Hydrologic Alteration Study for the Mahoning River

Prepared by the US Army Corps of Engineers, Pittsburgh District
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Section 1. Project Scope

Background

The US Army Corps of Engineers (USACE) owns and operates three reservoirs in the Mahoning River watershed: Berlin Reservoir, Michael J. Kirwan (M. J. Kirwan) Reservoir, and Mosquito Creek Reservoir. The three reservoirs are all authorized for flood control, water quality, low flow augmentation, water supply, fish and wildlife, and recreation. These reservoirs have contributed to the regulation of streamflow in the Mahoning River since they were constructed between the 1940s and 1960s.

Purpose

Maintaining natural hydrologic variability is necessary in conserving native ecosystems because hydrologic variation controls key habitat conditions within the river channel, floodplain and stream-influenced groundwater zones. Therefore, alterations in streamflow regimes may impair ecosystem connectivity (Richter et al. 1998).

The Indicators of Hydrologic Alteration (IHA) statistical analyses were conducted using available hydrologic data for the Mahoning River basin reservoirs and downstream gage locations to assess how flows have been altered as a result of upstream regulation. This information may be useful for understanding the impacts of human activities on water flows and recommending environmental flow criteria for long-term water management.

Project Approach

This project used hydrologic data to estimate the impacts of USACE reservoir operations on streamflows in the Mahoning River. The following approach was applied using the IHA software:

1. Isolate the effects of reservoir operations on stream flow.
2. Use flow data to define current and baseline flow conditions.
3. Compare a suite of flow statistics for the two conditions:
    - Baseline flow conditions are flows that are minimally impacted by dam and reservoir operations.
    - Current flow conditions include the impacts of existing operations.
4. Compare two "periods" representing pre- and post-alteration (dam construction) flow conditions.

Geographic Scope: Mahoning River

The Mahoning River drainage basin is situated in northeastern Ohio and west-central Pennsylvania and drains over 1,000 square miles. The Mahoning River flows generally northward to near Warren, Ohio, and then flows southeast through Youngstown, Ohio, into Pennsylvania (USACE 1977). The Mahoning

Rivers joins with the Shenango River to form the Beaver River, and the Beaver River is a tributary into the Upper Ohio River.

The study area was divided into six geographically-distinct reaches that account for variability across the regulated portions of the Mahoning River (Figure 1, Table 1). These reaches were defined based on potential influences from USACE reservoirs and downstream flow target locations. The upstream study reaches are represented by the locations of the three USACE reservoirs: 1) MJ Kirwan Dam (MJK1); 2) Mosquito Creek Dam (MOS1); and 3) Berlin Dam (MR1). The reach segments of the Mahoning River, downstream of the reservoir(s) are represented by the following locations: 1) Leavittsburg, OH (MR2); 2) Youngstown, OH (MR3); and 3) Lowellville, OH (MR4). Figure 1 indicates the approximate extent of each study reach. MR2 is downstream of MJ Kirwan and Berlin Reservoirs, while MR3 and MR4 are downstream of MJ Kirwan, Berlin, and Mosquito Reservoirs.

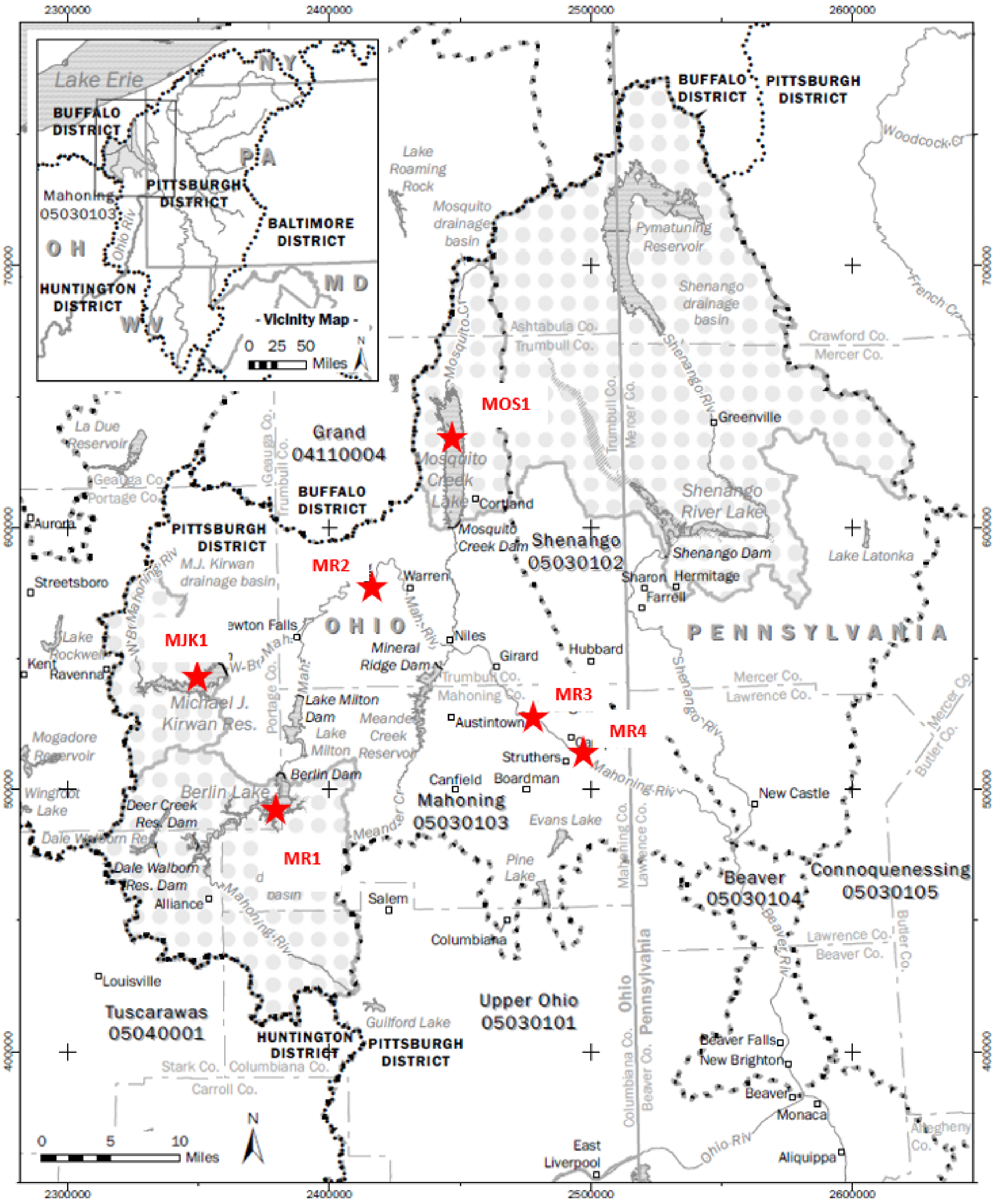

Figure 1. Map illustrating approximate locations of the six study reaches

Table 1. Descriptions of six reach segments were included in the study to account for variability across regulated portions of the Mahoning River.

Study Reach ID and Description			**Potential Hydrologic Influences on Study Reach**
West Branch Mahoning River	MJK1	MJ Kirwan to confluence with the Mahoning River (MJ Kirwan Dam)	Influence of MJ Kirwan Reservoir, authorized for flood control, low-flow augmentation, water quality control, water supply, fish and wildlife enhancement, and recreation
Mosquito Creek	MOS1	Mosquito to confluence with the Mahoning River (Mosquito Dam)	Influence of Mosquito Reservoir, authorized for flood control, low-flow augmentation, water quality control, water supply, fish and wildlife enhancement, and recreation
Mahoning River	MR1	Berlin to confluence with West Branch Mahoning River (Berlin Dam)	Influence of Berlin Reservoir, authorized for flood control, low-flow augmentation, water quality control, water supply, fish and wildlife enhancement, and recreation
Mahoning River	MR2	From confluence with the West Branch near Leavittsburg, OH to the confluence with Mosquito Creek	Influence of MJ Kirwan and Berlin Reservoirs, downstream of tributary inflow
Mahoning River	MR3	From confluence with Mosquito Creek to Youngstown, OH	Influence of MJ Kirwan, Berlin, and Mosquito Reservoirs, downstream of tributary inflow
Mahoning River	MR4	From Youngstown, OH downstream near the crossing of the Mahoning River into PA from OH (Lowellville, OH)	Influence of MJ Kirwan, Berlin, and Mosquito Reservoirs, downstream of tributary inflow

Section 2. Characterizing Current and Baseline Flow Regimes

Reservoir Construction and Operation

The three USACE reservoirs included in this report were authorized by the Flood Control Acts of 1936 and 1938 and constructed over a period of twenty years from the 1940s through the 1960s (Table 2). All three reservoirs are authorized for multiple purposes, which include flood control, low-flow augmentation, water quality control, water supply, fish and wildlife enhancement, and recreation

Table 2. Construction completion dates of three USACE reservoirs included in this study.

Reservoir	Completion Year
Michael J. Kirwan	1966
Mosquito Creek Lake	1944
Berlin Lake	1943

Methods

The alteration of streamflow in the Mahoning River due to operation of the upstream reservoirs was assessed using the Indicators of Hydrologic Alteration (IHA) 7.1.0.10 software developed by The Nature Conservancy (TNC). The IHA software provides information about hydrologic changes in ecologically-relevant terms. This program was specifically developed by scientists at TNC to facilitate hydrologic analysis in an ecologically-meaningful manner (TNC 2014). The potential impacts of a changing climate on streamflow in the Mahoning River basin were also qualitatively assessed using web-based tools developed by USACE.

Data Processing

The IHA software can be used to help statistically describe how the patterns have changed for a particular river or lake, due to abrupt impacts such as dam construction or more gradual trends associated with land- and water-use changes (TNC 2018). This is performed by comparing a “pre-impact”, or baseline, dataset with a “post-impact”, or current, dataset. The inputs and descriptions of the baseline and current datasets for each of the six study reaches analyzed in this project are provided in Table 3 below.

Table 3. Description of inputs for the six study reach datasets analyzed for the Mahoning River basin.

Study Reach ID	Flow Regime	Input(s) for Dataset	Drainage Area (mi^2)	Period of Record		Source(s)
				Start	End	
MJK1	Baseline	MJK Inflow	81	1968	2019	USACE
	Current	MJK Outflow	81	1968	2019	USACE
MOS1	Baseline	Mosquito Inflow	98	1945	2019	USACE
	Current	Mosquito Outflow	98	1945	2019	USACE
MR1	Baseline	Berlin Inflow	248	1945	2019	USACE
	Current	Berlin Outflow	248	1945	2019	USACE
MR2[1]	Baseline	MJK Inflow+Berlin Inflow+PHA[2]	426	1968	2019	USACE, USGS
	Current	Leavittsburg: 03094000	575	1968	2019	USGS
MR3[1]	Baseline	MJK Inflow+Berlin Inflow+MOS Inflow+PHA[2]	524	1968	2019	USACE, USGS
	Current	Youngstown: 03098600 + 03098000[3]	978	1968	2019	USGS
MR4[1]	Baseline	MJK Inflow+Berlin Inflow+MOS Inflow+PHA[2]	524	1968	2019	USACE, USGS
	Current	Lowellville: 03099500	1073	1968	2019	USGS

Notes:
1. Drainage area relationship used to transfer upstream flows to downstream location of interest.
2. The USGS 03093000 gage data from Phalanx Station (1926-current) was combined with data from other contributing sources to create the baseline dataset.
3. The USGS replaced gage 03098000 with gage 03098600 at Youngstown. The previous gage has a smaller drainage area (898 sq mi), so a drainage area relationship was used to transfer data at this gage to the new gage 03098600 to form a complete dataset.

The baseline and current datasets for each study reach used daily flow data over the same timeframe for at least a 50-year period of record, capturing droughts and floods of record. By using the same time period, underlying climatic and anthropogenic influences are constants for both time series of each study reach, isolating the incremental influence of reservoir operations. The current datasets were created directly from flow data retrieved from USACE and/or USGS. The baseline datasets, on the other hand, were created indirectly to represent current hydrologic conditions if upstream regulation was not present.

The baseline datasets for the three reservoirs (MJK1, MOS1, and MR1) were created by back calculating the inflow into each reservoir using the observed reservoir elevation and outflow gage data. The change in storage is calculated from the change in the reservoir elevation, assuming the most current storage-elevation relationship for each reservoir. The outflow is then added to the change in storage to estimate the inflow. These inflow calculations on a daily timestep were available from the Pittsburgh District's Water Management database until from the construction of each dam until the end of 2017. The Water Management Unit also had hourly inflow estimates to fill in the remainder of the dataset through 2019.

These hourly estimates were averaged into daily estimates and then merged with the previously mentioned dataset.

The baseline datasets for the three downstream Mahoning River reach segments (MR2, MR3, and MR4) were created by combining the applicable upstream, reservoir inflows, and USGS station flows. After these datasets were combined, a drainage area ratio was applied to account for the unregulated and ungaged portion of the drainage area to each respective reach segment. The standard drainage area ratio method is the most straightforward technique used for transferring streamflow when the ratio of the source and destination site drainages areas is assumed to be of similar land cover, use, and soil characteristics and size (Koltun 2003).

The IHA software does not analyze negative values in hydrologic datasets. Therefore, the negative values that were occasionally present in study reach datasets due to imperfect data were replaced with a low flow threshold value (equivalent to a 10-year, 1-day low flow). The estimates for these thresholds are listed in Table 4 below and were retrieved from StreamStats to more realistically represent low flow in the study reaches.

Table 4. Estimates of 10-year, 1-day low flow for study reaches retrieved from StreamStats (USGS 2020a).

Study Reach ID	10-year, 1-day Low Flow (cfs)
MJK1	6.7
MOS1	2.1
MR1	2.5
MR2	97
MR3	194
MR4	274

Indicators of Hydrologic Alteration (IHA)

The Indicators of Hydrologic Alteration (IHA) is a free software program developed by TNC that provides useful information for those trying to understand the hydrologic impacts of human activities or trying to develop environmental flow recommendations for water managers. A primary function of the IHA software is to compare to hydrological data sets and calculate a variety of statistics to assess the degree of hydrological alteration between them (TNC 2018).

The default type of statistics calculated in IHA is non-parametric (percentile) statistics, in which the recommended high flow and low flow thresholds are the median plus or minus 25 percent. The various IHA parameters that can be calculated with the software can be lumped into five groups: (1) magnitude of monthly flow conditions; (2) magnitude and duration of extreme flow events (e.g., high and low flows); 3) the timing of extreme flow events; (4) frequency and duration of high and low flow pulses; and (5) the rate and frequency of changes in flows. For these parameters, the IHA can perform a Range of Variability Analysis (RVA) (Opperman 2006). The RVA generates a series of Hydrologic Alteration (HA) factors which quantify the degree of alteration of the IHA flow parameters. These factors are calculated as follows (TNC 2009; Opperman 2006):

1. IHA divides the baseline data into three different categories, generally percentiles, for each parameter of interest. The recommended RVA category boundaries are the median plus or minus approximately 17 percent. Therefore, the lowest category contains all values less than or equal to the 33rd percentile; the middle category contains all values falling in the range of the 34th to 67th percentiles; and the highest category contains all values greater than the 67th percentile.
2. The program then analyzes the current data and compares the observed distribution of data with the distribution expected from the baseline data.
3. The HA factor is calculated using the following equation:

   HA Factor = (Observed Frequency - Expected Frequency) / Expected Frequency

   A positive HA factor means that the frequency of values in the category (percentile grouping) has increased in the baseline period to current period, while a negative HA factor means that the frequency of values in the category (percentile grouping) has decreased in the current period.

The IHA software also calculates five different types of Ecosystem Flow Components (EFCs): low flows, extreme low flows, high flow pulses, small floods, and large floods. This delineation of EFCs is based on the realization by research ecologists that river hydrographs can be divided into a repeating set of hydrographic patterns that are ecologically relevant (Table 5). The EFC algorithm initially separates high and low flows on the first pass, and then high flow events are divided into subcategories based on user-specified thresholds on the second pass. The default for defining floods is that small floods have a recurrence interval equal to or greater than 2 years and less than 10 years, while large floods have a recurrence interval equal to or greater than 10 years. The return intervals for small and large floods are based on data from the baseline dataset for each reach only. All initial high flows not classified as small floods or large floods are classified as high flow pulses. The third pass in the EFC algorithm includes assigning daily data to the extreme low flow class if the flow is less than or equal to the extreme low flow threshold. The default for defining extreme low flow events is that flows are below 10 percent of daily flows for the period of record (TNC 2009). A summary of the flow thresholds that were calculated in IHA based on the user specifications is provided in Table 6 below.

Table 5. Descriptions of ecosystem influences based on EFC type (TNC 2009)

EFC Type	Ecosystem Influences
Extreme Low Flows	- Enable recruitment of certain floodplain plant species
	- Purge invasive, introduced species from aquatic and riparian communities
	- Concentrate prey into limited areas to benefit predators
High Flow Pulses	- Shape physical character of river channel, including pools, riffles
	- Determine size of streambed substrates (sand, gravel, cobble)
	- Prevent riparian vegetation from encroaching into channel
	- Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants
	- Aerate eggs in spawning gravels, prevent siltation
	- Maintain suitable salinity conditions in estuaries
Small Floods, Large Floods	- Maintain balance of species in aquatic and riparian communities
	- Create sites for recruitment of colonizing plants
	- Shape physical habitats of floodplain
	- Deposit gravel and cobbles in spawning areas
	- Flush organic materials (food) and woody debris (habitat structures) into channel
	- Purge invasive, introduced species from aquatic and riparian communities
	- Disburse seeds and fruits of riparian plants
	- Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes)
	- Provide plant seedlings with prolonged access to soil moisture

Table 6. Summary flow thresholds calculated by IHA software for analysis of EFC parameters.

Study Reach ID	**IHA-Calculated Flow Threshold (cfs)**			
	High Flow	**Extreme Low Flow**	**Small Flood (2-yr) Min. Peak**	**Large Flood (10-yr) Min. Peak**
MJK1	108	7	1,828	3,599
MOS1	120	2	2,166	3,146
MR1	276	14	3,899	7,222
MR2	745	97	9,665	15,310
MR3	1,279	194	17,580	25,590
MR4	1,404	274	19,290	28,080

Qualitative Climate Change Assessment

A brief climate change qualitative assessment was performed using web-based tools developed by the USACE within the Time Series Toolbox (TST) (USACE 2020). The baseline (unregulated) flow datasets for the six study reaches previously developed for the IHA assessment were used as inputs in the TST. The tool can detect whether statistically significant trends or nonstationarities in unregulated flow datasets exist from post-dam construction through present day.

Assumptions and Limitations

- There are no direct measurements of total inflow to each reservoir. The inflows to the reservoirs, which comprised the MJK1, MOS1 and MR1 baseline datasets, were estimated using hourly outflow and storage data from the USACE Pittsburgh District Water Management database.
    - Negative values and values below 10-year, 1-day flows were removed from the datasets and replaced with the 10-year, 1-day flows to provide for a low flow threshold. These values were estimated at the points of interests using the StreamStats website (USGS 2020a).
- Drainage area weighting was used to develop several baseline datasets for this study. This method is applicable for transferring flows upstream or downstream to a location with a similar drainage area. It is also assumed that the watersheds are of similar land use, soil types, and experience similar precipitation patterns (Koltun 2003).
- The baseline datasets were compiled by summing flows from upstream locations and USGS gages and using drainage area weighting.
- The same period of record, at least 50 years, was used for baseline and current datasets for individual reaches in IHA. The period of record for each reach ran from the water year after upstream reservoir construction completion through water year 2019. Minor daily data gaps are filled in by linear interpolation within the IHA software (TNC 2009).
- There have been changes in water intakes and withdrawals (source, location, quantity and quality of water) within the Mahoning River basin over the periods of data analyzed for this study, although it is anticipated that this may have altered water quality than quantity at a daily time step. (Use of the TMT later in this study can provide information to support alteration in water quantity if changes were significant over the time periods of interest.)
- For two period analysis (or comparisons of two hydrology files), the return intervals for small and large floods and the flow level thresholds used to define extreme low flows and high flow pulses are based on data in the hydrology files that describes the pre-impact, or baseline period (TNC 2009).
- IHA default values for thresholds were used for EFC events in IHA, although these threshold values can be improved upon with stream-specific data. For example, a small flood was defined as an event with a recurrence interval between 2- and 10-years for all study reaches. However, this recurrence interval range can be refined or specific flows can be used to better define a small flood for each reach if site specific conditions are known.
- This assessment may focus on the cumulative impact of upstream reservoir operations to identify which reaches have the highest cumulative hydrologic alteration. However, it is not intended to track the incremental impact of each facility.
- RVA in the IHA software can only be used to estimate the HA factor of IHA parameters, not EFC parameters.
- A brief assessment of the degree of seasonal alteration provided in this report is based solely on HA factors calculated using the RVA in the IHA software. This assessment is a preliminary effort and additional ecological analyses are recommended for further research to support the determination of environmental flow needs.

Section 3. Assessment using Indicators of Hydrologic Alteration (IHA)

This section summarizes the reach-specific results of the hydrologic alteration assessment in the Mahoning River basin using the IHA software. Dozens of ecologically-relevant statistics can be calculated within the IHA software, and presented below are select statistics that are related to Ohio basin flow recommendations, as presented in a similar study for a river in the Upper Ohio River basin (TNC 2015). Each reach includes representations of changes to:

- Seasonality;
- Low Flow Events; and
- High Flow Events.

The seasonal HA factors that were calculated for each of the reaches is also summarized within this section.

Summary of Flow Alteration for MJK1

Seasonality

- Under current operations, median monthly flows are over 30% lower from February through April and over 100% higher from June through October as compared to the baseline conditions (Figure 2).
- March has the highest monthly median flows in baseline conditions but the lowest monthly median flows in current conditions.
- Median monthly flows peak in the summer months under current conditions, although these flows are at a minimum in baseline conditions.

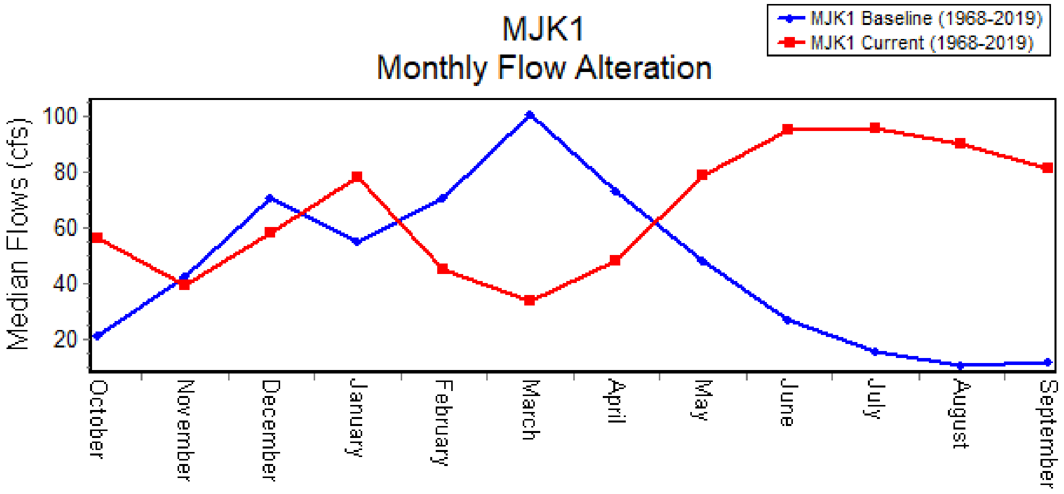

Figure 2. Seasonal flow alteration illustrated by baseline and current monthly median flows for MJK1.

FALL (MJK1)

- Under current conditions, the fall median flows – represented by October median flows – are more than 2.5 times the median flows of baseline conditions (Figure 3).
- Current fall flows are predominantly outside of the range of variability of baseline conditions.

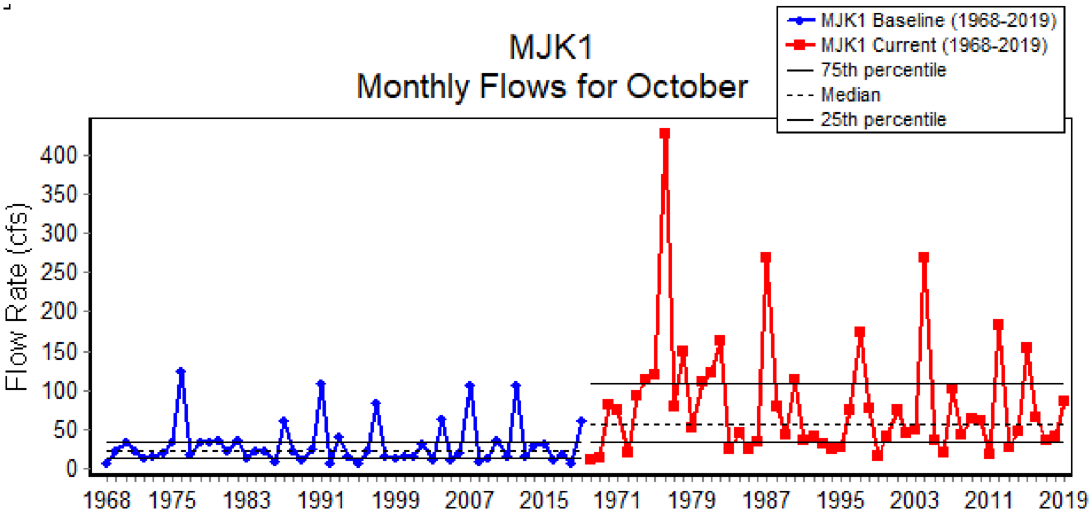

Figure 3. Alteration of median October flows at MJK1.

WINTER (MJK1)

- The winter median flow – represented by December median flow – is similar between baseline and current operations (Figure 4).

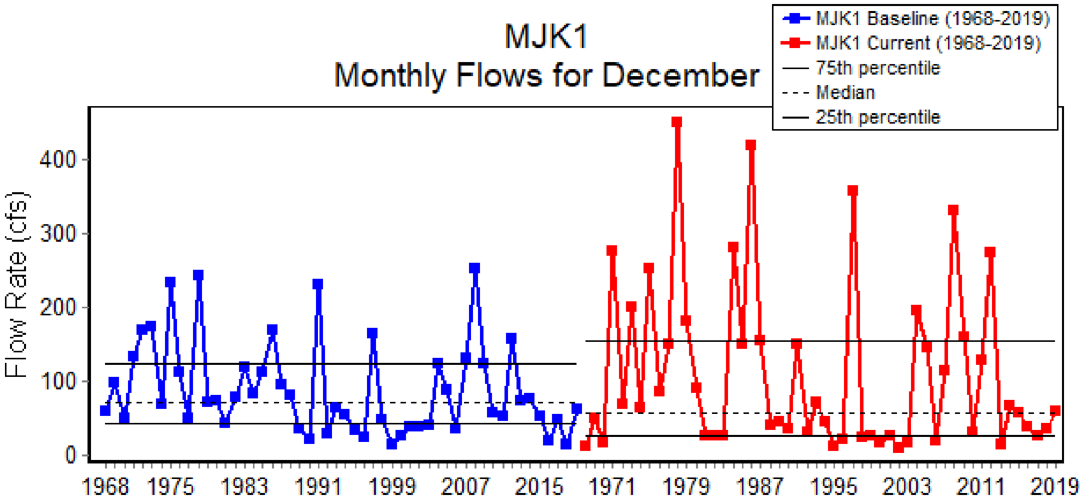

Figure 4. Alteration of median December flows at MJK1.

SPRING (MJK1)

- Under current conditions, the median spring flow – as represented by April median flow – is less than the lower range of variability (25th percentile) of baseline median spring flow (Figure 5).

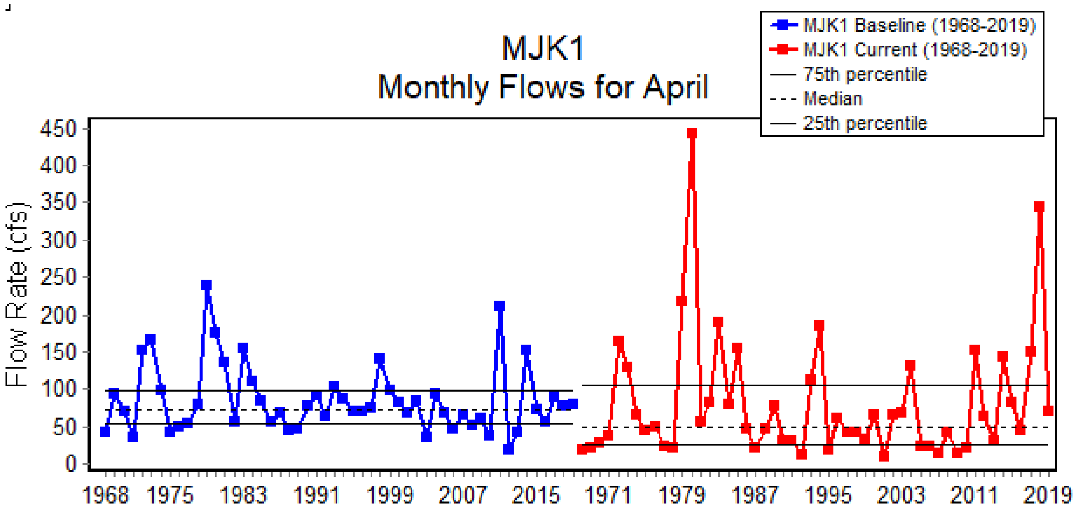

Figure 5. Alteration of median April flows at MJK1.

SUMMER (MJK1)

- Under current conditions, the summer median flow – represented by August median flow – is more than eight times higher than the baseline summer median flow (Figure 6).
- Current summer flows are well outside of the range of variability of baseline conditions.

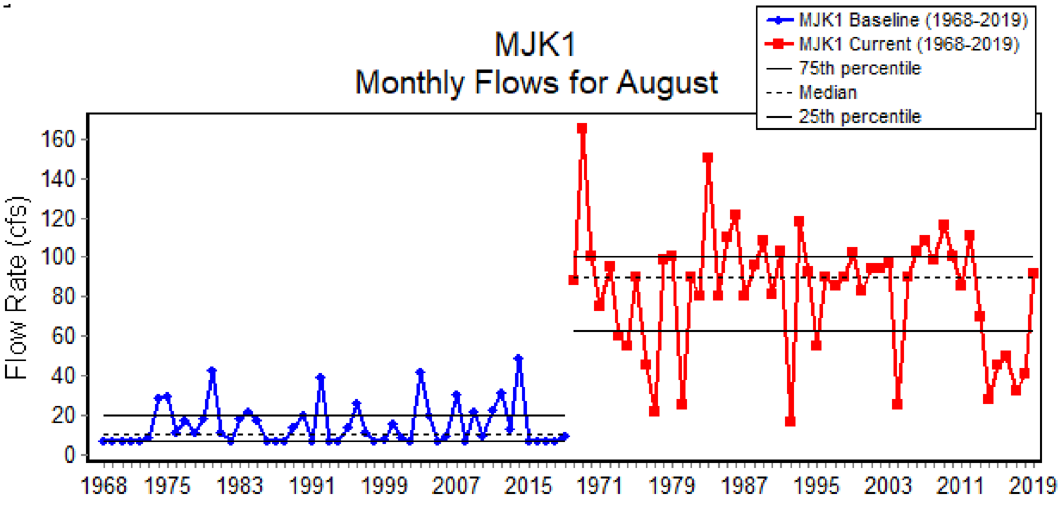

Figure 6. Alteration of median August flows at MJK1.

Low Flow Events

- Minimum flows – as represented by 1-day minimum flows – are higher in current conditions compared to baseline conditions (Figure 7). (Note that minimum baseline flows are constant overtime because negative values were set to the low flow threshold, equivalent to a 10-year, 1-day low flow.)
- The number of low flow pulses, as defined using the baseline dataset in IHA, has reduced significantly under conditions as compared to baseline conditions (Figure 8).
- Extreme low flow events, as defined using the baseline dataset in IHA, have nearly disappeared due to current operations (Figure 9).

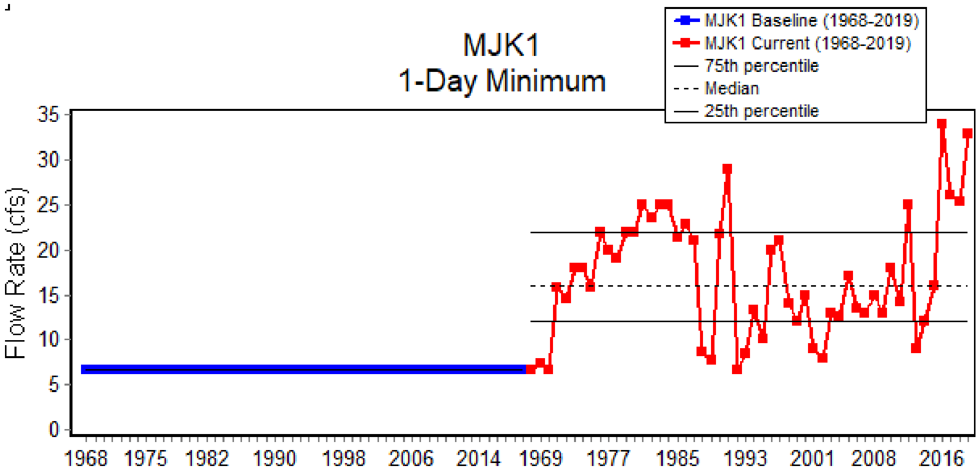

Figure 7. 1-day minimum flows at MJK1.

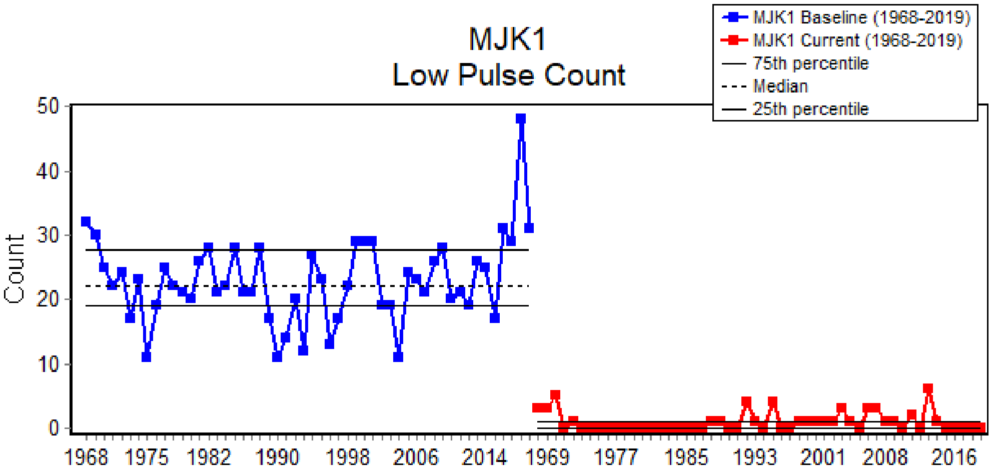

Figure 8. Low flow pulse count at MJK1.

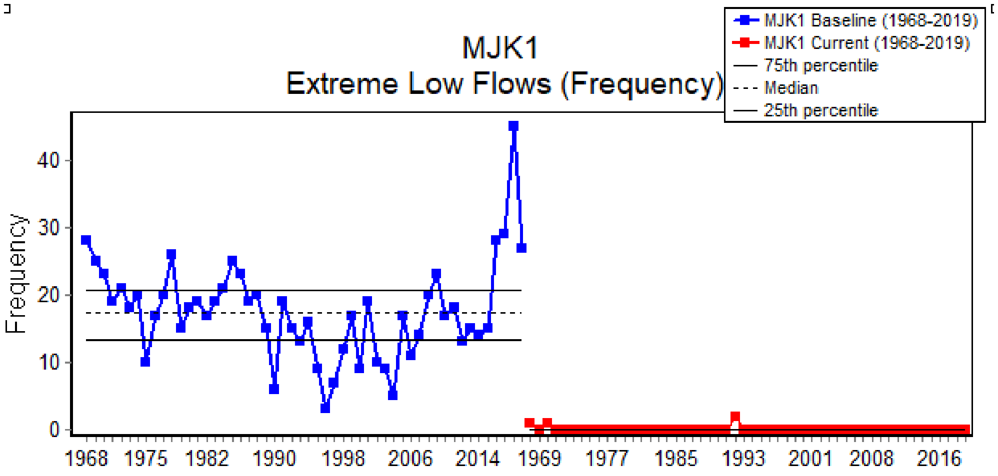

Figure 9. Frequency of extreme low flow events at MJK1

High Flow Events

- Under current conditions, the median maximum flow – as represented by the 1-day maximum flow – is less than half of the median maximum flow under baseline conditions (Figure 10).
- The number of annual high flow pulses has reduced significantly under current conditions as compared to baseline conditions (Figure 11).
- Under current conditions, there are no small or large floods, as defined using baseline flow data in IHA, at MJK1 (Figures 12 and 13).

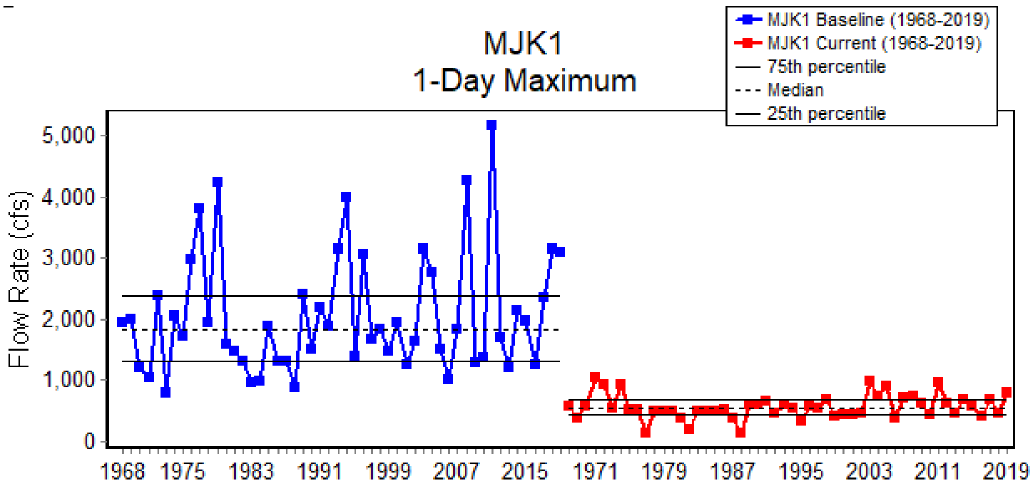

Figure 10. 1-day maximum flows at MJK1.

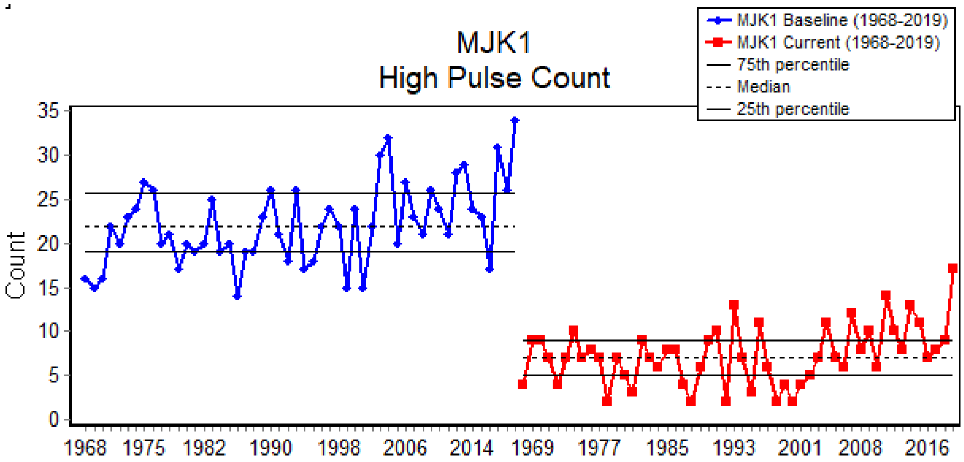

Figure 11. Annual count of high flow pulses at MJK1.

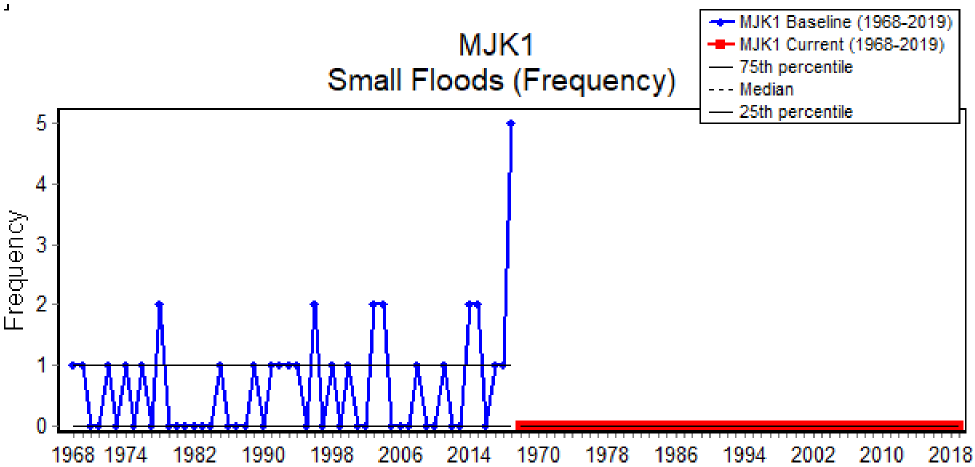

Figure 12. Frequency of small floods (flows greater than or equal to 2-year event and less than a 10-year event, as calculated from baseline data) at MJK1.

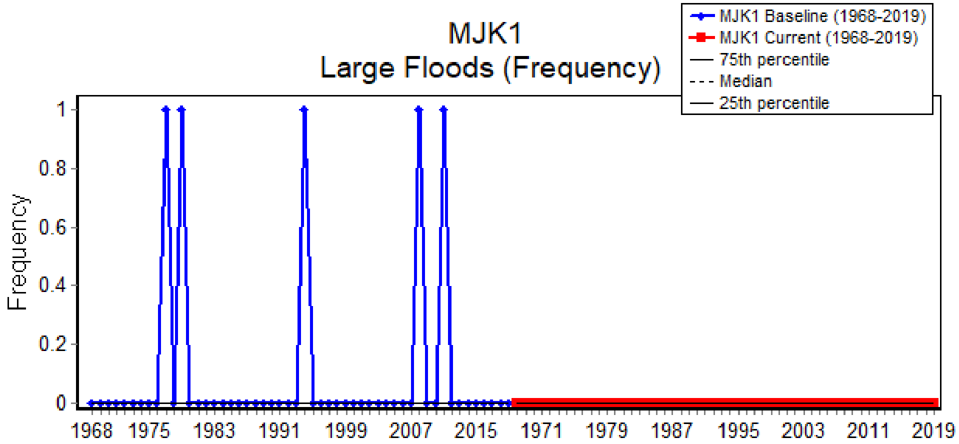

Figure 13. Frequency of large floods (greater than a 10-year event, as calculated from baseline data) at MJK1.

Alteration of Low and High Flow Events

- Minimum flows of all durations increased and short duration high flows are reduced under current operations (Figure 14).

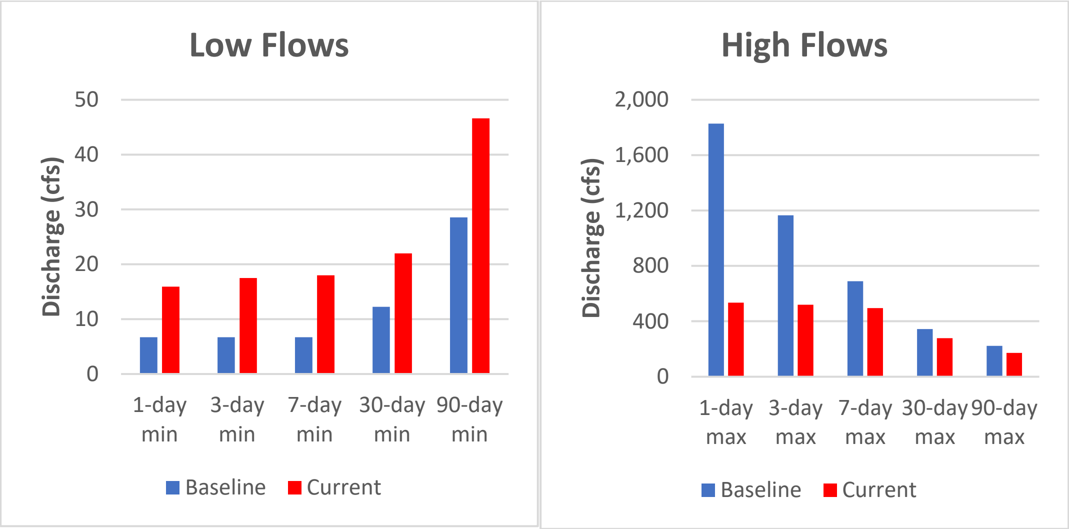

Figure 14. Alteration of high and low flow events of varying duration at MJK1.

Summary of Flow Alteration for MOS1

Seasonality

- Under current operations, the median monthly flows are at least 50 percent lower from February through April and at least 9 times higher from June through October than the baseline conditions (Figure 15).
- March has the highest median monthly flow in baseline conditions and the lowest median monthly flow in current conditions.
- July has the highest median monthly flow in current conditions and one of the lowest median monthly flows in baseline conditions.
- Extreme low flows naturally present in summer months are no longer present under current conditions.

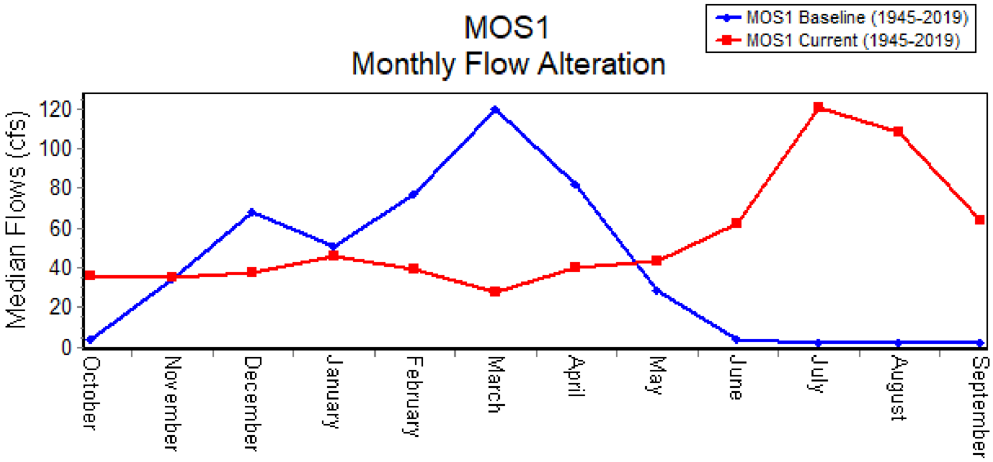

Figure 15. Seasonal flow alteration illustrated by baseline and current monthly median flows for MOS1.

FALL (MOS1)

- The fall median flow – represented by October median flow – is more than nine times higher under current conditions than the median flows of baseline conditions (Figure 16).
- Fall median flows under current conditions are more variable than the range of baseline fall flows.

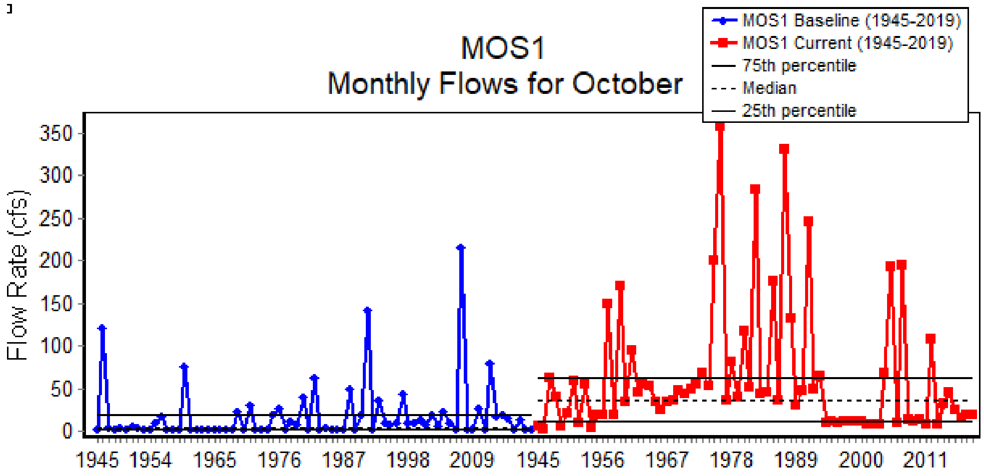

Figure 16. Alteration of median October flows at MOS1.

WINTER (MOS1)

- The winter median flow – represented by December median flow – is about 50 percent lower under current conditions as compared to baseline conditions, although the ranges of variability are similar between the two datasets (Figure 17).

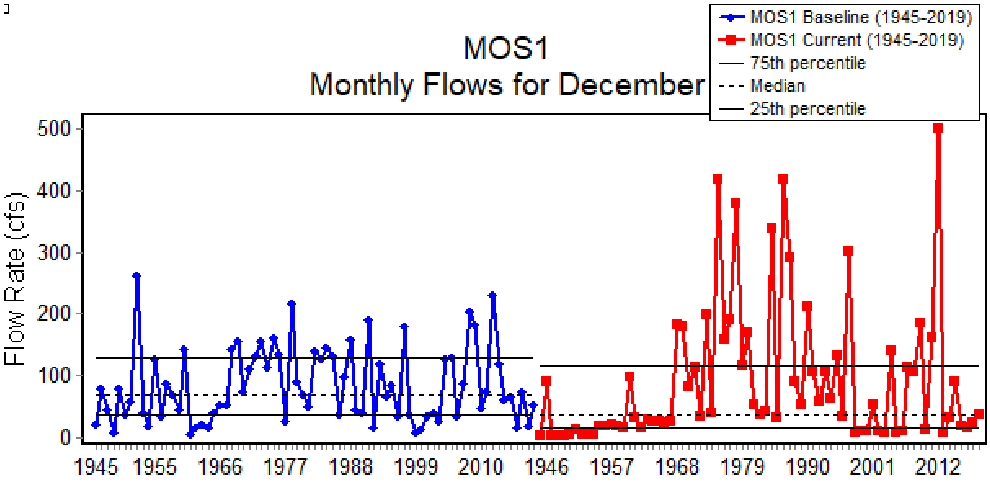

Figure 17. Alteration of median December flows at MOS1.

SPRING (MOS1)

- Under current conditions, the median spring flow – as represented by April median flow – is about 50 percent lower than baseline median spring flow (Figure 18).

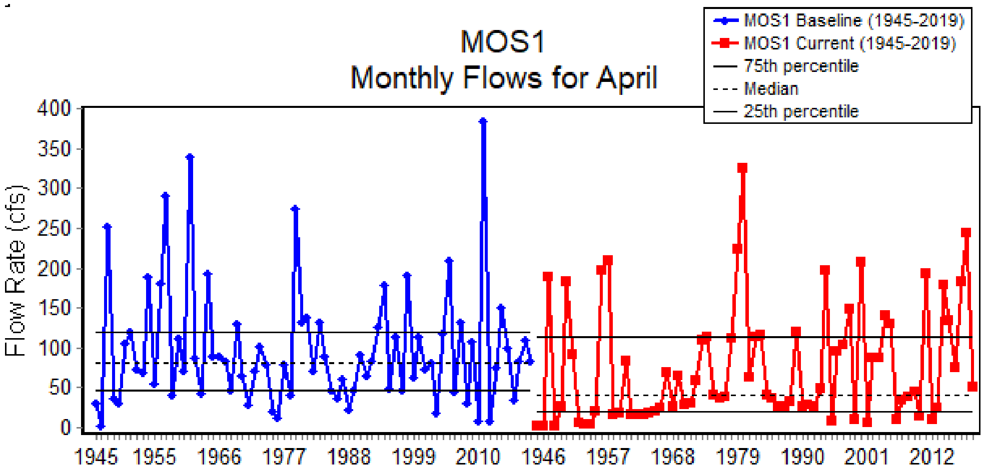

Figure 18. Alteration of median April flows at MJK1.

SUMMER (MOS1)

- Under current conditions, the summer median flow – represented by August median flow – is significantly higher than the baseline summer median flow (Figure 19).
- There is much more variability in summer median flows in current conditions as compared to baseline conditions.

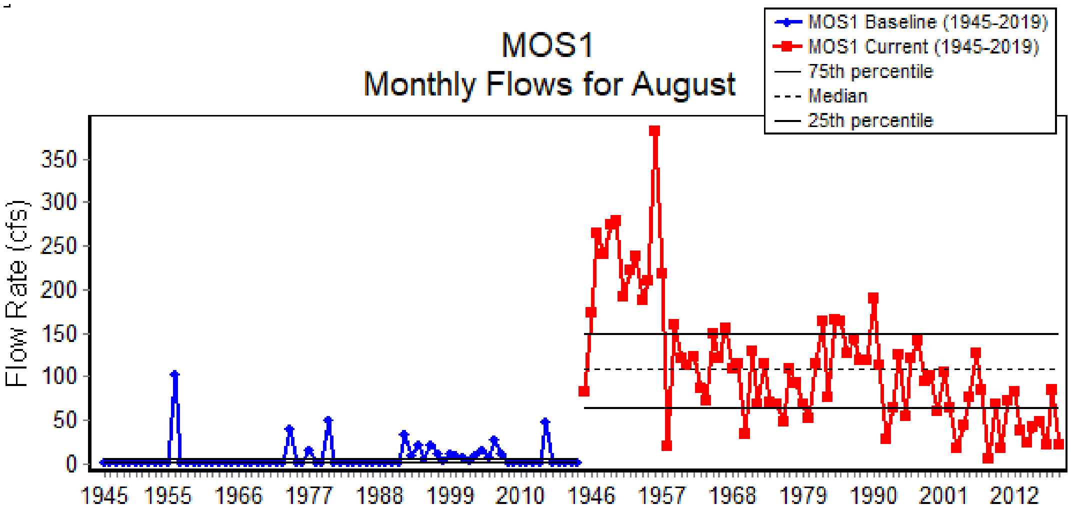

Figure 19. Alteration of median August flows at MOS1.

Low Flow Events

- Minimum flows – as represented by 1-day minimum flows – are higher in current conditions compared to baseline conditions (Figure 20). (Note that minimum baseline flows are constant overtime because negative values were set to the low flow threshold, equivalent to a 10-year, 1-day low flow.)
- Extreme low flow events, as defined using the baseline dataset in IHA, have nearly disappeared due to current operations (Figure 21).

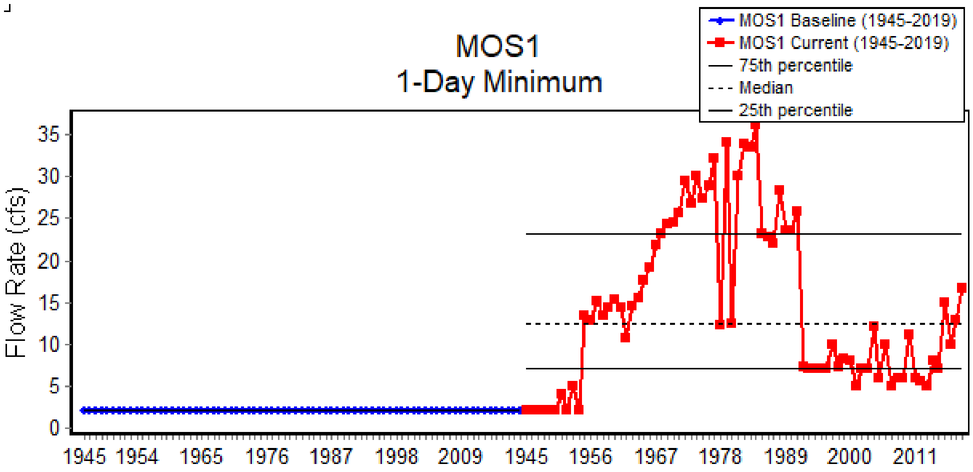

Figure 20. 1-day minimum flows at MOS1.

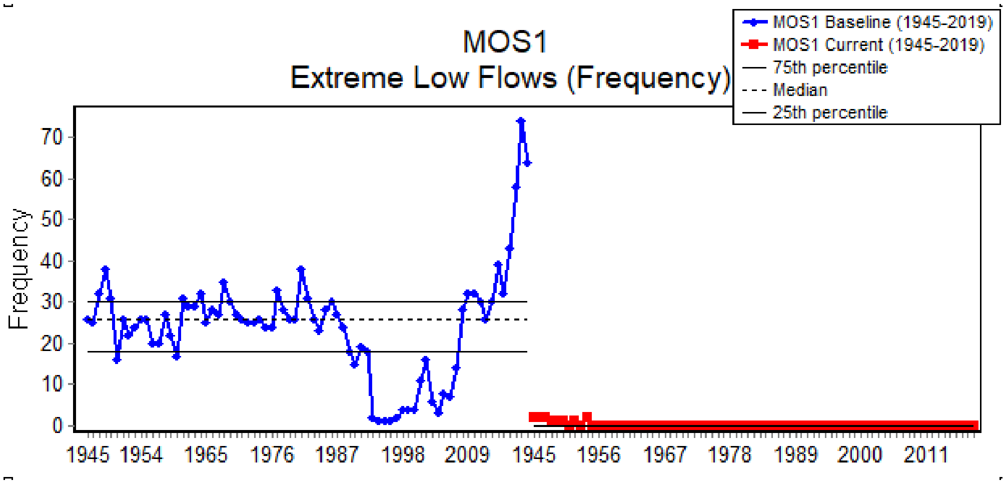

Figure 21. Frequency of extreme low flow events at MOS1.

High Flow Events

- Under current conditions, maximum flows – as represented by 1-day maximum flows – are less than half of the baseline conditions (Figure 22). These maximum flows are also less variable under current conditions.
- The number of annual high flow pulses has reduced significantly under current conditions as compared to baseline conditions (Figure 23).
- Under current conditions, there are no small or large floods, as defined using baseline flow data, at MOS1 (Figures 24 and 25).

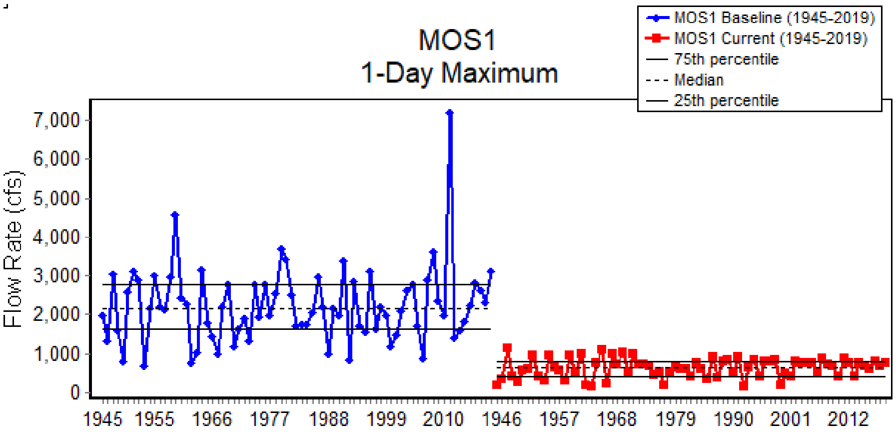

Figure 22. 1-day maximum flows at MOS1.

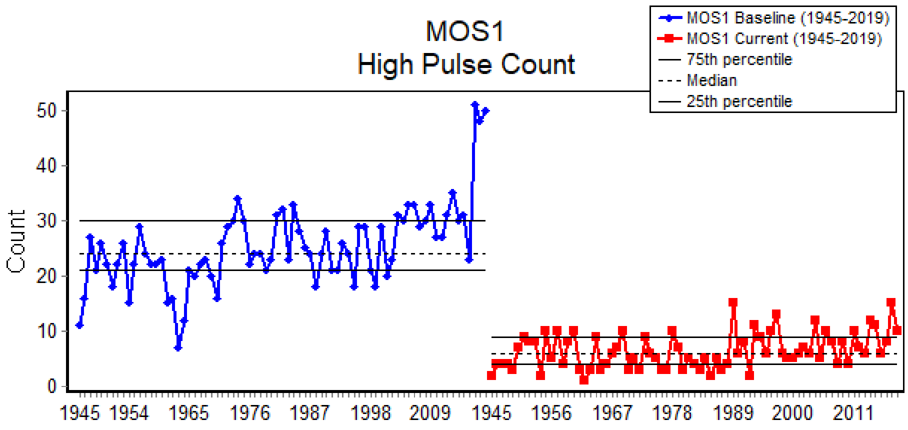

Figure 23. Annual count of high flow pulses at MOS1.

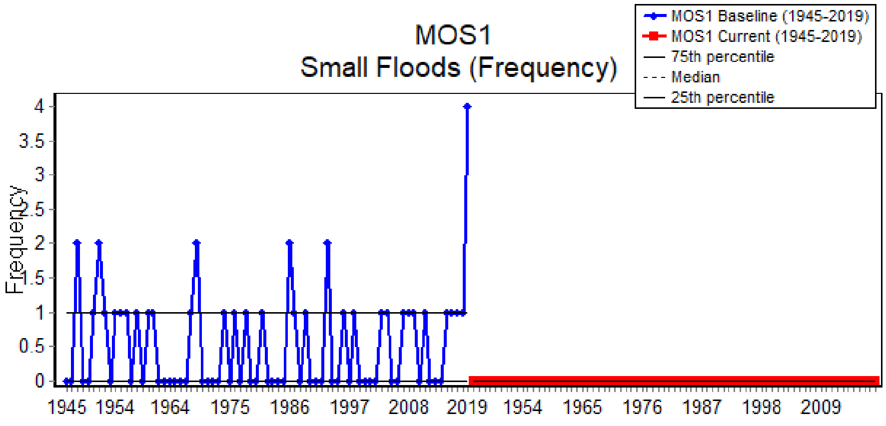

Figure 24. Frequency of small floods (flows greater than or equal to 2-year event and less than a 10-year event, as calculated from baseline data) at MOS1.

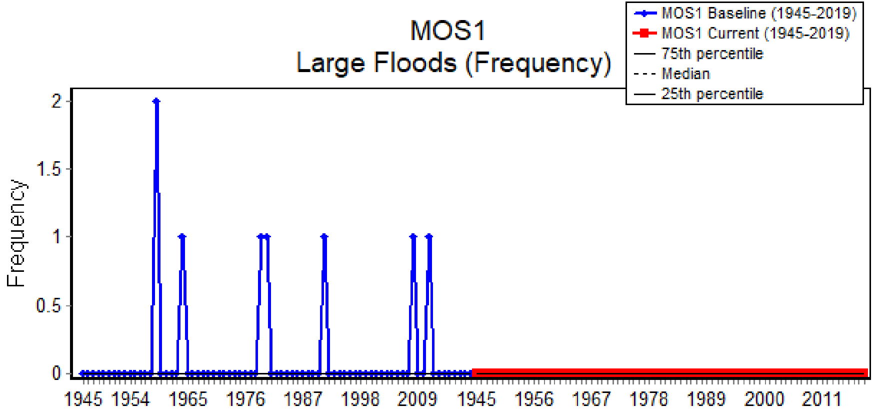

Figure 25. Frequency of large floods (greater than a 10-year event, as calculated from baseline data) at MOS1.

Alteration of Low and High Flow Events

- Minimum flows of all durations increased under current operations (Figure 26).
- Short duration high flows are reduced under current operations (Figure 26).

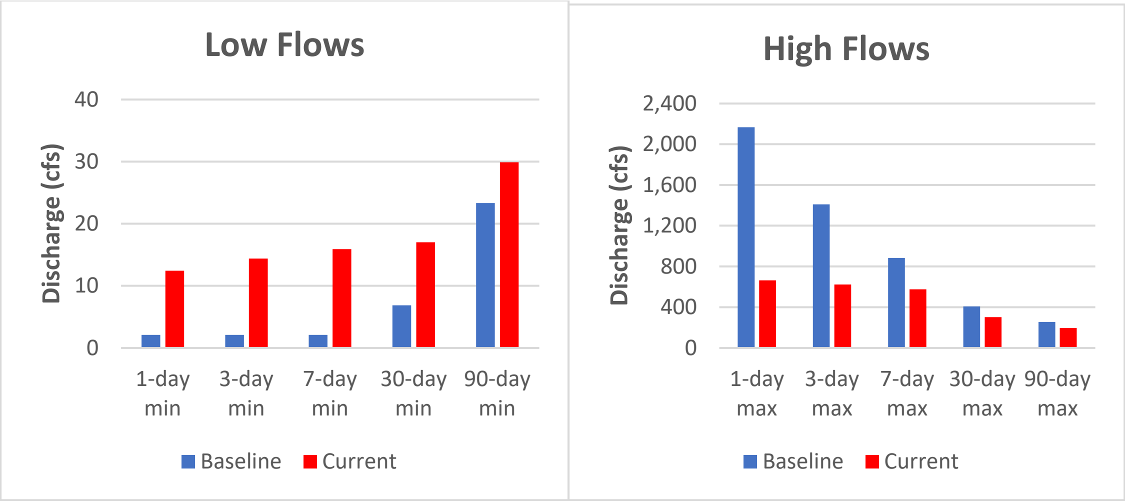

Figure 26. Alteration of high and low flow events of varying duration at MOS1.

Summary of Flow Alteration for MR1

Seasonality

- Under current operations, the median monthly flows are at least 35 percent lower in March and April and at least 2 times higher from June through October than the baseline conditions (Figure 27).
- Extreme low flows naturally present in summer months are no longer present under current conditions.

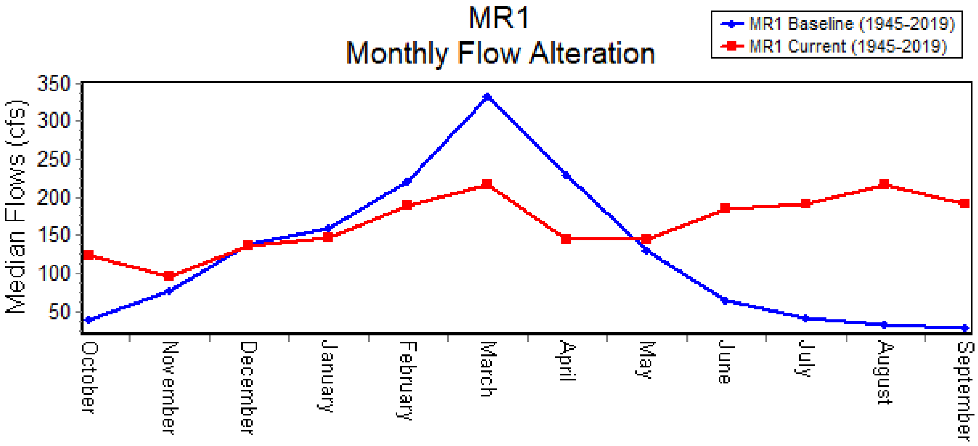

Figure 27. Seasonal flow alteration illustrated by baseline and current monthly median flows for MR1.

FALL (MR1)

- The fall median flow – represented by October median flow – is more than three times higher under current conditions than the median flows of baseline conditions (Figure 28).
- The lower range of variability (25th percentile) for fall median flows under current operations is approximately equivalent to the upper range of variability (75th percentile) for baseline conditions.

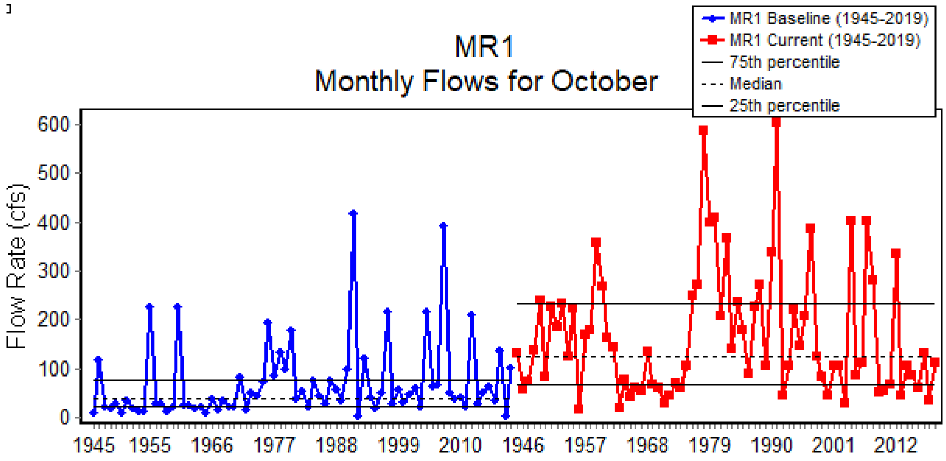

Figure 28. Alteration of median October flows at MR1.

WINTER (MR1)

- The winter median flow – represented by December median flow – for baseline and current conditions is approximately the same, although flows in current conditions are more variable (Figure 29).

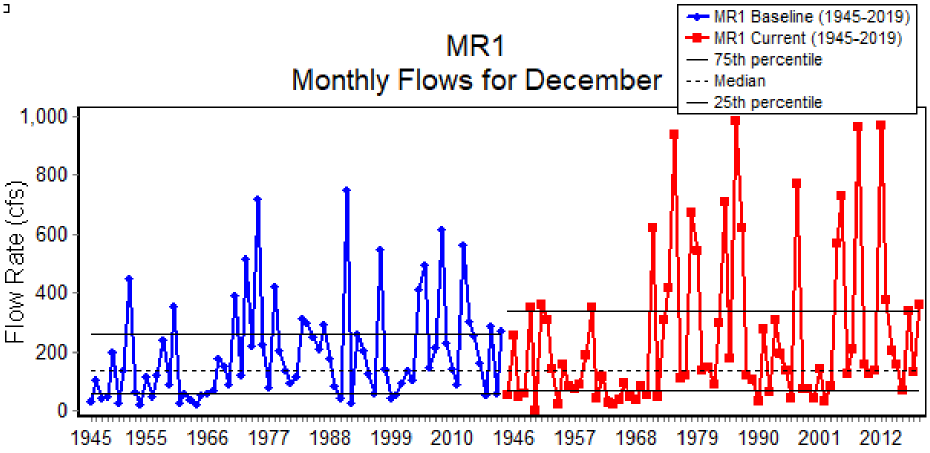

Figure 29. Alteration of median December flows at MR1.

SPRING (MR1)

- The median spring flow – as represented by April median flow – is more than 30 percent lower under current conditions as compared to baseline conditions (Figure 30).

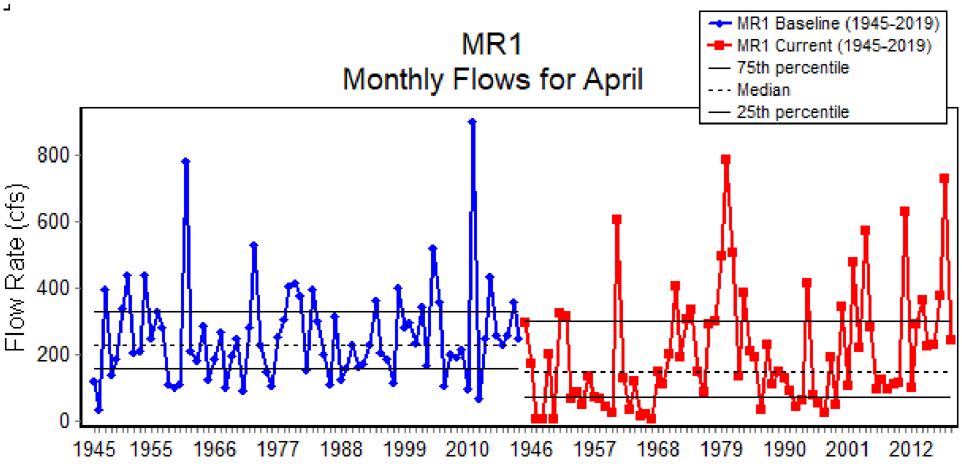

Figure 30. Alteration of median April flows at MR1.

SUMMER (MR1)

- Under current conditions, the summer median flow – represented by August median flow – is more than six times higher than the baseline summer median flow (Figure 31).
- Current summer flows are well outside of the range of variability of baseline conditions.

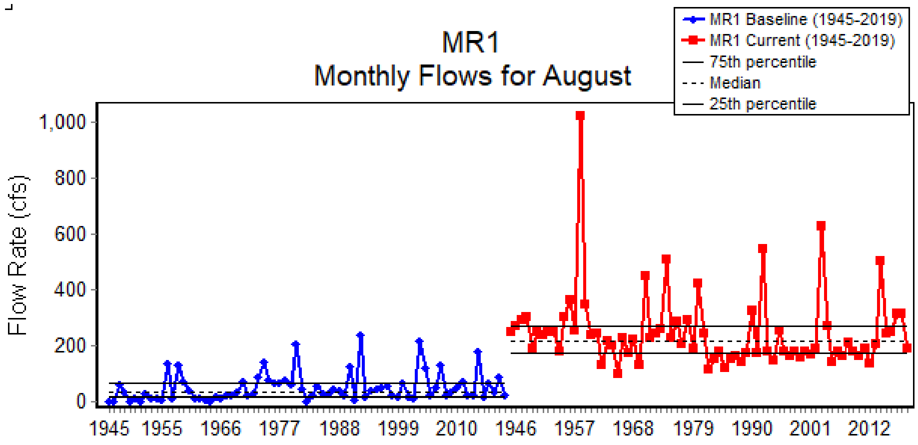

Figure 31. Alteration of median August flows at MR1.

Low Flow Events

- Minimum flows – as represented by 1-day minimum flows – are higher and more variable in current conditions compared to baseline conditions (Figure 32). (Note that minimum baseline

flows are nearly constant overtime because negative values were set to the low flow threshold, equivalent to a 10-year, 1-day low flow.)

- The annual number of low flow pulses has decreased significantly under current conditions as compared to baseline conditions (Figure 33).
- The frequency of extreme low flow events, as defined using the baseline dataset in IHA, has decreased significantly due to current operations (Figure 34).

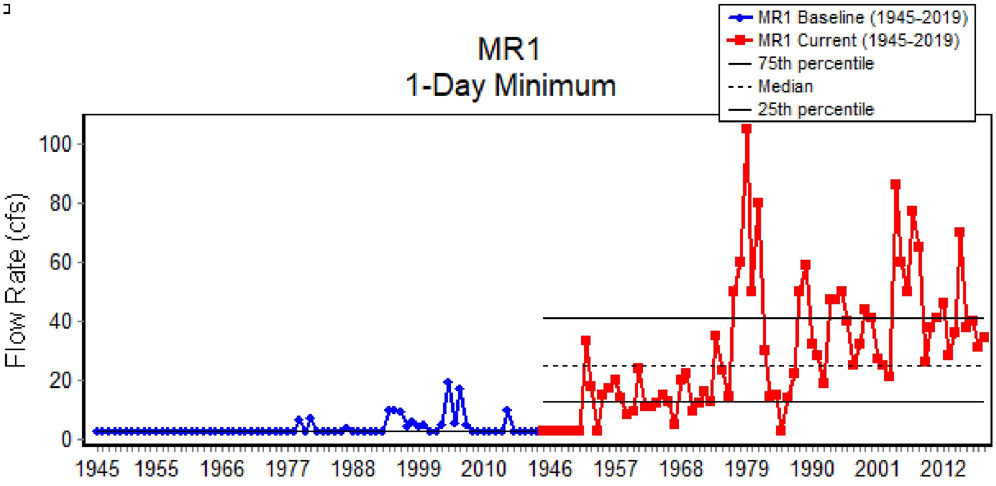

Figure 32. 1-day minimum flows at MR1.

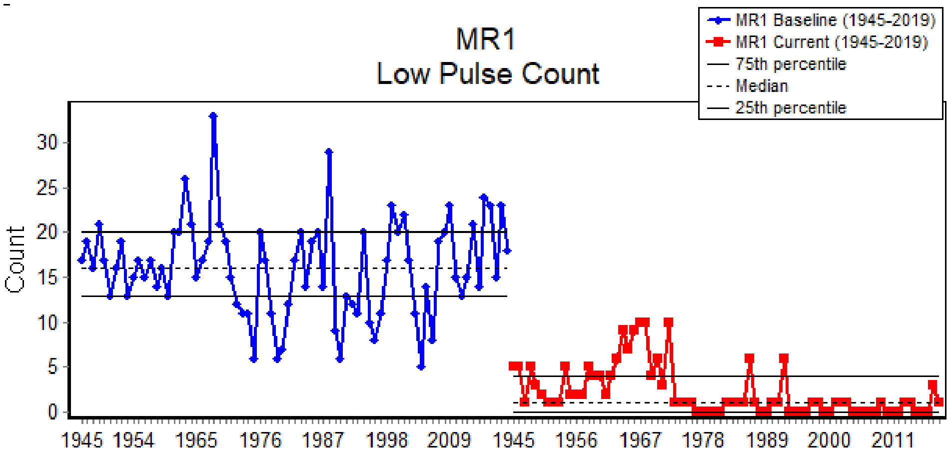

Figure 33. Number of annual low flow pulses at MR1.

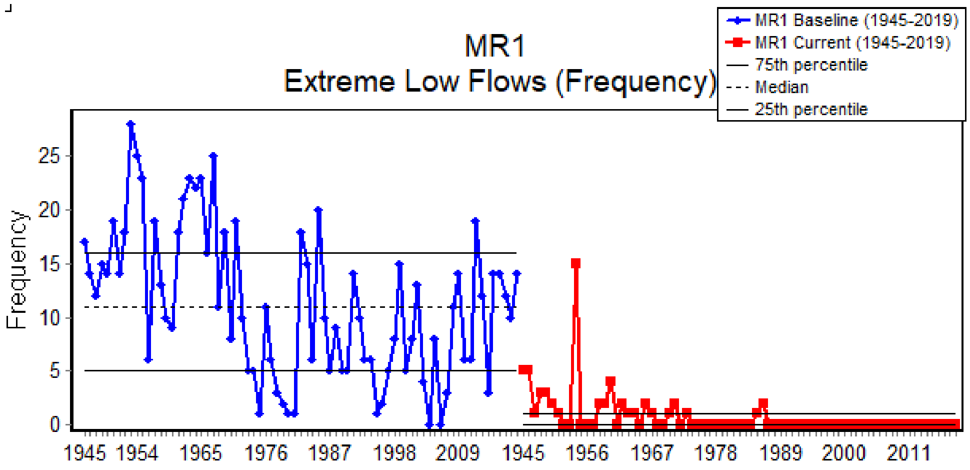

Figure 34. Frequency of extreme low flow events at MR1.

High Flow Events

- Under current conditions, maximum flows – as represented by 1-day maximum flows – are less than half of the baseline conditions (Figure 35). These maximum flows are also less variable under current conditions.
- The number and variability of annual high flow pulses has decreased under current conditions as compared to baseline conditions (Figure 36).
- Under current conditions, there are no small or large floods, as defined using baseline flow data, at MR1 (Figures 37 and 38).

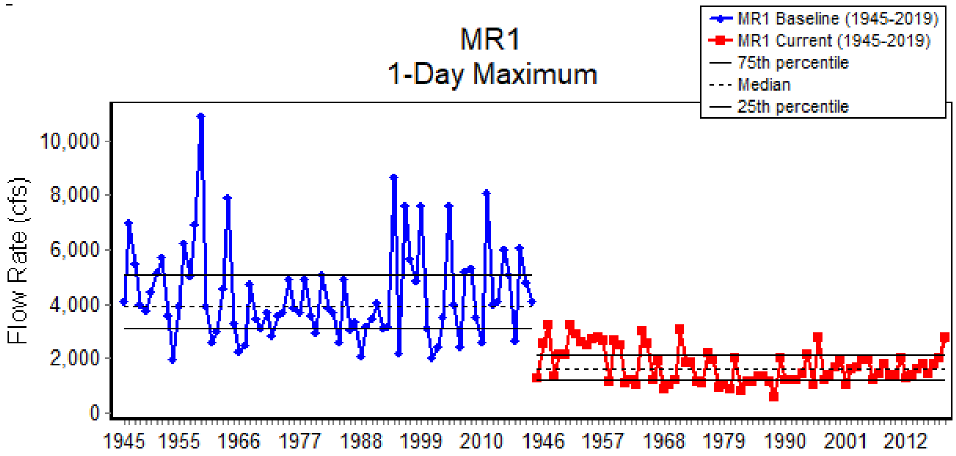

Figure 35. 1-day maximum flows at MR1.

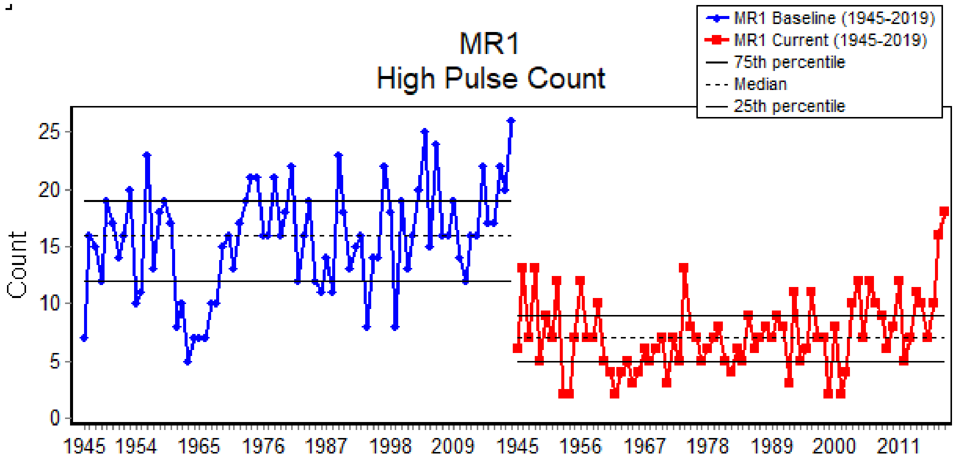

Figure 36. Annual count of high flow pulses at MR1.

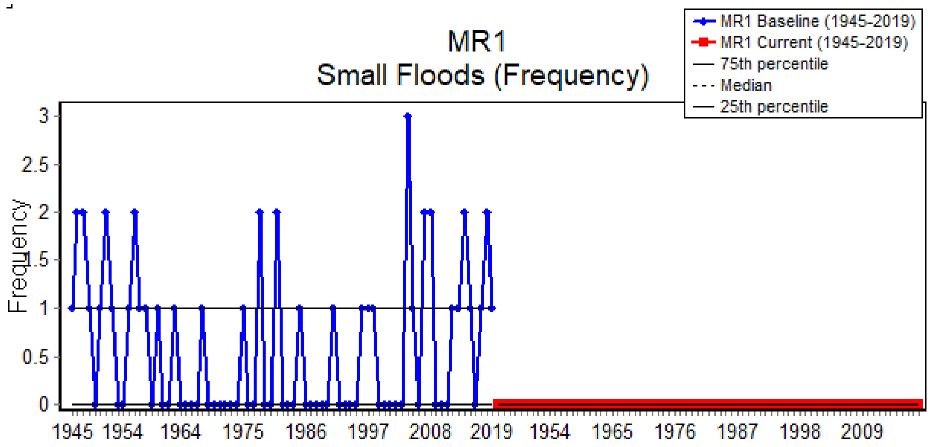

Figure 37. Frequency of small floods (flows greater than or equal to 2-year event and less than a 10-year event, as calculated from baseline data in IHA) at MR1.

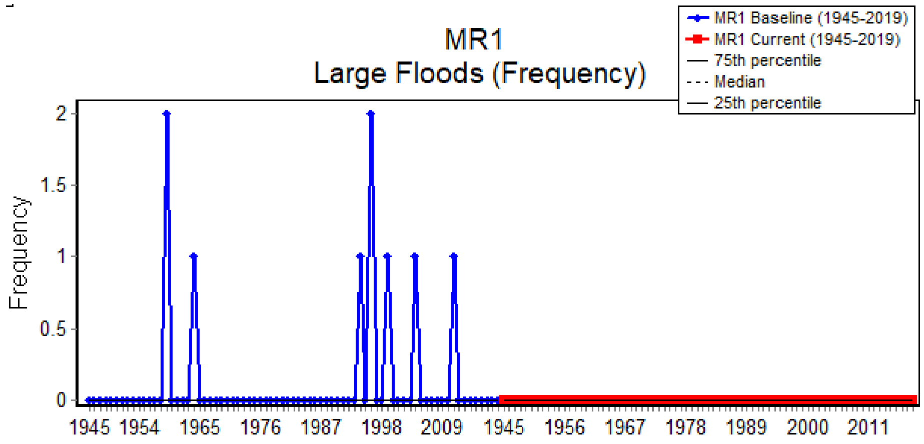

Figure 38. Frequency of large floods (greater than a 10-year event, as calculated from baseline data) at MR1.

Alteration of Low and High Flow Events

- Minimum flows of all durations increased and short duration high flows are reduced under current operations (Figure 39). The largest percent differences between the baseline and current conditions for low and high flows are the 1-day minimum and 1-day maximum flows, respectively.

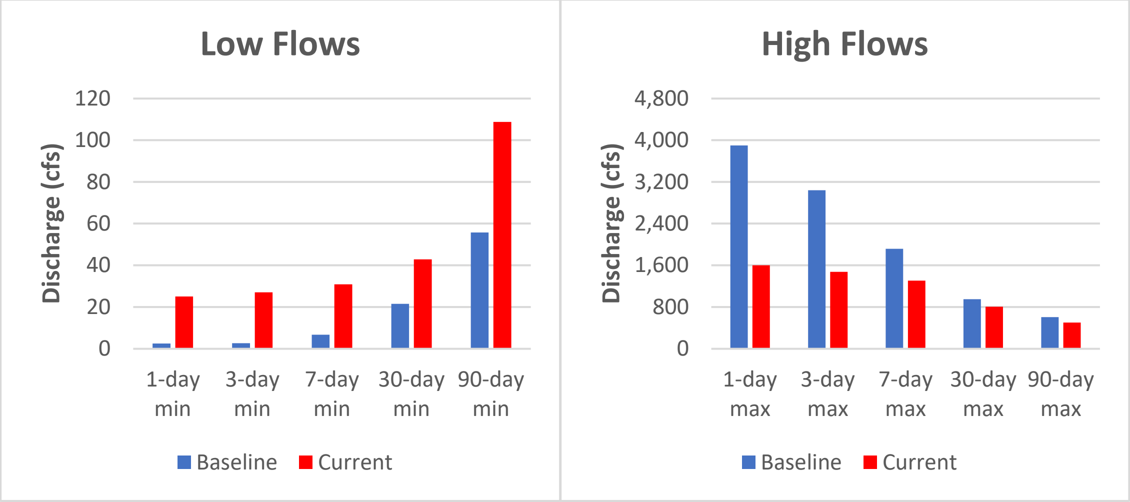

Figure 39. Alteration of high and low flow events of varying duration at MR1.

Summary of Flow Alteration for MR2

Seasonality

- Under current operations, the median monthly flows are at least 2 times higher from July through October than the baseline conditions (Figure 40).
- Current February through May median monthly flows are within 20% of baseline flows.

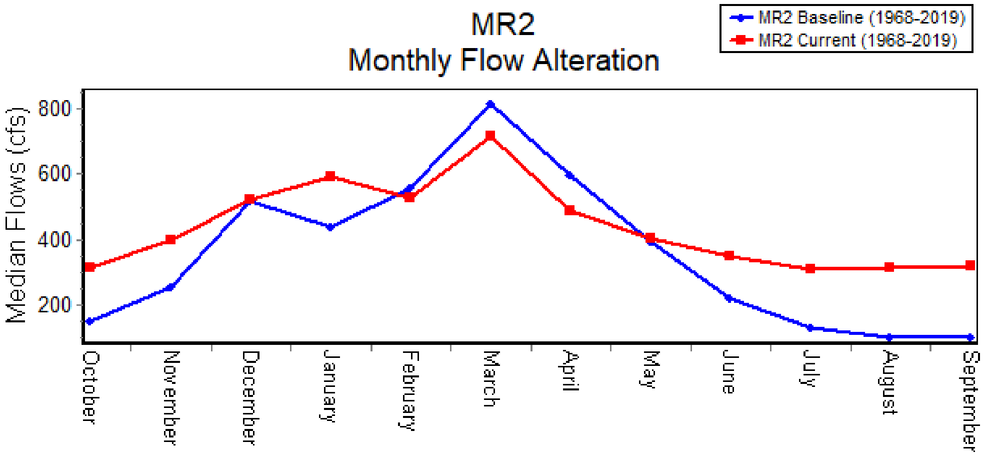

Figure 40. Seasonal flow alteration illustrated by baseline and current monthly median flows for MR2.

FALL (MR2)

- The fall median flow – represented by October median flow – is more than two times higher under current conditions than the median flows of baseline conditions (Figure 41).
- The lower range of variability (25th percentile) for fall median flows under current operations is approximately equivalent to the upper range of variability (75th percentile) for baseline conditions.

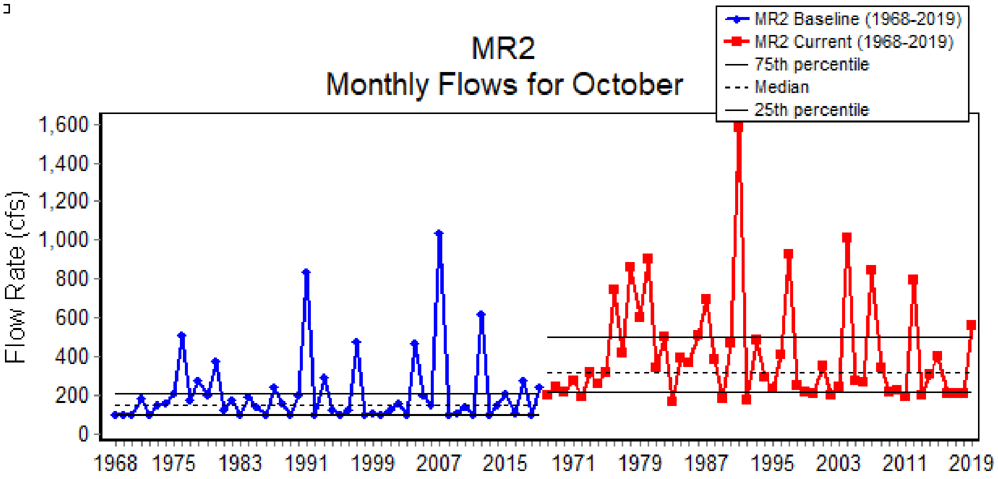

Figure 41. Alteration of median October flows at MR2.

WINTER (MR2)

- The winter median flow – represented by December median flow – for baseline and current conditions is approximately the same, although flows in current conditions are more variable (Figure 42).

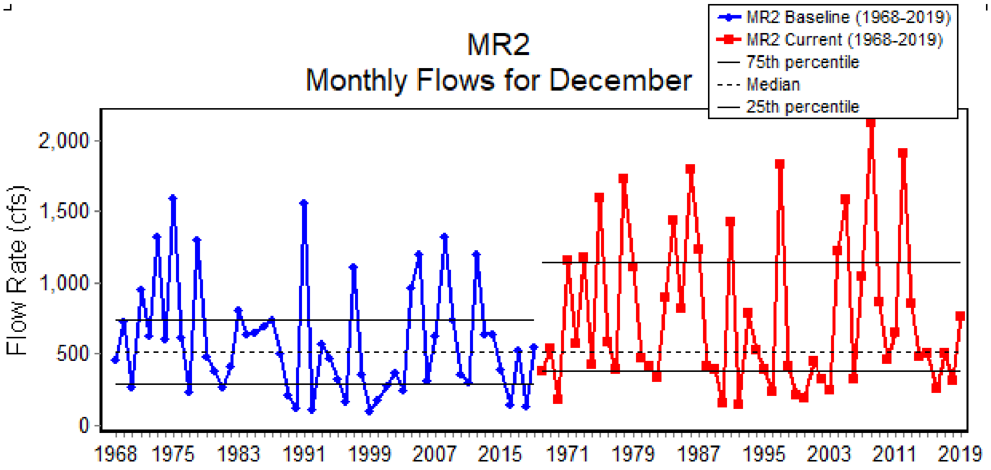

Figure 42. Alteration of median December flows at MR2.

SPRING (MR2)

- The median spring flow – as represented by April median flow – is approximately 20 percent lower under current conditions as compared to baseline conditions (Figure 43).

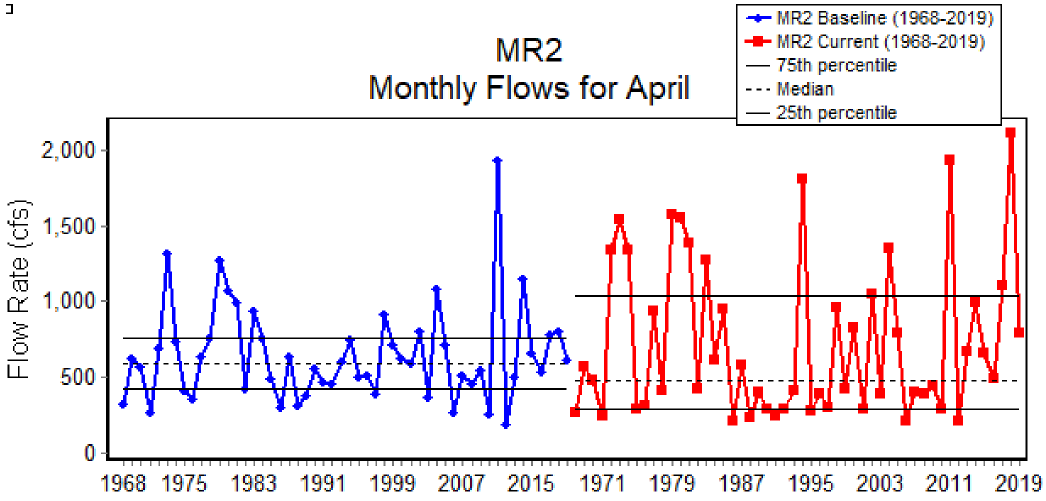

Figure 43. Alteration of median April flows at MR2.

SUMMER (MR2)

- Under current conditions, the summer median flow – represented by August median flow – is more than three times higher than the baseline summer median flow (Figure 44).

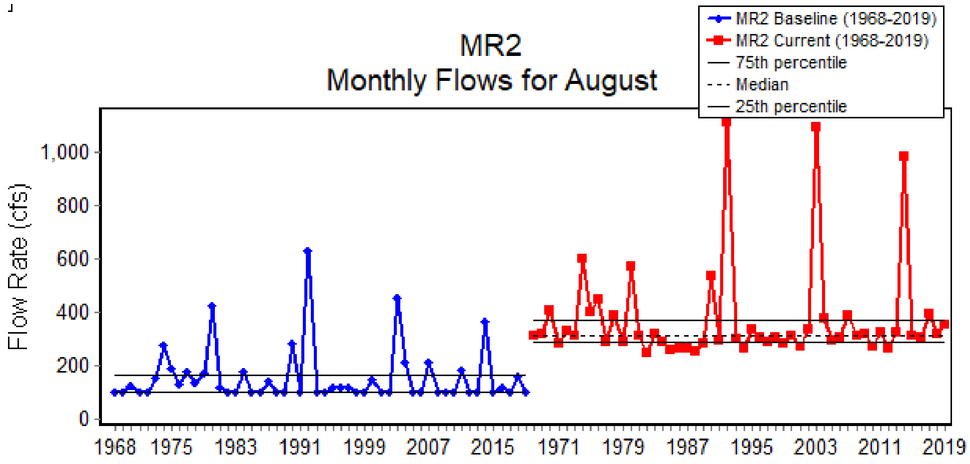

Figure 44. Alteration of median August flows at MR2.

Low Flow Events

- Minimum flows – as represented by 1-day minimum flows – are higher and more variable in current conditions compared to baseline conditions (Figure 45). (Note that minimum baseline

flows are constant overtime because negative values were set to the low flow threshold, equivalent to a 10-year, 1-day low flow.)

- The annual number of low flow pulses has decreased significantly under current conditions as compared to baseline conditions (Figure 46).
- Extreme low flow events, as defined using the baseline dataset in IHA, are not present in current operations (Figure 47).

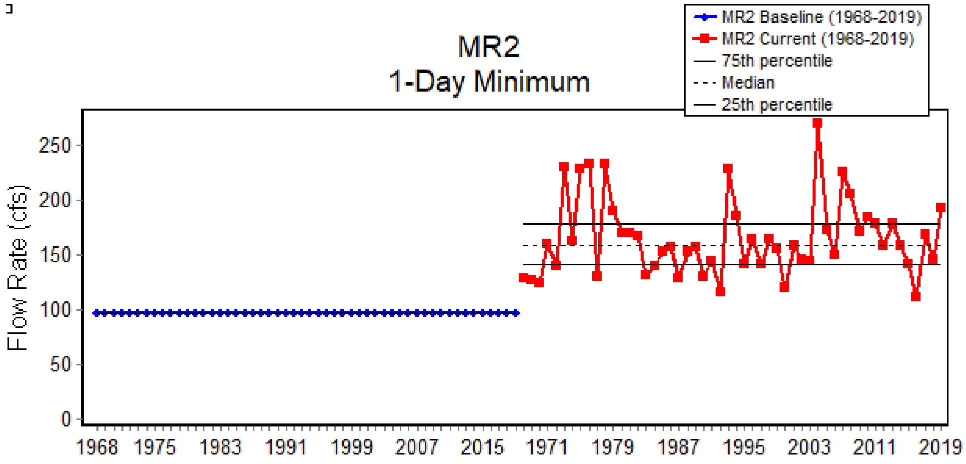

Figure 45. 1-day minimum flows at MR2.

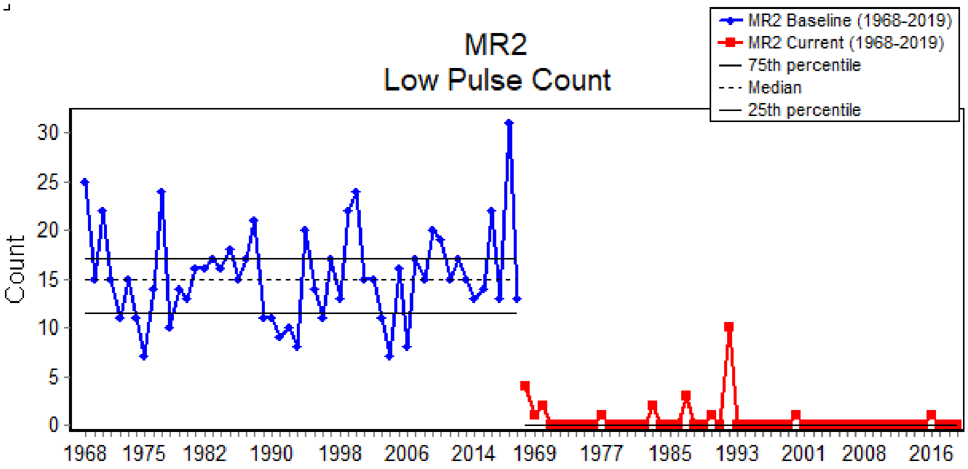

Figure 46. Number of annual low flow pulses at MR2.

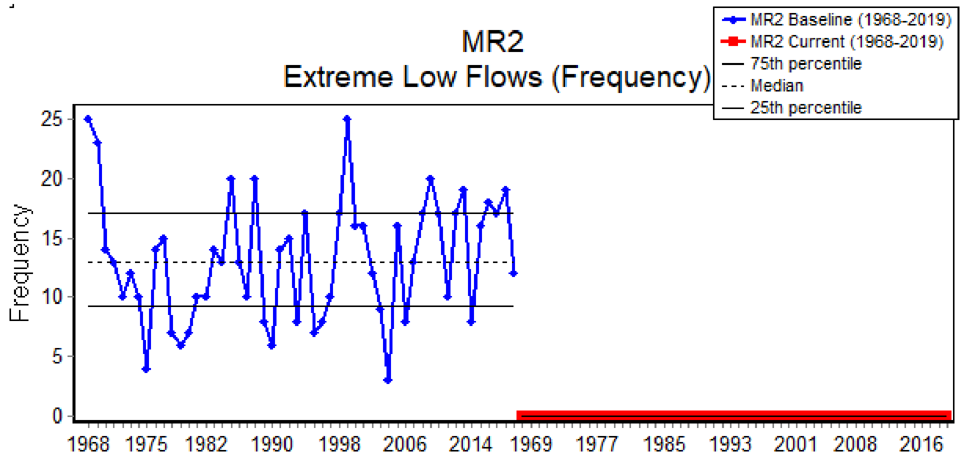

Figure 47. Frequency of extreme low flow events at MR2.

High Flow Events

- Under current conditions, maximum flows – as represented by 1-day maximum flows – are approximately half of the baseline conditions (Figure 48). These maximum flows are also less variable under current conditions.
- The number and variability of annual high flow pulses has decreased under current conditions as compared to baseline conditions (Figure 49).
- Under current conditions, there are no small or large floods, as defined using baseline flow data, at MR2 (Figures 50 and 51).

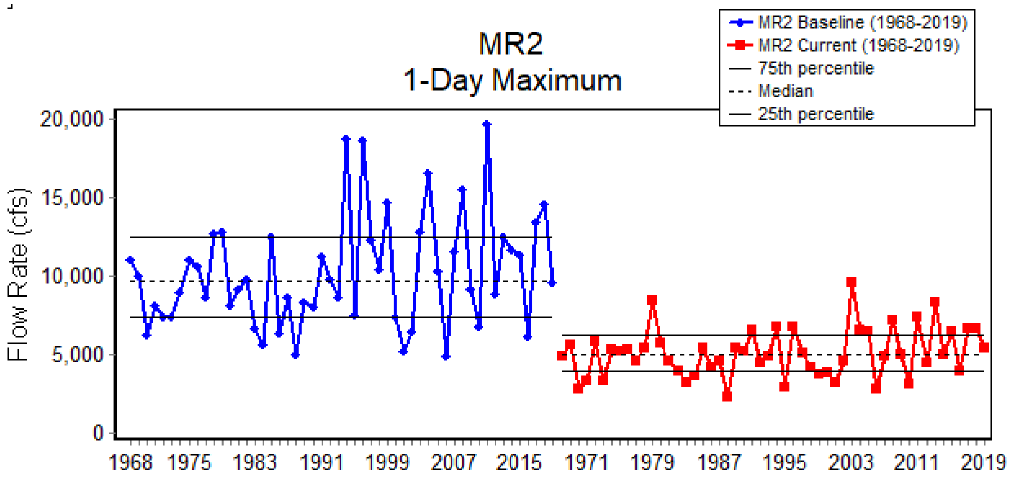

Figure 48. 1-day maximum flows at MR2.

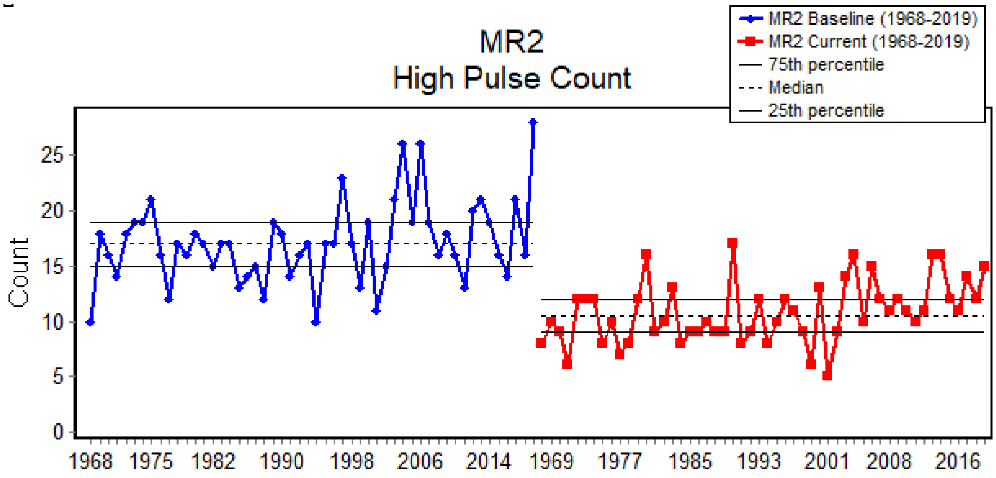

Figure 49. Annual count of high flow pulses at MR2.

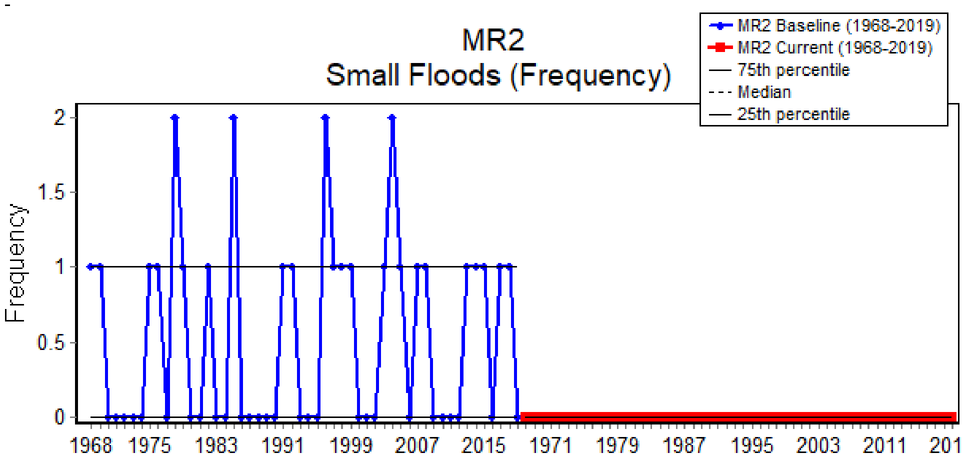

Figure 50. Frequency of small floods (flows greater than or equal to 2-year event and less than a 10-year event, as calculated from baseline data in IHA) at MR2.

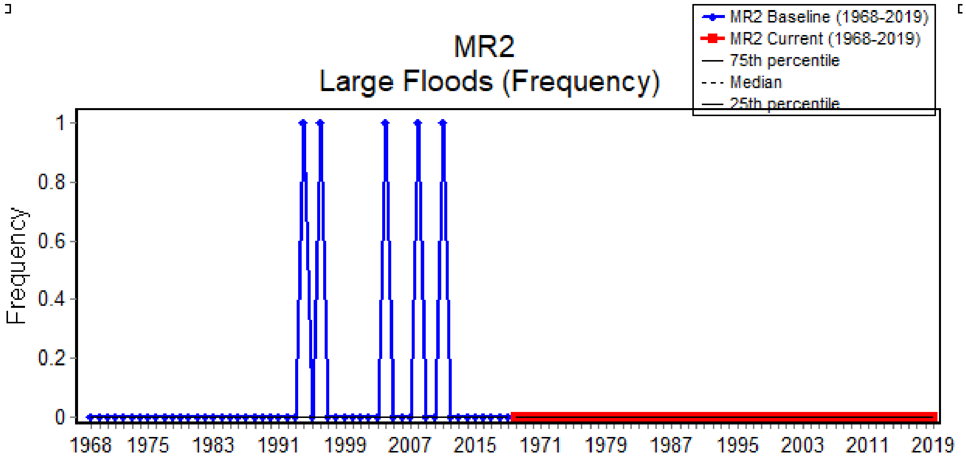

Figure 51. Frequency of large floods (greater than a 10-year event, as calculated from baseline data) at MR2.

Alteration of Low and High Flow Events

- Minimum flows of all durations increased and short duration high flows are reduced under current operations (Figure 52). The largest differences between the baseline and current conditions for low and high flows for shorter durations.

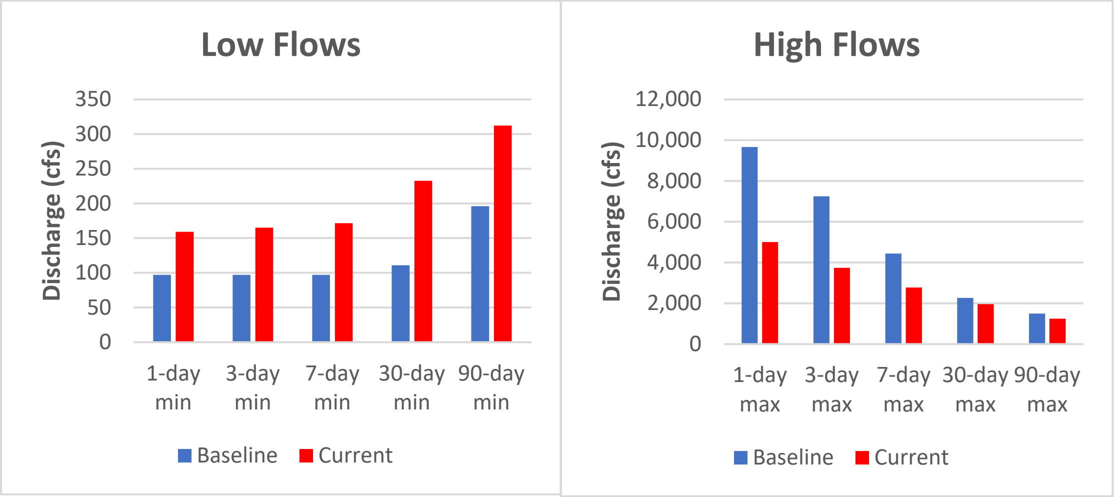

Figure 52. Alteration of high and low flow events of varying duration at MR2.

Summary of Flow Alteration for MR3

Seasonality

- Under current operations, the median monthly flows are at least 2 times higher from July through September than the baseline conditions (Figure 53). November through May median monthly flows in current conditions are within 30% of baseline median monthly flows.

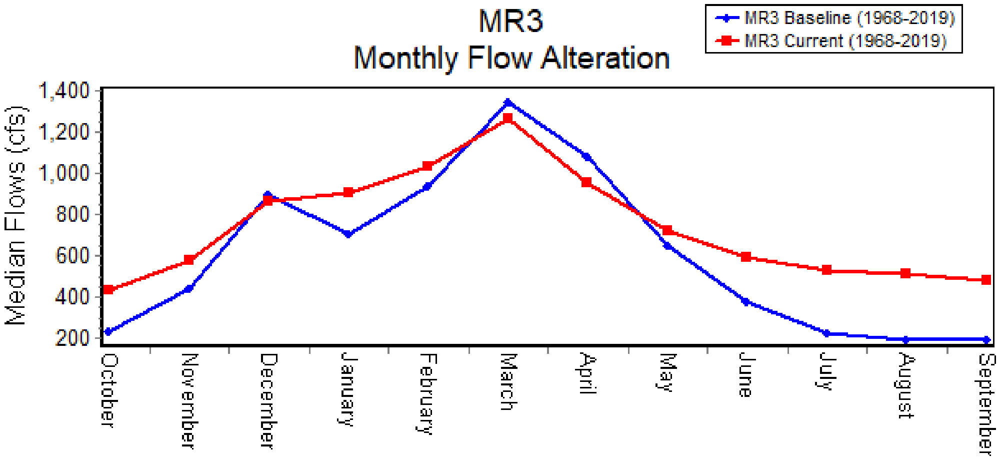

Figure 53. Seasonal flow alteration illustrated by baseline and current monthly median flows for MR3.

FALL (MR3)

- The fall median flow – represented by October median flow – is almost two times higher under current conditions than the median flows of baseline conditions (Figure 54).
- The current fall median flows are more variable than baseline flows.

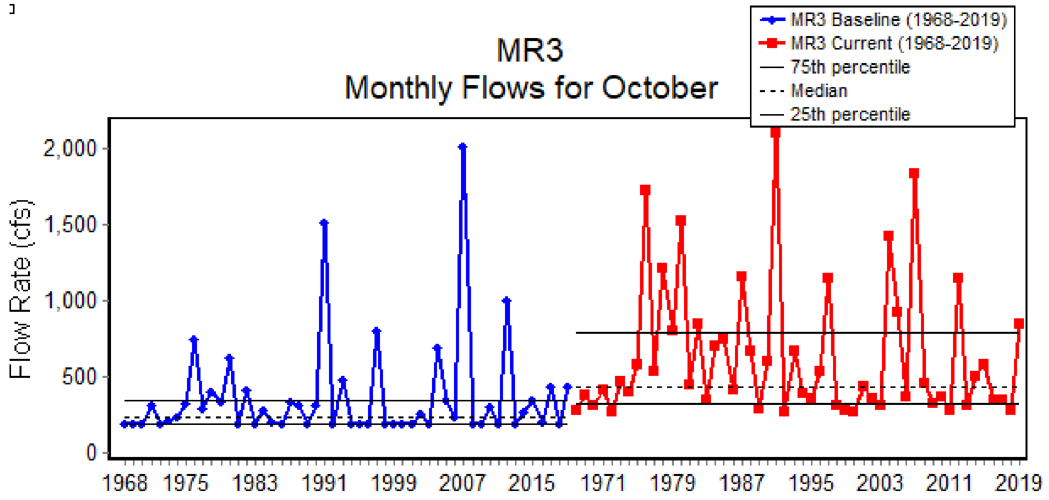

Figure 54. Alteration of median October flows at MR3.

WINTER (MR3)

- The winter median flow – represented by December median flow – for baseline and current conditions is approximately the same (Figure 55).

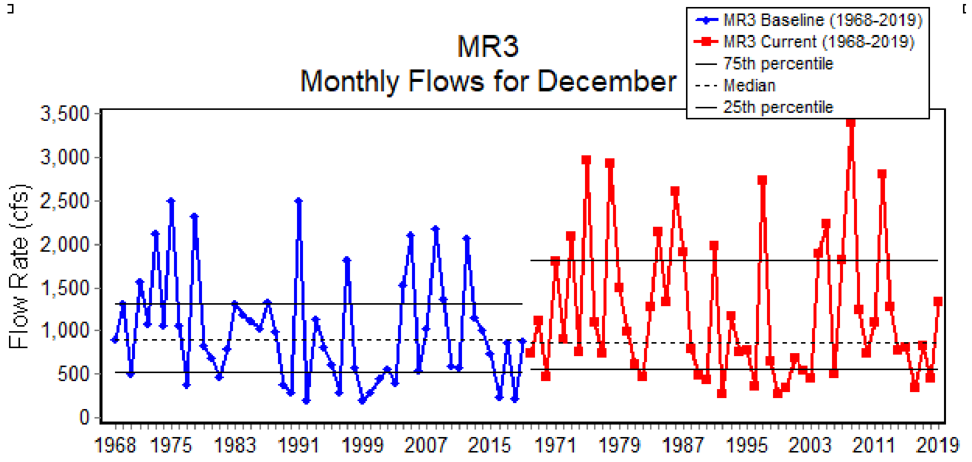

Figure 55. Alteration of median December flows at MR3.

SPRING (MR3)

- Under current conditions, the median spring flow – as represented by April median flow – is similar (approximately 10 percent lower) to the baseline median spring flow (Figure 56).

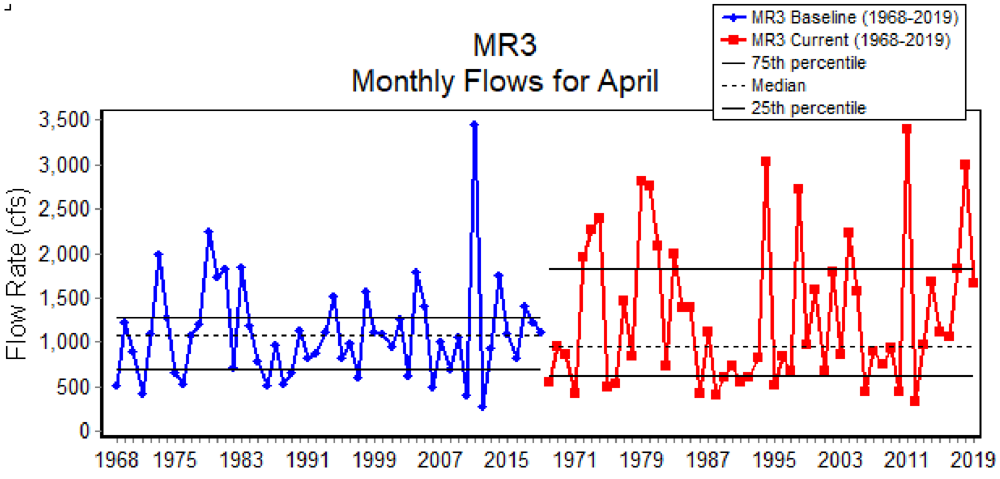

Figure 56. Alteration of median April flows at MR3.

SUMMER (MR3)

- Under current conditions, the summer median flow – represented by August median flow – is more than two times higher than the baseline summer median flow (Figure 57).

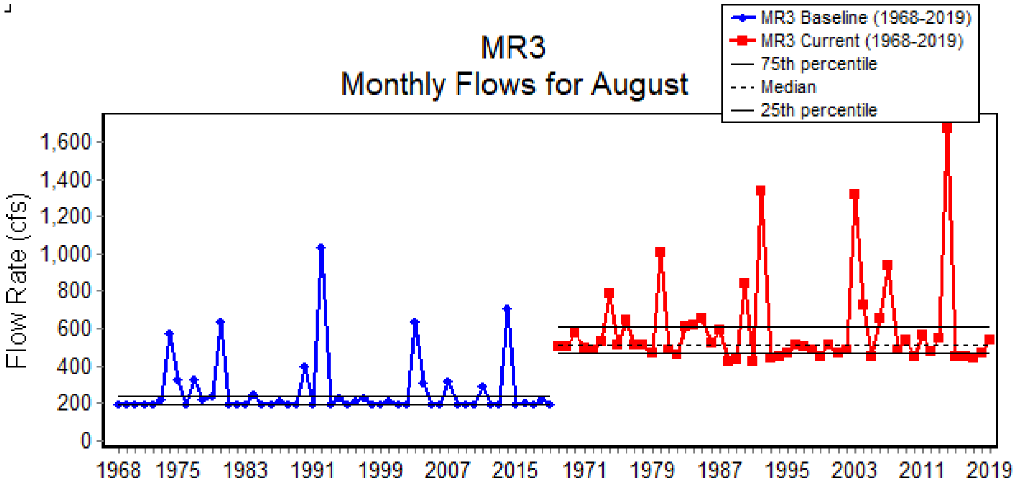

Figure 57. Alteration of median August flows at MR3.

Low Flow Events

- Minimum flows – as represented by 1-day minimum flows – are higher and more variable in current conditions compared to baseline conditions (Figure 58). (Note that minimum baseline

flows are constant overtime because negative values were set to the low flow threshold, equivalent to a 10-year, 1-day low flow.)

- The low flow pulses are much less prevalent in current conditions as compared to baseline conditions (Figure 59).
- Extreme low flow events, as defined using the baseline dataset in IHA, are barely present in current operations (Figure 60).

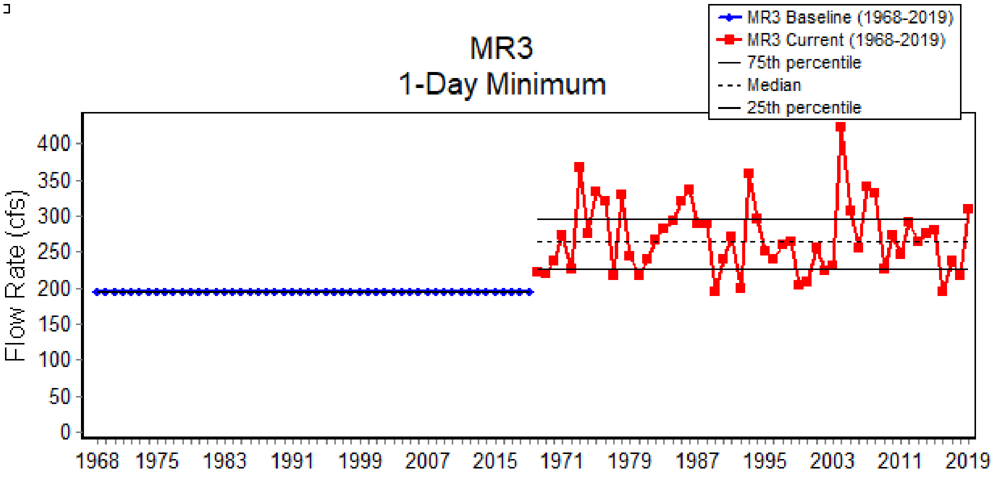

Figure 58. 1-day minimum flows at MR3.

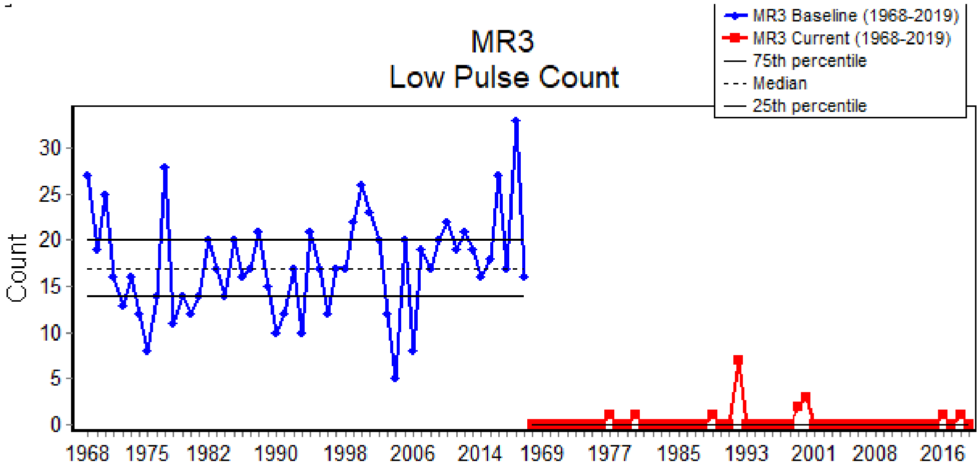

Figure 59. Number of annual low flow pulses at MR3.

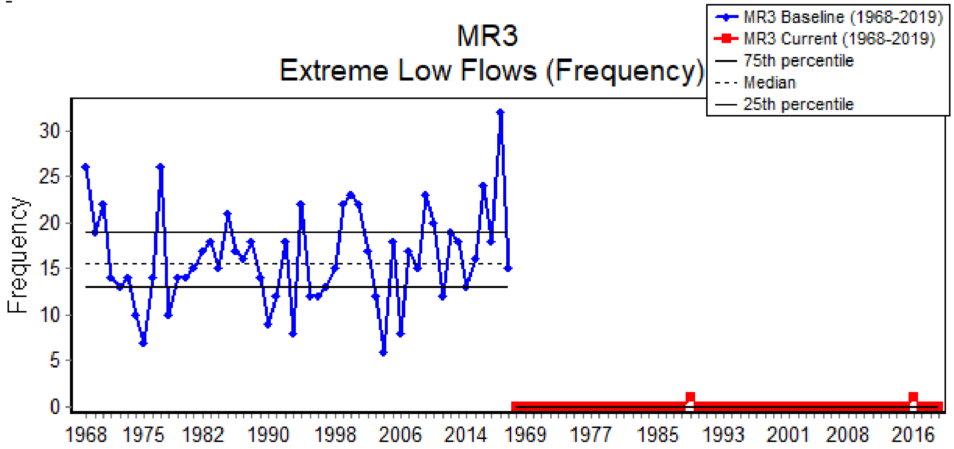

Figure 60. Frequency of extreme low flow events at MR3.

High Flow Events

- Under current conditions, maximum flows – as represented by 1-day maximum flows – are approximately half of the baseline conditions (Figure 61). These maximum flows are also less variable under current conditions.
- The number of high flow pulses has reduced under current conditions (Figure 62).
- Under current conditions, there are no small or large floods, as defined using baseline flow data, at MR3 (Figures 63 and 64).

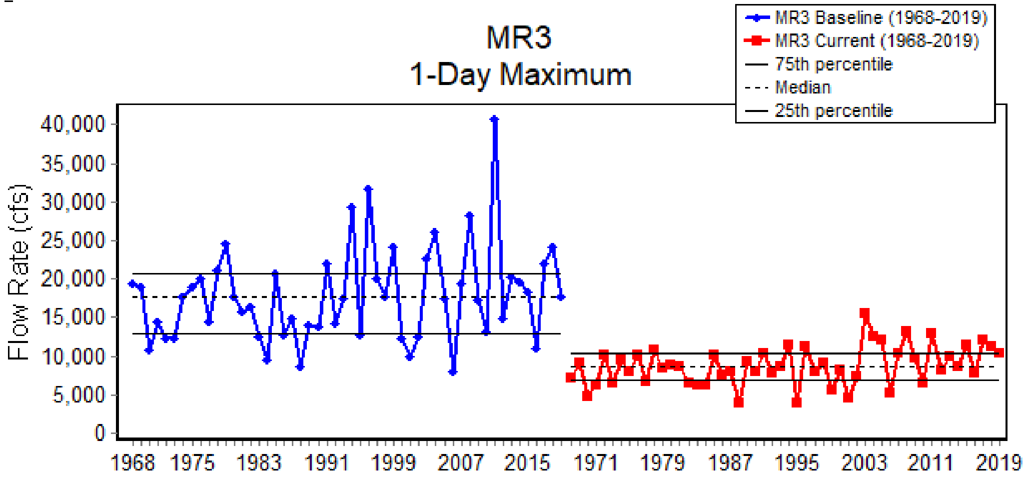

Figure 61. 1-day maximum flows at MR3.

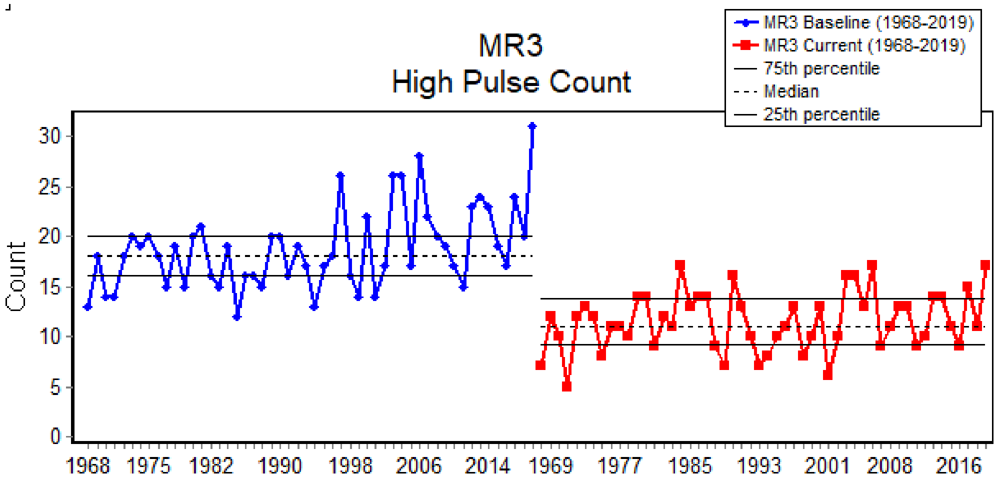

Figure 62. Annual count of high flow pulses at MR3.

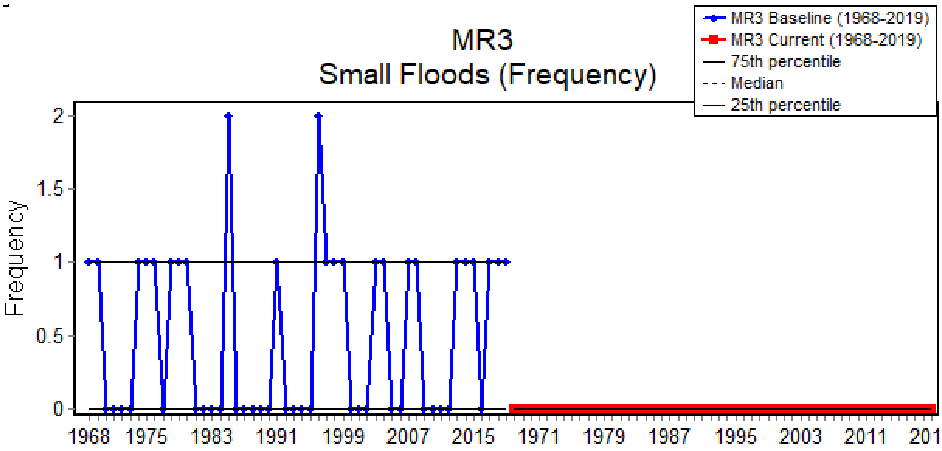

Figure 63. Frequency of small floods (flows greater than or equal to 2-year event and less than a 10-year event, as calculated from baseline data in IHA) at MR3.

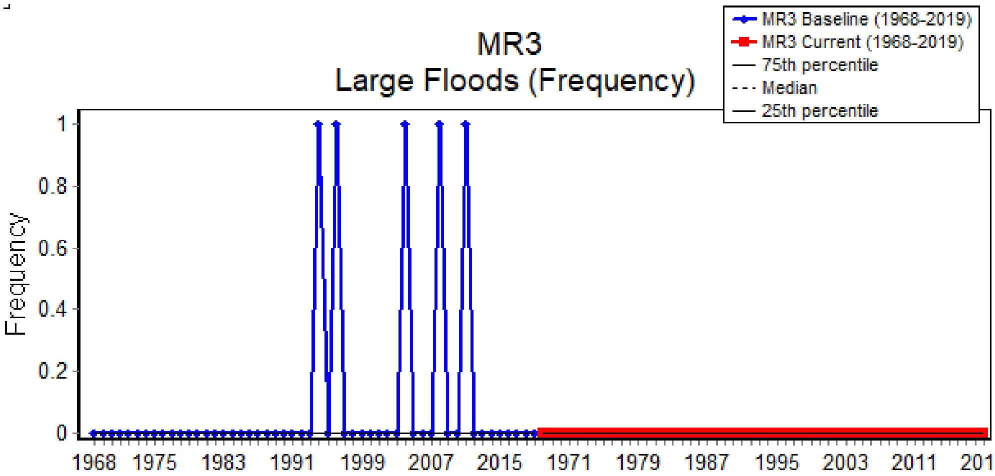

Figure 64. Frequency of large floods (greater than a 10-year event, as calculated from baseline data) at MR3.

Alteration of Low and High Flow Events

- Minimum flows of all durations increased and short duration high flows are reduced under current operations (Figure 65).

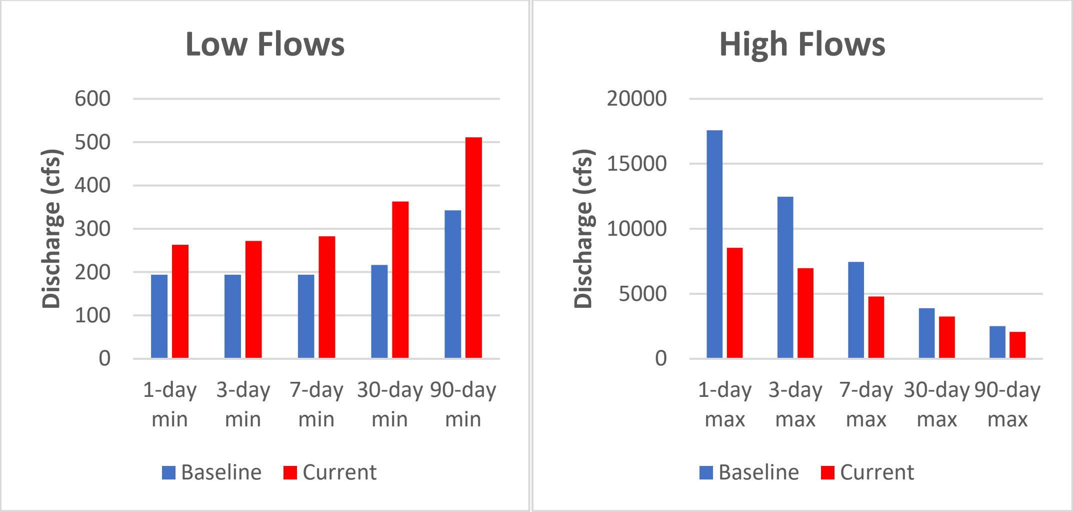

Figure 65. Alteration of high and low flow events of varying duration at MR3.

Summary of Flow Alteration for MR4

Seasonality

- Under current operations, the median monthly flows are at least 2 times higher from July through September than the baseline conditions (Figure 66). February through April median monthly flows in current conditions are within 10% of baseline median monthly flows.

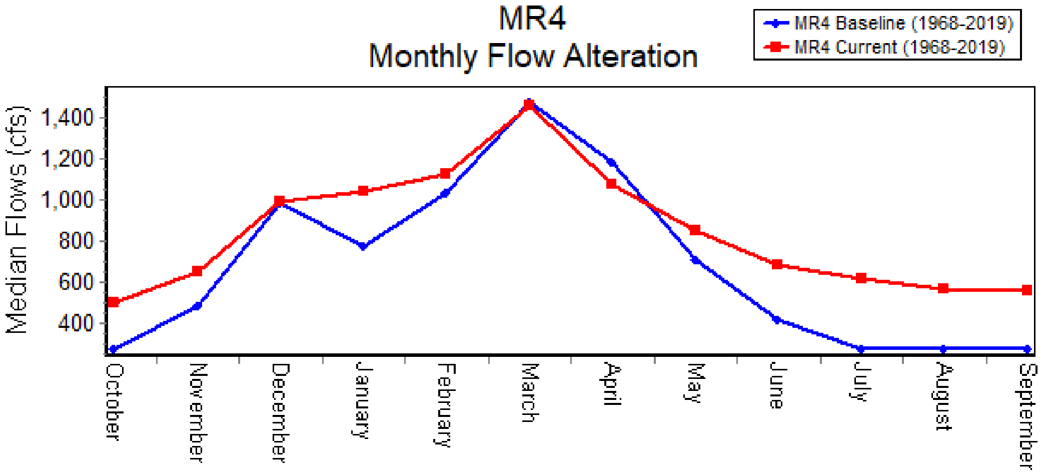

Figure 66. Seasonal flow alteration illustrated by baseline and current monthly median flows for MR4.

FALL (MR4)

- The lower range of variability (25th percentile) for current fall median flow – represented by October median flow – is approximately equal to the higher range of variability (75th percentile) for the baseline fall median flow (Figure 67).
- The fall median monthly flow is current conditions is almost two times the fall median monthly flow in baseline conditions.

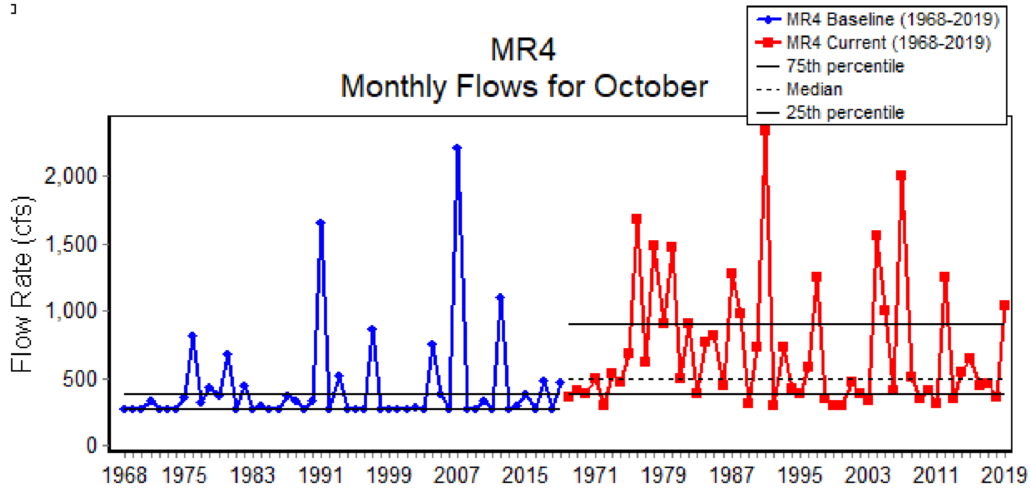

Figure 67. Alteration of median October flows at MR4.

WINTER (MR4)

- The winter median flow – represented by December median flow – for baseline and current conditions is approximately equivalent (Figure 68).

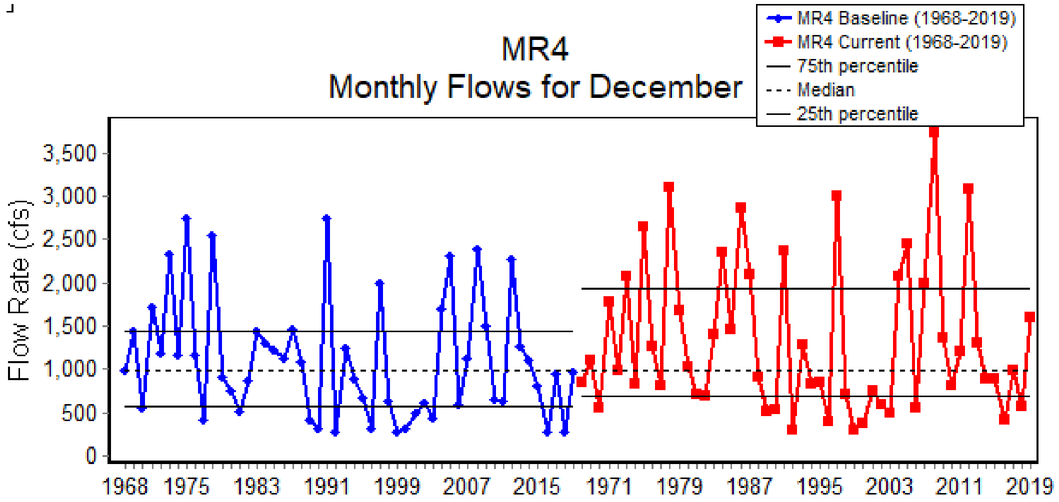

Figure 68. Alteration of median December flows at MR4.

SPRING (MR4)

- Under current conditions, the median spring flow – as represented by April median flow – is similar (approximately 10 percent lower) to the baseline median spring flow (Figure 69).

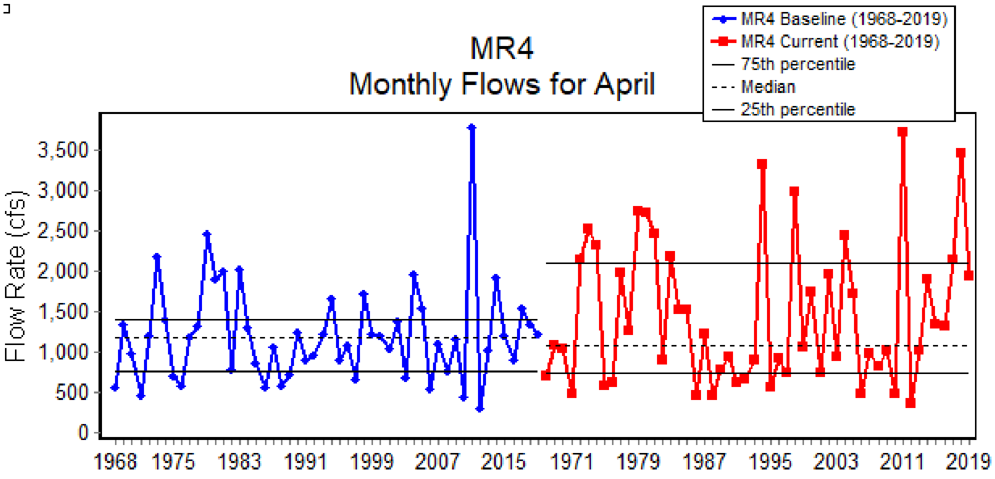

Figure 69. Alteration of median April flows at MR4.

SUMMER (MR4)

- Under current conditions, the summer median flow – represented by August median flow – is more than two times higher than the baseline summer median flow (Figure 70).

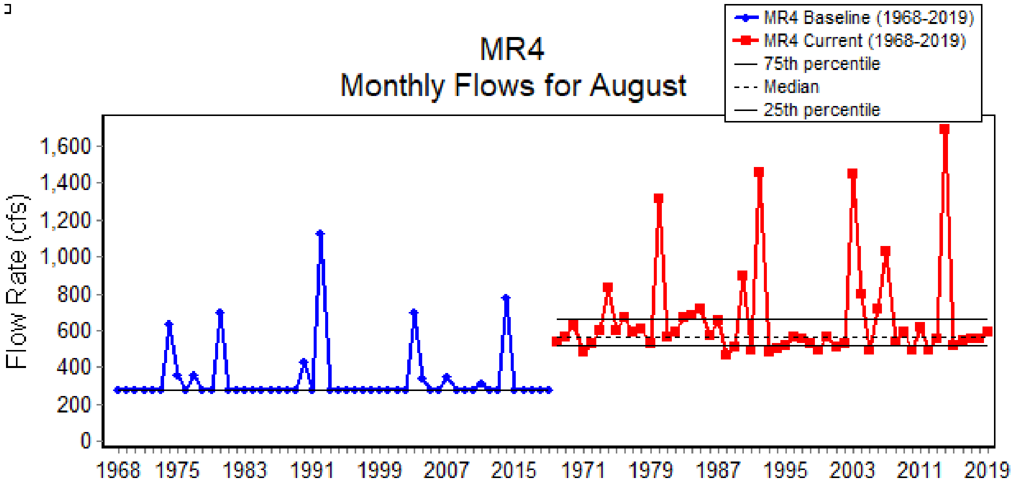

Figure 70. Alteration of median August flows at MR4.

Low Flow Events

- Minimum flows – as represented by 1-day minimum flows – are higher in current conditions compared to baseline conditions (Figure 71). (Note that minimum baseline flows are constant overtime because negative values were set to the low flow threshold, equivalent to a 10-year, 1-day low flow.)

- Extreme low flow events, as defined using the baseline dataset in IHA, are much less prevalent in current operations as compared to baseline conditions (Figure 72).

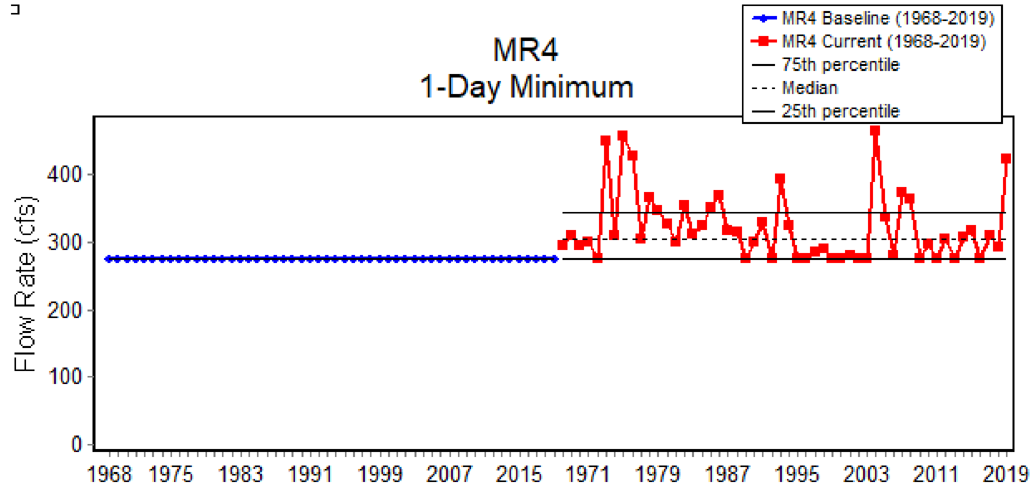

Figure 71. 1-day minimum flows at MR4.

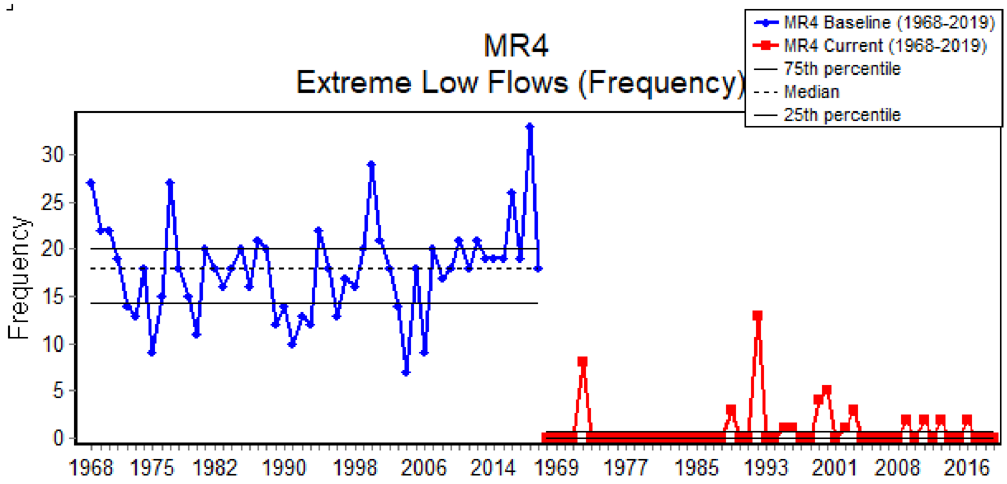

Figure 72. Frequency of extreme low flow events at MR4.

High Flow Events

- Under current conditions, maximum flows – as represented by 1-day maximum flows – are approximately half of the baseline conditions (Figure 73).
- The number of high flow pulses has reduced under current conditions (Figure 74).
- Under current conditions, there are no small or large floods, as defined using baseline flow data, at MR3 (Figures 75 and 76).

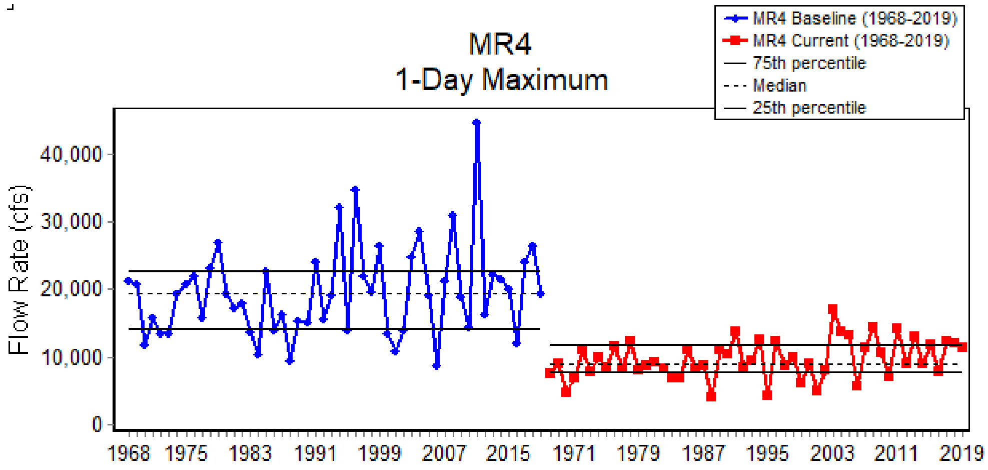

Figure 73. 1-day maximum flows at MR4.

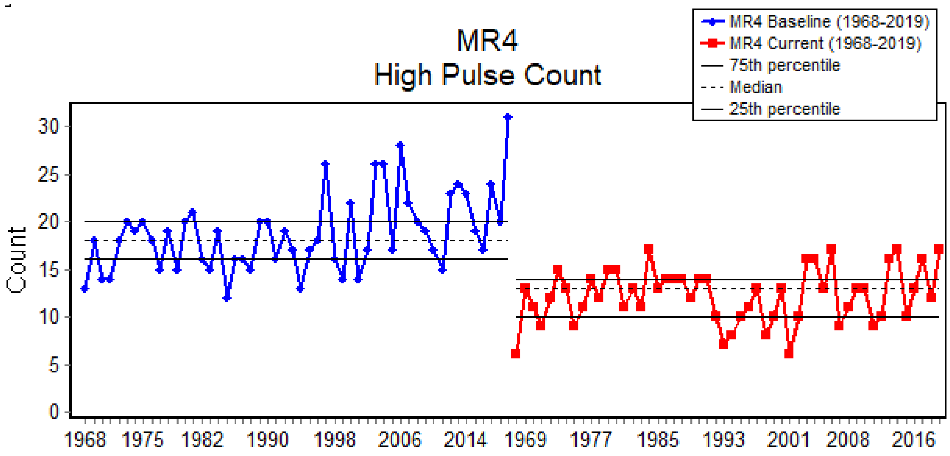

Figure 74. Annual count of high flow pulses at MR4.

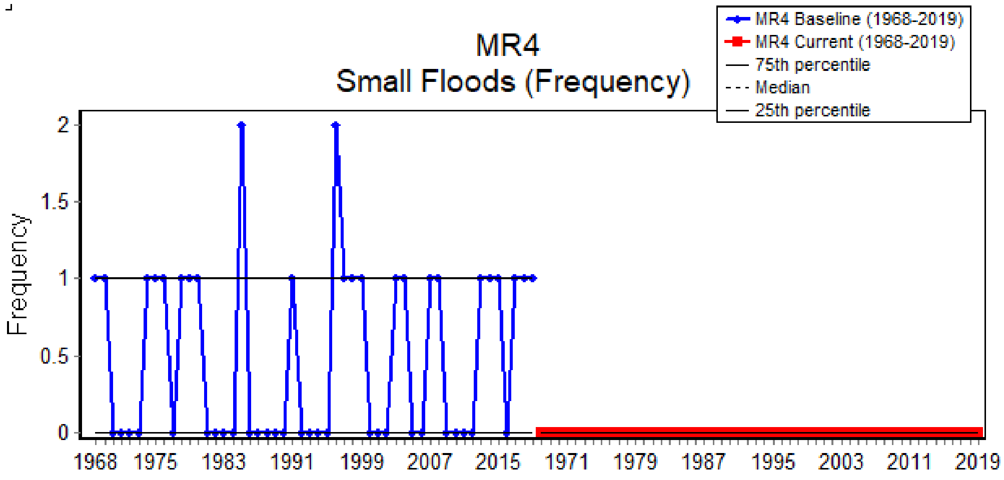

Figure 75. Frequency of small floods (flows greater than or equal to 2-year event and less than a 10-year event, as calculated from baseline data in IHA) at MR4.

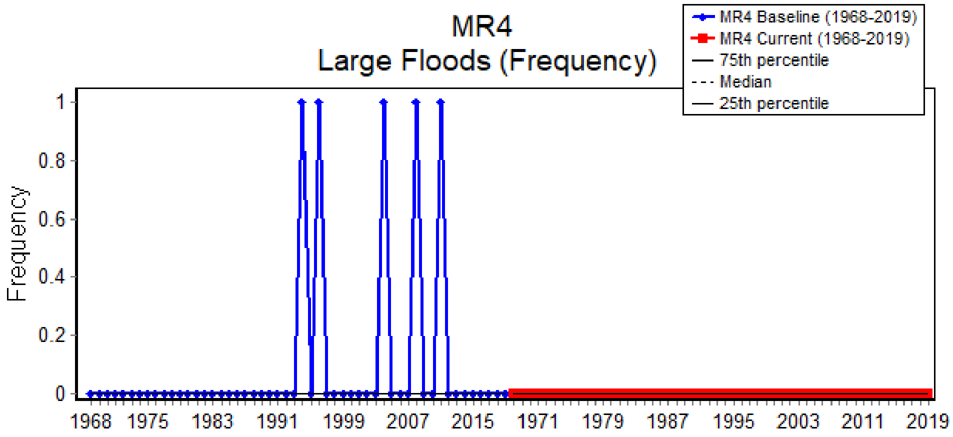

Figure 76. Frequency of large floods (greater than a 10-year event, as calculated from baseline data) at MR4.

Alteration of Low and High Flow Events

- Minimum flows of all durations increased and short duration high flows are reduced under current operations (Figure 77).

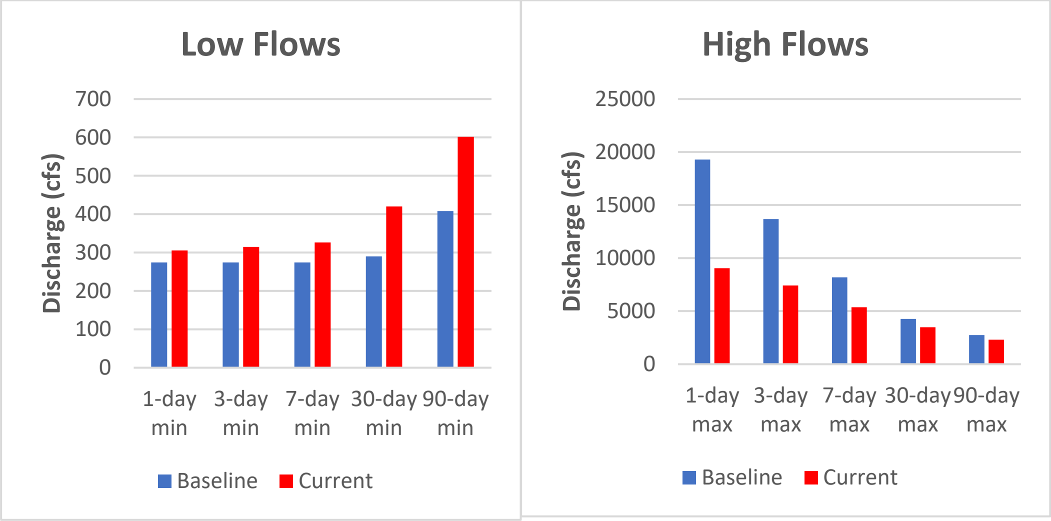

Figure 77. Alteration of high and low flow events of varying duration at MR4.

Summary of Primary HA Factor for All Reaches

The RVA target range for each hydrologic parameter is based upon the selected percentile level for the baseline flow regime, and the management objective is to have the current river attain the targeted range at the same frequency as occurred in the baseline regime. The degree to which the RVA target range is not attained is a measure of hydrologic alteration (HA). Based on the HA factors calculated in the IHA software, Figure 78 illustrates the relative degree of hydrologic alteration (low, medium, or high category) of seasonal flows. Most notably, the seasons of fall (as represented by October) and summer (as represented by August) have large, positive HA factors in the high RVA category, meaning that high flows, relative to baseline, are more common under current conditions as compared to baseline conditions. Furthermore, less observed than expected flows in the low to medium RVA categories occur during the fall and summer. There are more observed than expected events in low RVA category and less observed than expected events in middle RVA category during spring (as represented by April) and winter (as represented by December). However, these effects tend to diminish further downstream of the reservoirs (ie for study reaches MR2, MR3, and MR4).

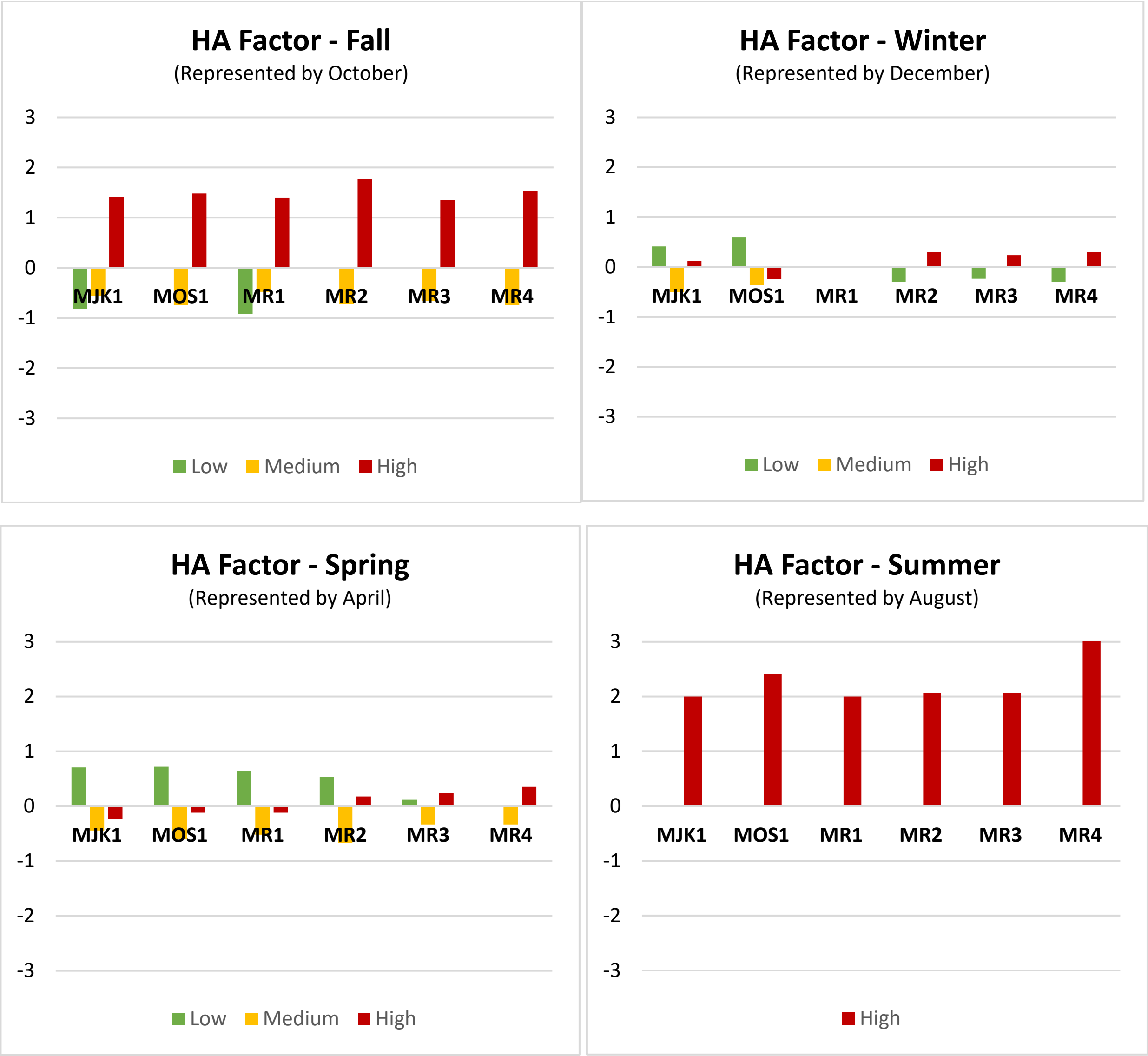

Figure 78. Seasonal Hydrologic Alteration (HA) factors as calculated for each RVA category (low, medium, high) for the six study reaches. [Notes: 1) HA Factor = (Observed Frequency – Expected Frequency) / Expected Frequency; 2) A positive HA factor means that the frequency of values in the category has increased in the baseline period to current period, while a negative HA factor means that the frequency of values in the category has decreased in the current period.; and 3) RVA category not shown for specific reach if observed and/or expected number of events was zero in the IHA calculations.]

Section 4. Potential Hydrologic Alteration due to a Changing Climate

The Time Series Toolbox (TST) was used to qualitatively assess potential hydrologic alterations to flow in the Mahoning River as a result of a changing climate. The TST is a web-based analytical tool developed by USACE that blends time series analysis and nonstationarity detection. The baseline datasets previously developed for the six study reaches were used as input to the tool, removing the impacts on hydrology from upstream regulation.

A time series analysis was performed on the baseline datasets to determine whether statistically significant trends in the flows are present. Two slopes are calculated for the trend analysis, a transitional slope (least squares regression) and Sen's Slope, which is a more robust, nonparametric estimate of slope for data that may not fit a straight line or is sensitive to outliers. MR1 has a negative slope while the other five reaches have positive slopes. However, for all six reaches, the trends in flow over the period of record are not statistically significant (i.e., p-value greater than 0.05) Examples of the positive and negative trend analyses in baseline flow at MJK1 and MR1, respectively, are included in Figures 79 and 80 below.

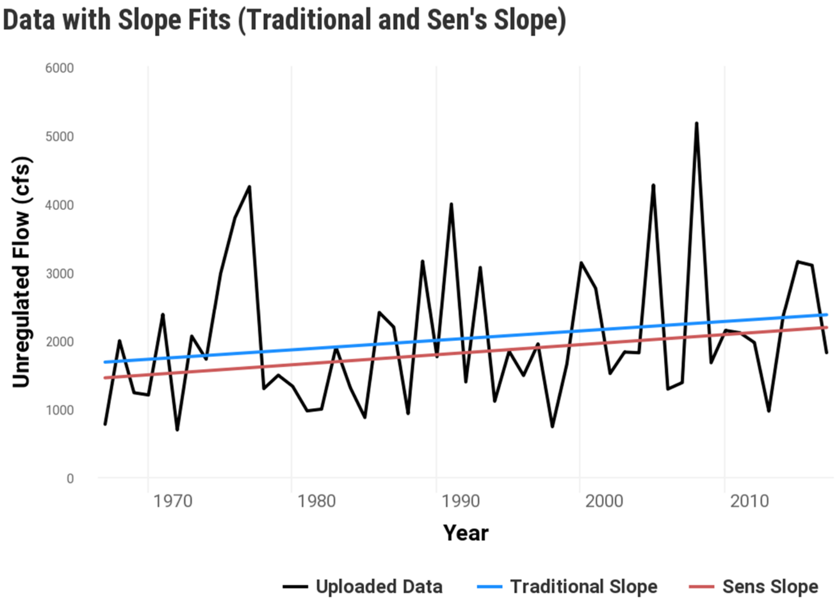

Figure 79. Positive trends in baseline flow conditions at MJK1 that are not statistically significant.

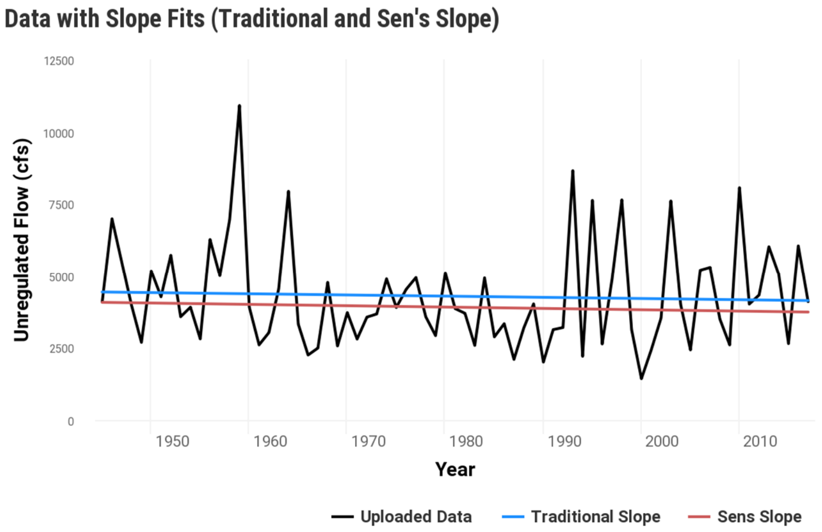

Figure 80. Negative trends in baseline flow conditions at MR1 that are not statistically significant.

Although the stationarity assumption has been foundational to climate and engineering decision-making in the past, recent scientific evidence shows that in some places, climate change and human modifications are undermining this fundamental assumption. Therefore, the TST was also used to detect the presence of nonstationarities in the baseline datasets. The TST uses statistical testing to examine the data for nonstationarities (or changes) in the mean, variance or distribution of annual maximum discharges at gages with over 30 years of record (USACE 2020).

There were no nonstationarities detected in mean, variance, or distribution of annual maximum discharges for five study reaches (MJK1, MR1, MR2, MR3, and MR4). There was one nonstationarity detected in the MOS1 baseline dataset in 1966 (Figure 81). However, only one of the statistics was identified using one method, so the nonstationarity is not considered to be strong (USACE 2020). Furthermore, no breakpoints, or points in the data that reflect sharp changes in behavior that would suggest the need for segmented analyses, were detected.

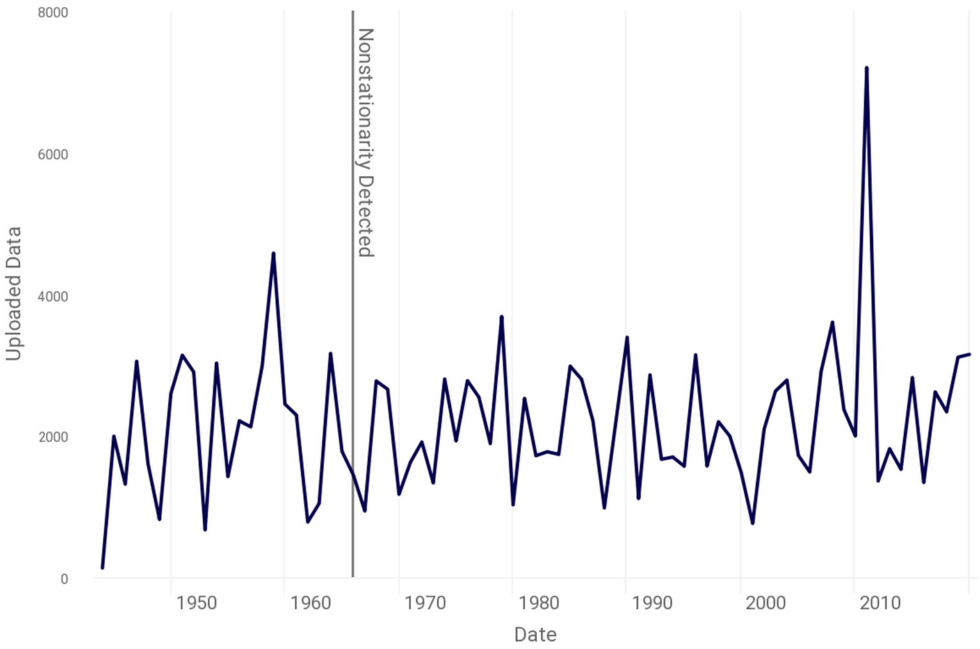

Figure 81. Nonstationarity detected in the one of the statistics using one of the methods in year 1966 at study reach MOS1.

Potential hydrologic alteration in the Mahoning River as a result of a changing climate was investigated using baseline datasets for the six study reaches as input to the TST. No statistically significant trends in annual maximum streamflow were detected. One nonstationarity was detected in one year at study reach MOS1, but because there is not consensus among multiple nonstationarity detection methods, it is not considered to be strong. Thus, there is not strong evidence based on the historical baseline datasets to suggest that a changing climate is currently altering hydrology in the Mahoning River.

Section 5. Summary of Mahoning Watershed Alteration

Hydrologic alteration in the Mahoning River basin was analyzed for six study reaches using statistical analyses in the IHA software. Baseline and current hydrological datasets were compiled for each of the study reaches, and statistics were compared to assess the degree of hydrological alteration between them. This information may be useful for understanding the impacts of human activities on water flows and recommending environmental flow criteria for long-term water management.

The trends between baseline and current hydrological datasets that were identified using the IHA software were fairly consistent across the six study reaches in the Mahoning River basin. Below is a summary of the potential alteration in seasonal, low flow, and high flow events:

- **Seasonal:** The upstream reservoirs (MJ Kirwan, Mosquito, and Berlin) primarily store water during the spring, lowering spring median flows, and release water during the summer and fall, increasing summer and fall median flows. The extreme low flows naturally present in the baseline summer months are no longer present in current conditions (see current reservoir guide curves in Appendix A). These patterns are consistent in the IHA results for the six study reaches in the Mahoning River basin.

  Fall. During the fall– as represented by October - median flows in current conditions increased in all study reaches as compared to baseline conditions. The ratio between current and baseline median monthly flows was largest for study reach MOS1. This ratio decreases in study reaches further downstream of the reservoirs. The current fall flows are also predominantly outside of the range of variability of baseline conditions.

  Winter. Hydrologic alteration is lower in winter than in fall and summer. The winter median flow – represented by December median flow – is similar between baseline and current operations for all study reaches aside from MOS1. The current winter median flow is about 50 percent lower as compared to baseline conditions.

  Spring. Under current conditions, during the spring – represented by April - all study reaches stream reaches have median monthly flows below baseline conditions, with the most significant affects occurring directly below three the reservoirs (MJK1, MOS1, and MR1). During these months the reservoirs are filling to meet summer pool elevations.

  Summer. During the summer– as represented by August - median flows in current conditions increased on all study reaches as compared to baseline conditions. The patterns of alteration are similar to the fall months, described above.

- **High Flow Events**: The reservoirs in the Mahoning River basin operate to retain high flow pulses and floods. Therefore, as expected, maximum flows and frequency of high pulses have reduced significantly under current conditions as compared to baseline conditions. Furthermore, under current conditions, there are no small or large floods, as defined using baseline flow data in IHA for each study reach.
- **Low Flow Events:** Due to upstream regulation, minimum flows under all durations are higher in current conditions compared to baseline conditions. Similarly, the frequency of low pulses and extreme low flows, as defined using the baseline datasets, have reduced significantly in current conditions as compared to baseline conditions.

The HA factors were calculated within the IHA software for the seasonal flows. Based on these factors, it is evident that high flows, relative to baseline, under current conditions as compared to baseline conditions are more common in the fall and summer seasons. The degree of alteration is reduced in the spring and winter seasons (i.e. there are more observed than expected events in the low RVA category and less observed than expected events in the middle RVA category), and the magnitude of the HA factor tends to diminish further downstream.

Potential hydrologic alteration in the Mahoning River basin from a changing climate was also investigated using the TST. No statistically significant trends in annual maximum streamflows were detected. One nonstationarity was detected in one year at study reach MOS1, but because there is not consensus among multiple nonstationarity detection methods, it is not considered to be strong. Thus, there is not strong evidence based on the historical baseline datasets to suggest that a changing climate is currently altering hydrology in the Mahoning River.

Section 6. Additional Considerations

This limited assessment of alteration in the Mahoning River basin is based solely on hydrologic data. In order to follow the approach of the Ecologically Sustainable Water Management (ESWM) framework used previously for other rivers within the Upper Ohio River basin, ecosystem flow requirements need to also be quantified to identify areas of potential incompatibility. Estimating ecosystem flow requirements in the ESWM framework requires information about 1) which flow-sensitive species are present and 2) how they might respond to changes in streamflow (TNC 2015).

Initial assessment of hydrologic alteration was performed using the RVA in the IHA software. This can be improved upon following steps performed for other studies in the Ohio River watershed. Specifically, flow alteration in each reach can be compared to the Ohio basin Ecosystem Flow Recommendations for tributaries and large rivers in order to identify whether the alteration is within the recommended limits for that stream type (TNC 2015).

After performing additional analyses to better understand the degree of hydrologic alteration on each reach with the potentially affected ecological resources, conservation or restoration opportunities, such as the development of reservoir-specific flow prescriptions, can be identified for priority reaches.

Section 7. References

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Section 8. Appendix A: Guide Curves for Mahoning Basin Reservoirs (Figures 82-84)

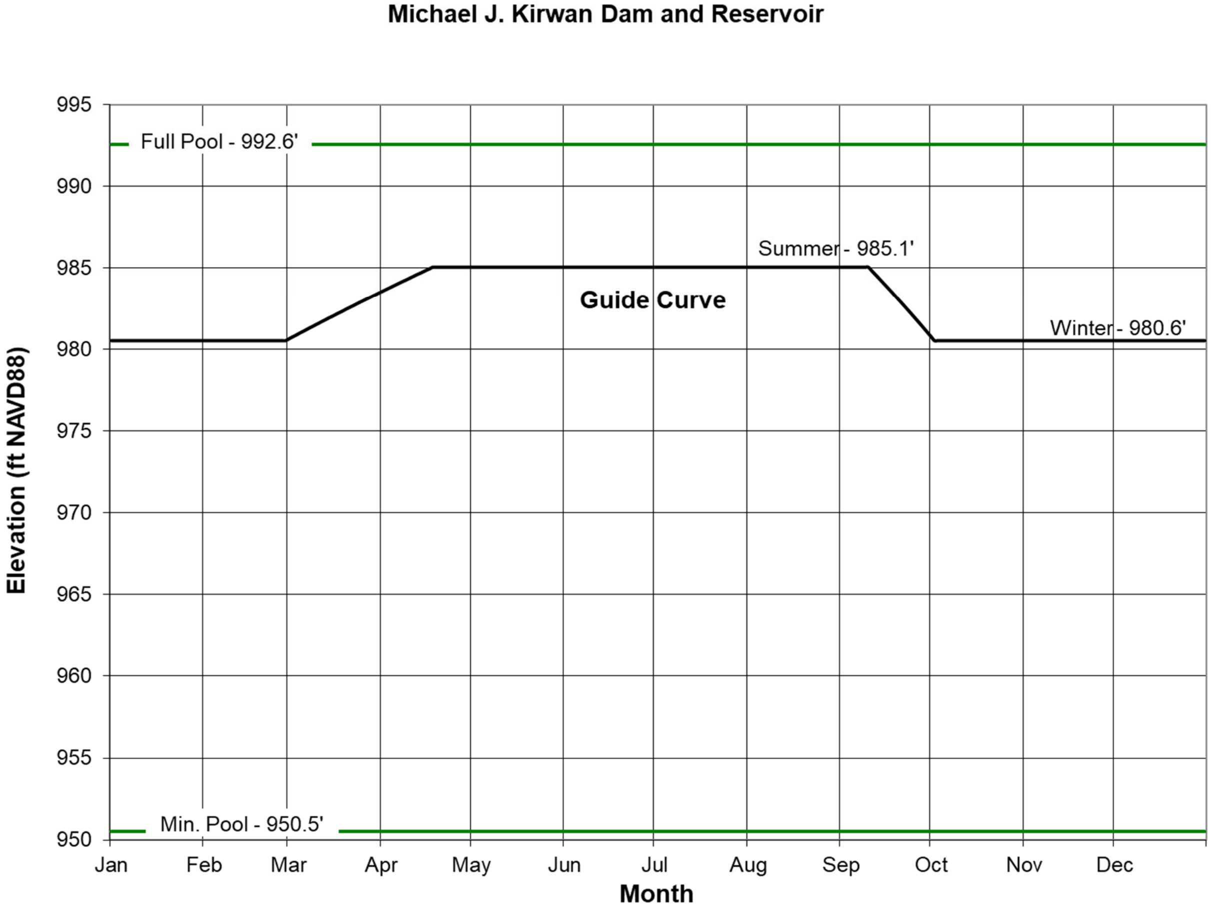

Figure 82. Guide curve for MJ Kirwan Reservoir based on existing Water Control Manual

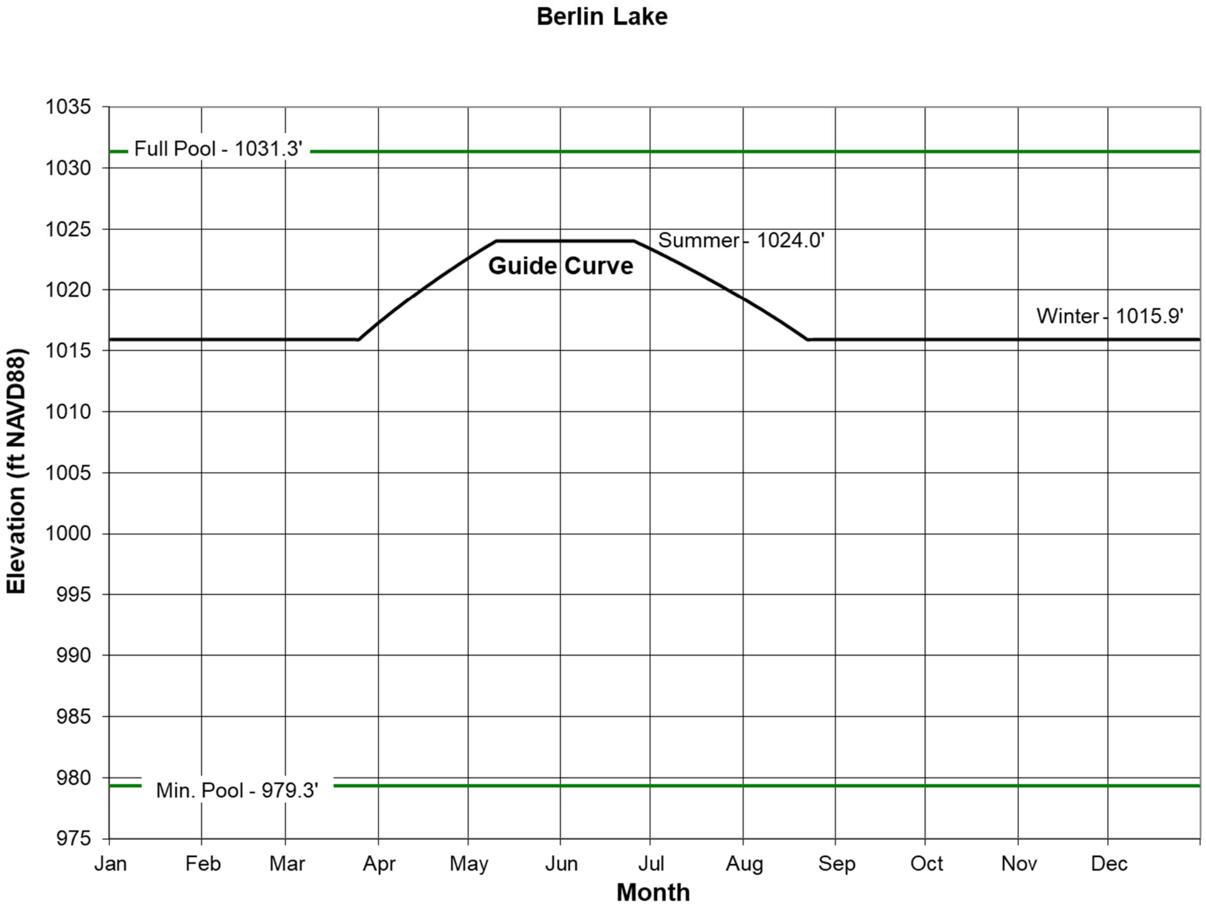

Figure 83. Guide curve for Berlin Reservoir based on existing Water Control Manual

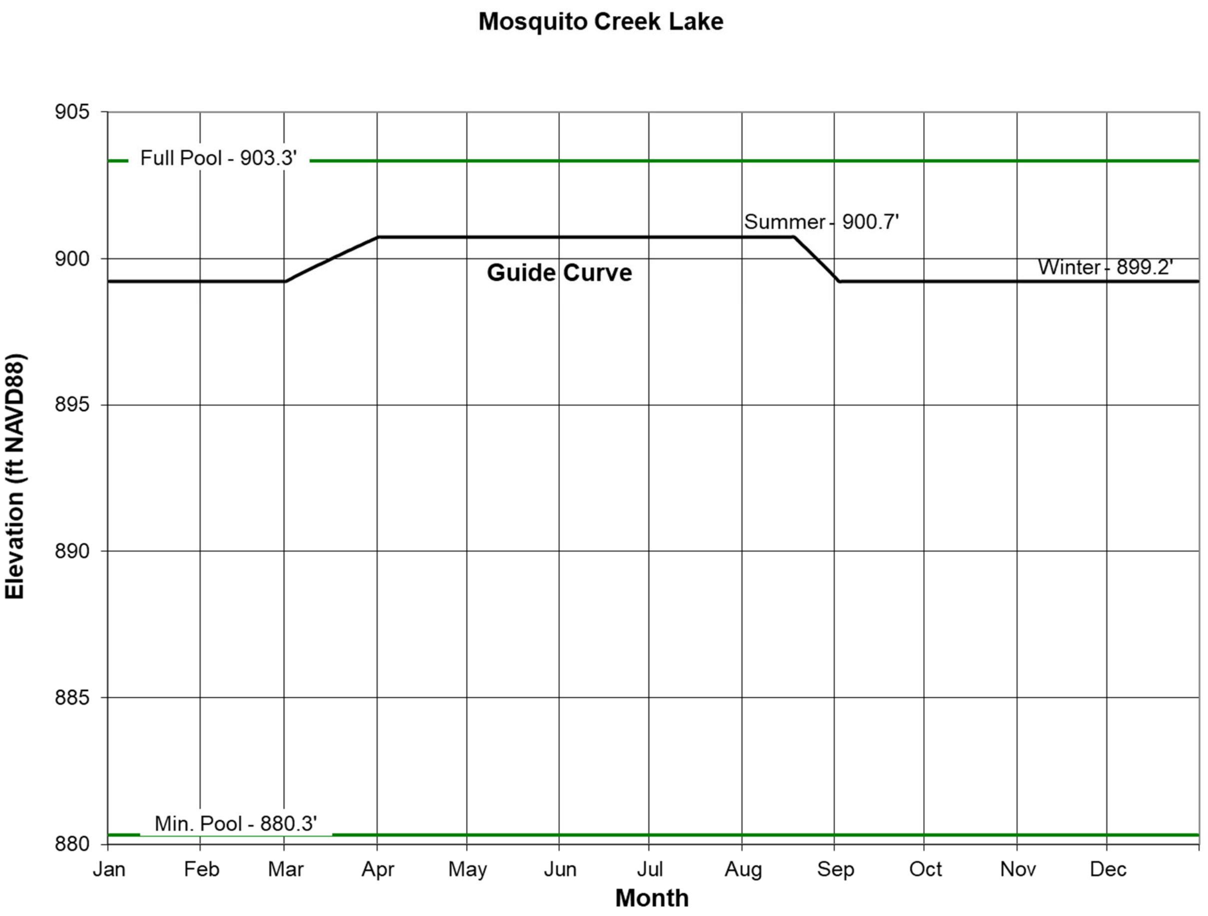

Figure 84. Guide curve for Mosquito Creek Reservoir based on existing Water Control Manual