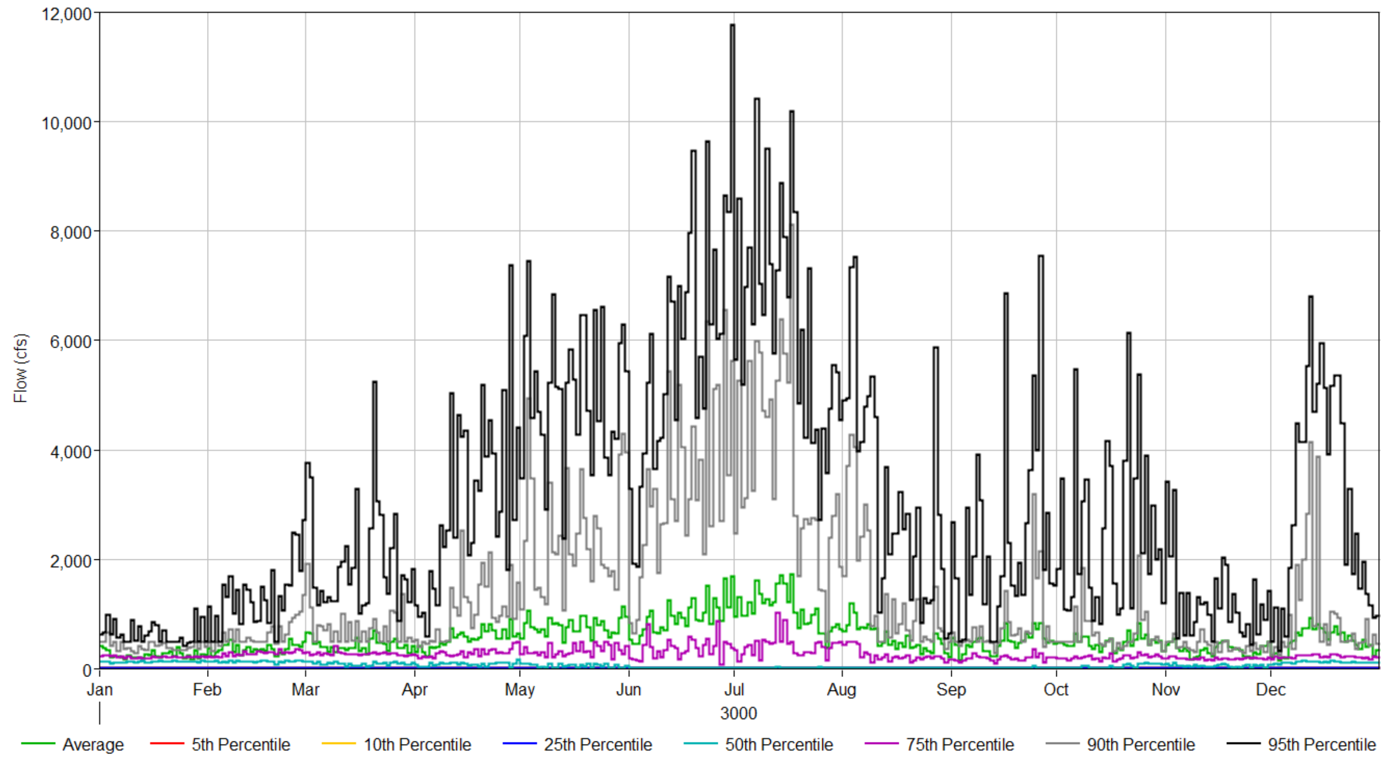


Figure 4-117. Perry outflow statistics for the 100-year FWOP at 2074 sediment conditions.

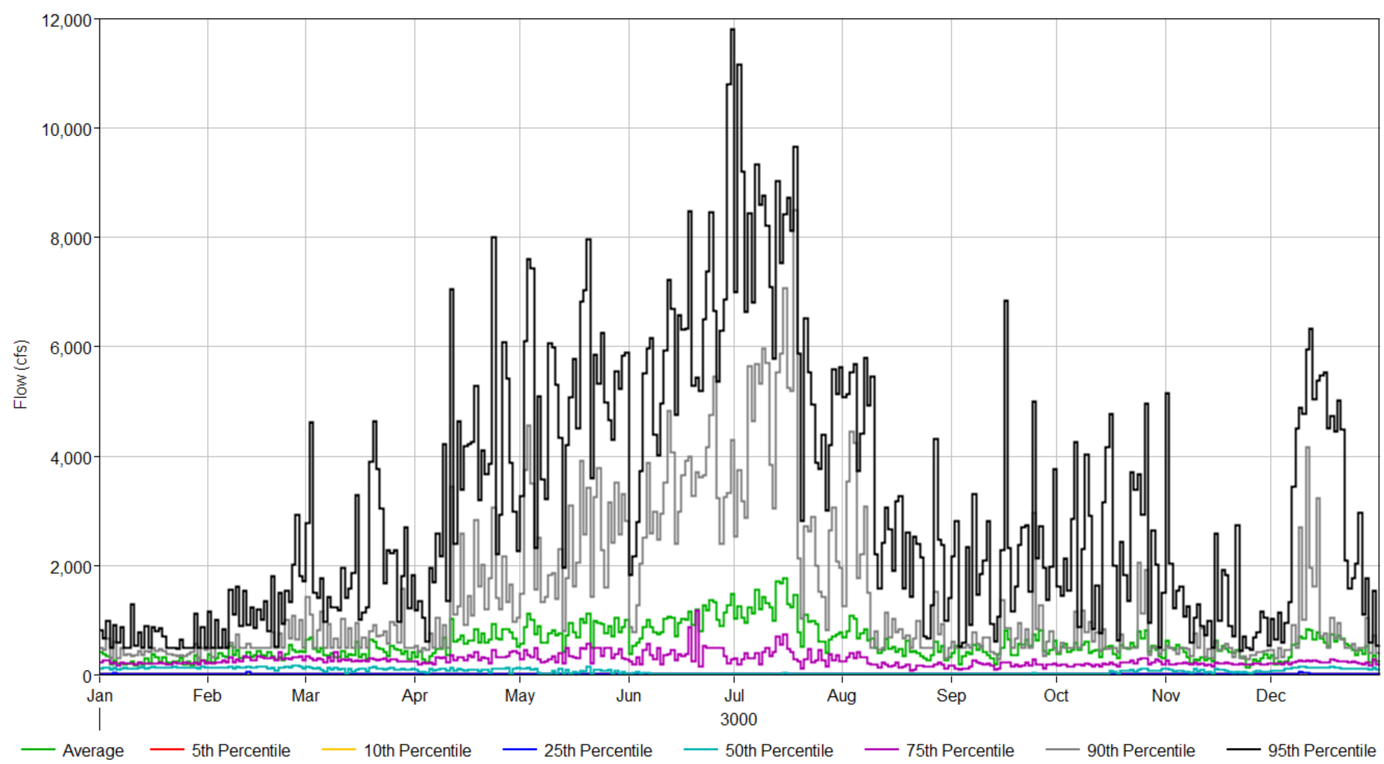


Figure 4-118. Perry outflow statistics for the 100-year FWOP at 2124 sediment conditions.

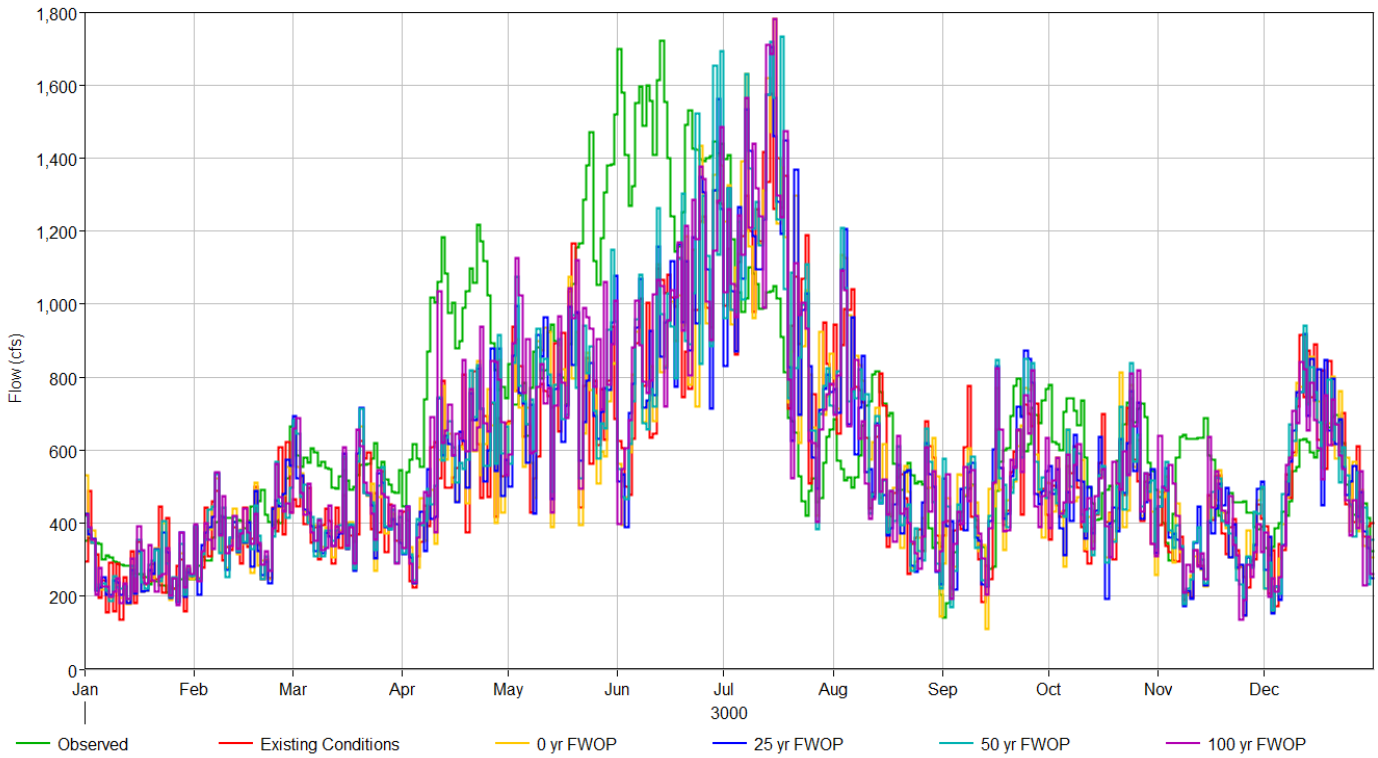


Figure 4-119. Daily average Perry outflow for each set of data..

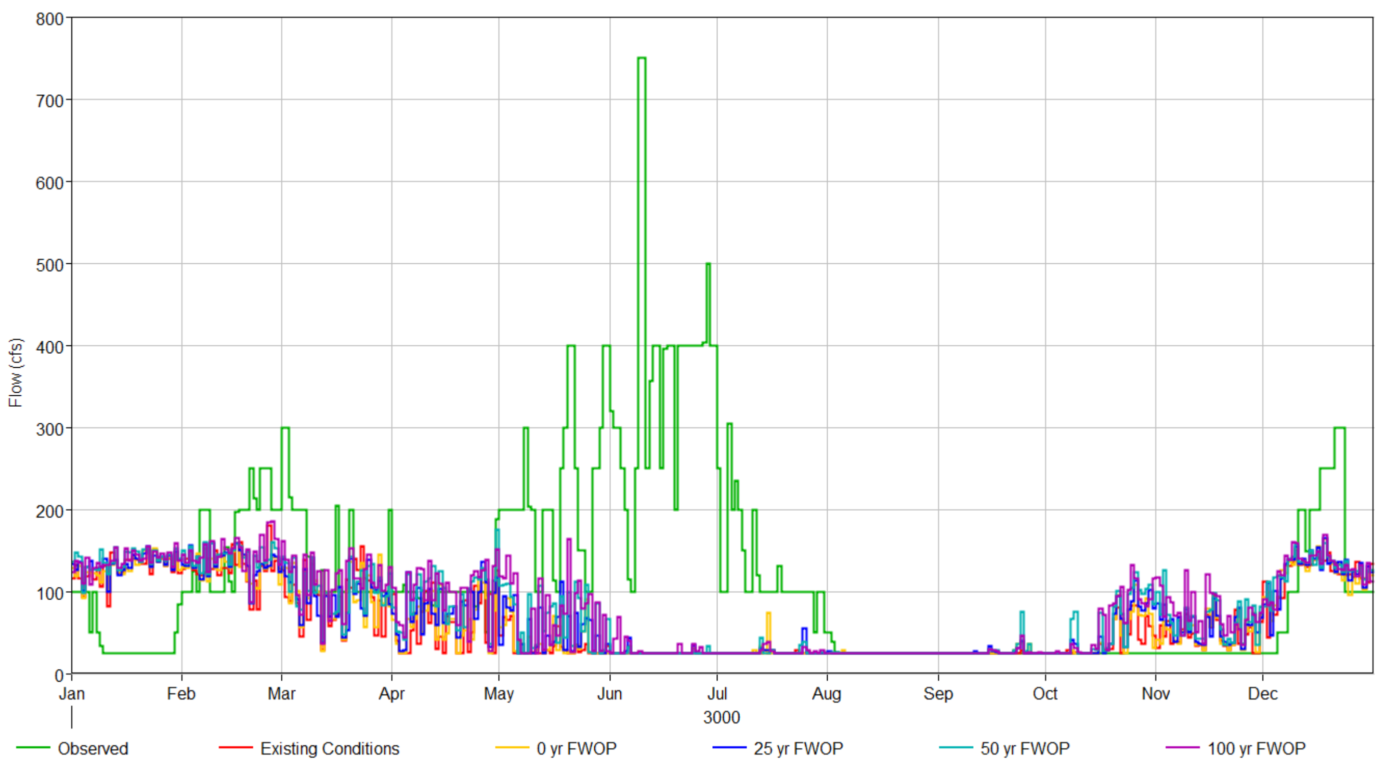


Figure 4-120. Daily median (50th Percentile) Perry flow for each set of data.

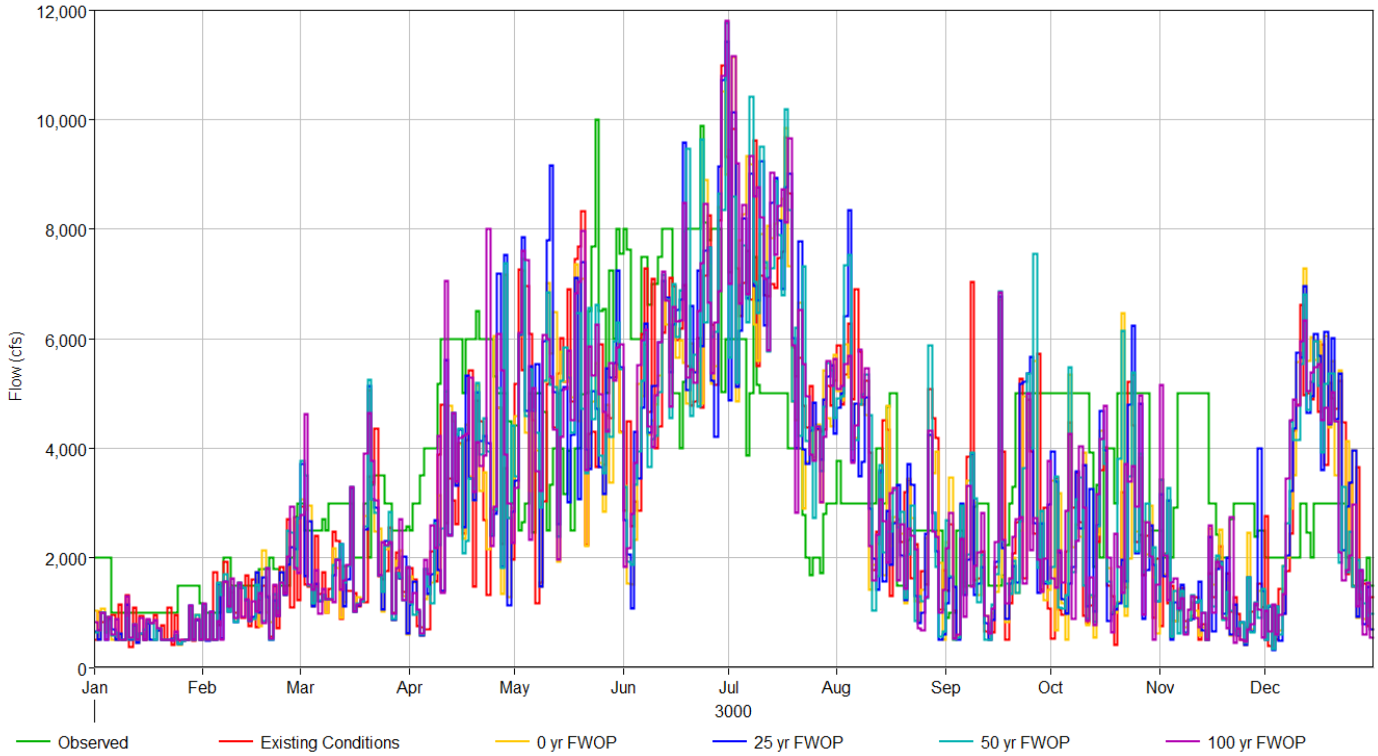


Figure 4-121. Daily 95th Percentile Perry flow for each set of data.

The pool elevation duration is shown in Figure 4-122. It shows increased frequency in the flood control pool as the storage diminishes due to sedimentation. The 2124 FWOP initially has lessening drops into the multi-purpose pool and then it drops farther than any other scenario due to running out of storage while supporting water quality releases.

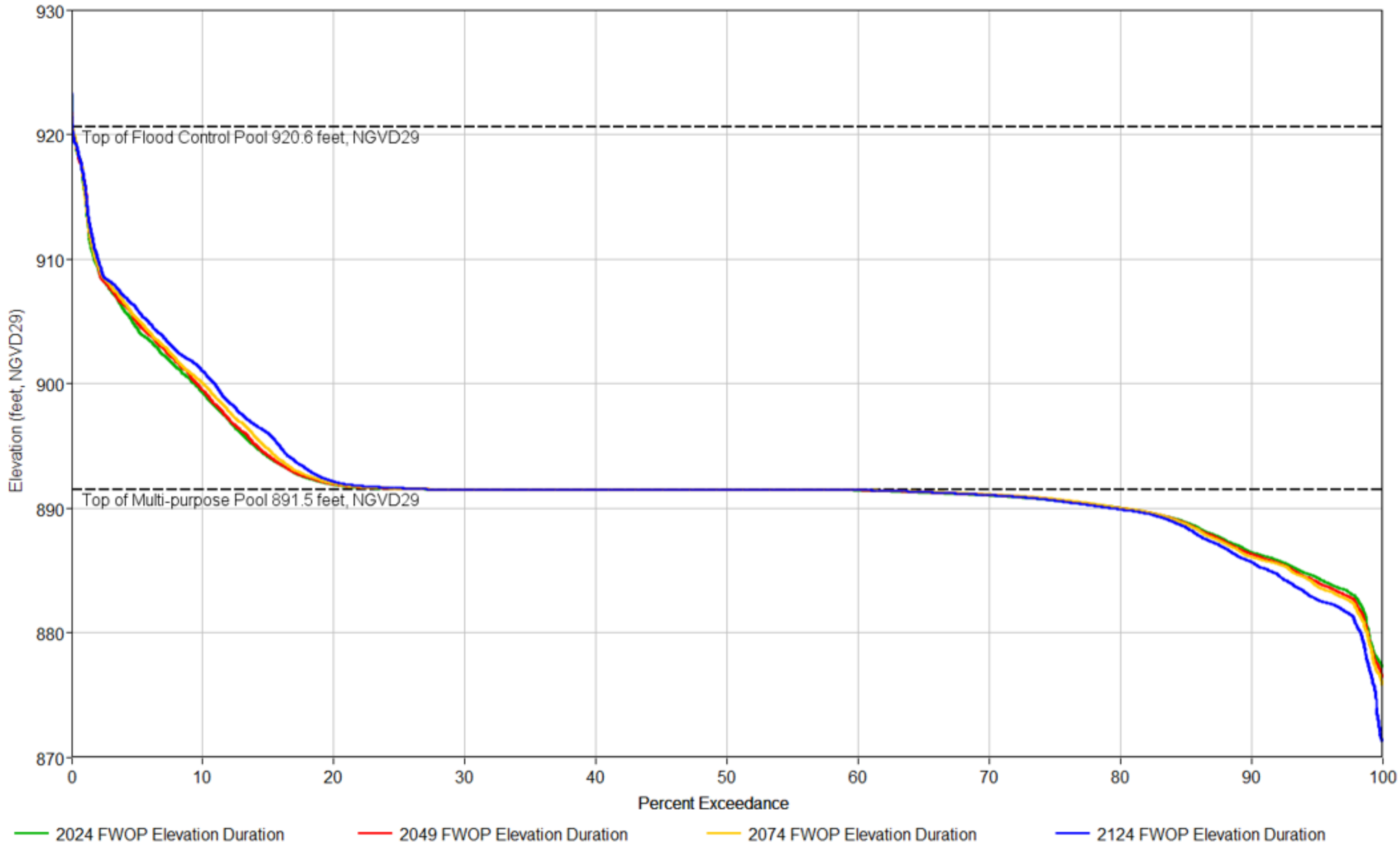


Figure 4-122. Perry pool elevation duration for the four non-navigation FWOP scenarios.

Navigation flow support is provided from Perry in the 2024 FWOP navigation scenario. This results in increased frequency of pool elevations below the multi-purpose pool. High pool elevations are unchanged. Figure 4-123 shows the pool duration plot for 2024 FWOP scenarios with and without navigation. Figure 4-124 to Figure 4-126 show the rest of the FWOP Perry pool elevation duration plots. In these scenarios, Perry does not provide navigation support flows, but some small impacts are assessed because of Tuttle Creek providing the navigation support flows which then requires Perry to give additional releases to support water quality.

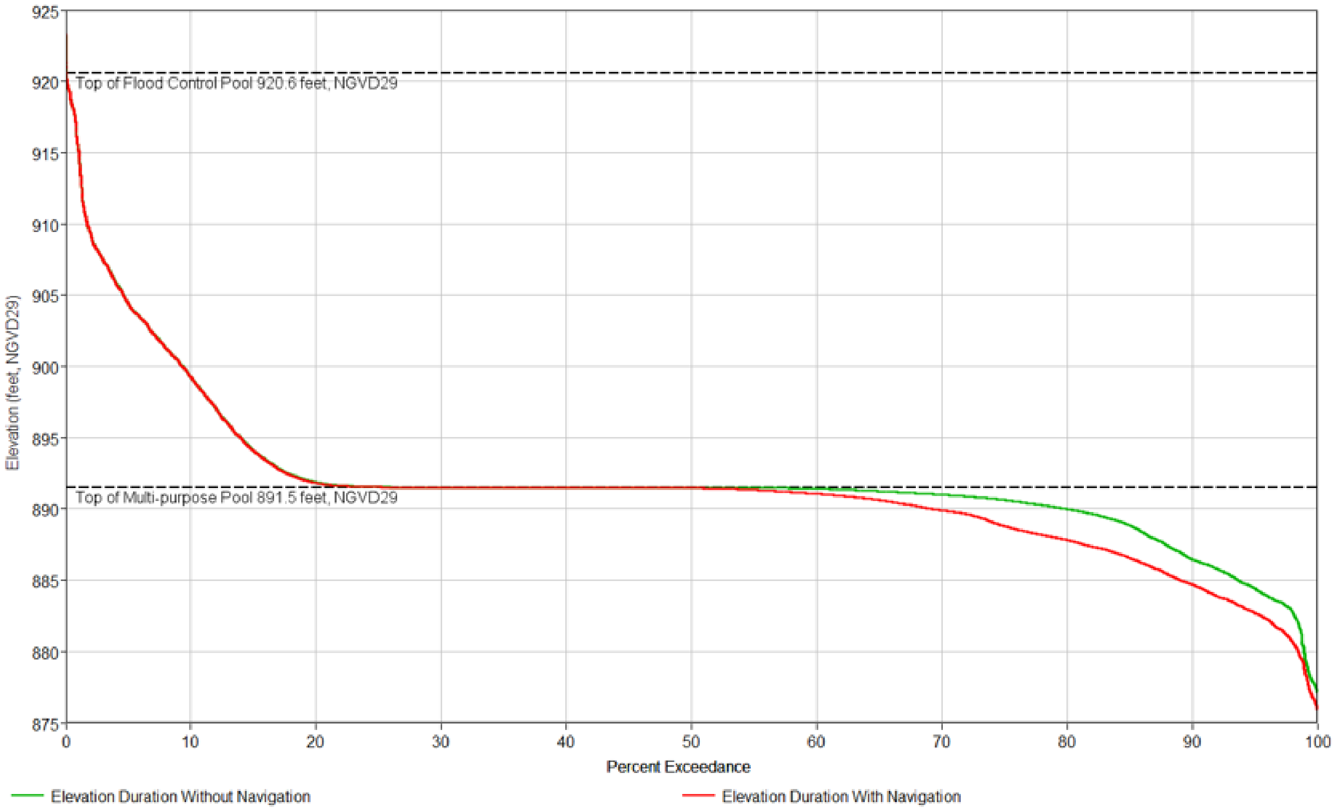


Figure 4-123. Perry 2024 FWOP pool elevation duration with and without navigation.

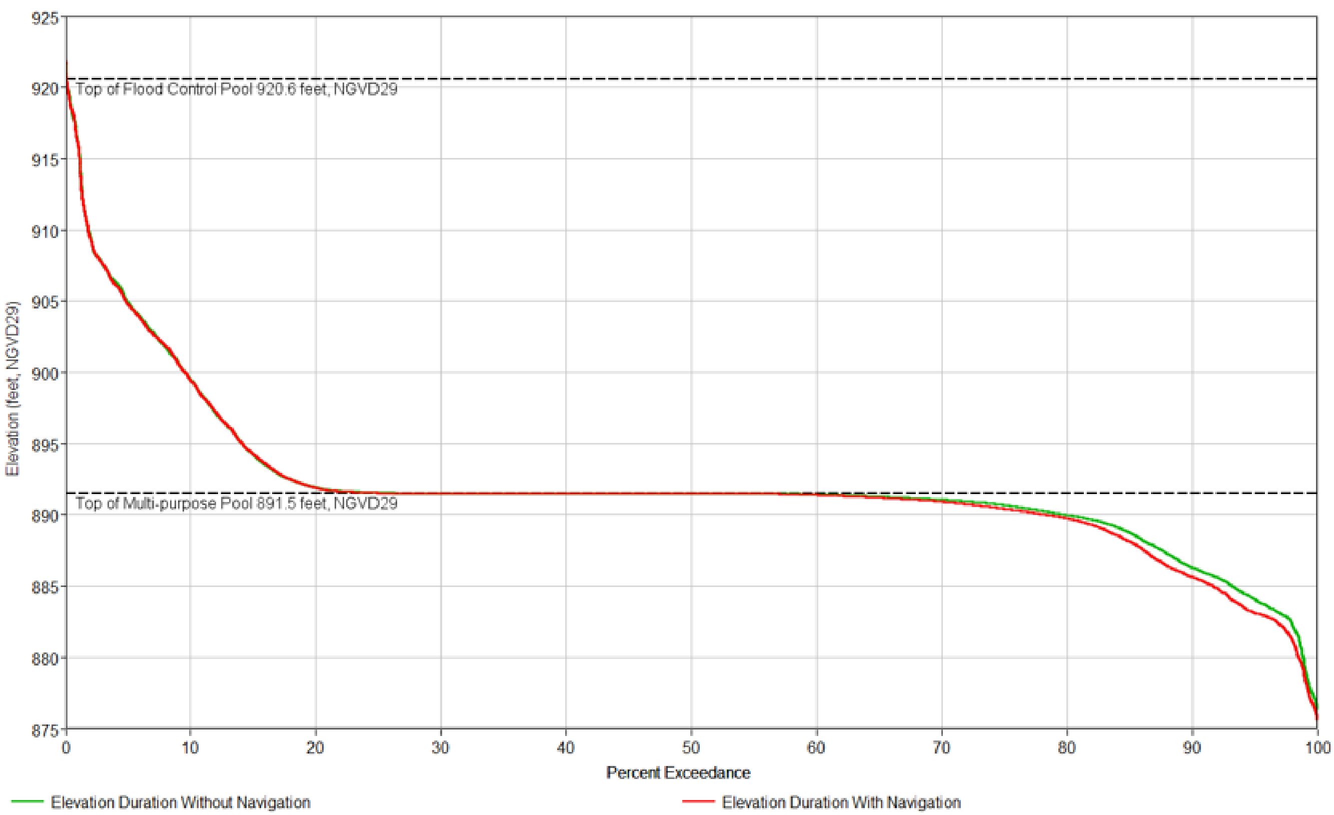


Figure 4-124. Perry 2049 FWOP pool elevation duration with and without navigation.

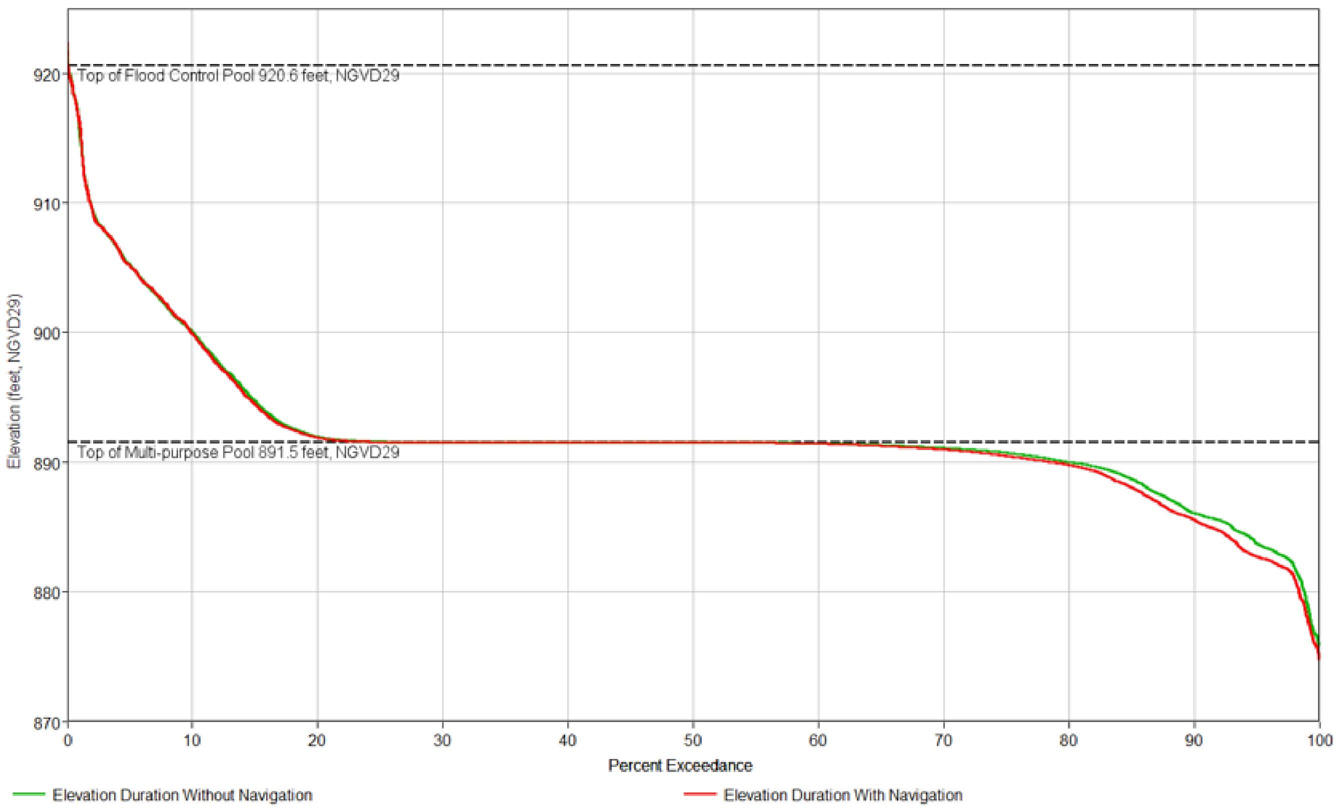


Figure 4-125. Perry 2074 FWOP pool elevation duration with and without navigation.

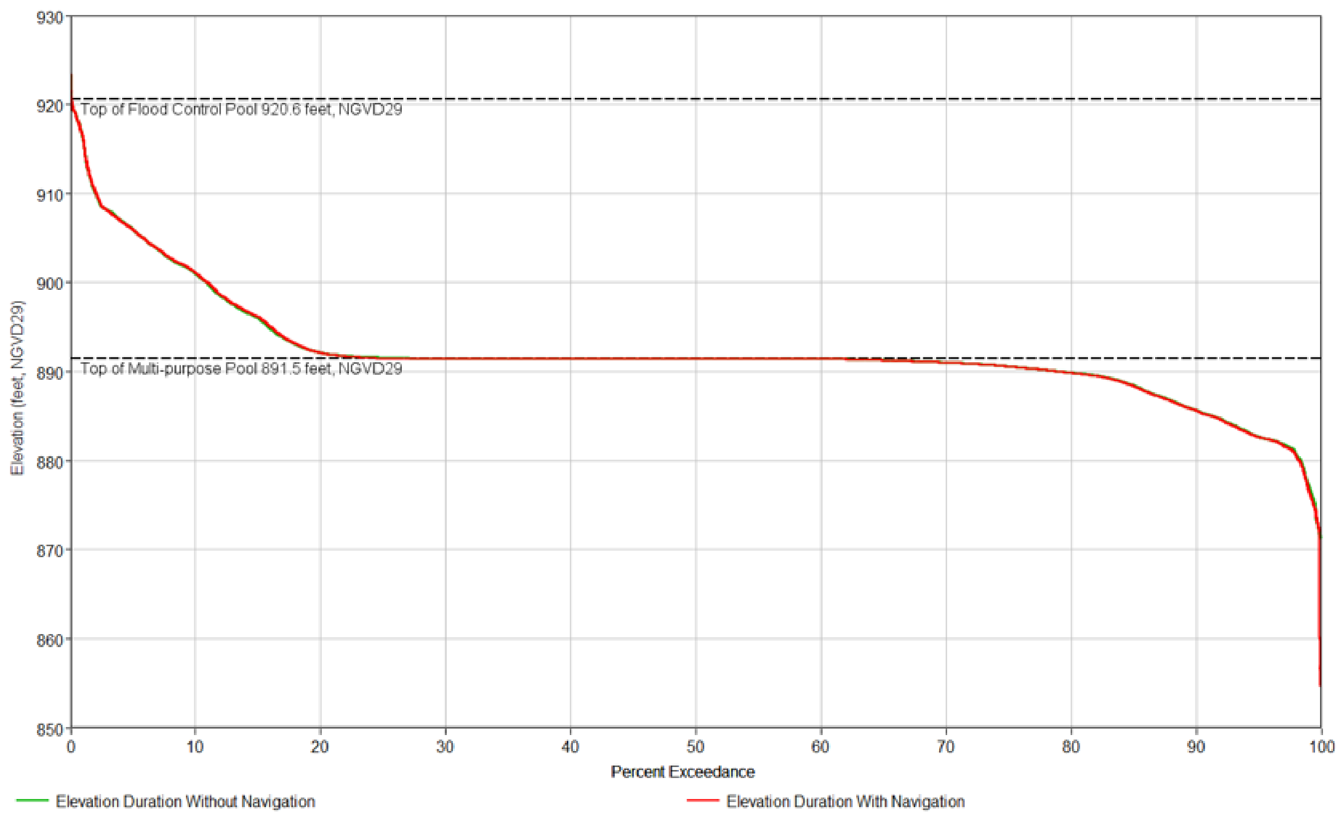


Figure 4-126. Perry 2124 FWOP pool elevation duration with and without navigation.

4.1.7 Clinton

Clinton observed data is from first fill of April 1980 through November 2021. The Clinton family of curves are shown in Figure 4-127 to Figure 4-144. Navigation did not impact Clinton and the navigation FWOP scenarios were identical to the non-navigation. The median modeled pool elevation tends to be near the top of the multi-purpose pool since that was used as the guide curve in HEC-ResSim but is slightly lower (within about a foot) from July to March as water quality releases draw the lake down in the dry season. Median observed pool elevation is consistently higher and more variable with some pool raises and drawdowns as part of the routine operations. All the model scenarios have high pool elevations in the 95th percentile data set as some years required constrained releases in flood control operations for the Missouri River at Waverly. The observed data set does not have the extended high pool elevation because deviations were utilized in the real-time operations.

Average time series were compared for each scenario. The observed data is consistently higher than the modeled pool elevations. This may indicate that the model was more aggressive with releases when the real time operations are often constrained due to chances of rainfall or concerns in the downstream channel. The modeled existing conditions and 2024 FWOP scenarios are very similar as the sediment conditions do not change dramatically between these two scenarios. However, as more sediment accumulates with each additional FWOP the average pool elevation also increases.

The modeled outflow data matches the observed data generally well, especially the 95th percentile flows. The observed low outflow of the median percentile is somewhat higher than the models, although still low. There are a few notable peaks around June. The average observed outflow peaks higher than modeled during the warm months. This may be due to historical deviations from the water management plan or other factors previously noted.

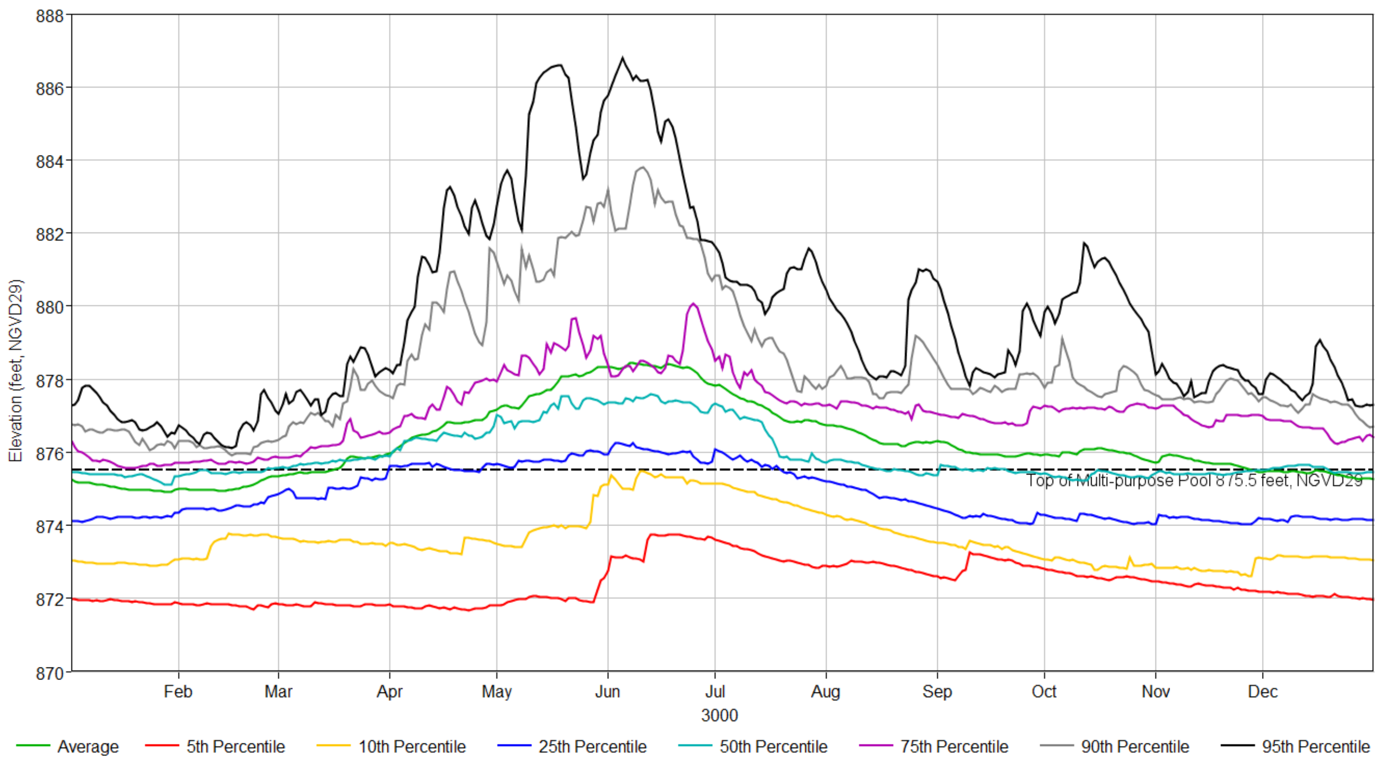


Figure 4-127. Clinton pool elevation statistics for the observed data from first fill Apr 1980 to Dec 2021.

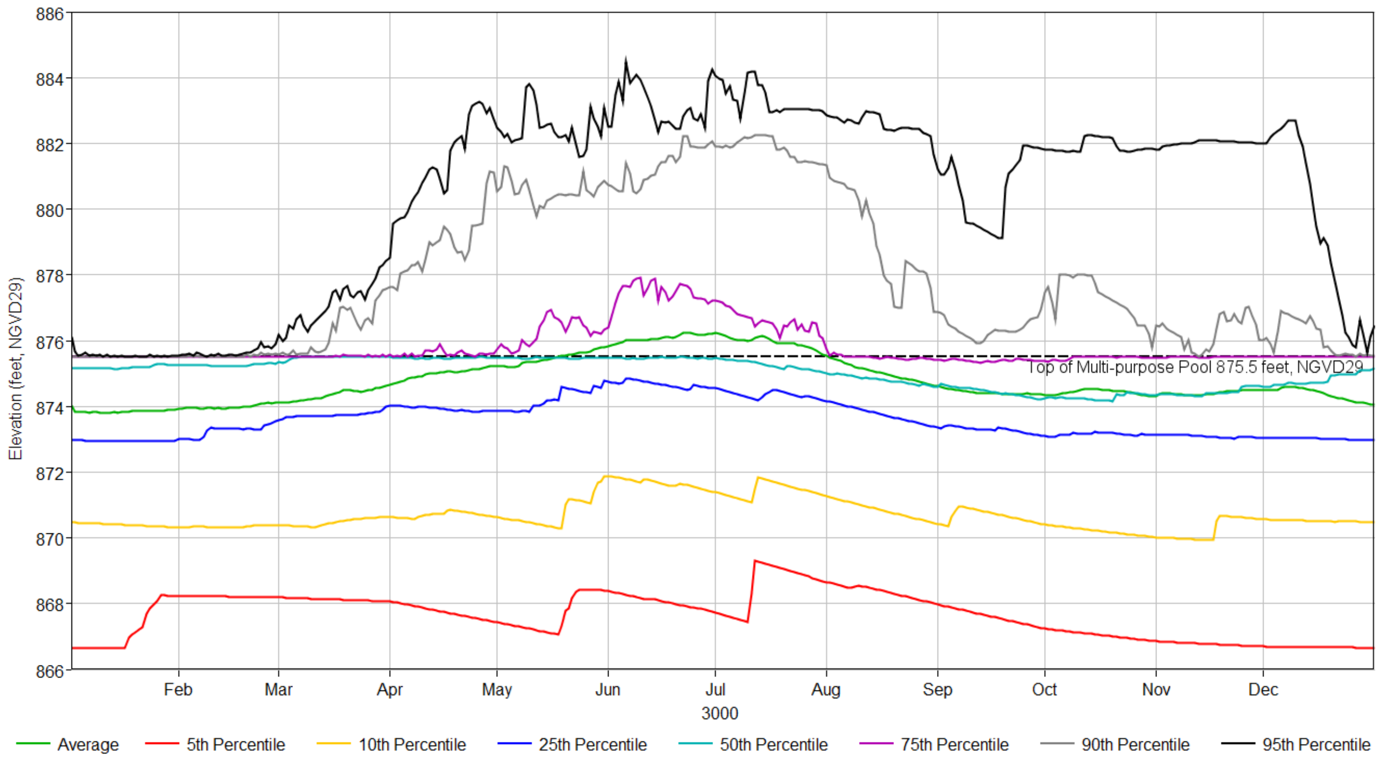


Figure 4-128. Clinton pool elevation statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

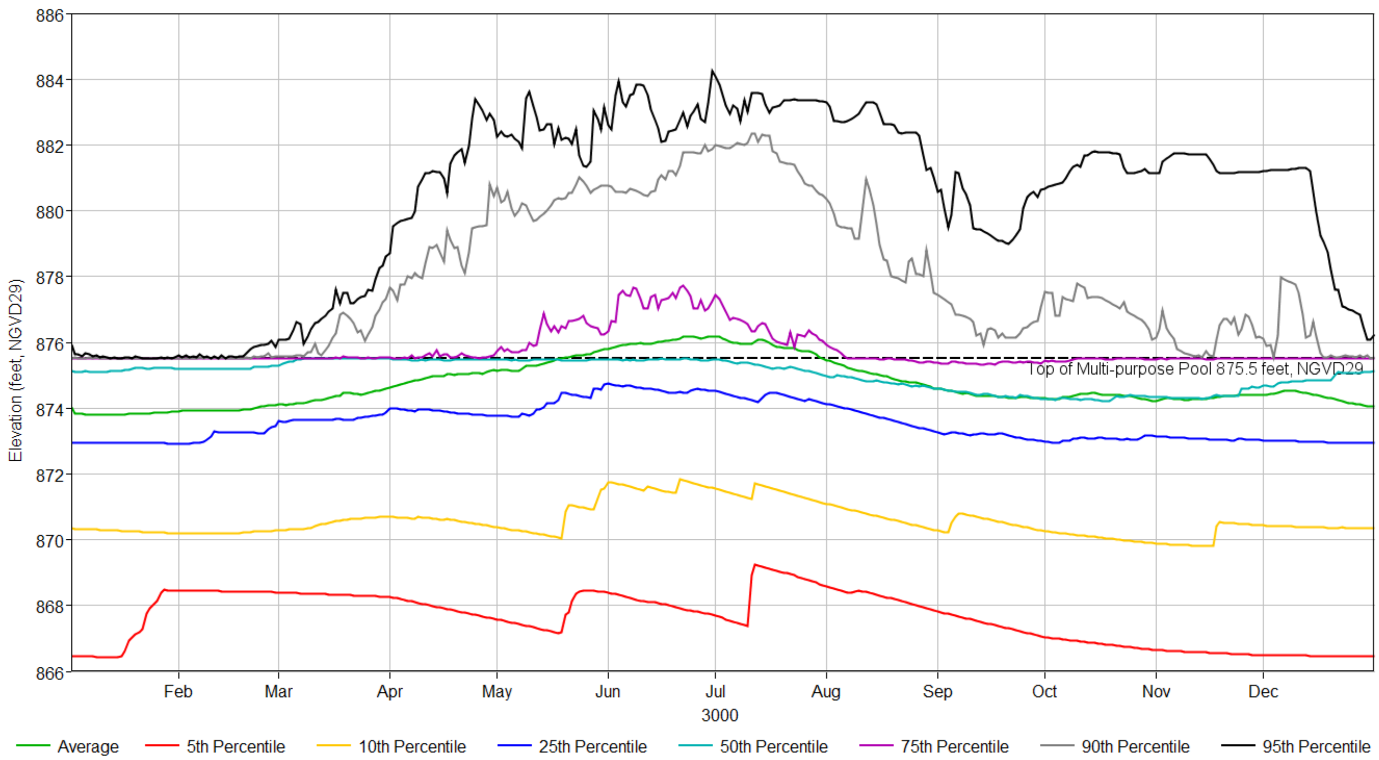


Figure 4-129. Clinton pool elevation statistics for the 100-year FWOP at 2024 sediment conditions.

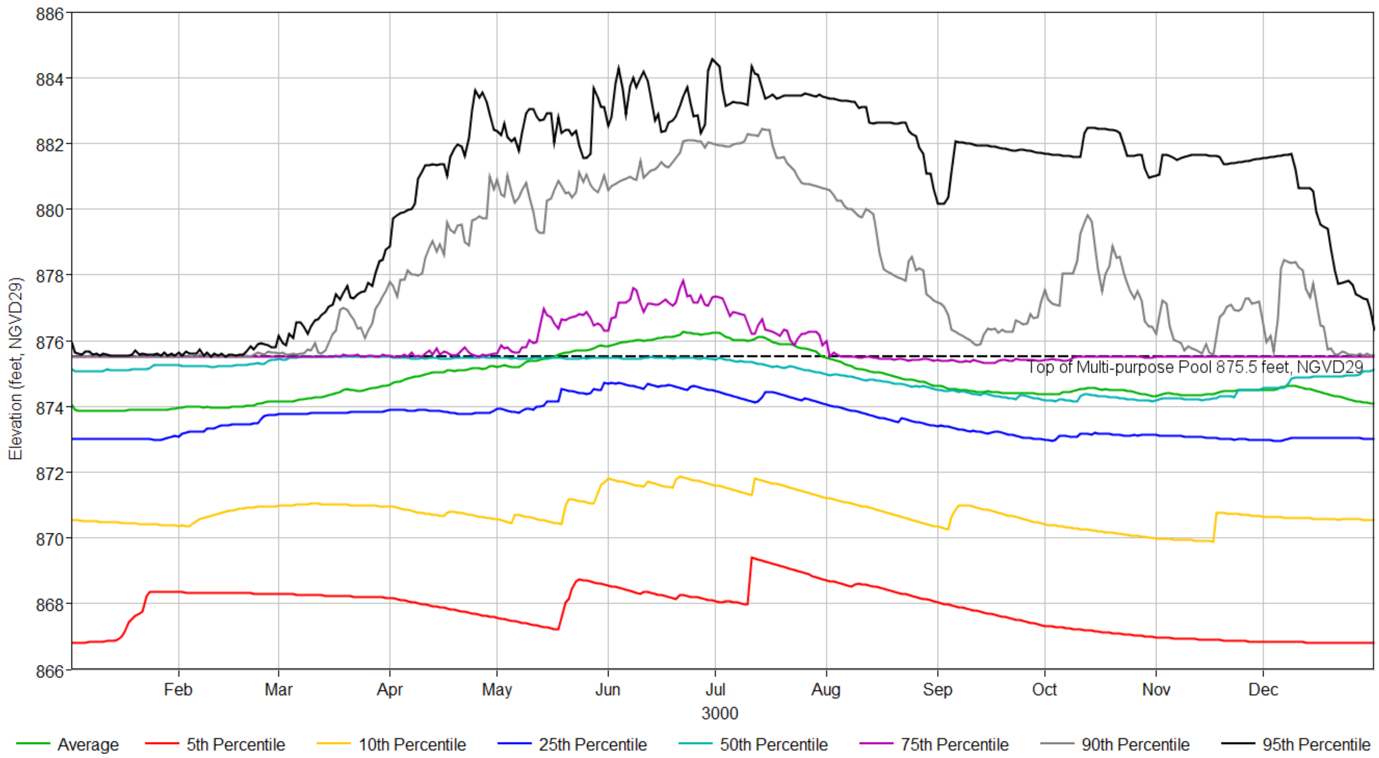


Figure 4-130. Clinton pool elevation statistics for the 100-year FWOP at 2049 sediment conditions.

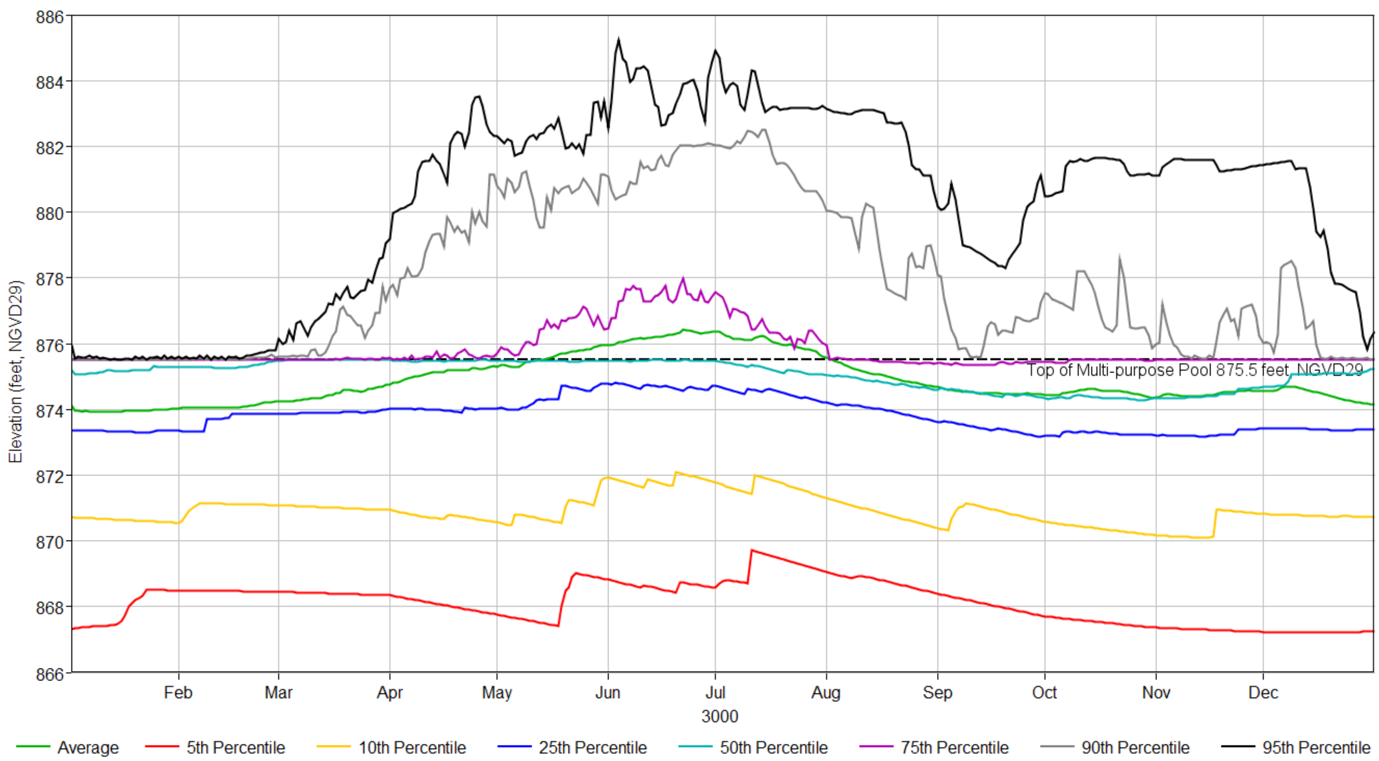


Figure 4-131. Clinton pool elevation statistics for the 100-year FWOP at 2074 sediment conditions.

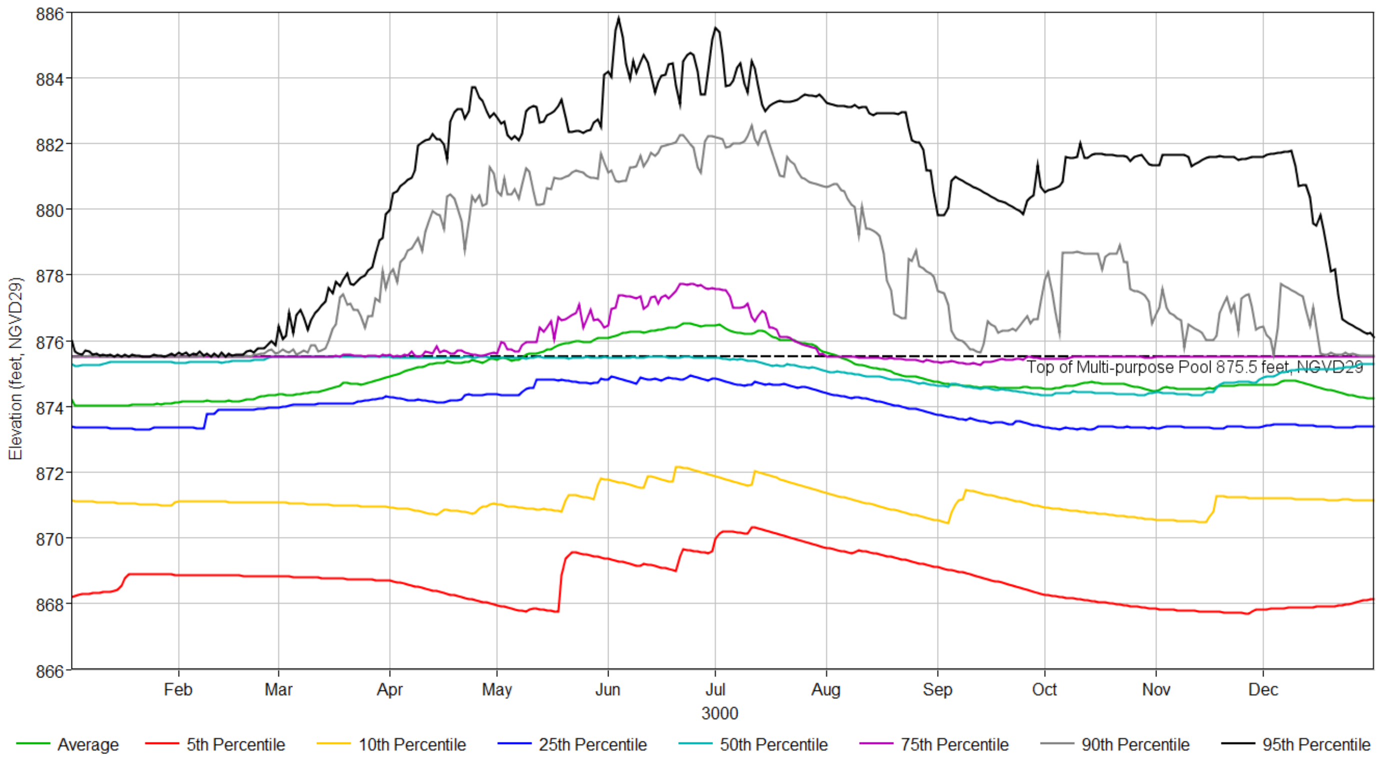


Figure 4-132. Clinton pool elevation statistics for the 100-year FWOP at 2124 sediment conditions.

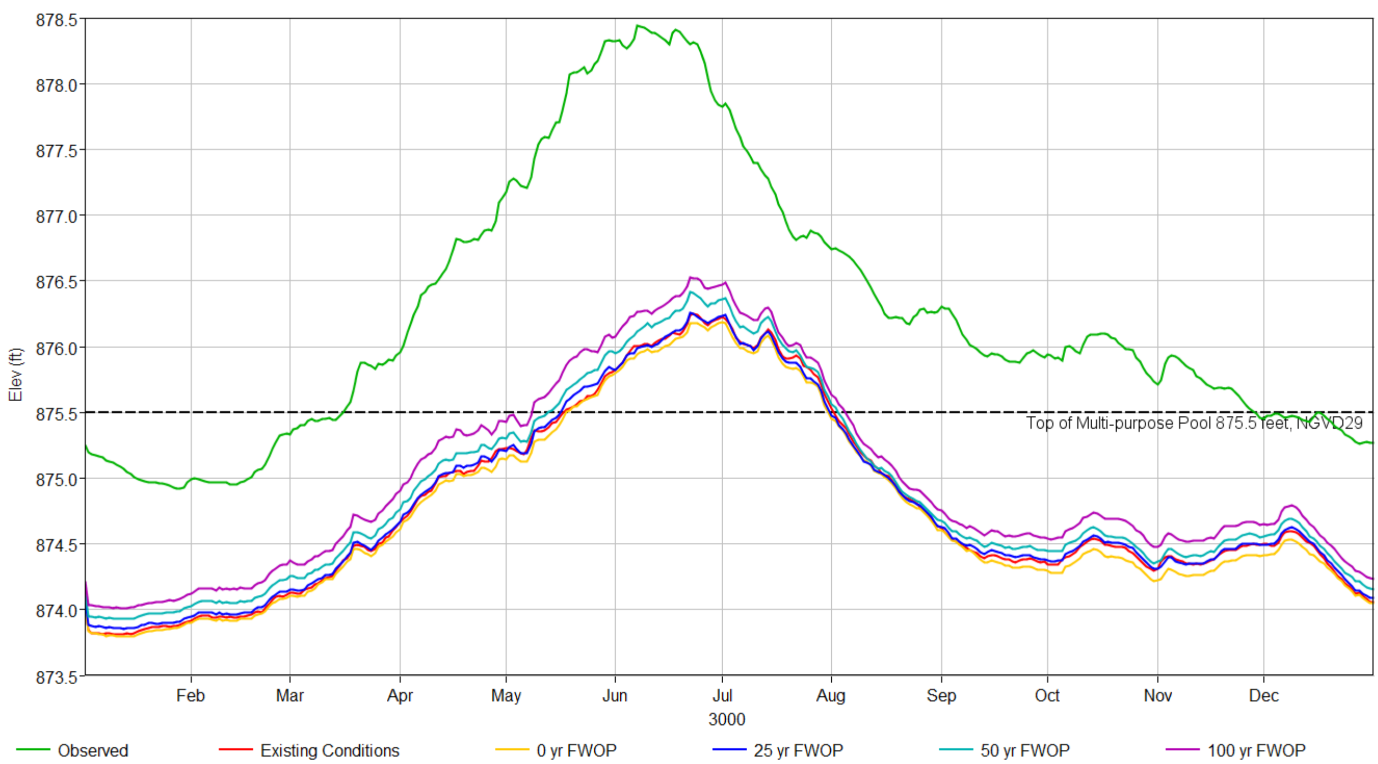


Figure 4-133. Daily average Clinton pool elevation for each set of data.

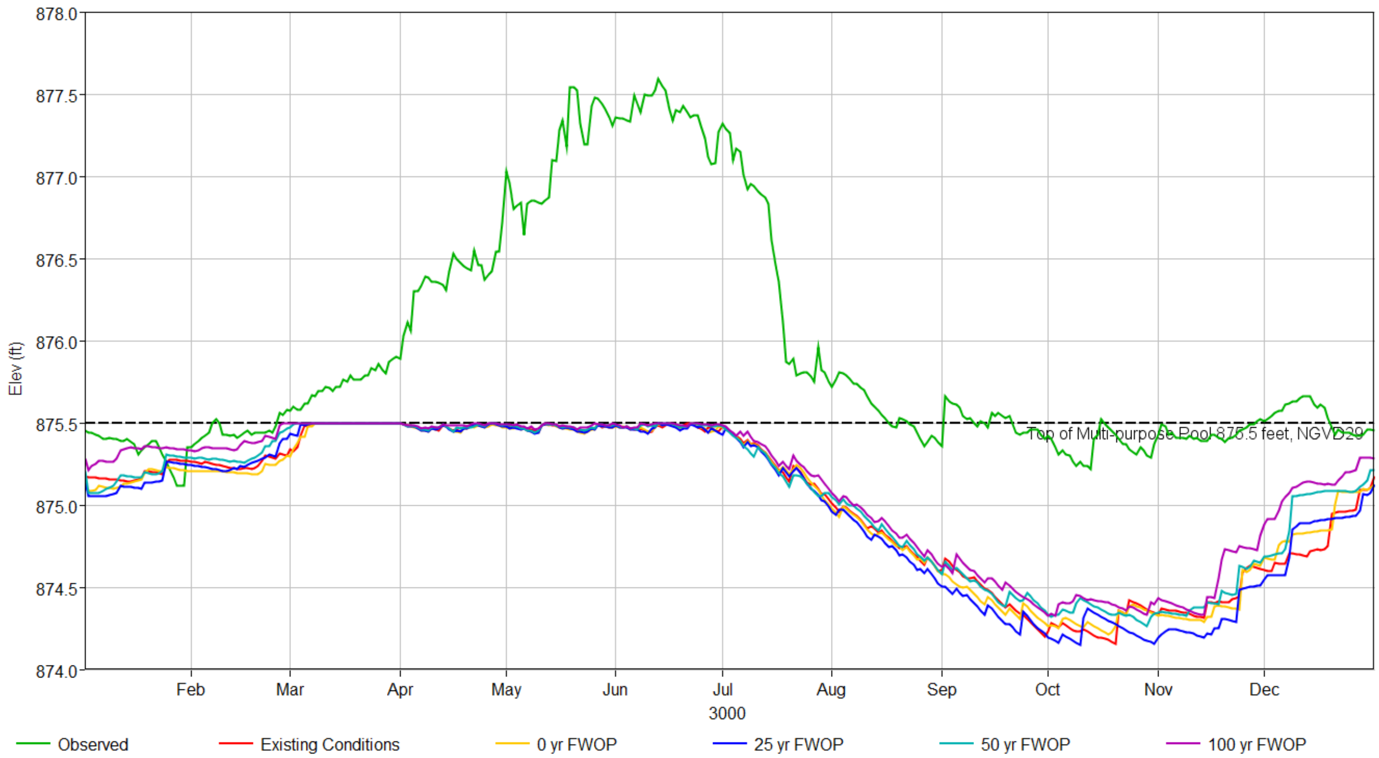


Figure 4-134. Daily median (50th Percentile) Clinton pool elevation for each set of data.

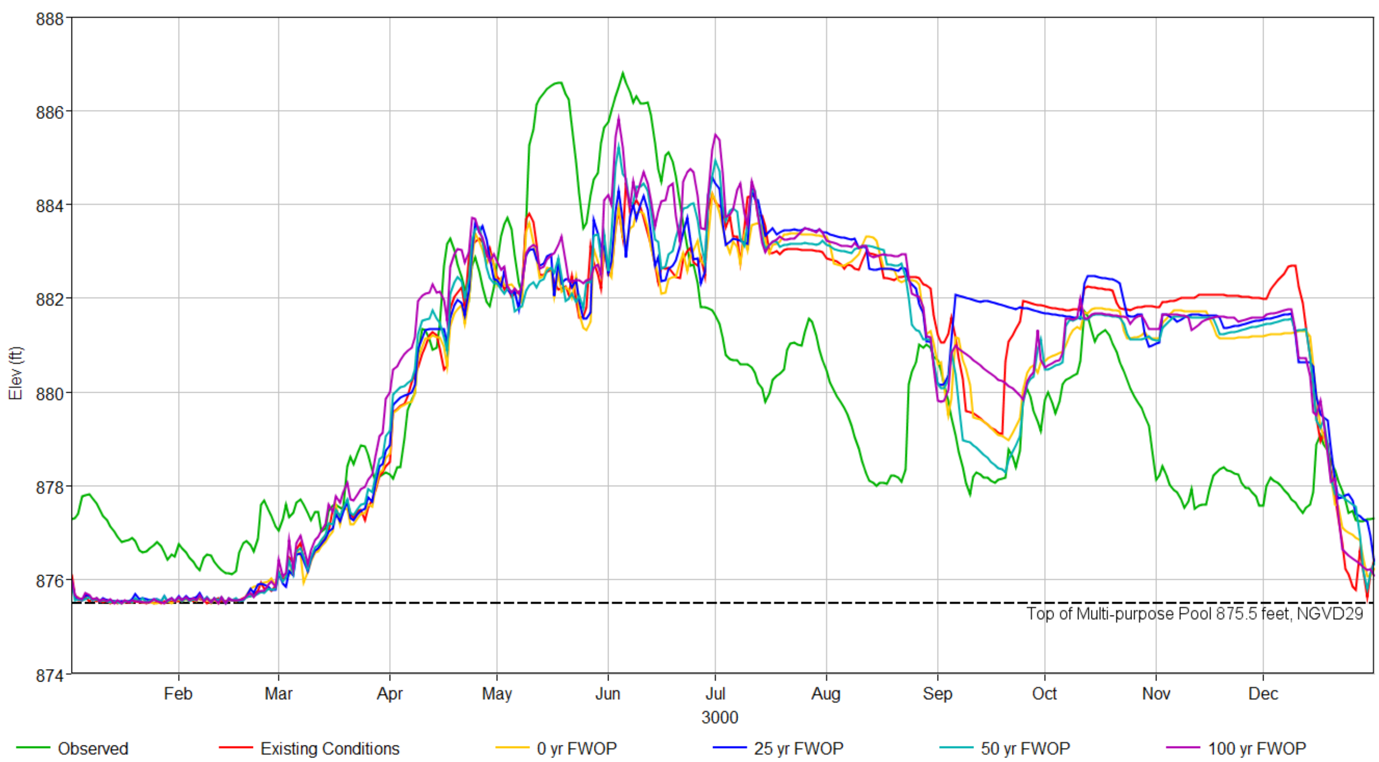


Figure 4-135. Daily 95th Percentile Clinton pool elevation for each set of data.

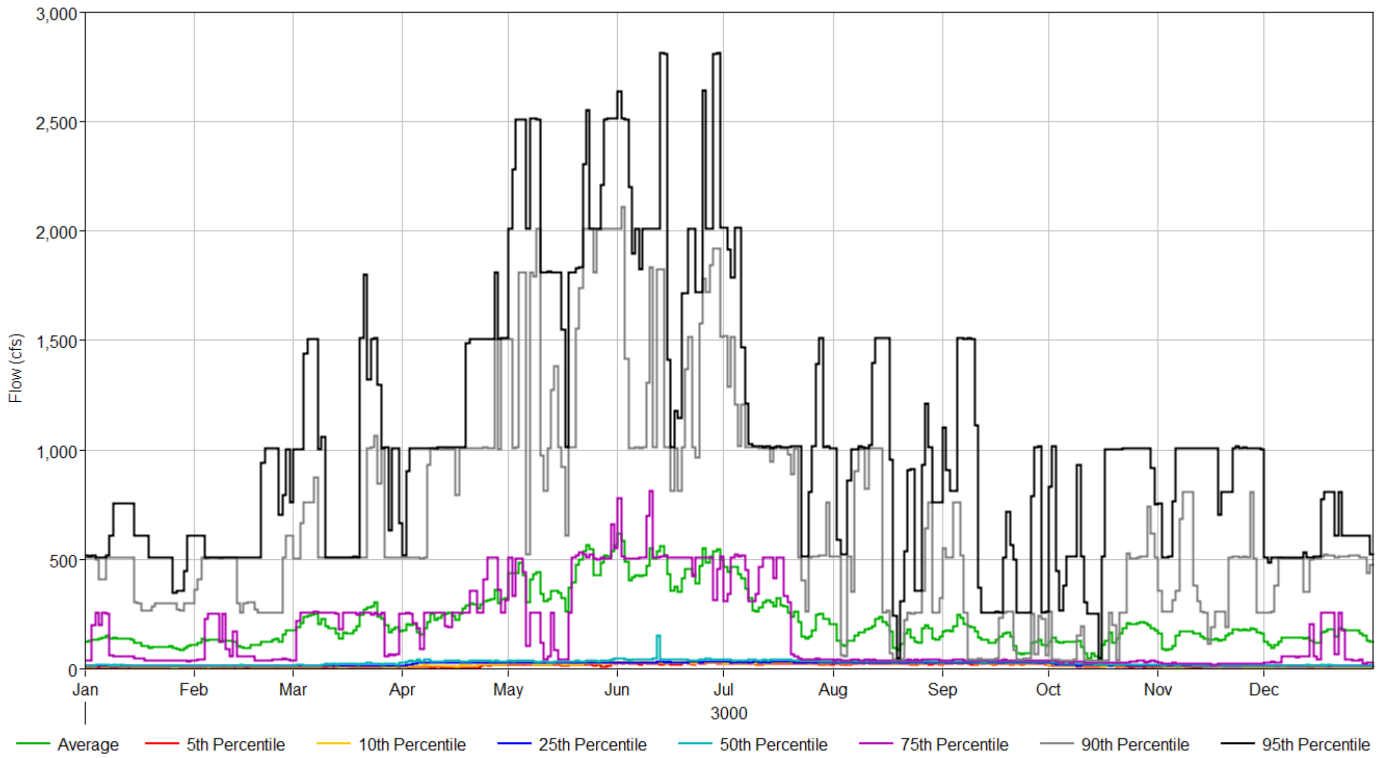


Figure 4-136. Clinton outflow statistics for the observed data from the first fill Dec 1977 to Dec 2021.

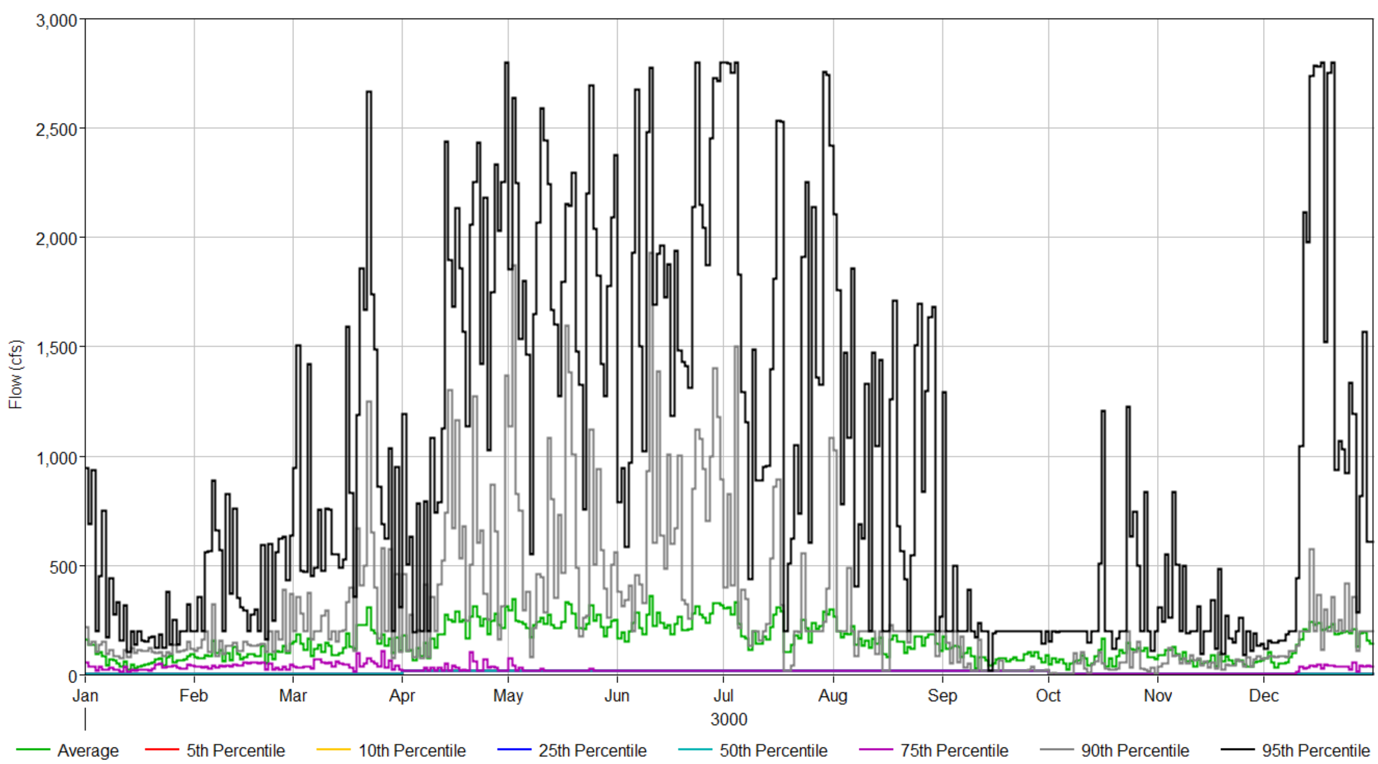


Figure 4-137. Clinton outflow statistics for the 100-year Existing Conditions modeling from 1920 to 2019.

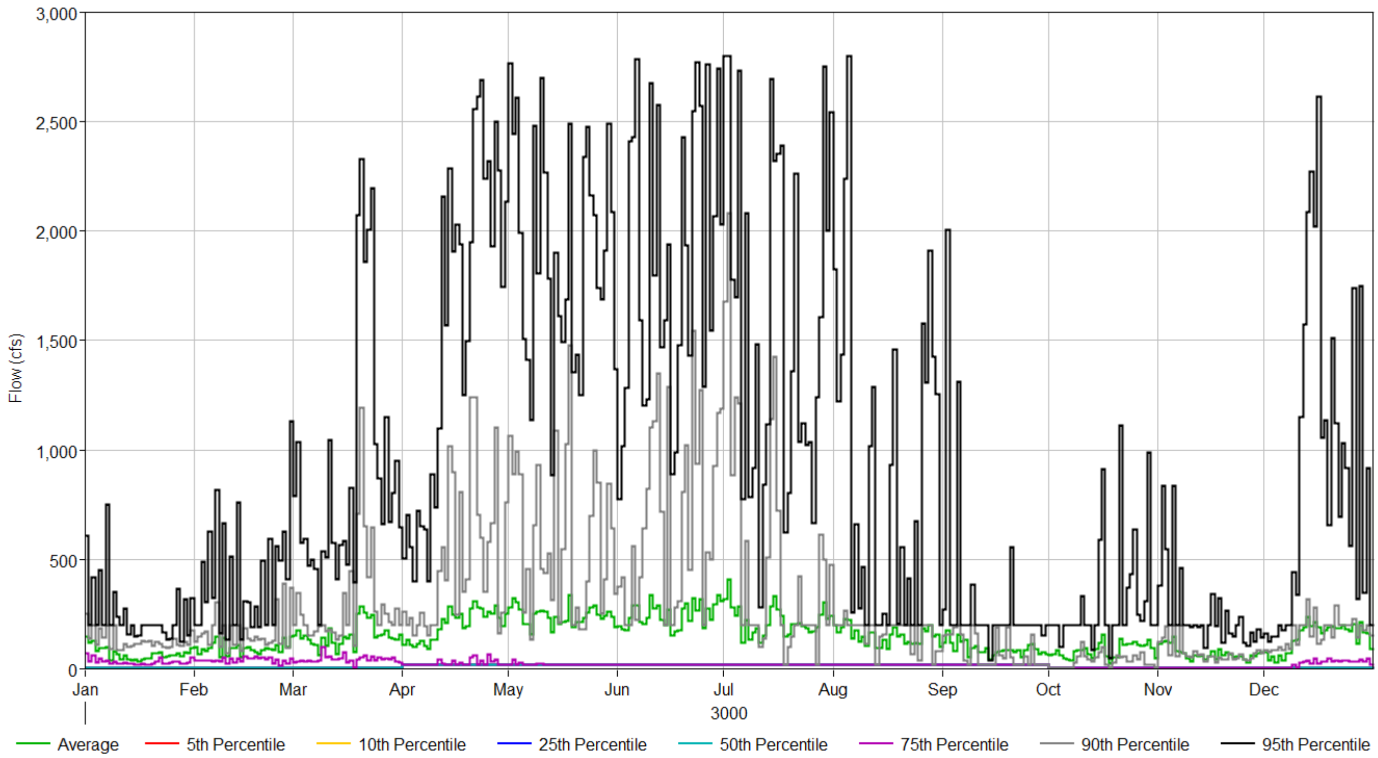


Figure 4-138. Clinton outflow statistics for the 100-year FWOP at 2024 sediment conditions.

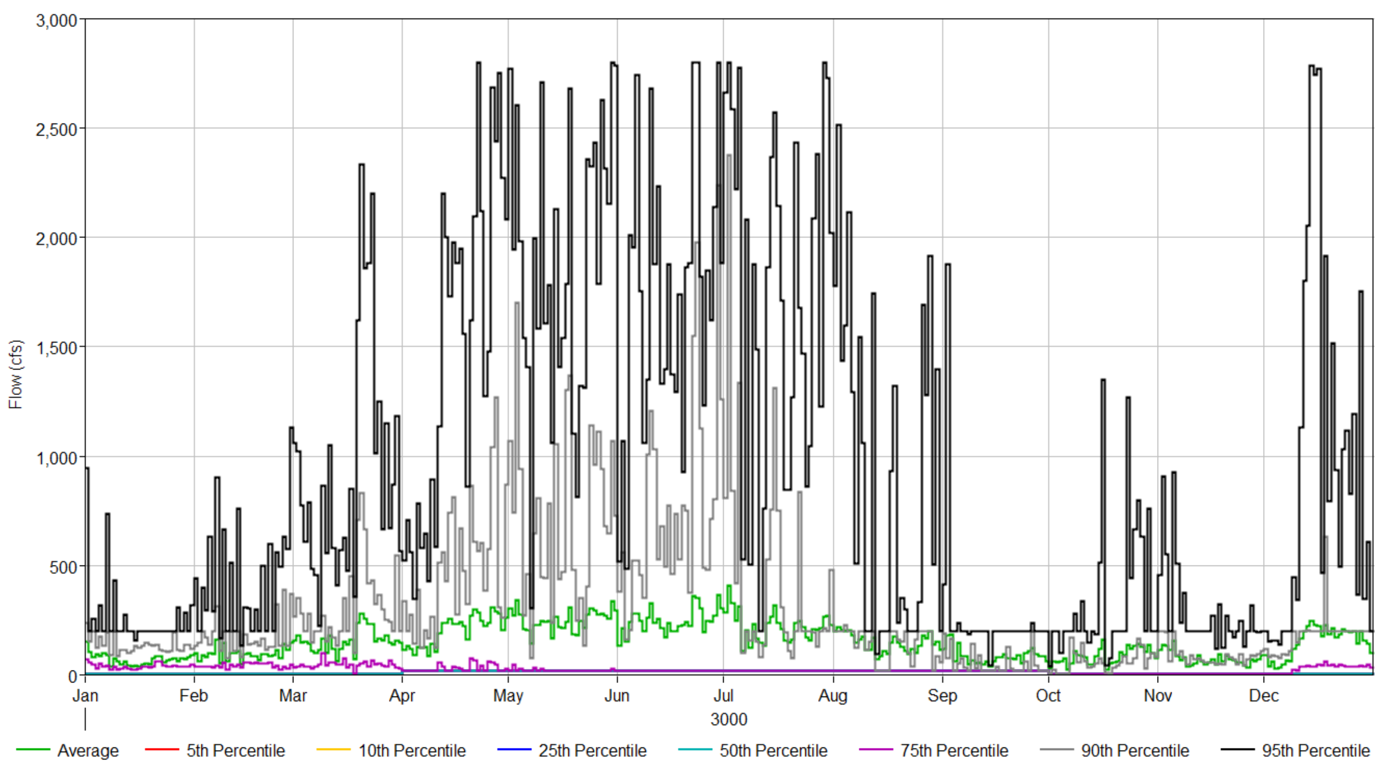


Figure 4-139. Clinton outflow statistics for the 100-year FWOP at 2049 sediment conditions.

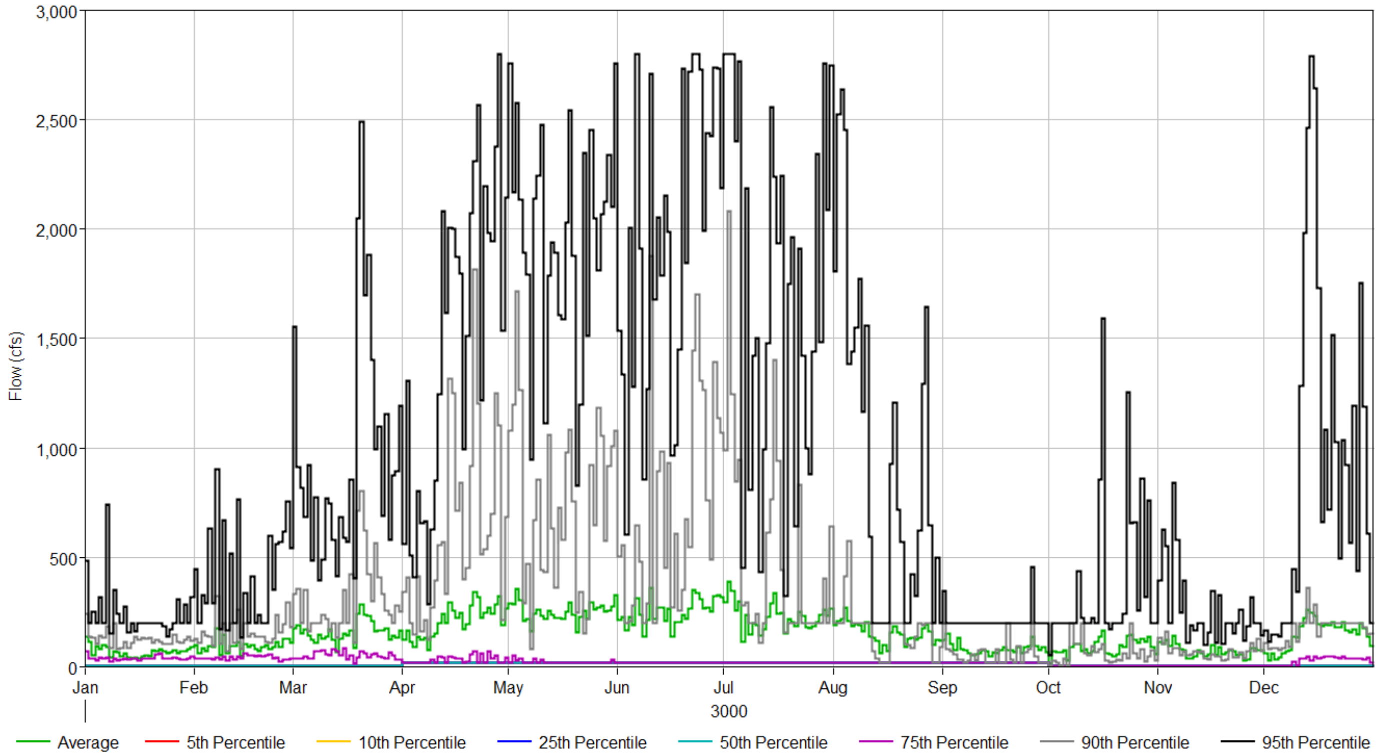


Figure 4-140. Clinton outflow statistics for the 100-year FWOP at 2074 sediment conditions.

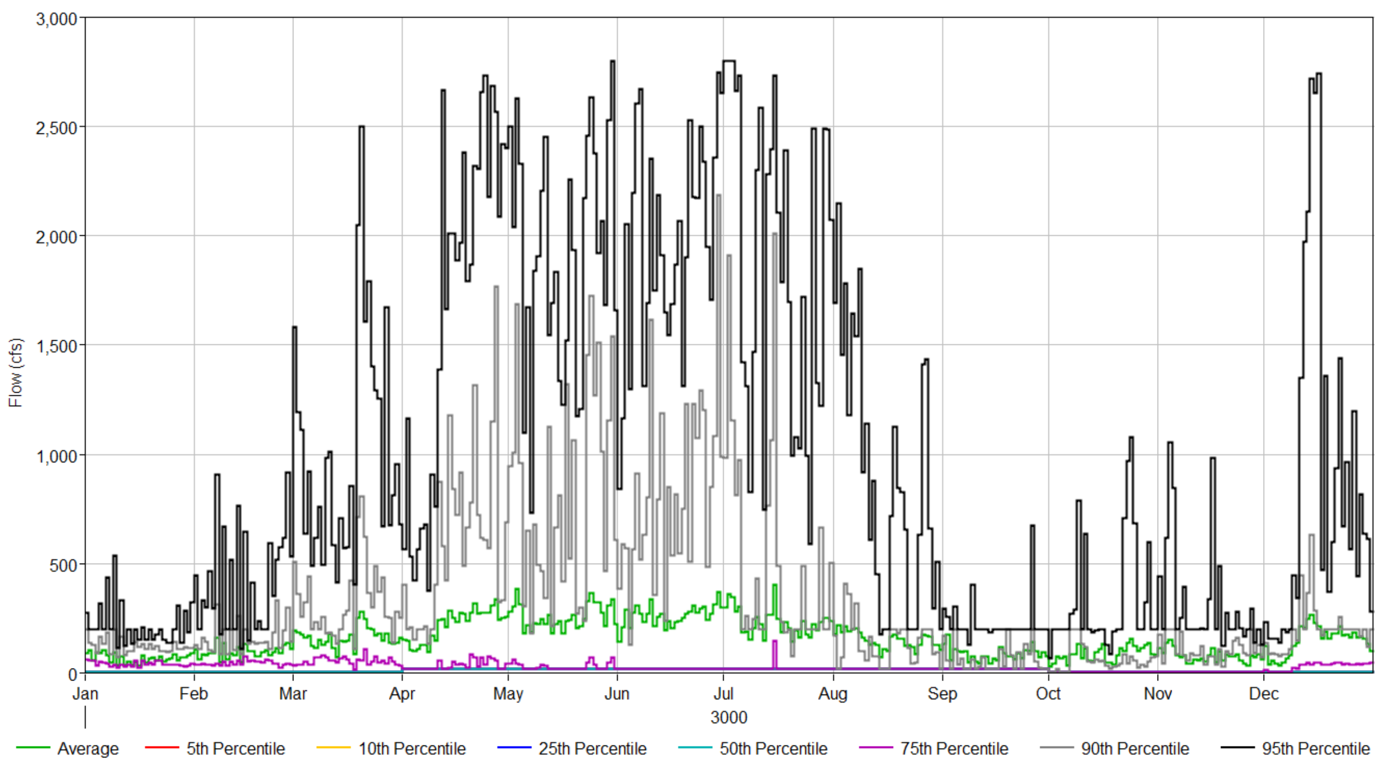


Figure 4-141. Clinton outflow statistics for the 100-year FWOP at 2124 sediment conditions.

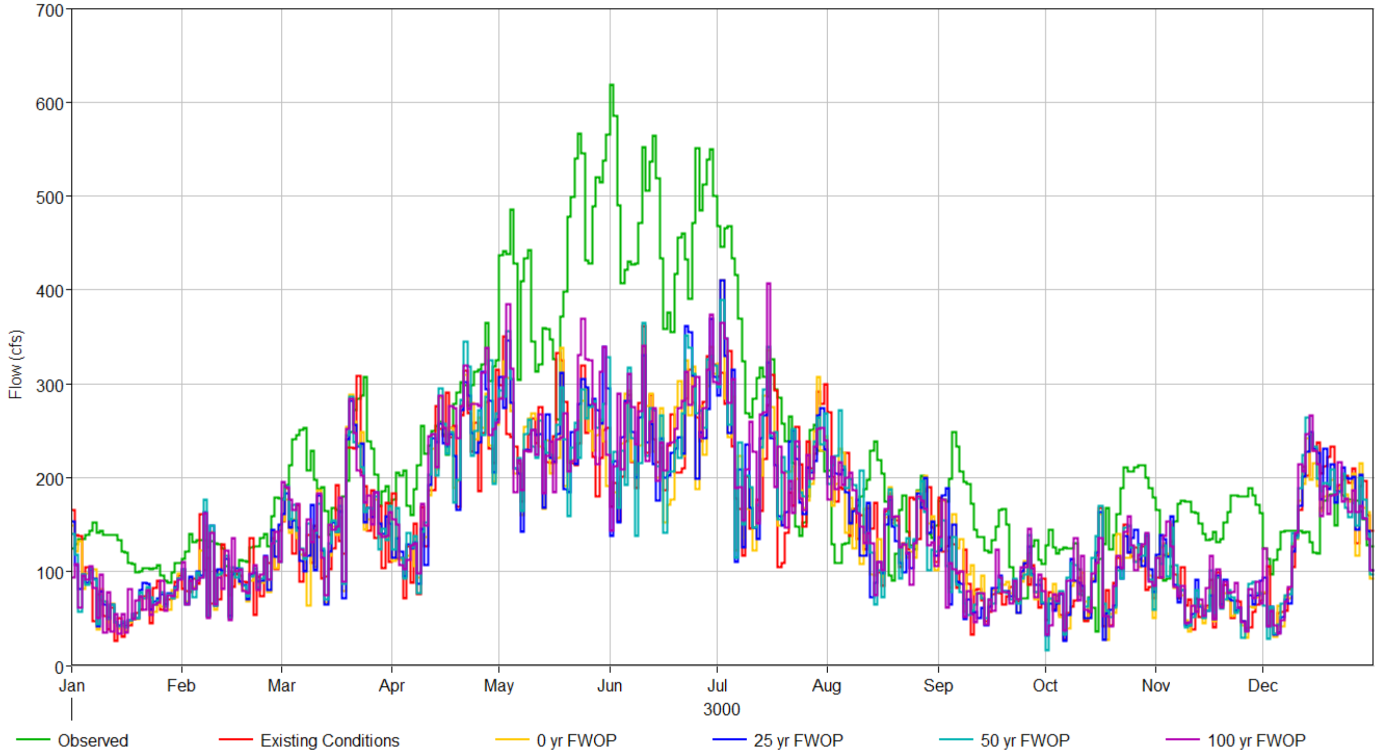


Figure 4-142. Daily average Clinton outflow for each set of data..

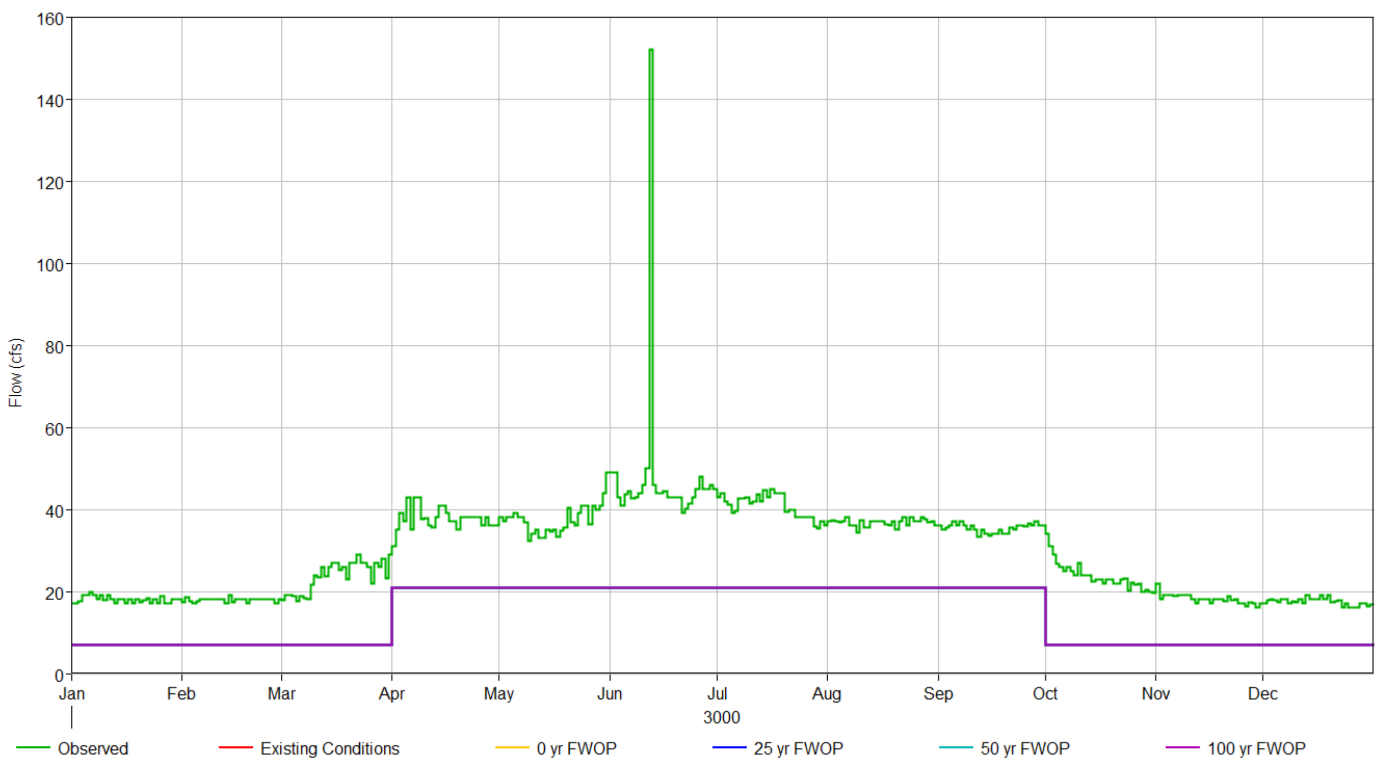


Figure 4-143. Daily median (50th Percentile) Clinton flow for each set of data.

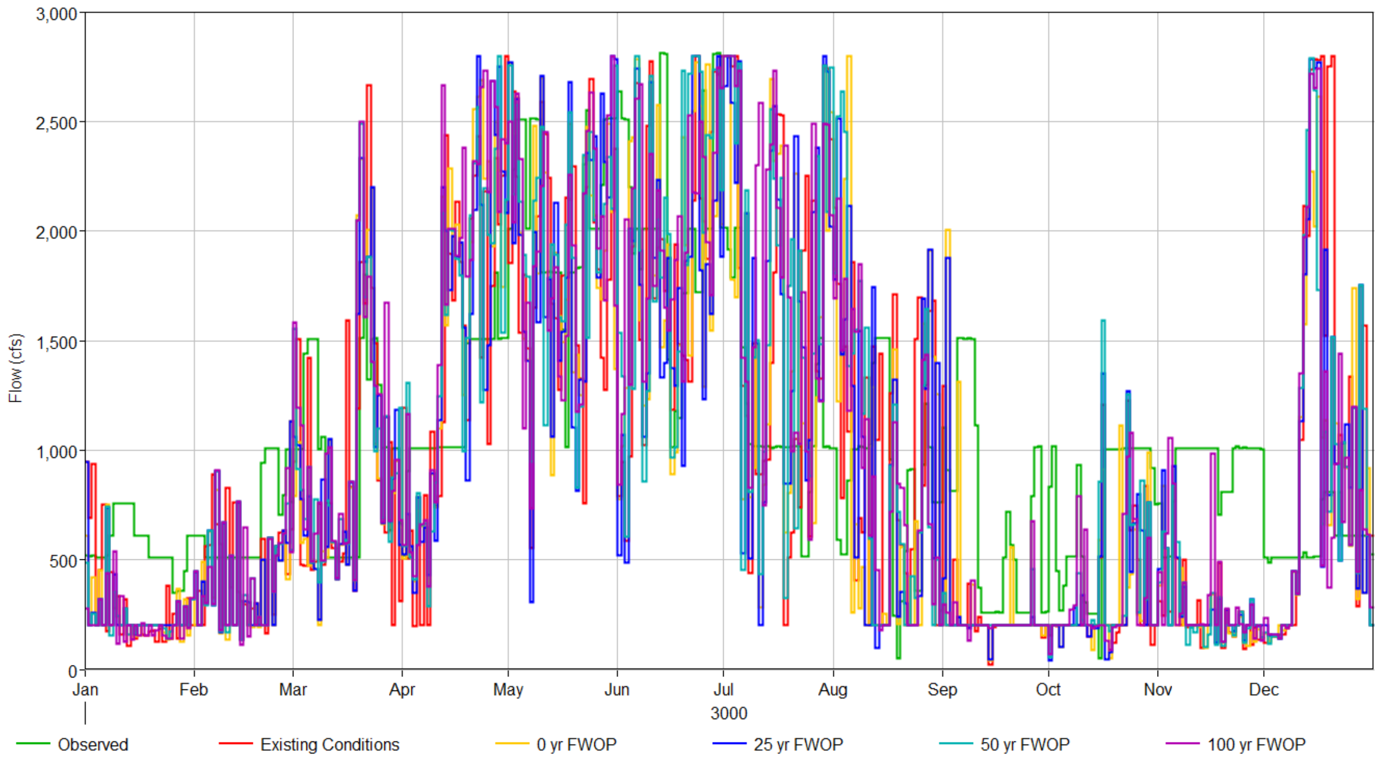


Figure 4-144. Daily 95th Percentile Clinton flow for each set of data.

The pool elevation duration is shown in Figure 4-145. It shows that the Clinton pool elevation does not drop as far into the multi-purpose pool in the later FWOP scenarios. This is probably because of reduced evaporation from smaller pool areas. Evaporation is a large driver of pool elevation in Clinton. There are also small increased frequencies of higher pool elevations in the flood control pool.

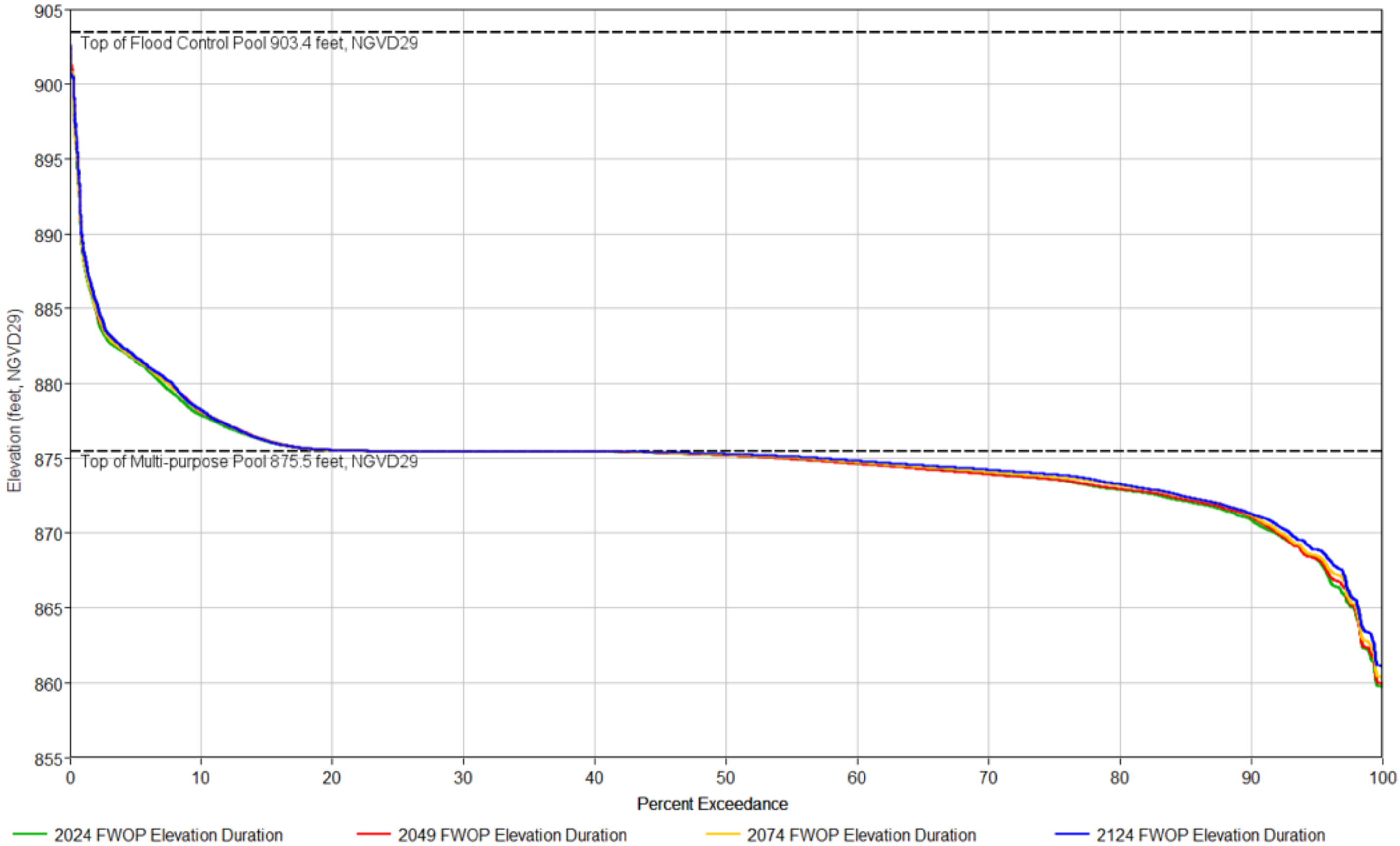


Figure 4-145. Clinton pool elevation duration for the four non-navigation FWOP scenarios.

4.1.8 Gage Locations

Statistical analysis was conducted for selected downstream gages. There appears to be small increases in average flow, but no trend in the 95th percentile flow. Figure 4-139 to Figure 4-144 show the average and 95th percentile flows for Enterprise, Topeka, and Desoto.

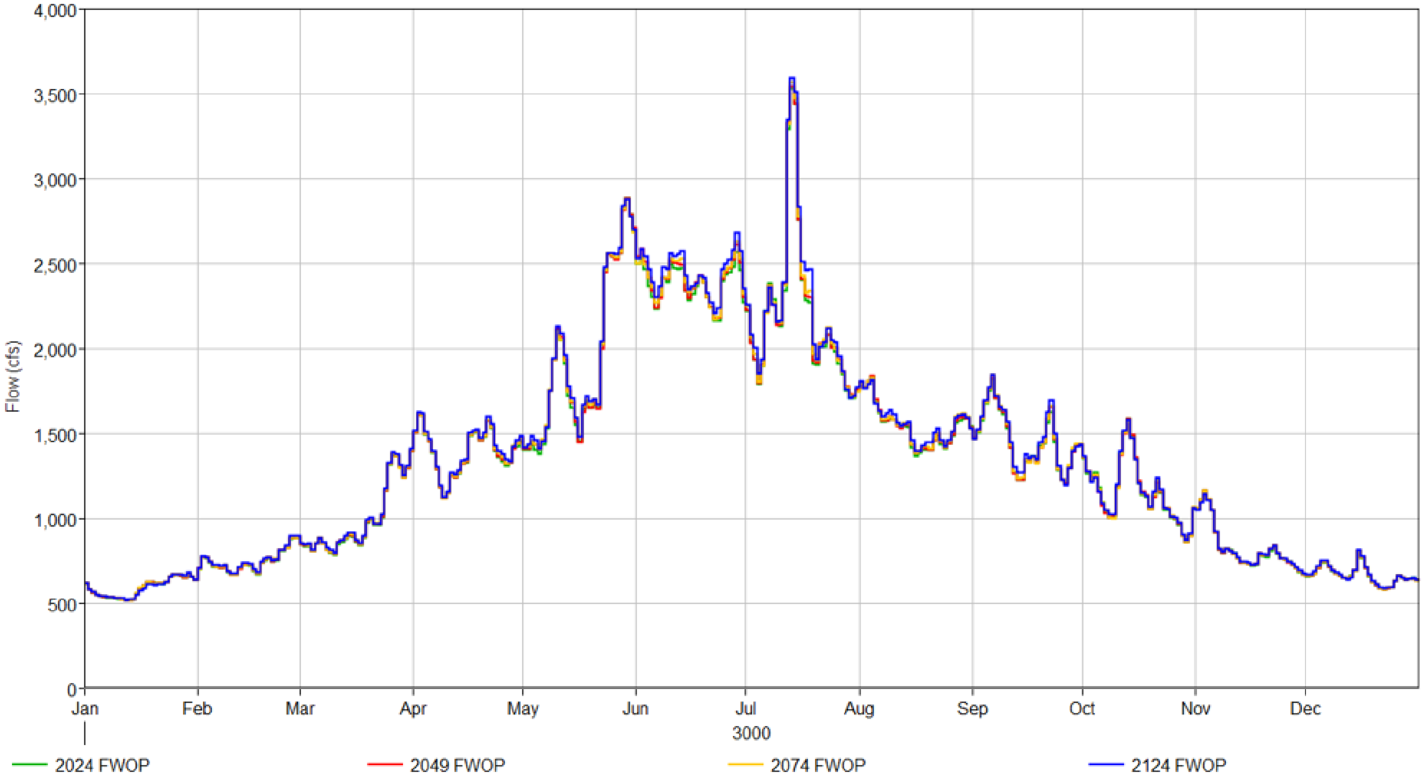


Figure 4-146. Smoky Hill River at Enterprise average flow compared for each FWOP scenario.

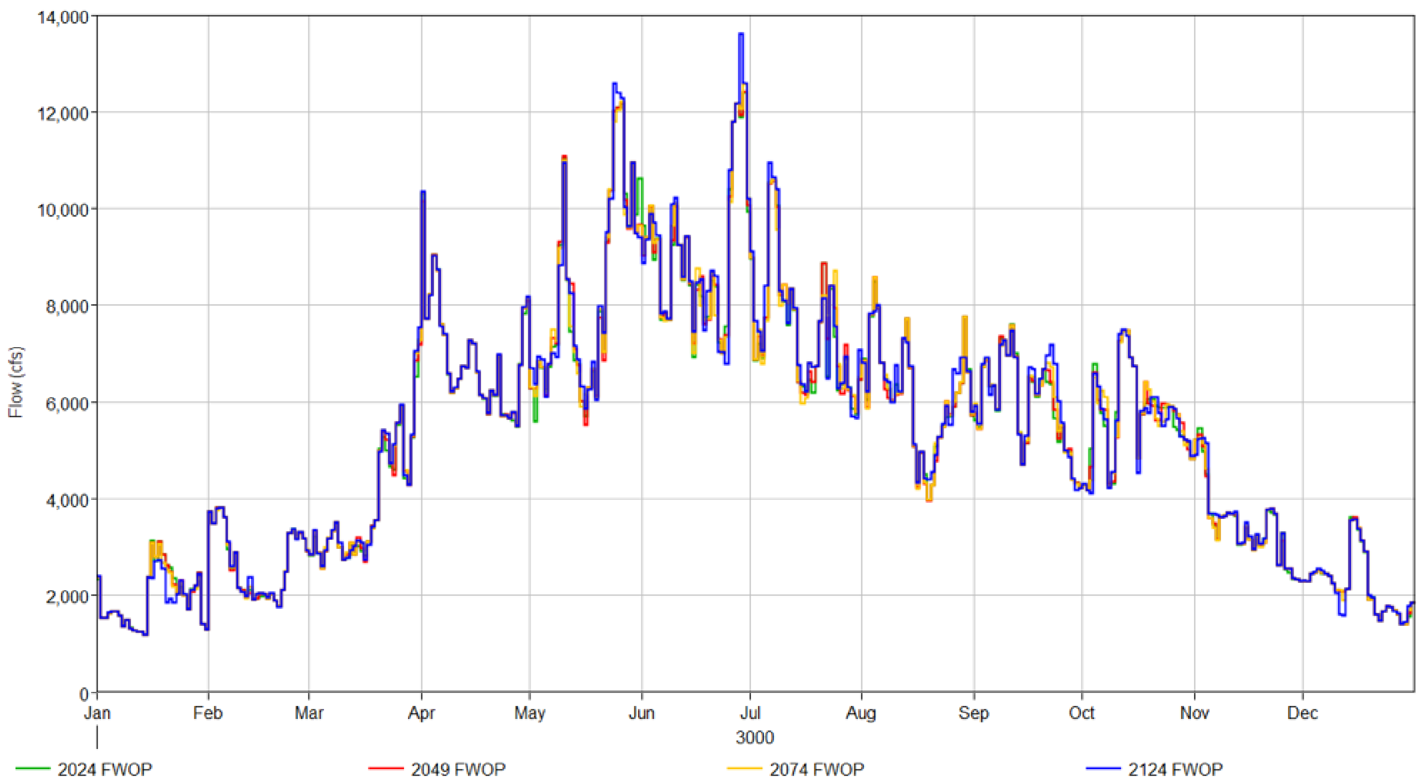


Figure 4-147. Smoky Hill River at Enterprise 95th percentile flow compared for each FWOP scenario.

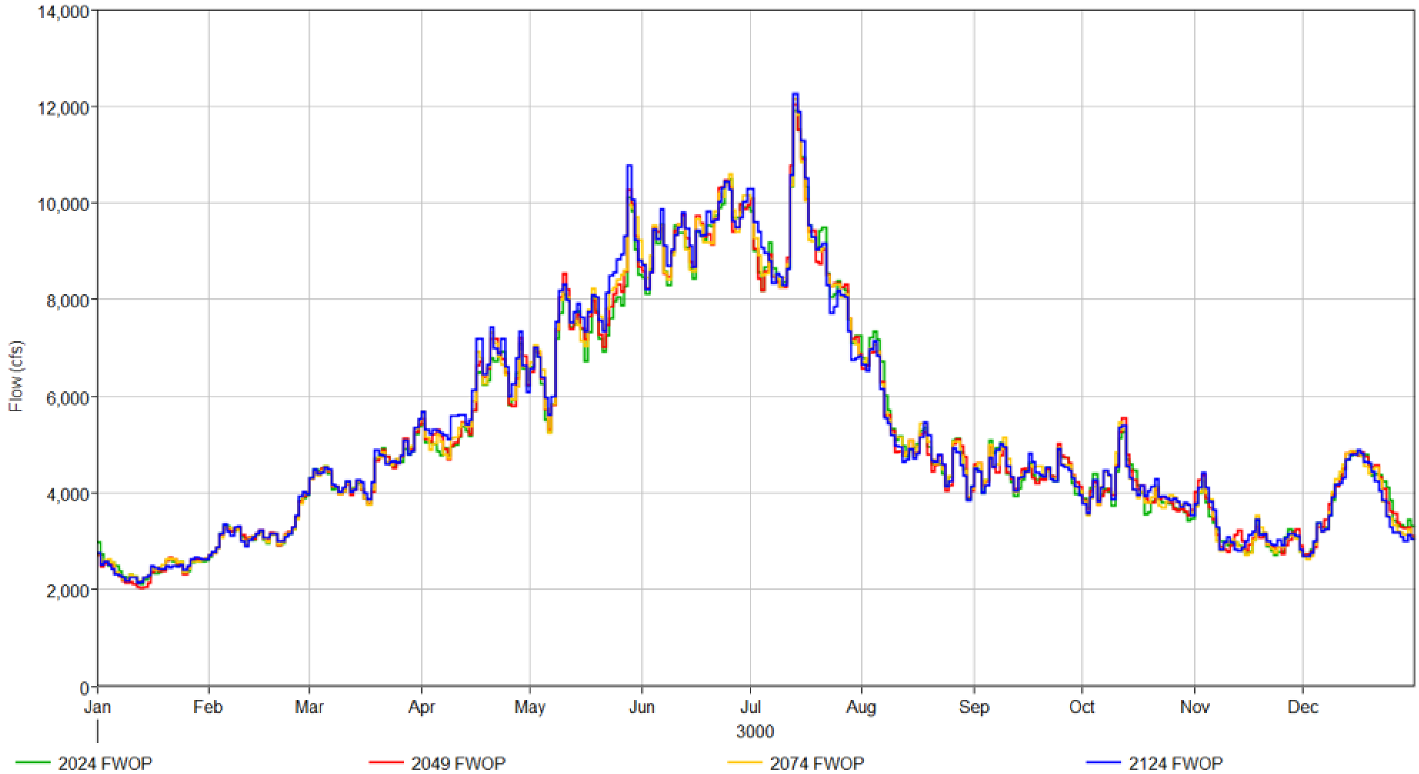


Figure 4-148. Kansas River at Topeka average flow compared for each FWOP scenario.

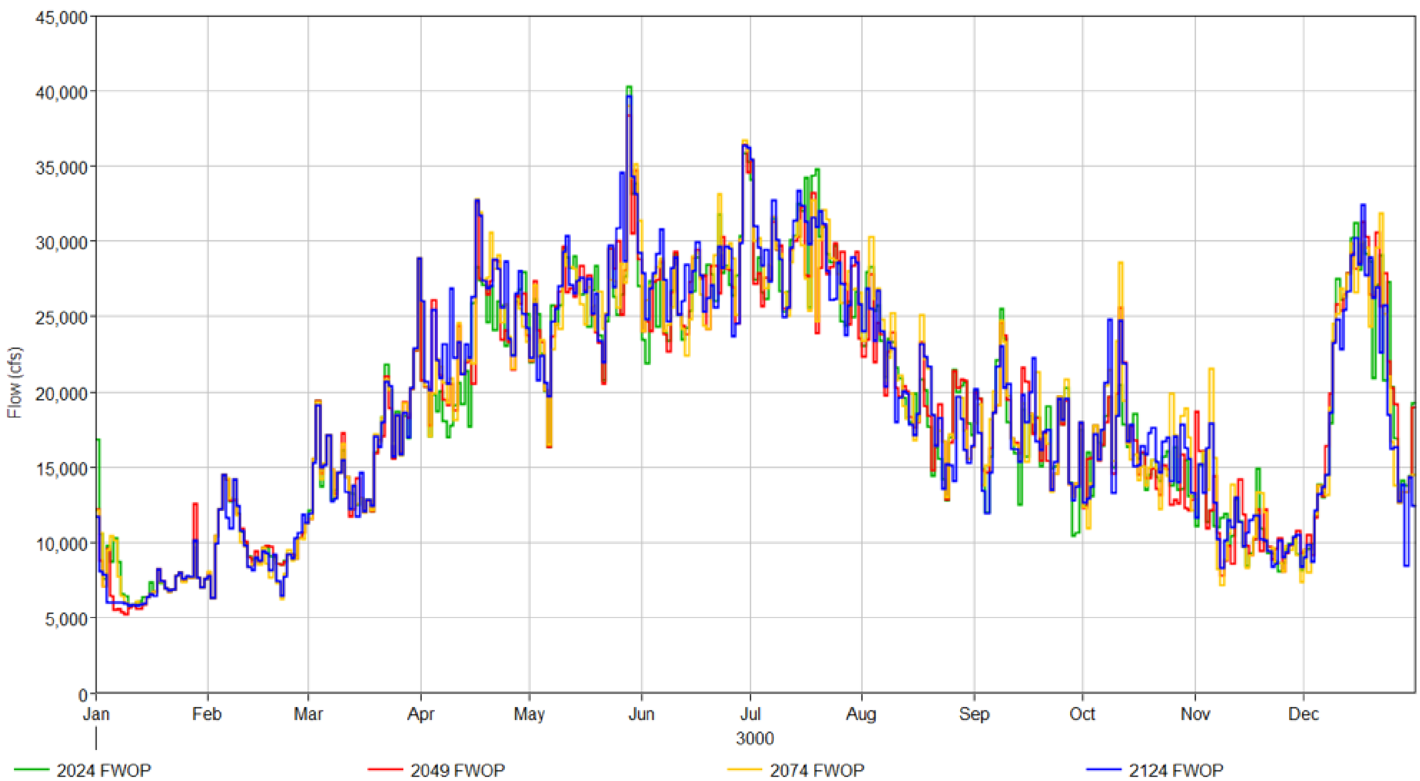


Figure 4-149. Kansas River at Topeka 95th percentile flow compared for each FWOP scenario.

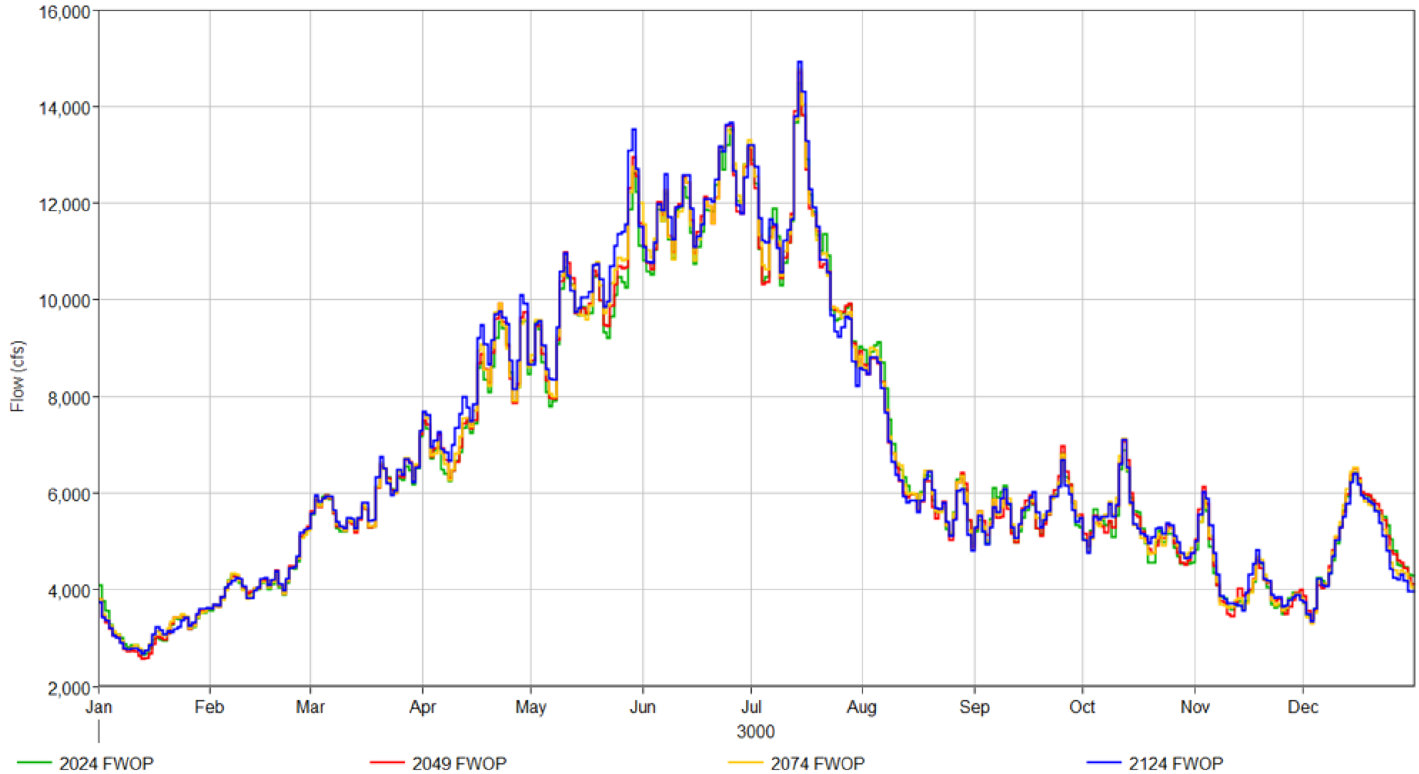


Figure 4-150. Kansas River at Desoto average flow compared for each FWOP scenario.

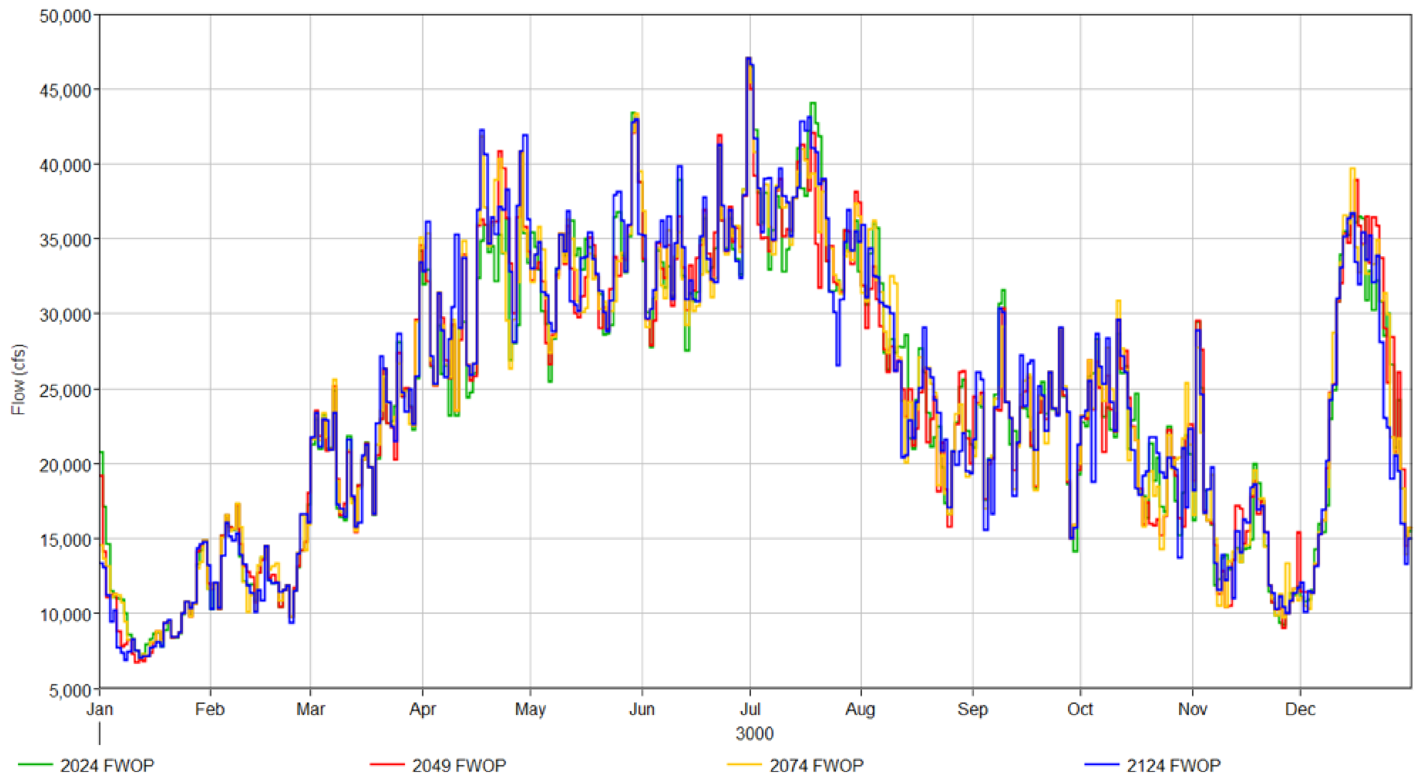


Figure 4-151. Kansas River at Desoto 95th percentile flow compared for each FWOP scenario.

These plots indicate very little impact on the downstream gages from increased sedimentation. There are some subtle impacts and changes. The water quality targets at the Kansas River at Topeka and Desoto were evaluated to determine how often the target flows were not met. Of the 36,526 days in the 100-year modeling period a few days dropped below target as shown in Table 4-1. The ResSim computations will get close to the target, but there may be some minor adjustment below target even when there is plenty of water. To differentiate between small adjustments versus if the system ran out of water, the table also shows how many days the target was more than 50 cfs below target. Between the various FWOP scenarios, the only clear trend is the increased days more than 50 cfs below the Topeka target in the 2124 scenarios. The navigation scenarios also show more days below target than their non-navigation counterparts. Fewer days below minimum target in the 2124 scenario is counter intuitive. The scripted rule, described in Section 3, that smoothed multi-purpose releases near the lower portions of the multi-purpose pool appears to also provide smoother flows even though there is less water and lower pool elevations. The bulk of the days below target are for a day or two as ResSim adjusts reservoir releases to meet targets; however, the drought of record does show systematic loss of water to meet downstream water quality targets in the 2124 scenario.

Table 4-1. Days below the water quality minimum flow target at Topeka and Desoto.

	Kansas River at Topeka		Kansas River at Desoto	
Scenario	Days below the Minimum Target	Days more the 50 cfs below Minimum Target	Days below the Minimum Target	Days more the 50 cfs below Minimum Target
2024 FWOP Non-Navigation	672	38	1395	326
2024 FWOP Navigation	739	40	1399	383
2049 FWOP Non-Navigation	638	33	1382	362
2049 FWOP Navigation	726	33	1465	431
2074 FWOP Non-Navigation	616	37	1347	354
2074 FWOP Navigation	673	45	1503	479
2124 FWOP Non-Navigation	531	76	1179	290
2124 FWOP Navigation	533	82	1141	271

5 Conclusion

Of the four FWOP non-navigation scenarios that were analyzed, some clear trends were established. Reservoir storage decreased with each successive FWOP scenario. Multi-purpose storage loss was largest at Kanopolis, Tuttle Creek, and Perry. Small losses in the flood control pool area also experienced in all the reservoirs. The clear trends shown by the data are:

1. As sediment accumulates in the multi-purpose pool, the average pool elevation increases. Some small increases are also seen in the higher 95th percentile pool elevations, but the trend is not as clear. The exception to this trend is Milford as pool elevations are lower than due to increased water quality releases.
2. As sediment accumulates in the multi-purpose pool, the reservoir outflows remain virtually unchanged. Average releases are slightly increased for some reservoirs. The is no difference in the 95th percentile outflows for each FWOP scenario.
3. As the Tuttle Creek multi-purpose storage decreases, more of the Topeka and Desoto water quality releases are shifted to Milford and Perry. This results in lower pool elevations at Milford. There are some trends that the river flows drop below the water quality targets more often in the future. Milford and Perry water supply storage is, at times, needed to meet the flow targets.
4. River high flows are very similar across the FWOP scenarios. Average flows are slightly increased. There is trend for increased flows in the high 95th percentile flows.

In the four FWOP navigation flow support scenarios, trends are like the non-navigation scenarios. Navigation flow support leads to lower multi-purpose pool elevations at Milford, Tuttle Creek, and Perry. The water quality flows also drop below target more often when supporting navigation flows.

Other disciplines will continue to evaluate this model output to assess the impacts of the FWOP scenarios on flow frequency, flood impacts, recreation, and water quality.

WAVERLY ALTERNATIVE ANALYSIS

Kansas River Reservoirs Flood and Sediment Study
HEC-ResSim Waverly Alternative Analysis
Simulation Review and Documentation

ATR Report: October 2023
USACE Kansas City District

Executive Summary

The Kansas River Reservoirs Flood and Sediment Study (KRRFSS) included an analysis of two alternative reservoir releases for the Missouri River at Waverly, MO control point. The first alternative removed the Waverly control point for the lower Kansas River reservoirs to benchmark the impact of these reservoirs on the flow at Waverly, leaving the Kansas City control point to limit flows on the Missouri River. The second alternative investigated using the receding limb of the Missouri River at Waverly hydrograph as the criteria for flood control reservoir releases on the Kansas River Reservoirs. These alternatives were compared to the existing conditions modeling that was conducted for KRRFSS and documented in Appendix B ResSim documentation.

Both alternatives allowed flood storage to be released faster from the reservoirs and thus reduced the duration and frequency of high reservoir pool elevations. Flow durations on the Missouri River showed some variations with reduced flow duration below 90,000 cfs and increased flow duration in the range between 90,000 cfs 300,000 cfs, with some key differences between the two alternatives. Both alternatives provided reduced flow duration for the most extreme events above 300,000 cfs.

Alternatives were aimed to determine whether further investigation of potential modification of downstream flow targets are warranted to reduce future flood risk on the Kansas and Missouri Rivers. Further definition of these and other alternatives, including low-flow scenarios, the consideration of the positive and negative impacts, and public comment is required before recommending any change to flood operation criteria as part of a Water Control Manual (WCM) update. Although one or both alternatives may not be carried forward exactly as modeled in this study, further consideration of similar alternatives is warranted as part of a WCM update.

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1 Introduction

This document provides the methodology used to simulate alternative reservoir regulation flow on the Kansas River and portions of the Missouri River from January 1920 through December 2019. Reservoir modeling was conducted using Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) version 3.5. The full model setup is described in Appendix B ResSim documentation.

All analysis is conducted as part of the Kansas River Reservoirs Flood and Sediment Study (KRRFSS). The existing conditions simulation was used as a baseline for comparison with alternatives to evaluate changes to reservoir operations. The alternatives were only evaluated for the existing conditions without incorporation of future reservoir sediment estimates. No alternatives were developed in the future without project scenarios. These alternatives were designed to test potential benefits of considering alterations to current operations and are not reflective of any proposed changes to operations at this time. Any proposed changes to water control manuals would be conducted through a separate process with additional points where public comment could be incorporated into the alternatives and decisions regarding potential changes.

2 Alternative Description

The four lower Kansas Reservoirs (Milford, Tuttle Creek, Perry, and Clinton) are operated for a series of gages along the Kansas and Missouri Rivers. These gages are called control points and have an associated flow rate depending on the phase of the flood control pool that is occupied. The Kansas River Basin reservoirs and the corresponding control point gages for flood control operations are shown in Figure 2-1.

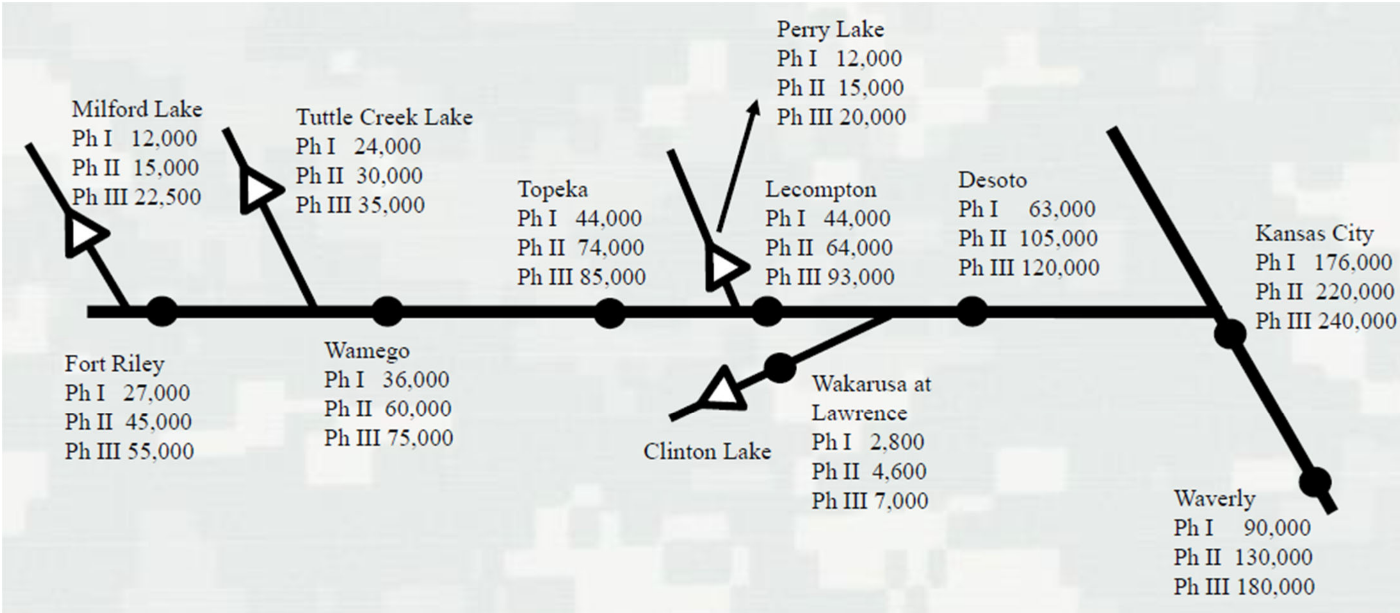

Figure 2-1. Schematic of the Kansas River Basin reservoirs and control points, flows in cfs.

During a flood event, the Kansas River control points will typically only rise above the criteria flows for a few days. During that time reservoir releases are restricted, but once the gage has dropped accumulated storage in the flood control pools could be released. The Missouri River control points, especially at Waverly, can rise above criteria for long periods of time and remain above criteria for weeks to months depending on the flood event. Reservoir releases need to be restricted while the Missouri River at Waverly is above criteria, so it leads to higher pool elevations and risks at the reservoirs including increased chances of surcharge operations.

As shown in Figure 2-2, significant watershed area is contributing to the Waverly flows. This watershed includes unregulated areas and other systems of reservoirs including the Missouri River mainstem reservoirs. When this area gets wet and is in a wet pattern, flows can be out of bank for extended time periods causing risk to communities in the region. Depending on storm location, reservoirs may have a large or insignificant impact on reducing flood risk at a given location, such as Waverly. For example, a large storm impacting the Platte River below Kingsley Dam, as in March 2019, could produce major flows in areas without reservoirs.

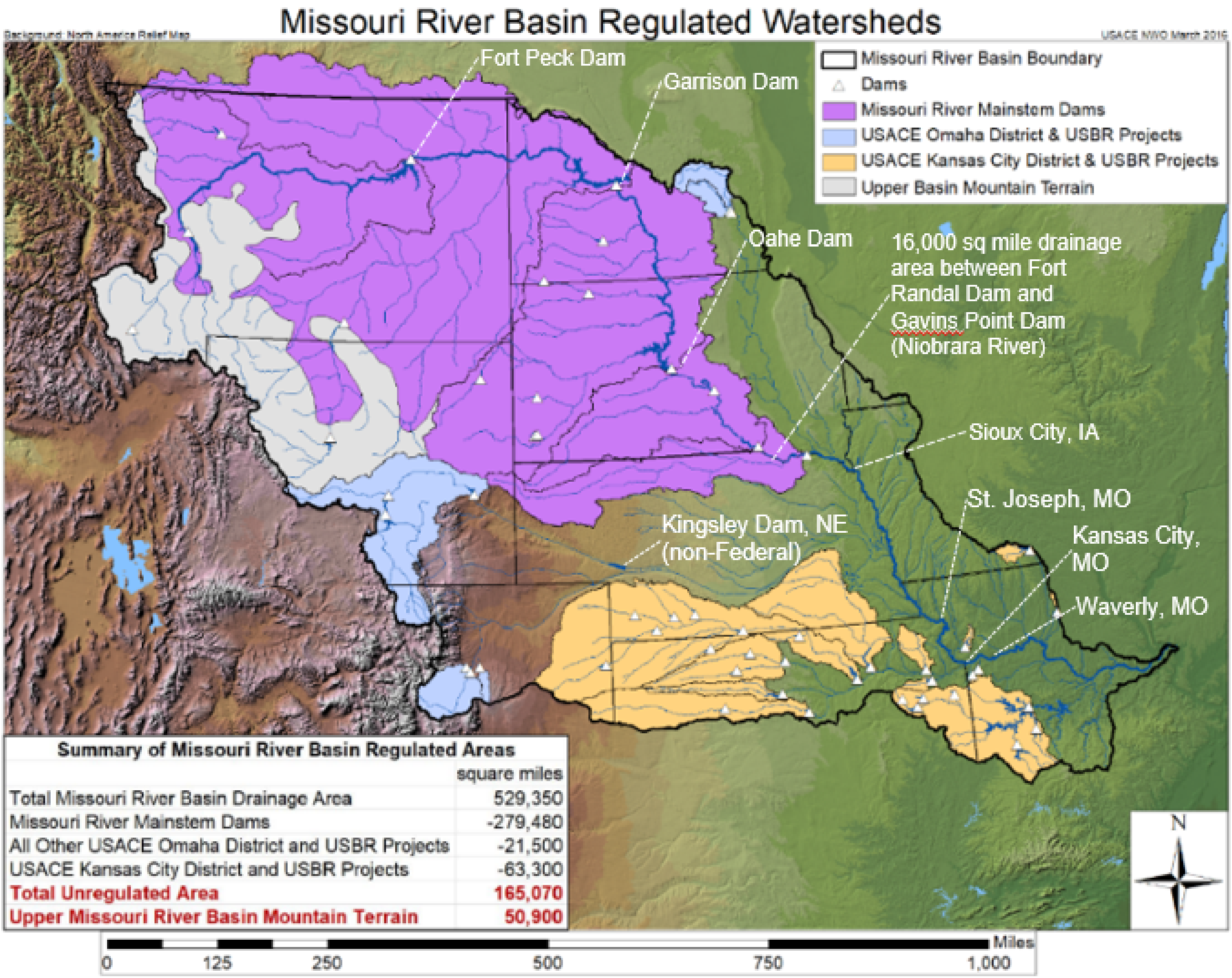

Figure 2-2. Missouri River watershed showing regulated and unregulated areas within the basin.

The Kansas City criteria is higher than the downstream, Waverly, gage. At Kansas City a robust levee system protects the areas near the river leading to higher criteria flows. The Waverly gage is used to assess impacts for an approximately 100 mile stretch of river and its nearby communities and interests. This section of the river begins downstream of the Kansas City levees and extends approximately to the mouth of the Grand River. Along this section of the river, are several privately owned levees, farms, public wildlife areas, and communities.

The Kansas River Master Manual outlines the Missouri River criteria flows that were shown in Figure 2-1. The Phase I level of 90,000 cfs allows gravity drainage of agricultural land behind the levees in the Waverly reach. Not all drainage structures can drain at this level, but below 90,000 cfs most of the agricultural activities can proceed without pumping local runoff over the levees. The Phase II level of 130,000 cfs is approximately channel capacity on the Missouri River in this reach. Above this, there is loading on the toe of the levees and increased seepage concerns on the levees. The Phase III level of 180,000 cfs is associated with significant loading of the levees in the area but provides freeboard for additional runoff before there is risk of levee overtopping. Many levees in the Waverly reach overtop between 250,000 cfs and 300,000 cfs; these flows may vary depending on how many measures are incorporated into preventing overtopping. Generally, USACE will consider levee overtopping flows assuming no intervention such as sandbagging occurs.

A water control plan update is required to change the flow levels, but there is interest in investigating a change to better balance flood risks in the basin. Reasons for a change include the ability to release accumulated flood storage more quickly at the reservoirs, reduced risks of uncontrolled spillway flows and associated risks to the communities downstream including those on the Missouri River, reduced impacts to in-lake interests such as recreational facilities, and a better mechanism to provide low-flow releases to the Kansas River during Missouri River flooding. The Kansas Watershed Study is beginning the investigation of alternatives to address the above issues, but further analysis is needed as part of a water control manual update. The following paragraphs details the alternatives.

2.1 Kansas City Target Only

The first alternative removes the Waverly criteria and sets reservoir releases based all the other control points. The only Missouri River control point is Kansas City which allows higher flows than the Waverly criteria.

With the importance of flood protection in the Waverly reach of the river, it is unlikely that this is a viable alternative. Rather, the main intent of this alternative is to assess the effect of the Kansas River operation on the Missouri River at Waverly. Much of the flood protection is provided by the Missouri River mainstem reservoirs, but the Kansas River reservoirs can provide situational benefits if a rain event occurs on the Kansas River or in the Kansas City area, especially in major Kansas River floods such as 1951.

2.2 Waverly Flow Behind the Peak Over 90,000 cfs

The second alternative keeps the Waverly control point and allows flood control releases (from any phase of the flood pool) after the Missouri River at Waverly has crested. This specific alternative allows releases when Waverly is below 90,000 cfs; as the gage rises above 90,000 cfs releases are reduced to low flow; after the gage has dropped to 90% of its peak flows flood control releases can be resumed. After the crest, flood control releases will be made regardless of the flow at Waverly. All other control point criteria remains unchanged.

Several variations of this alternative could be made by fluctuating the threshold for shutting off releases on the rising limb of a flood or the percent below the crest on the falling limb for when releases can resume.

3 Methodology

HEC-ResSim version 3.5 was used to simulate reservoir operations and route water through the basin. The KRRFSS existing conditions (without navigation) alternative was used as a starting point for each alternative. No impacts of navigation were assessed for these alternatives.

3.1 Kansas City Target Only

The model setup for the “Kansas City Target Only” alternative simply disabled the “WVMO CP” rule for all zones for each reservoir. No other rules were modified. Figure 3-1 shows the Milford operation set as an example of how this alternative is setup.

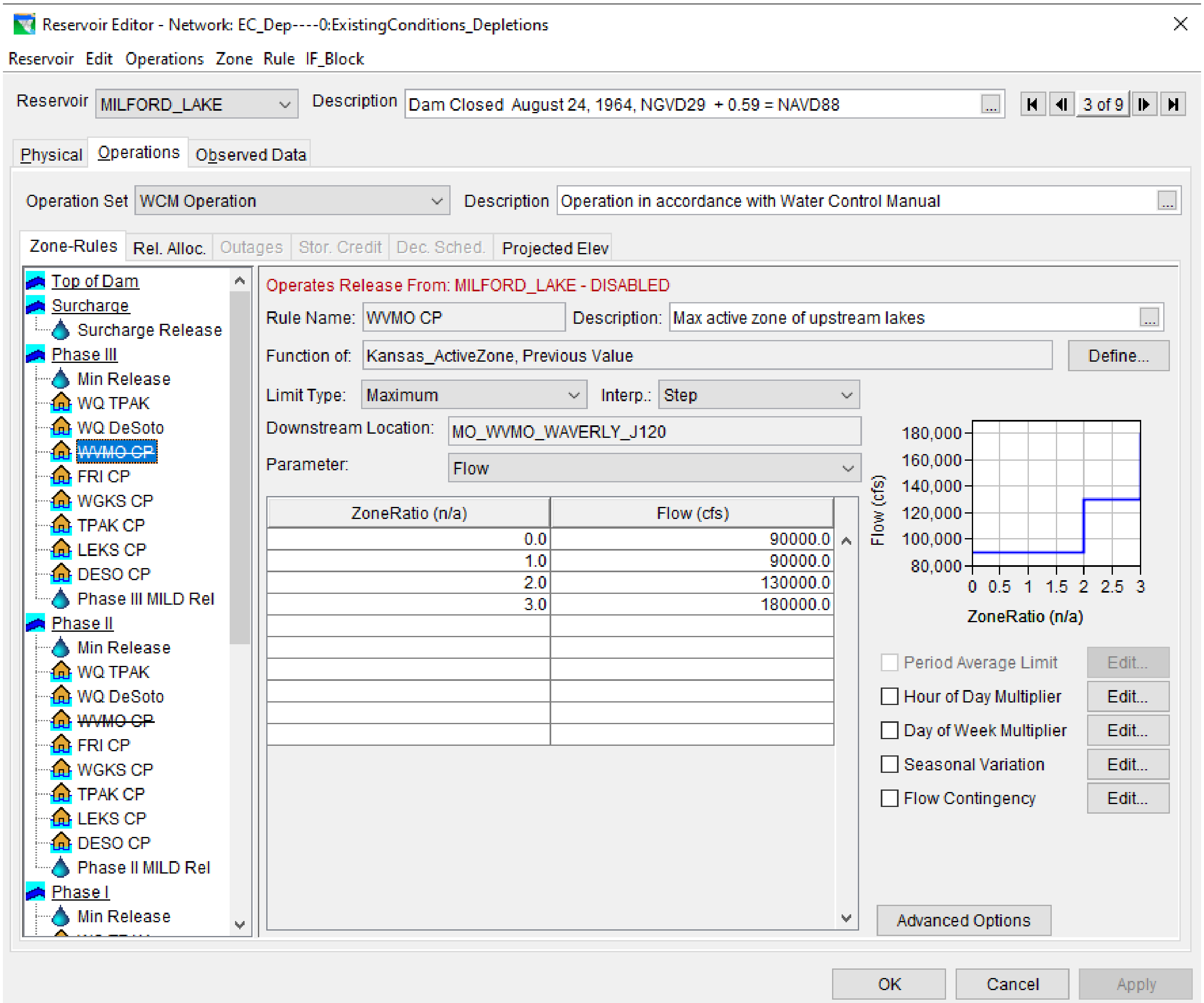

Figure 3-1. Milford Reservoir operation set for the "Kansas City Target Only" alternative.

3.2 Waverly Flow Behind the Peak Over 90,000 cfs

The model setup for the "Waverly Flow Behind the Peak Over 90,000 cfs" alternative removed the "WVMO CP" rule and added a new ruled called "WVMO below peak" for all zones for each reservoir. This rule looks at the last 60 days of Waverly flows and allows a maximum flow of 90% of the peak flow from that time period. Below 90,000 cfs any release can be made. If a second peak occurs during the 60-day period the model will ignore it if it is less than the first (greater peak). Having the long lookback period helped to adequately model extended floods. However, it is recommended to add additional capability that allows ResSim to cut releases if a second peak occurs if a water control plan update is evaluated. No other rules were modified. Figure 3-2 shows the Milford operation set as an example of how this alternative is setup.

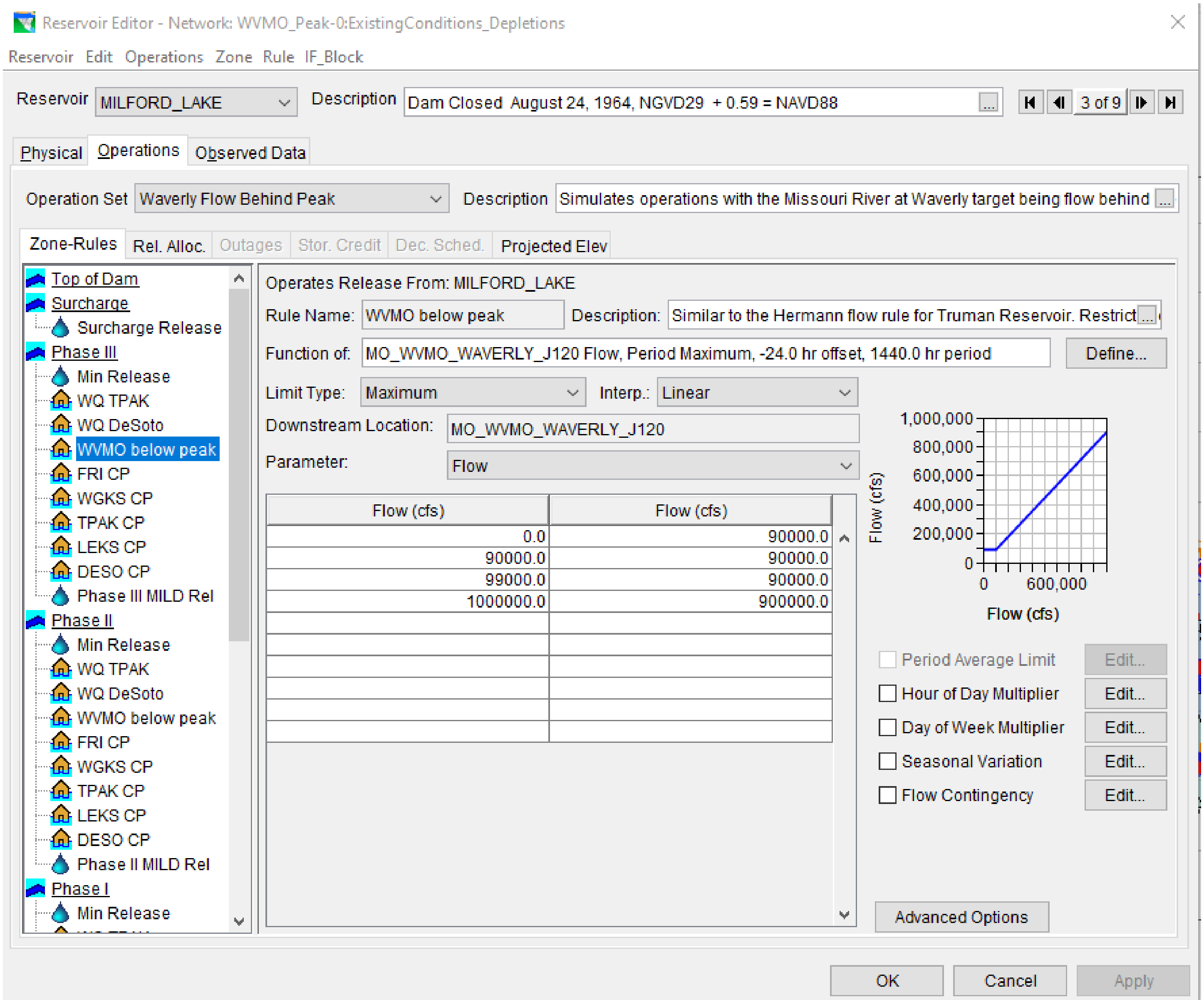

Figure 3-2. Milford Reservoir operation set for the "Waverly Flow Behind the Peak Over 90,000 cfs" alternative.

4 Model Results

The two alternatives were run using a lookback period of 01Dec1919 to 31Dec1919; the forecast time was 01 Jan 1920 to 02 Jan 2020. Model results were graphically compared to the existing conditions modeling for comparison.

4.1 Missouri River at Waverly Flow

The period of record flow was analyzed for the Missouri River at Waverly to assess impacts from the alternatives. Figure 4-1 shows the annual exceedance probability (AEP) plot for the Missouri River at Waverly flows. Selected AEP and the maximum flow from certain events are shown in Table 4-1.

There are small, important differences between alternatives. The “Kansas City Target Only” alternative is consistently higher because it is not operating for Waverly; however, between the 10% and 1% AEP it drops lower than the other alternatives because it provides lower flow for the most extreme events likely by reducing the frequency of surcharge events. By not constraining releases to maintain the existing conditions Waverly flow targets, some surcharge events are avoided or reduced, and the most extreme events are lower.

The “Flow Behind the Peak” alternative is identical with the existing conditions except for the most extreme events where it maintains or reduces flow compared to the existing condition. Since this alternative is designed to not add to peak flows this is a reasonable result. The reduced flow for extreme events shows that water is more efficiently released from the flood control pools and flood control or surcharge releases can be lower.

Depending on the location of the rainfall and the starting conditions of the reservoirs, the alternative flows may be the same as the existing conditions. Flood events from 1951 and 1993 had reduced flows in one or both of the alternatives as shown in Table 4-1. Other flood events like 2007 and 2019 had no change in peak flows or minimal change.

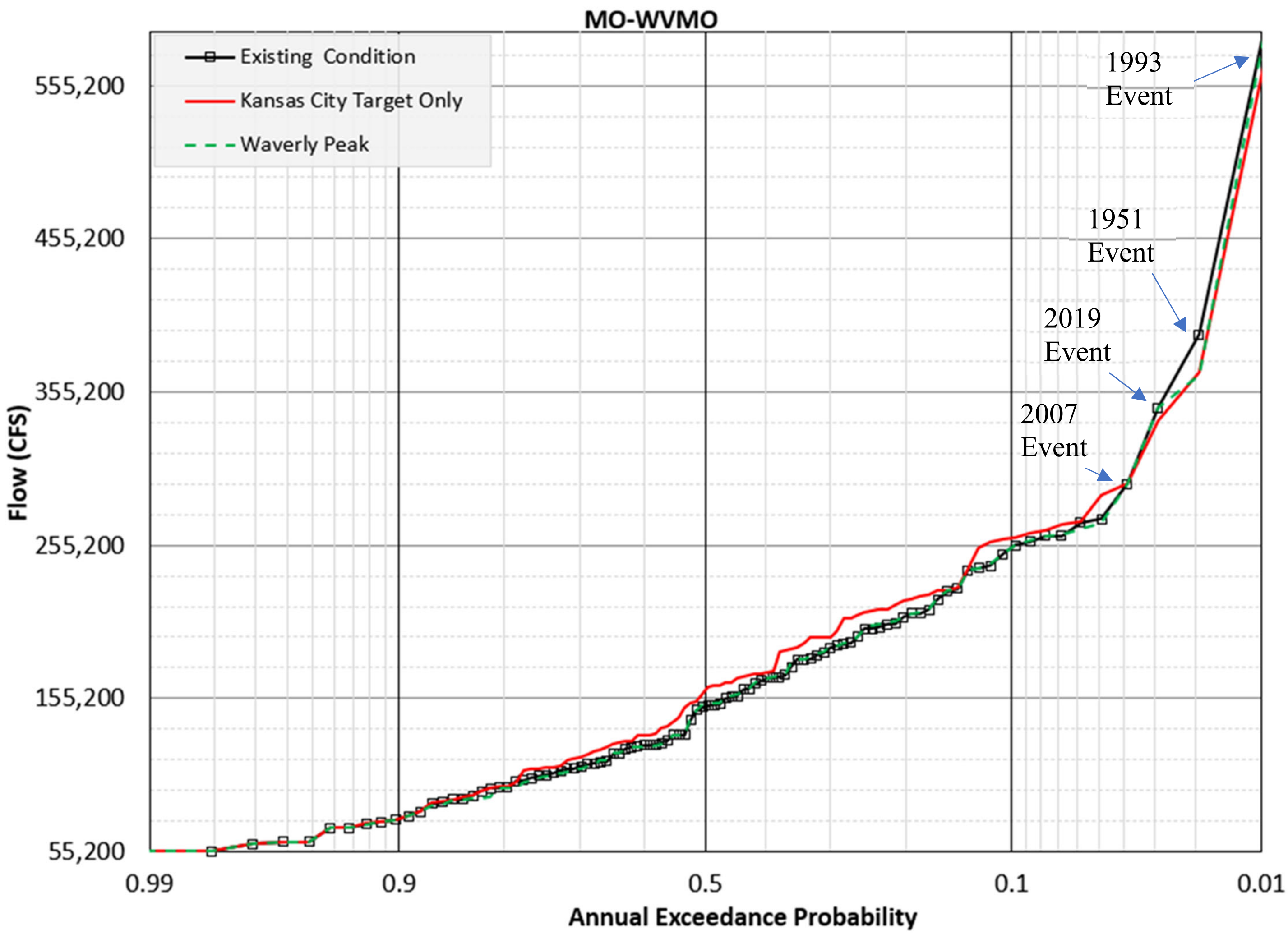

Figure 4-1. The Missouri River at Waverly Annual Exceedance Probability.

Table 4-1. Specific AEP for the Missouri River at Waverly.

Simulation	50% AEP (cfs)	10% AEP (cfs)	1951 Peak Flow (cfs)	1993 Peak Flow (cfs)
Existing Conditions	151,000	255,000	393,000	590,000
KC Target Only	163,000	260,000	337,000	568,000
Flow Behind the Peak	151,000	255,000	366,000	586,000

The AEP plots tell a piece of the story, but to assess subtle differences between alternatives the flow duration plot was developed using daily flows from the model results. Figure 4-2 shows the Waverly flow duration for the 40% probability and less frequent; lower flows than are shown in this plot are similar between all alternatives. Figure 4-3 shows the duration for the most extreme flows that occur 1% of the time and less.

Below 90,000 cfs the existing condition has higher flow duration because the phase I flood control releases are occurring below this level. In the existing condition, Phase I releases are held until Waverly drops to 90,000 cfs and then flood releases begin holding Waverly closer to 90,000 cfs for a longer time. During the alternatives, flood control releases are made sooner, and when Waverly drops below 90,000 cfs, there is not as much flood storage, so the Waverly flow continues to drop faster than in the existing condition.

Between approximately 90,000 cfs and 300,000 cfs, both alternatives have higher flow than existing conditions since flood control releases are occurring in this range, with much of the difference occurring on the falling limb of the hydrograph after a larger flow had already occurred. Generally, the "Kansas City Target Only" has the higher flows between 90,000 to 300,000 cfs compared to the other alternatives. While all or most of this flow range is considered within the levees, additional risk could be assumed by having higher flows and warrants further study in a water control manual update.

Between 300,000 and 350,000 cfs, the lines cross again, and the existing condition flows are the highest. This indicates that either alternative may help to reduce the most extreme flooding that would overtop most levees in the vicinity of Waverly, and potentially avoid some surcharge events. Further study is needed to understand impacts and benefits each alternative could have on the river reach around Waverly.

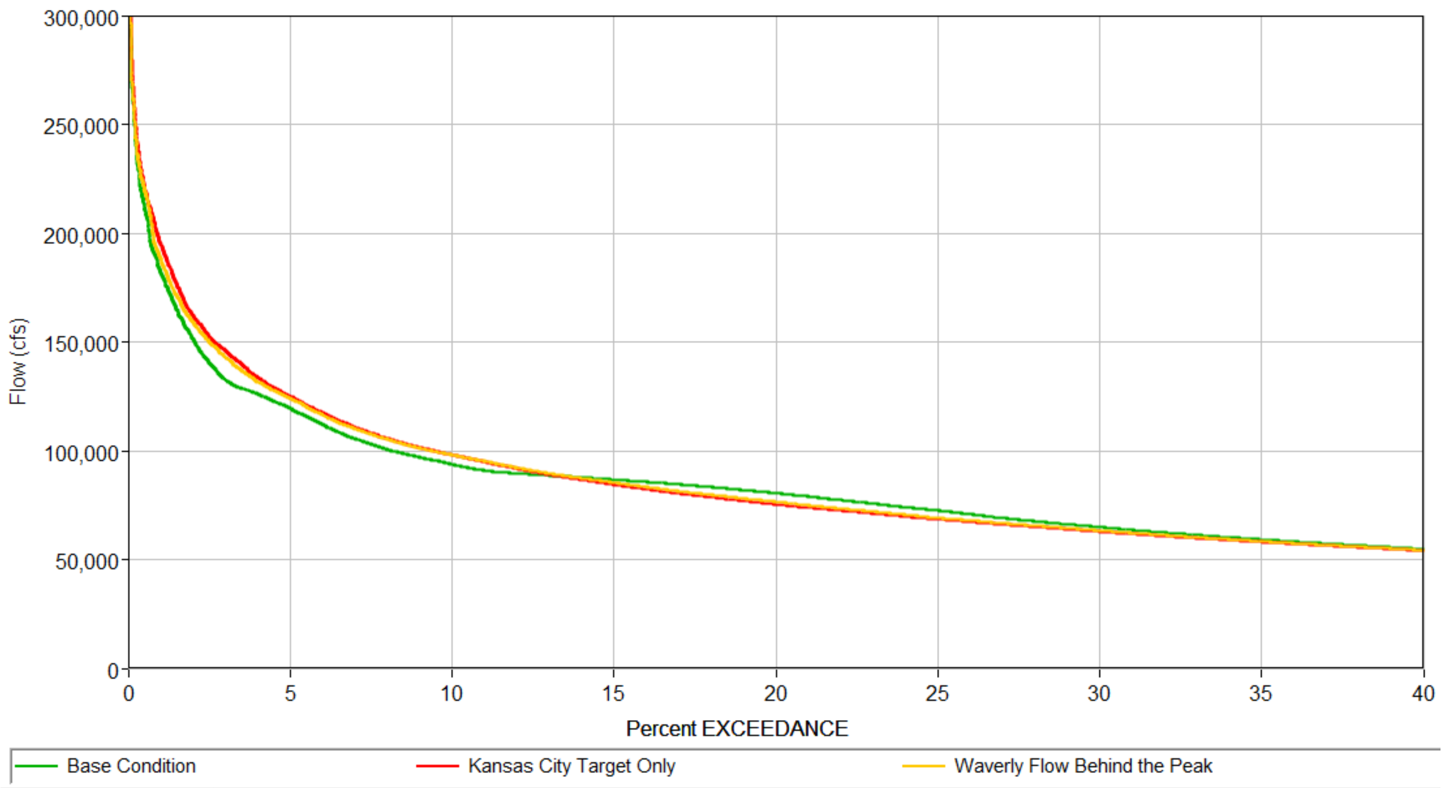

Figure 4-2. Missouri River at Waverly flow duration.

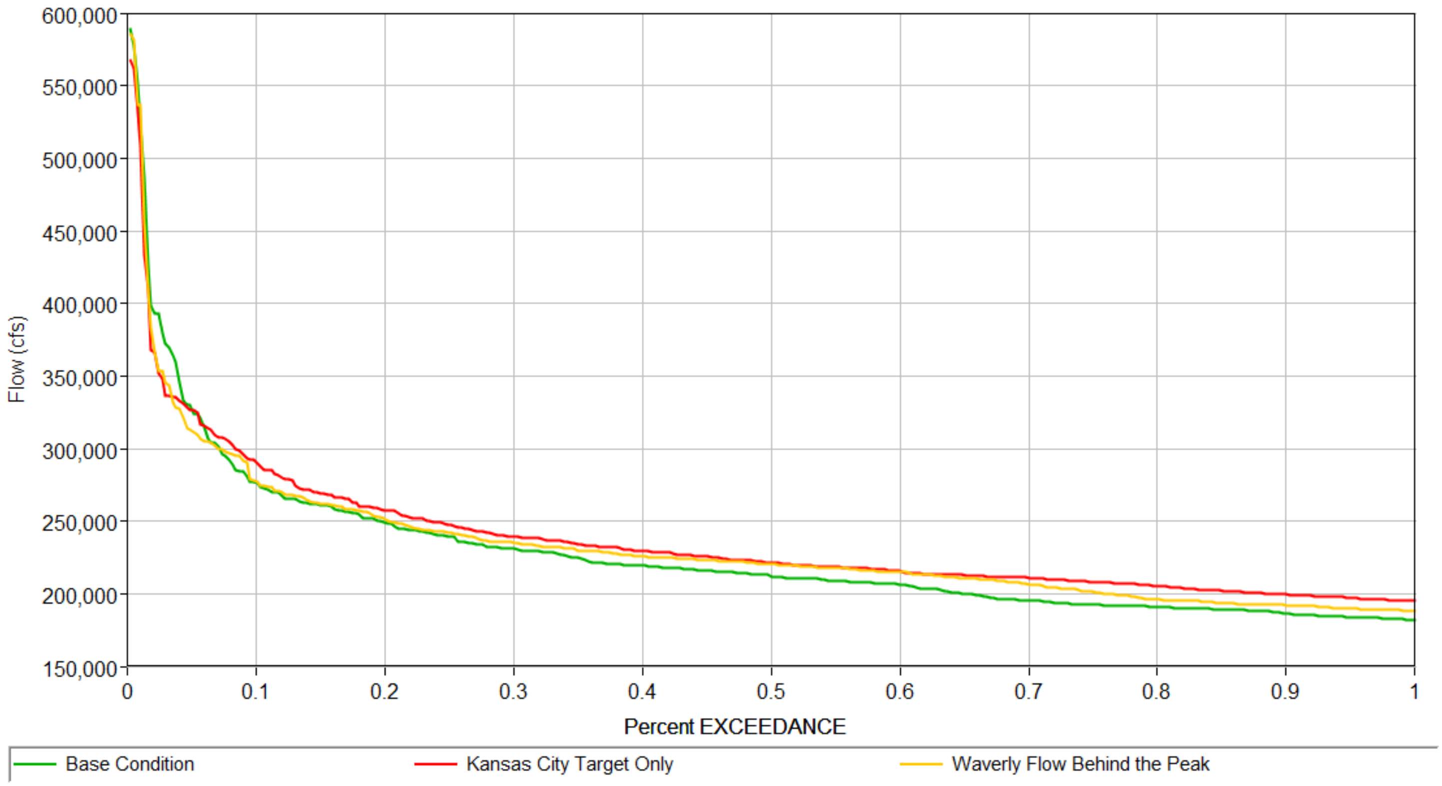

Figure 4-3. Missouri River at Waverly flow duration for the most extreme events that occur less than 1% of the time.

4.2 Kansas River at Desoto Flow

The period of record flow was analyzed for the Kansas River at Desoto to assess impacts from the alternatives. The regulating rules for Desoto were not changed, but there are incidental changes from the alternative Waverly rules. Figure 4-4 shows the annual exceedance probability (AEP) plot for the Kansas River at Desoto flows. Selected AEP and the maximum flow for certain events are shown in Table 4-2Table 4-1. Both alternatives show sizable reduction in the peak flows.

There are small, important differences between alternatives. The "Kansas City Target Only" alternative is consistently higher in the middle flow range; however, between the 10% and 1% AEP it drops lower than the other alternatives because it provides lower flow for the most extreme events likely by reducing the frequency of surcharge events. By not constraining releases to maintain the existing conditions Waverly flow targets, some surcharge events are avoided or reduced, and the most extreme events are lower which provides a benefit to Desoto.

The "Flow Behind the Peak" alternative is very similar to existing conditions except for the most extreme events where it maintains or reduces flow compared to the existing condition. Since this alternative is designed to not add to peak flows this is a reasonable result. The reduced flow for extreme events shows that water is more efficiently reduced from the flood control pools and flood control or surcharge releases can be lower.

For specific events, 1951 is the highest for all three scenarios, and 1993 is the second highest. For the 2019 event, it is the third highest in the existing condition, but the alternative flows are lower and did not rise to third highest.

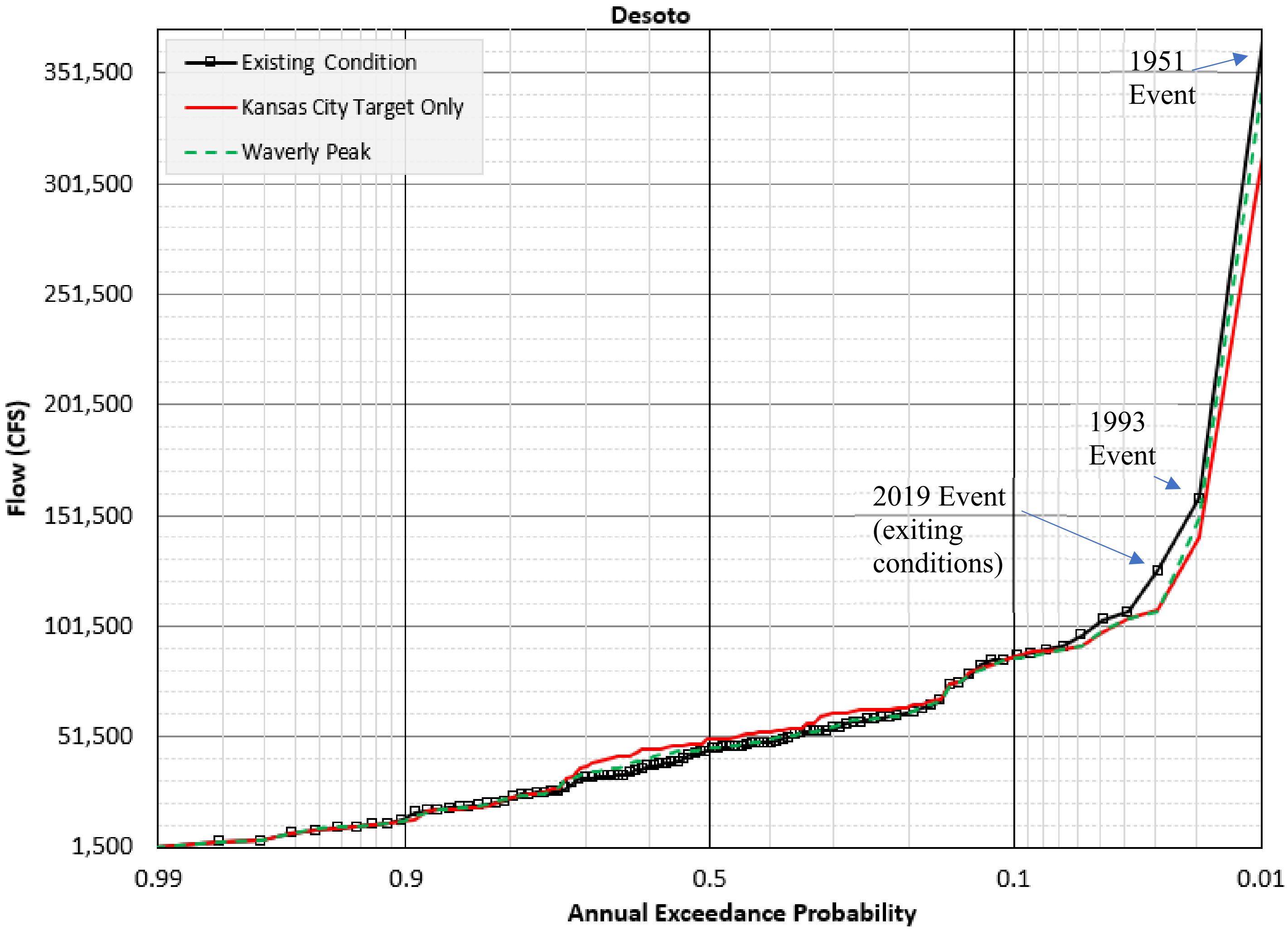

Figure 4-4. The Kansas River at Desoto Annual Exceedance Probability.

Table 4-2. Specific AEP for the Kansas River at Desoto.

Simulation	50% AEP (cfs)	10% AEP (cfs)	1951 Peak Flow (cfs)	1993 Peak Flow (cfs)
Existing Conditions	45,900	88,000	371,000	159,000
KC Target Only	50,300	88,200	319,000	141,000
Flow Behind the Peak	46,500	87,000	351,000	150,000

The Desoto flow duration plots show a similar result as Waverly because Phase I flood control releases are being constrained longer with the current Waverly operating criteria. Flow duration plots were developed using daily flows from the model results. Figure 4-5 shows the Desoto flow duration for the 40% probability and less frequent; flows lower than are shown in this plot were similar between all alternatives. Figure 4-6 shows the duration for the most extreme flows that occur 1% of the time and less.

Below 20,000 cfs the existing condition has higher flow duration. Between approximately 20,000 cfs and 45,000 cfs, both alternatives have higher flow than existing conditions as a function of how the reservoir flood control releases are being made in the alternatives. Generally, the “Kansas City Target Only” has the higher flows. However, just below 100,000 cfs, the lines cross again, and the existing condition flows are the highest.

This indicates that either alternative may help to reduce the most extreme flooding and potentially avoid some surcharge events. Channel capacity on the Kansas River at Desoto generally exceeds 100,000 cfs.

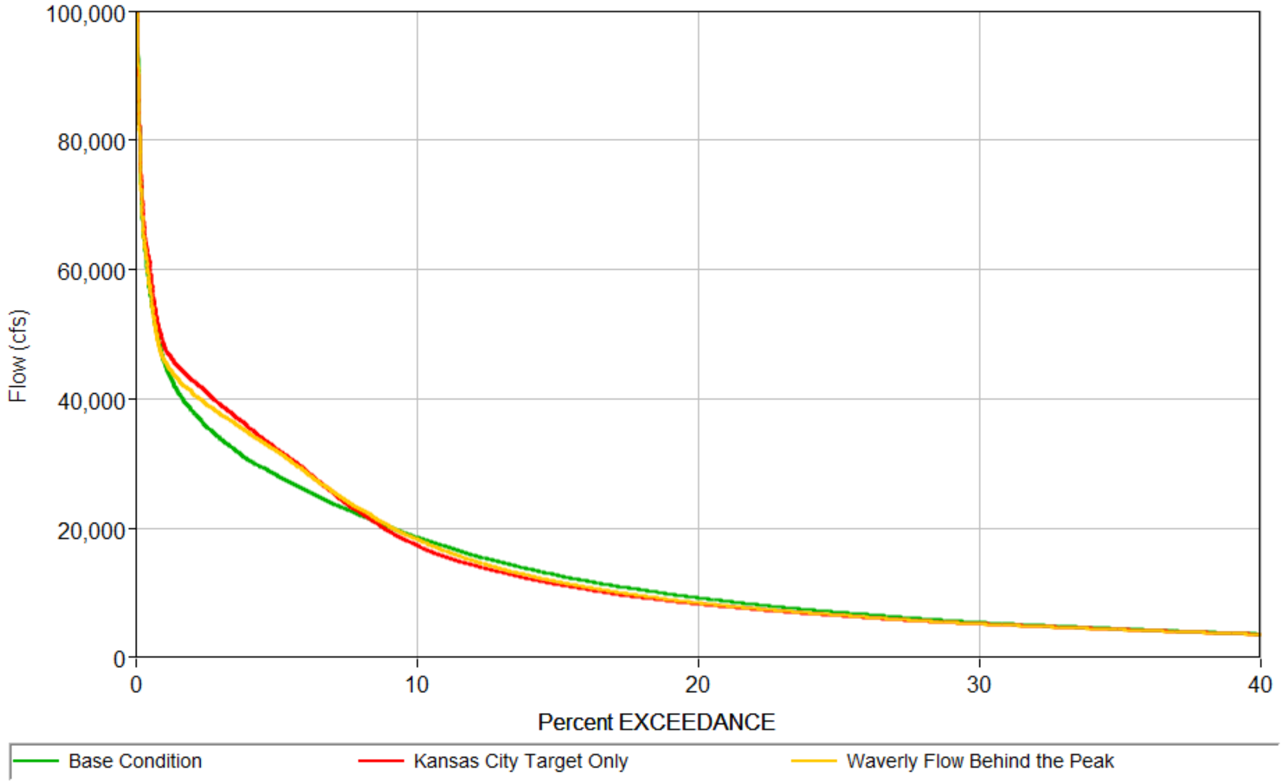

Figure 4-5. Kansas River at Desoto flow duration.

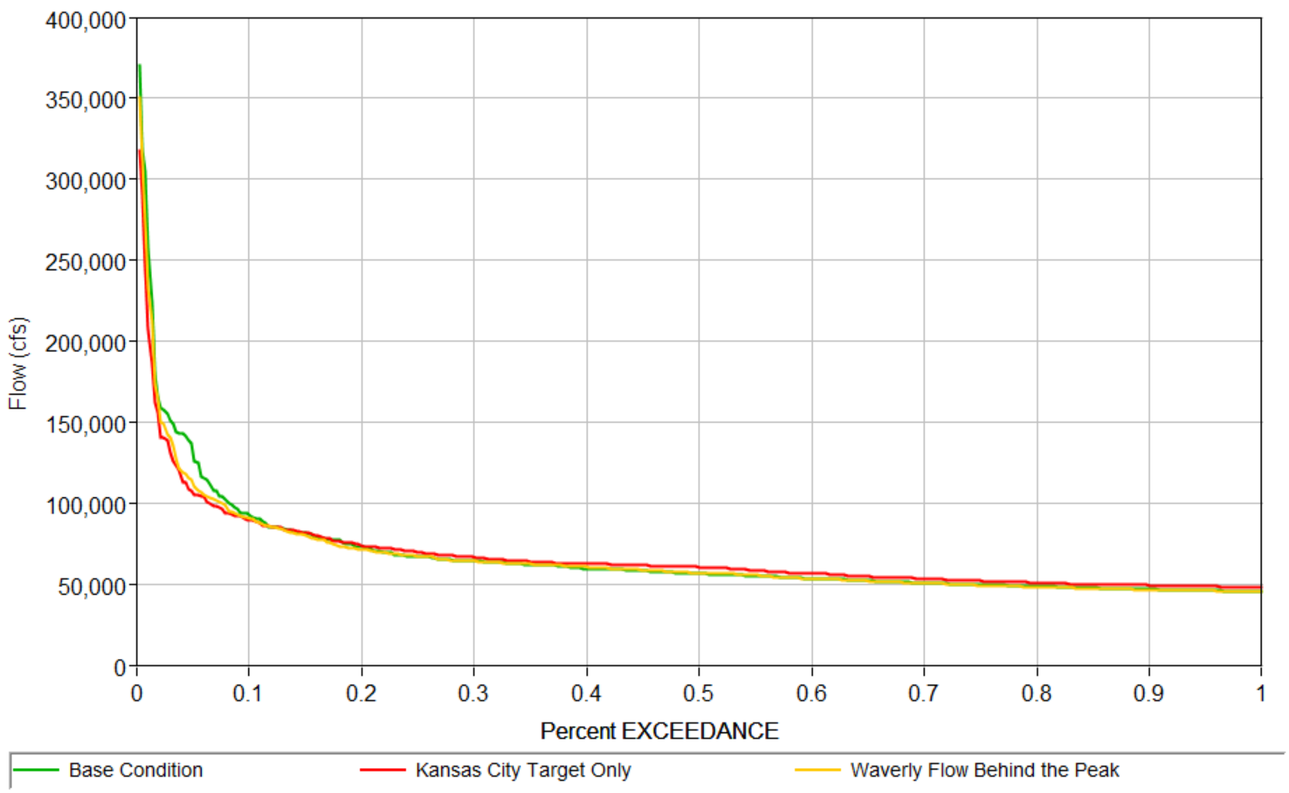

Figure 4-6. Kansas River at Desoto flow duration for the most extreme events that occur less than 1% of the time.

4.3 Milford Reservoir Pool Elevation

The period of record pool elevation was analyzed for Milford Reservoir to assess impacts from the alternatives. Figure 4-4 shows the annual exceedance probability (AEP) plot for the Milford Reservoir Pool elevation. The thresholds for top of Phase I and II change throughout the year; **Error! Reference source not found.** show the lowest elevation for these thresholds which is during May and June each year. The May and June thresholds are shown because many of the annual peaks occur during this time. Selected AEP and the maximum pool elevation for the two largest events are shown in Table 4-3Table 4-1.

Both alternatives show sizable reduction in flood control pool elevation frequencies. There are smaller reductions in pool elevation for the extreme surcharge events. The "Kansas City Target Only" alternative provides the greatest reduction in pool elevation frequency.

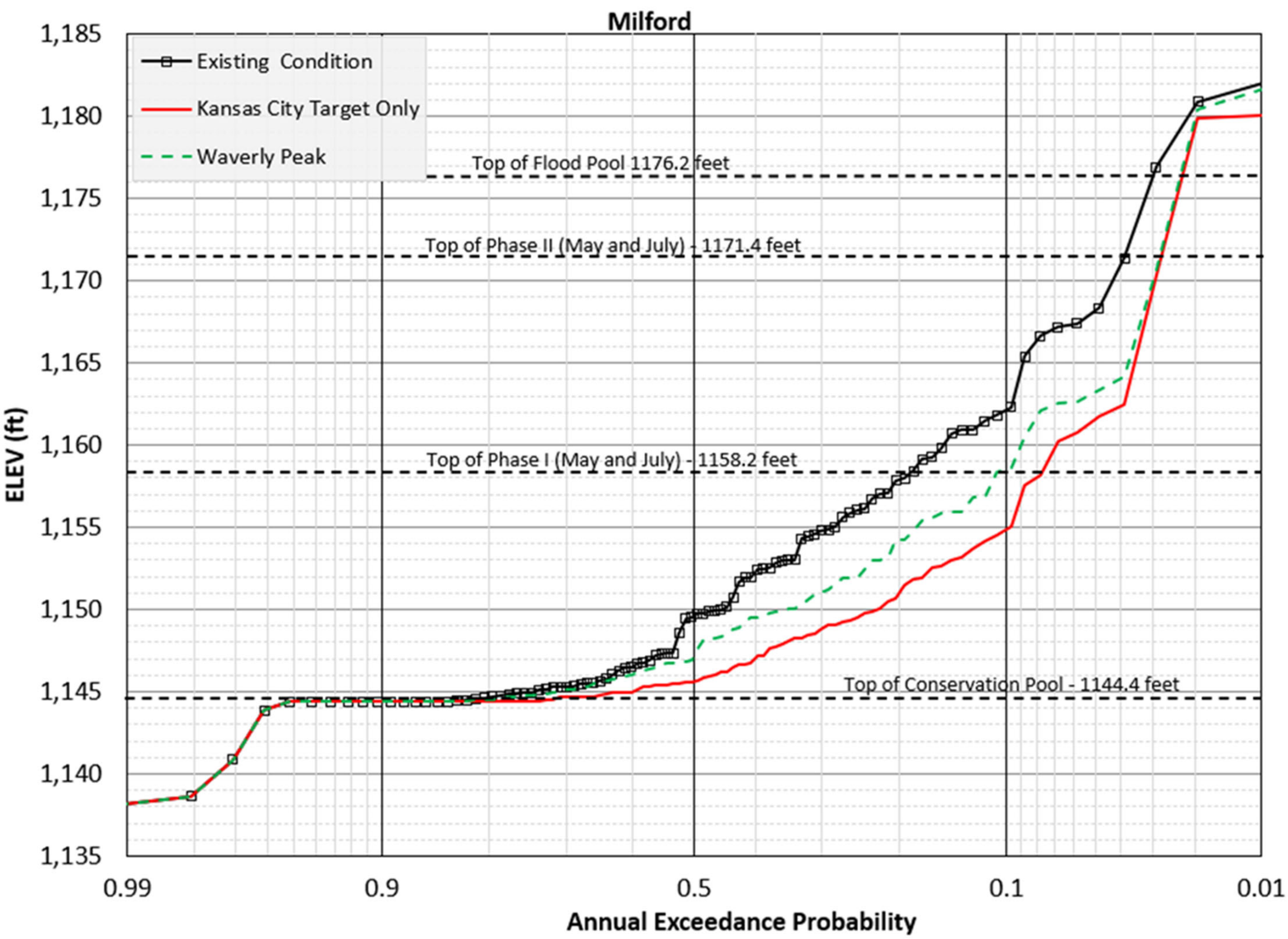

Figure 4-7. Milford Reservoir Pool Elevation Annual Exceedance Probability.

Table 4-3. Specific AEP for the Milford Reservoir Pool Elevations

Simulation	50% AEP (feet)	10% AEP (feet)	1951 Peak Pool (feet)	1993 Peak Pool (feet)
Existing Conditions	1149.7	1162.3	1182.1	1180.9
KC Target Only	1145.6	1155.1	1180.0	1179.9
Flow Behind the Peak	1147.6	1158.7	1181.7	1180.5

The Milford Reservoir pool elevation duration plots show similar results as the AEP plot. Pool elevation duration plots were developed using daily flows from the model results. Figure 4-8 shows the Milford Reservoir pool elevation duration for the 30% probability and less frequent; flows lower than are shown in this plot were similar between all alternatives. Figure 4-9 shows the duration for the most extreme pool elevations that occur 3% of the time and less.

The existing condition simulation consistently produces the highest pool elevations. The "Flow Behind the Peak" alternative is in the middle with significantly reduced pool elevations compared to the existing conditions. The "Kansas City Target Only" alternative consistently results in the lowest pool elevations. These alternatives could also lead to reduced risk of surcharge releases and lower flows when in surcharge as shown in Figure 4-9. Additionally, with lower pools, phased releases would also be reduced from Milford Dam, allowing evacuation of flood waters with potentially lower flows from the outlet works in many floods. Further analysis is needed to understand the risk upstream and downstream of each project.

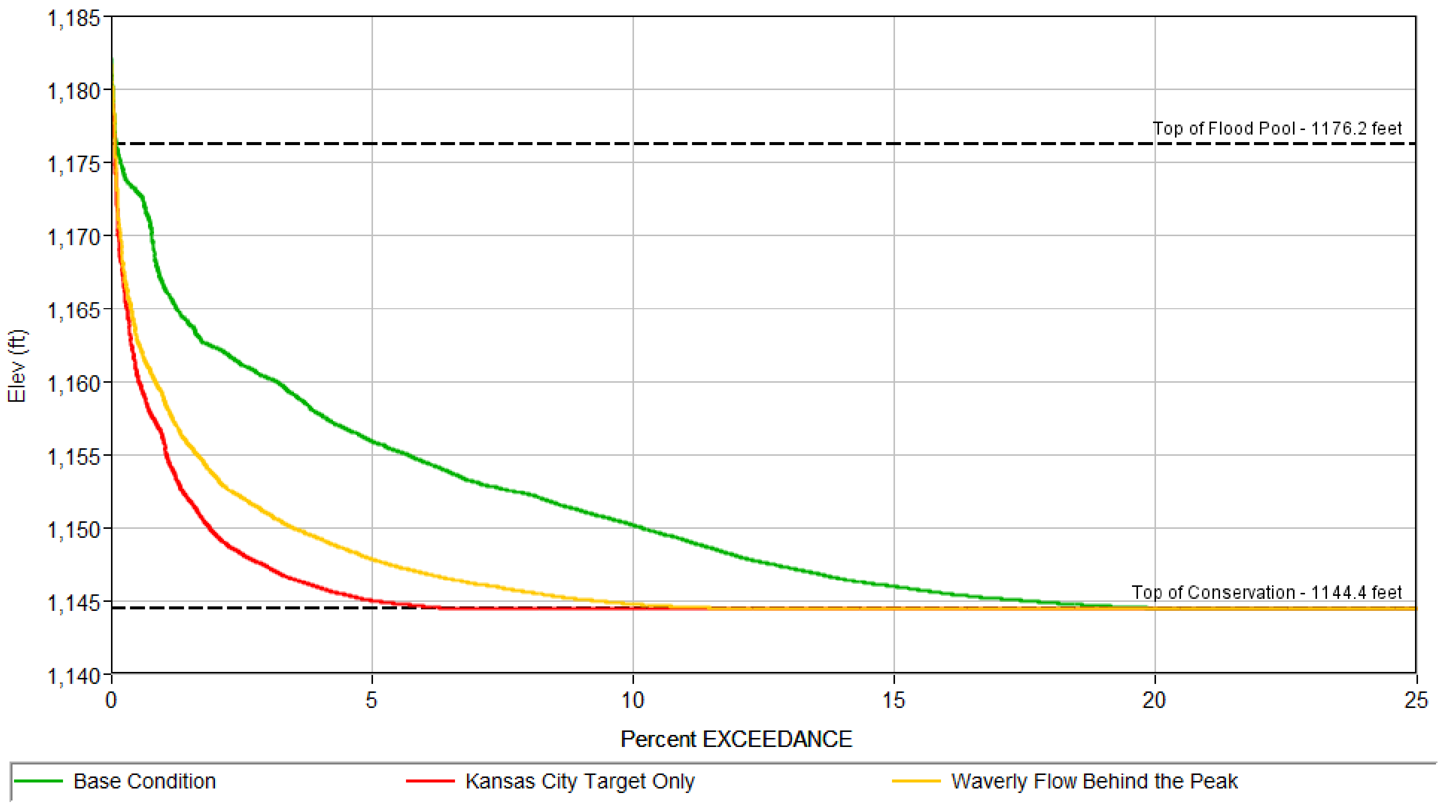

Figure 4-8. Milford Reservoir pool elevation duration.

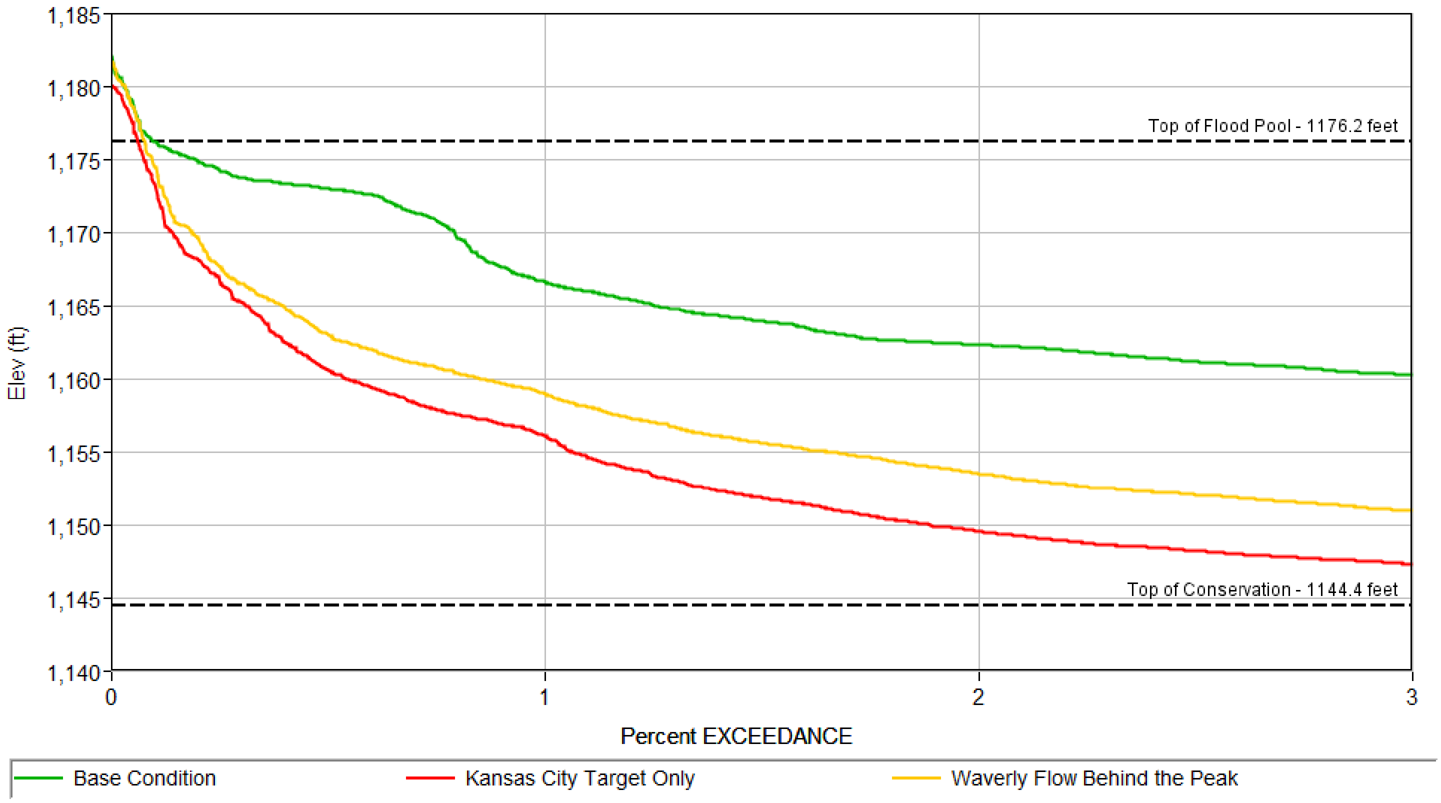

Figure 4-9. Milford Reservoir pool elevation duration for the most extreme events that occur less than 3% of the time.

4.4 Tuttle Creek Reservoir Pool Elevation

The period of record pool elevation was analyzed for Tuttle Creek Reservoir to assess impacts from the alternatives. Figure 4-10 shows the annual exceedance probability (AEP) plot for the Tuttle Creek Reservoir Pool elevation. The thresholds for top of Phase I and II change throughout the year; Figure 4-10 shows the lowest elevation for these thresholds which is during May and June each year. The May and June thresholds are shown because many of the annual peaks occur during this time. Selected AEP and the maximum pool elevation for the two largest events are shown in Table 4-4Table 4-1.

Both alternatives show sizable reduction in flood control pool elevation frequencies. There are smaller reductions in pool elevation for the extreme surcharge events. The “Kansas City Target Only” alternative provides the greatest reduction in pool elevation frequency. Once the project enters surcharge pool above elevation 1136 feet, the analysis shows that the alternatives begin to converge, indicating diminishing downstream flow reductions for large floods entering the surcharge pool of the project.

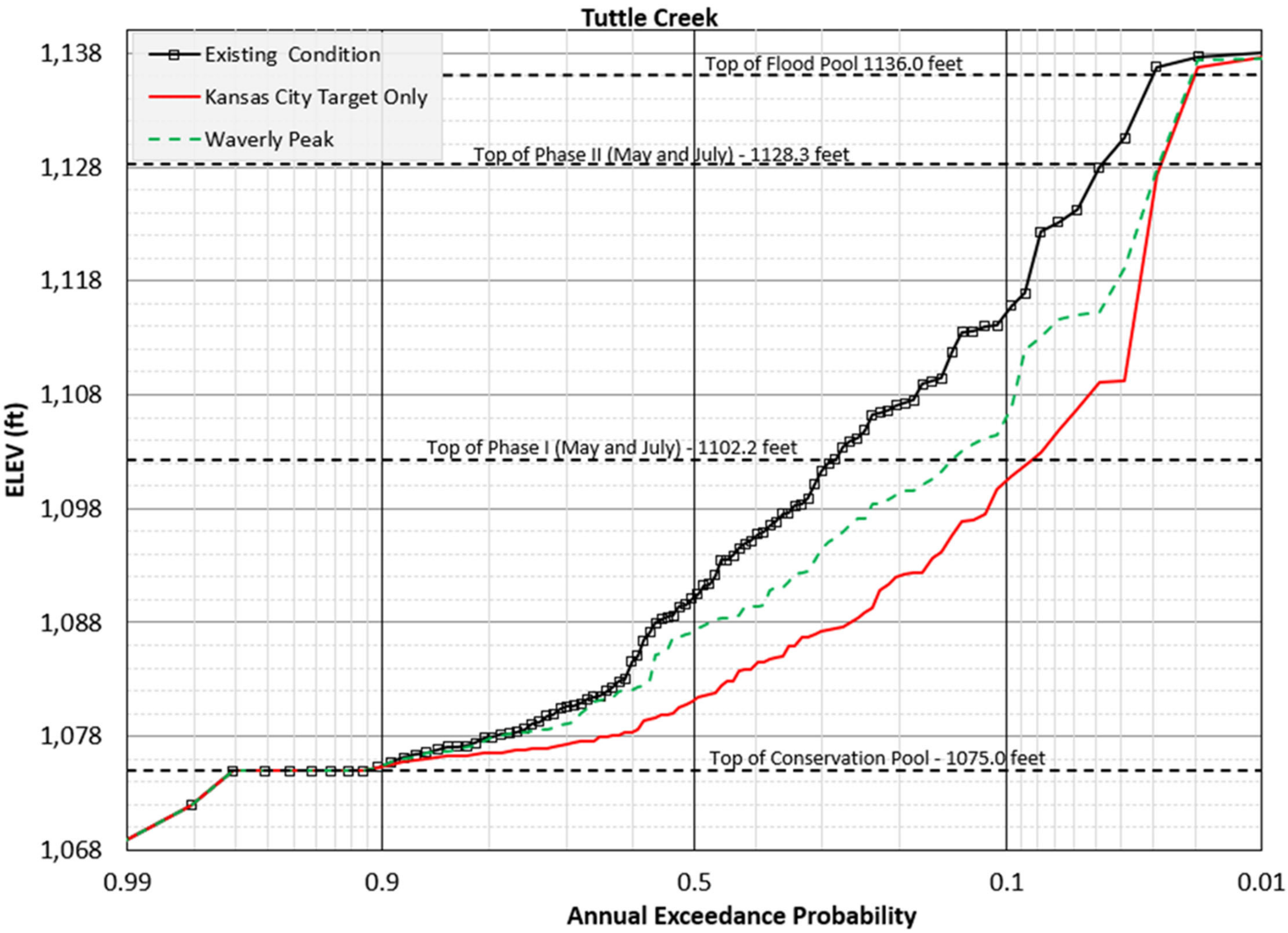

Figure 4-10. Tuttle Creek Reservoir Pool Elevation Annual Exceedance Probability.

Table 4-4. Specific AEP for the Tuttle Creek Reservoir Pool Elevations

Simulation	50% AEP (feet)	10% AEP (feet)	1951 Peak Pool (feet)	1993 Peak Pool (feet)
Existing Conditions	1090.5	1115.8	1138.1	1137.7
KC Target Only	1081.5	1100.8	1136.7	1137.6
Flow Behind the Peak	1087.4	1106.9	1137.6	1137.3

The Tuttle Creek Reservoir pool elevation duration plots show similar results as the AEP plot. Pool elevation duration plots were developed using daily flows from the model results. Figure 4-11 shows the Tuttle Creek Reservoir pool elevation duration for the 30% probability and less frequent; flows lower than are shown in this plot were similar between all alternatives. Figure 4-12 shows the duration for the most extreme pool elevations that occur 3% of the time and less.

The existing condition simulation consistently produces the highest pool elevations. The “Flow Behind the Peak” alternative is in the middle with significantly reduced pool elevations compared to the existing conditions. The “Kansas City Target Only” alternative consistently results in the lowest pool elevations. These alternatives could also lead to reduced risk of surcharge releases and lower flows when in surcharge as shown in Figure 4-12Figure 4-9. Additionally, with lower pools, phased releases would also be reduced from Tuttle Creek Dam, allowing evacuation of flood waters with potentially lower flows from the outlet works in many floods. Further analysis is needed to understand the risk upstream and downstream of each project.

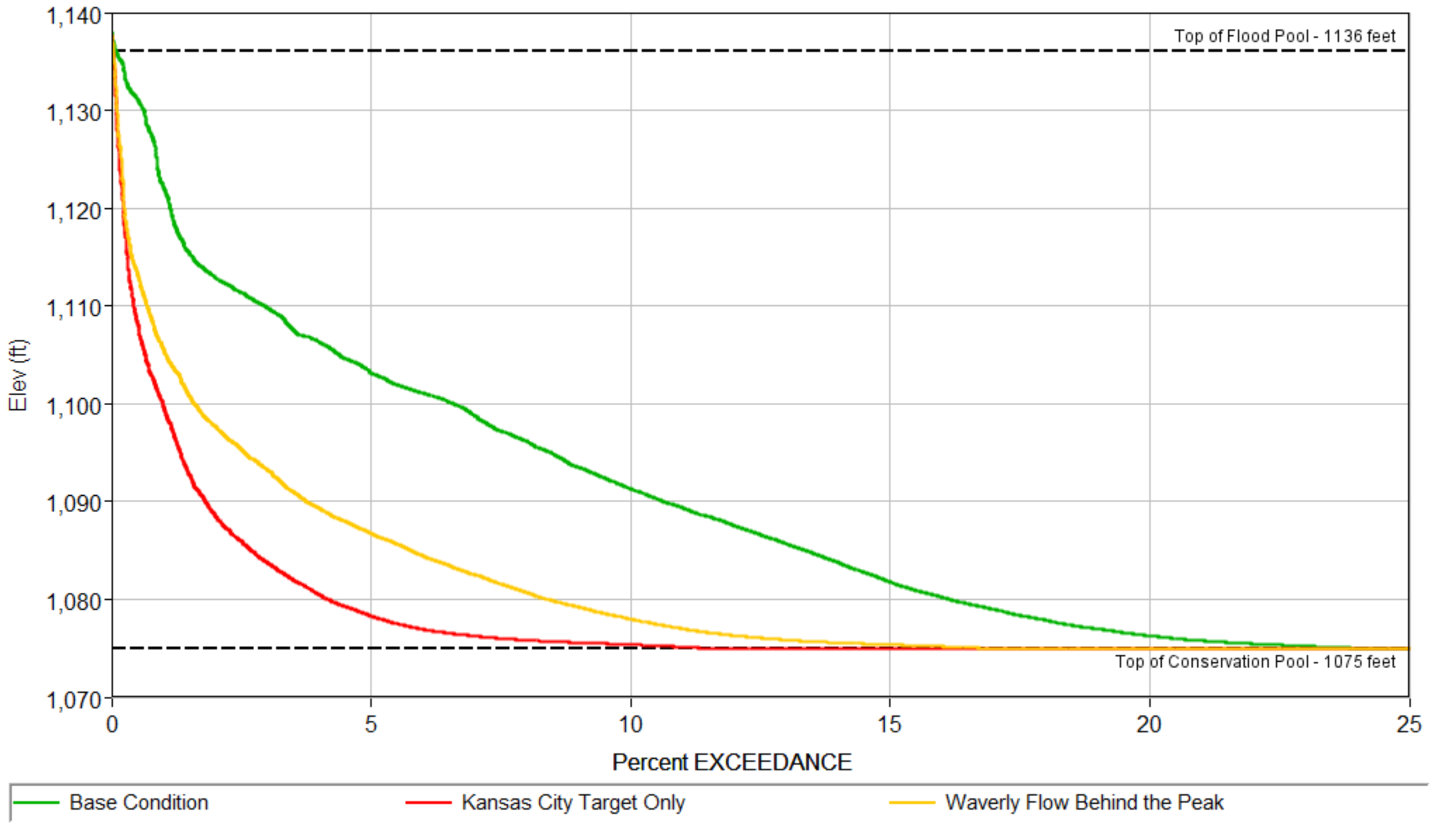

Figure 4-11. Tuttle Creek Reservoir pool elevation duration.

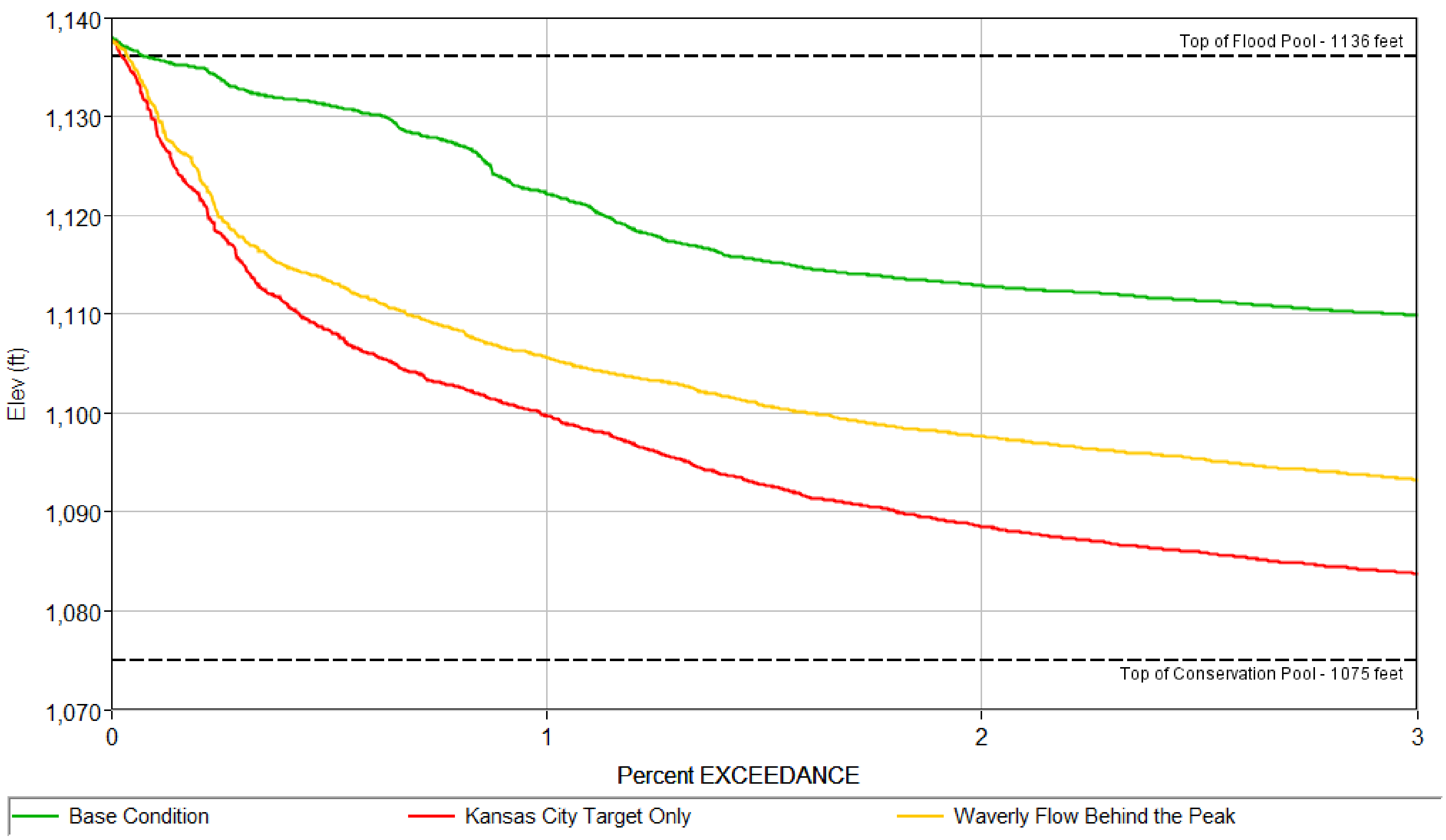

Figure 4-12. Tuttle Creek Reservoir pool elevation duration for the most extreme events that occur less than 3% of the time.

4.5 Perry Reservoir Pool Elevation

The period of record pool elevation was analyzed for Perry Reservoir to assess impacts from the alternatives. Figure 4-13 shows the annual exceedance probability (AEP) plot for the Perry Reservoir Pool elevation. Unlike Milford and Tuttle Creek, the Phase I and II thresholds do not vairy by season at Perry. The static Phase lines are shown in Figure 4-13. Selected AEP and the maximum pool elevation for the two largest events are shown in Table 4-5Table 4-1.

Both alternatives show sizable reduction in flood control pool elevation frequencies. There are smaller reductions in pool elevation for the extreme surcharge events. The “Kansas City Target Only” alternative provides the greatest reduction in pool elevation frequency. The largest event, 1951, has a modest reduction of around one foot or less depending on the alternative. However, the second largest event, 2019, has a peak pool elevation reduction of between 10 and 13 feet depending on the alternative. The third largest event, 1984, is similar with an over 16-foot reduction in the Kansas City Target Only alternative and over 7 feet for the flow behind the peak alternative. These indicate a larger variability in the Perry pool elevation by event than at the other lakes.

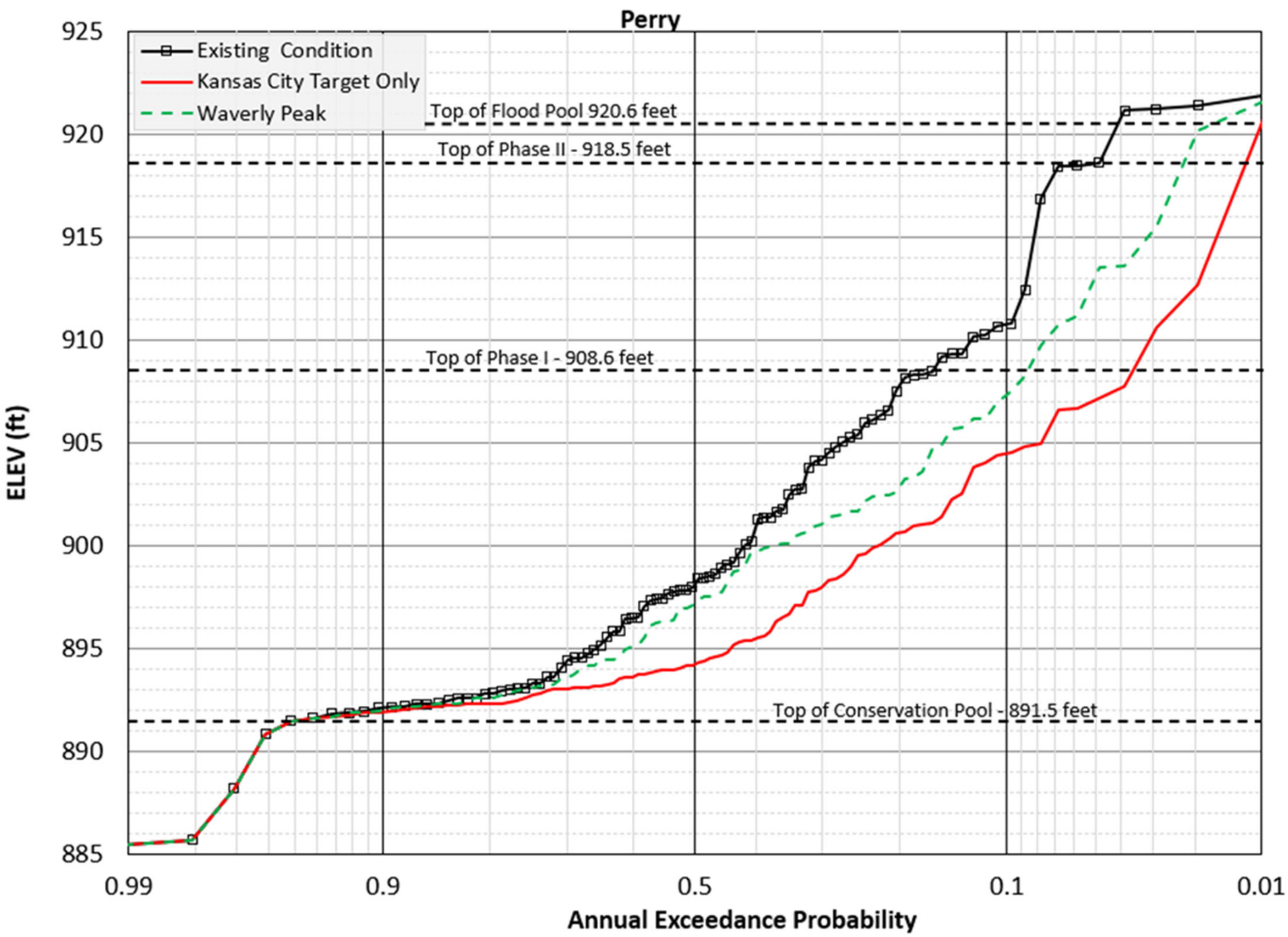

Figure 4-13. Perry Reservoir Pool Elevation Annual Exceedance Probability.

Table 4-5. Specific AEP for the Perry Reservoir Pool Elevations

Simulation	50% AEP (feet)	10% AEP (feet)	1951 Peak Pool (feet)	2019 Peak Pool (feet)
Existing Conditions	898.4	910.8	921.9	921.4
KC Target Only	894.3	904.6	920.8	907.7
Flow Behind the Peak	897.4	907.5	921.6	911.2

The Perry Reservoir pool elevation duration plots show similar results as the AEP plot. Pool elevation duration plots were developed using daily flows from the model results. Figure 4-14 shows the Perry Reservoir pool elevation duration for the 25% probability and less frequent; flows lower than are shown in this plot were similar between all alternatives. Figure 4-15 shows the duration for the most extreme pool elevations that occur 3% of the time and less.

The existing condition simulation consistently produces the highest pool elevations. The "Flow Behind the Peak" alternative is in the middle with significantly reduced pool elevations compared to the existing conditions. The "Kansas City Target Only" alternative consistently results in the lowest pool elevations. Additionally, with lower pools, phased releases would also be reduced from Perry Dam, allowing evacuation of flood waters with potentially lower flows from the outlet works in many floods. Further analysis is needed to understand the risk upstream and downstream of each project.

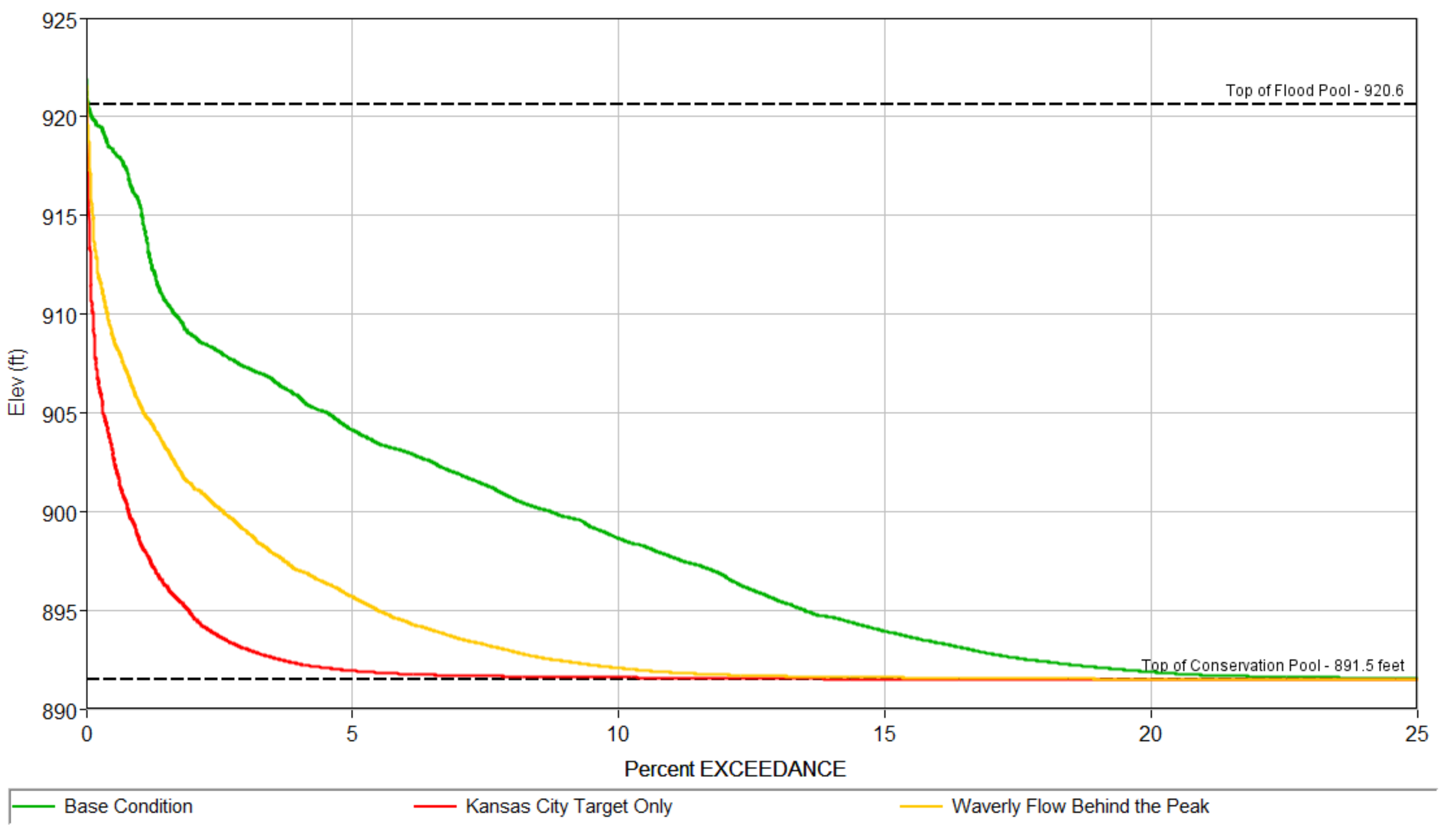

Figure 4-14. Perry Reservoir pool elevation duration.

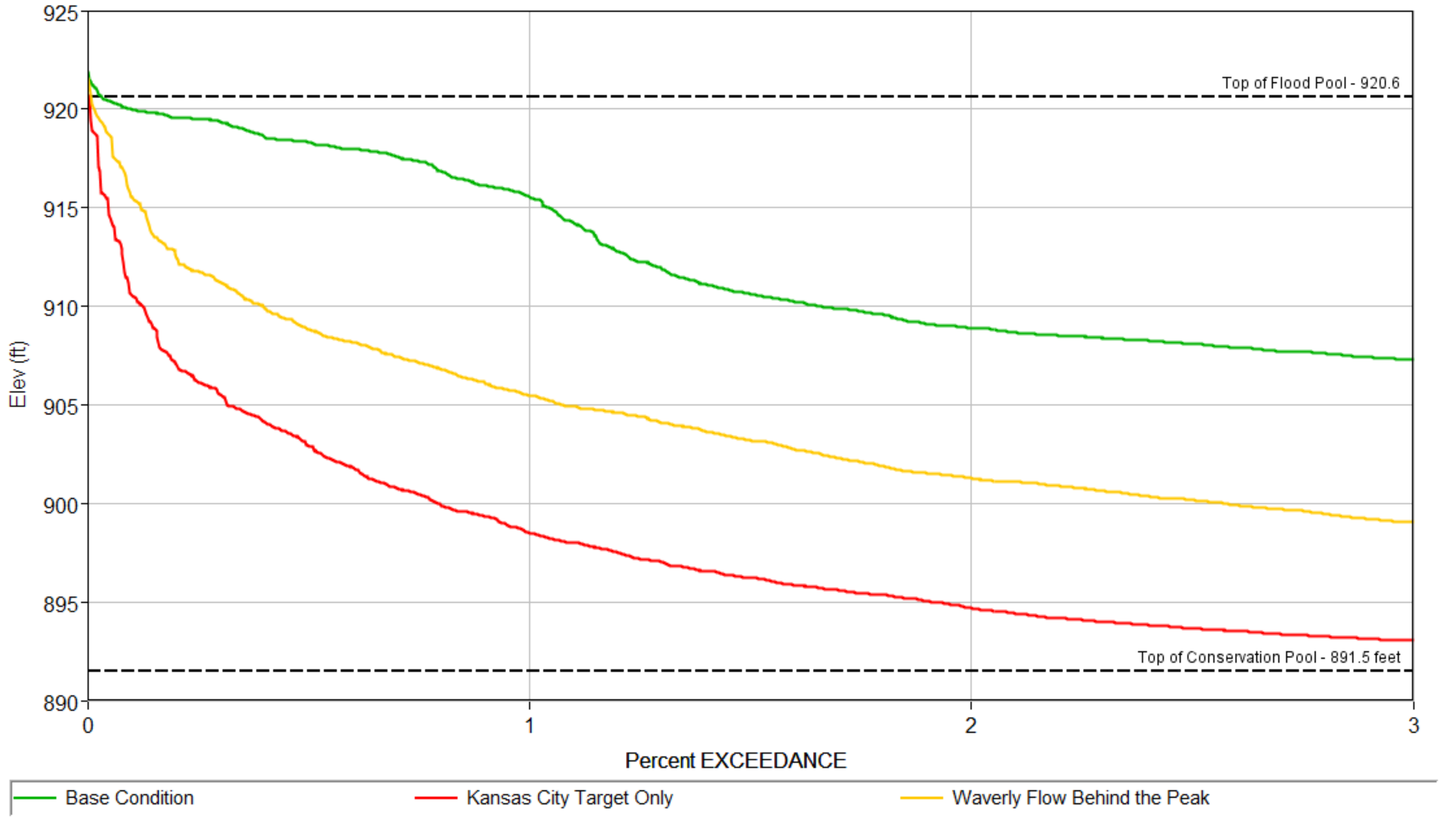

Figure 4-15. Perry Reservoir pool elevation duration for the most extreme events that occur less than 3% of the time.

4.6 Clinton Reservoir Pool Elevation

A detailed analysis was not conducted for Clinton Reservoir since it has never been in the surcharge pool. The alternatives would provide similar trends for getting water out of the flood control pool as was seen at Milford, Tuttle Creek, and Perry.

4.7 Event Specific Plots

Several plots were prepared to demonstrate the alternative reservoir operation strategies for specific large flood events as shown in the flowing paragraphs. These events are shown for both the Kansas River at Desoto and the Missouri River at Waverly.

4.7.1 July 1951

Figure 4-16 and Figure 4-17 show the Desoto and Waverly flows, respectively. This large flood event was primarily from heavy rain over the Kansas River which in-turn resulted in flooding on the Missouri River at Kansas City and downstream as the flood hydrograph routed downstream. Although this was before most of the reservoirs in the basin were constructed, simulations show that some of the reservoirs would have reached their surcharge pools. As demonstrated in the plots, both alternatives show marked reductions in the peak flows at these gages. Desoto and Waverly percent reductions are shown in Table 4-6.

Figure 4-16. Kansas River at Desoto July 1951 flows.

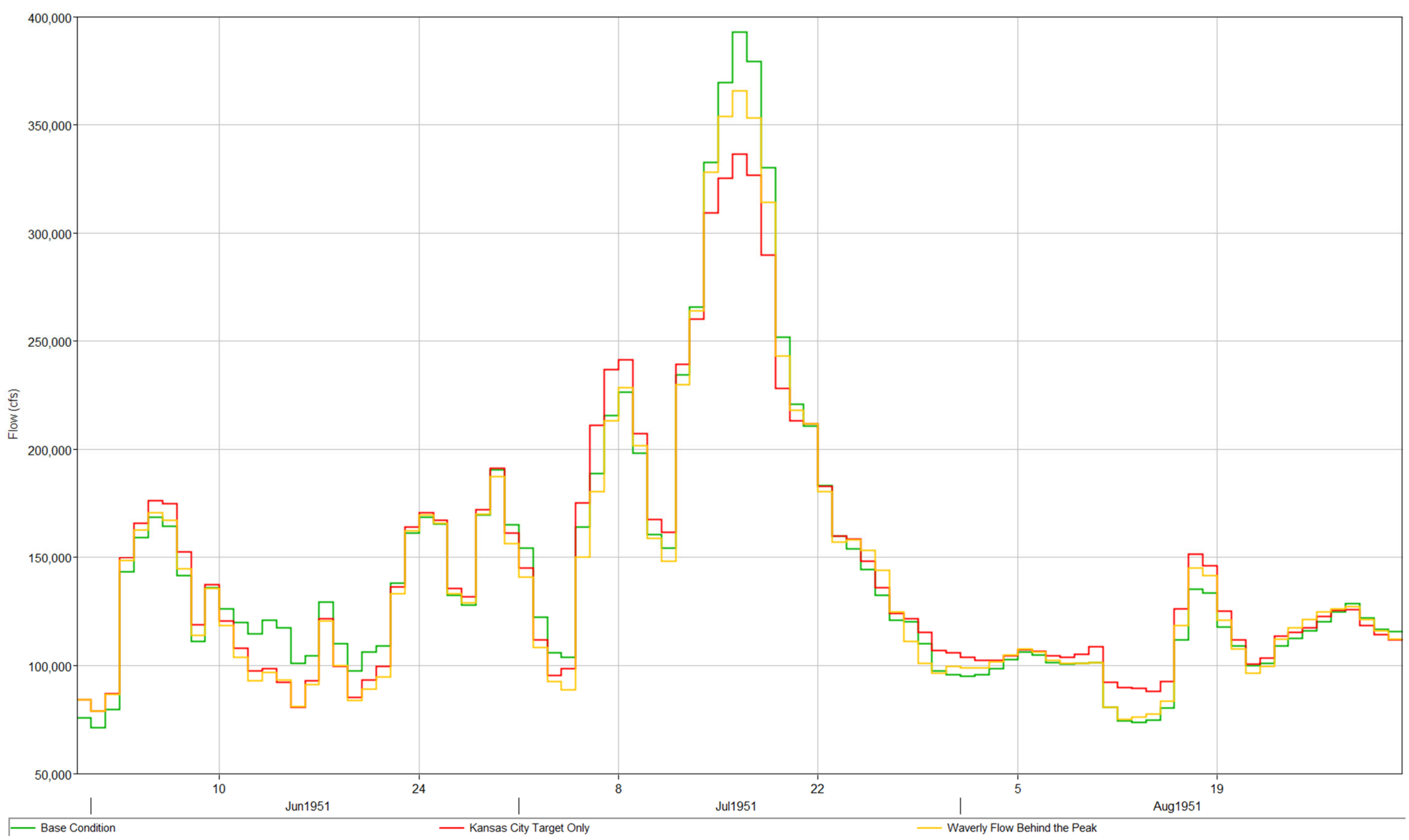

Figure 4-17. Missouri River at Waverly July 1951 flows.

Table 4-6. Desoto and Waverly peak flows and percent reduction for the 1951 flood event.

	Desoto		Waverly	
	Peak Flow (cfs)	% Reduction	Peak Flow (cfs)	% Reduction
Existing Conditions	371,000		393,000	
Kansas City Target Only	319,000	-14.1%	337,000	-14.3%
Waverly flow behind the peak	351,000	-5.4%	366,000	-6.9%

4.7.2 July 1993

Figure 4-18 and Figure 4-19 show the Desoto and Waverly flows, respectively. This large flood event was from heavy rain over the lower Missouri River basin including some locations on the Kansas River. Milford and Tuttle Creek both had significant surcharge events. As demonstrated in the plots, both alternatives had some small reductions in the peak flows at these gages. After the peak, the reservoir release alternatives vary in how the flood control releases are made. Desoto and Waverly percent reductions are shown in Table 4-7.

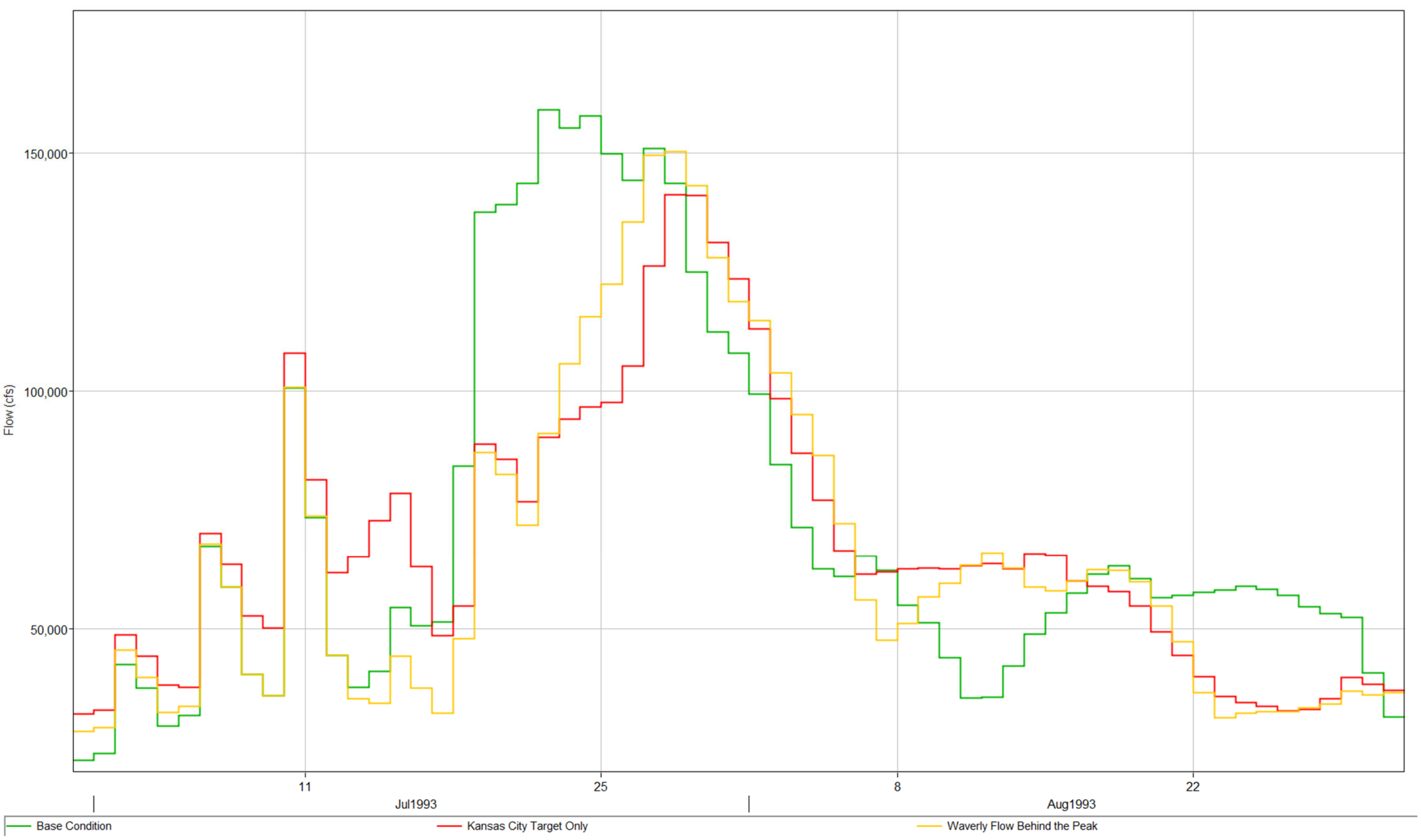

Figure 4-18. Kansas River at Desoto July 1993 flows.

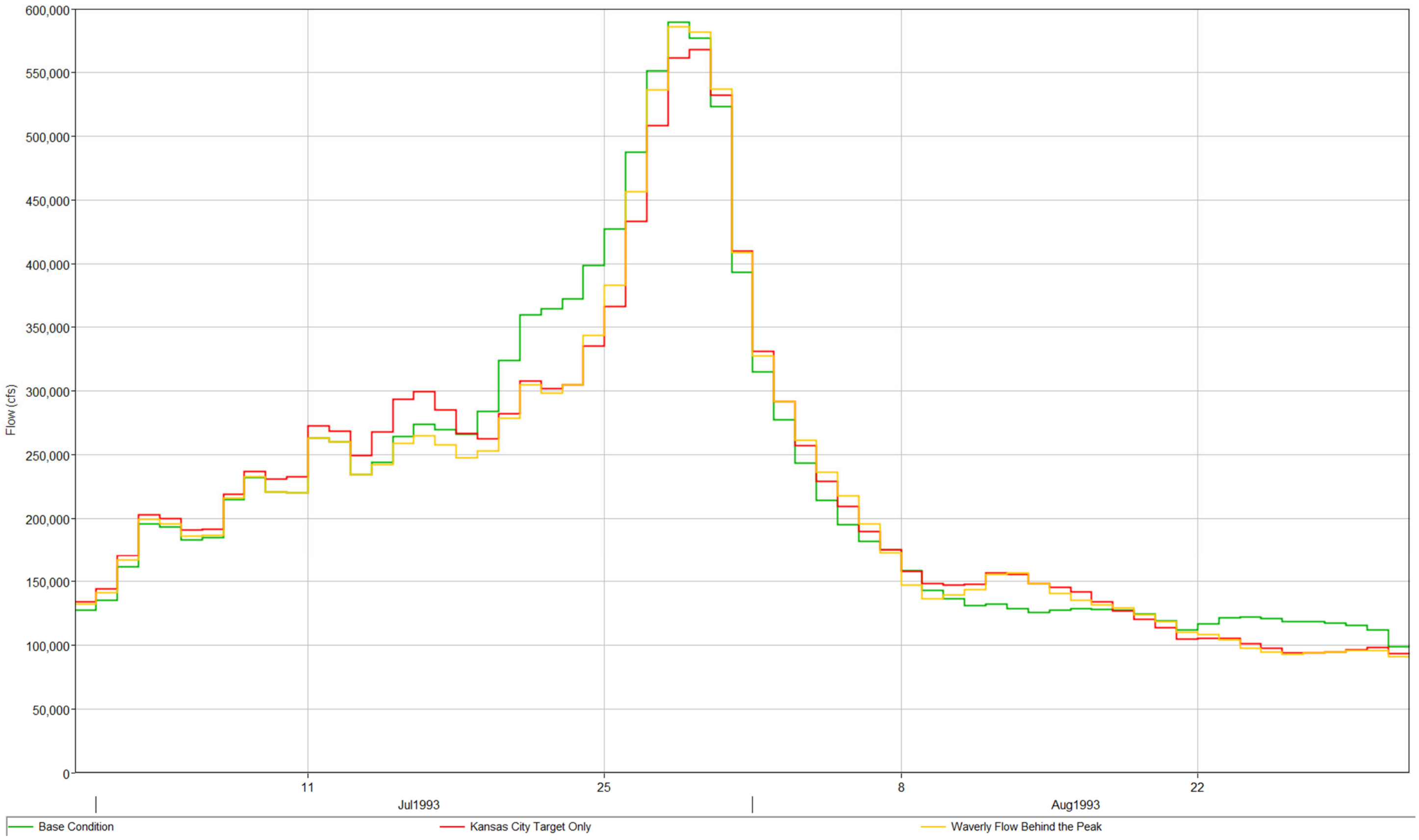

Figure 4-19. Missouri River at Waverly July 1993 flows.

Table 4-7. Desoto and Waverly peak flows and percent reduction for the 1993 flood event.

	Desoto		Waverly	
	Peak Flow (cfs)	% Reduction	Peak Flow (cfs)	% Reduction
Existing Conditions	159,000		590,000	
Kansas City Target Only	141,000	-11.3%	568,000	-3.7%
Waverly flow behind the peak	351,000	-5.6%	585,000	-0.8%

4.7.3 June 2019

Figure 4-20 and Figure 4-21 show the Desoto and Waverly flows, respectively. Table 4-8 shows the peak flows and percent reduction for each alternative. This large flood event was from heavy rain and snowmelt in the upper and middle Missouri River basin. Rain in the Kansas River basin was heavy at times, but generally not the main driver of flooding on the Missouri River. Tuttle Creek and Perry both made small surcharge releases. As demonstrated in the plots, the alternatives lead to large flow reductions of over 35% on the Kansas River because surcharge releases are avoided. On the Missouri River the “Kansas City Target Only” alternative lead to 3.7% higher flows on the Missouri River which is an indication that it is not an ideal final alternative. The “Flow Behind the Peak” alternative was consistently lower than the other two scenarios on the Missouri River.

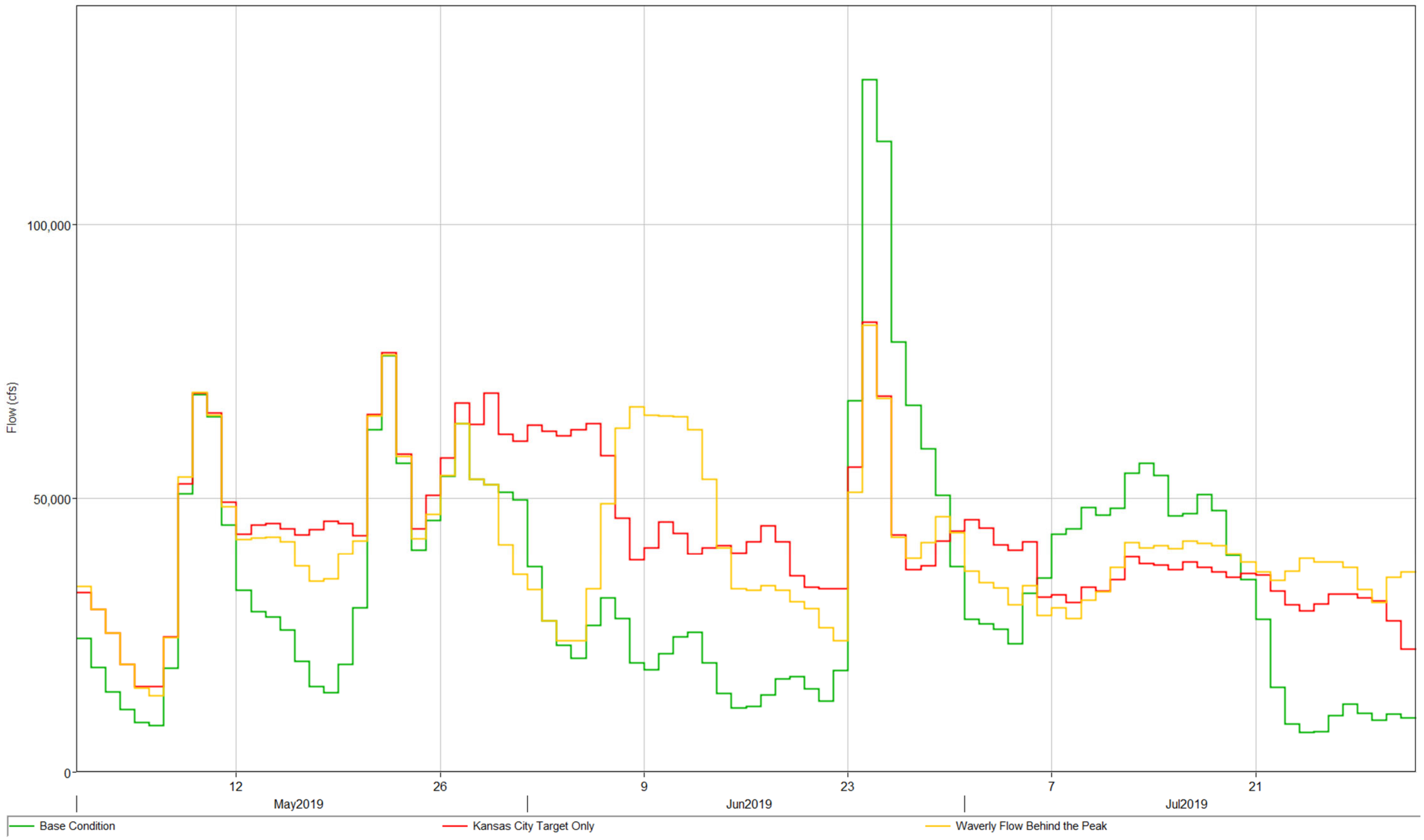

Figure 4-20. Kansas River at Desoto June 2019 flows.

Figure 4-21. Missouri River at Waverly June 2019 flows.

Table 4-8. Desoto and Waverly peak flows and percent reduction for the 2019 flood event.

	Desoto		Waverly	
	Peak Flow (cfs)	% Reduction	Peak Flow (cfs)	% Reduction
Existing Conditions	126,000		324,000	
Kansas City Target Only	82,000	-35.1%	336,000	3.7%
Waverly flow behind the peak	82,000	-35.4%	313,000	-3.5%

5 Conclusions

Two alternatives were developed and compared to the existing condition (non-navigation) modeling. Both alternatives demonstrated lower pool elevations and the potential to reduce extreme events on both the Kansas and Missouri Rivers such as 1951 and 1993. The flow behind the peak alternative showed no change in mid-range peak flows on the Kansas and Missouri River; whereas, the Kansas City Target Only alternative showed small increases in peak flows. Both alternatives showed increased flow duration for flow ranges that are still within the river channel or levee systems, but further detailed analysis is needed to understand potential positive or negative impacts to under seepage and levee performance.

Assessing several variations to these alternatives will help to refine the best alternative. Factors such as the peak threshold for shutting down releases and timing of the resumption of releases need to be studied. Other alternatives could explore adjusting the flow targets for the Missouri River at Kansas City or Waverly while still operating in the traditional method of Phase I, II, and III target flows. The ideal alternative will provide reduced frequency of pool elevation and reduced risk or no increase to risk below the dam. Reservoir surcharge events pose a risk at the dam and to the downstream communities. Alternatives that reduce the risk of surcharge may be able to provide benefits to all interests related to the Kansas River reservoirs.