Technical Memo

Illinois River Watershed Total Phosphorus Criterion Revision Critical Condition: Hydrograph Separation Analysis

DRAFT

DRAFT
September 10, 2020

Table of Contents

DRAFT

Introduction

The Second Statement of Joint Principles and Actions between Arkansas and Oklahoma Environmental Agencies was signed in February 2013. Under this agreement the states completed the Joint Phosphorus Criteria Study (Joint Study) managed by the Joint Study Committee. The committee was composed of six members, three from each state. The Joint Study was conducted from 2014 through 2016 and culminated in a Final Report submitted to both state governors on December 19, 2016. The key task of the Joint Study Committee was to make a recommendation regarding *"… what phosphorus levels, and what frequency and duration components of measure, are necessary to protect the aesthetics beneficial use and scenic river (Outstanding Resource Water) designations…"* To that end, the Joint Study Committee made the following recommendation in the Final Report (Joint Study Committee and Scientific Professional, 2016).

> *"A six-month average total phosphorus level of not to exceed 0.035 mg/L based on water samples taken during the critical condition, as previously defined…"*

The Joint Study Committee defined the term critical condition as *"the conditions where surface runoff is not the dominant influence of total flow and stream ecosystem processes."*

The critical condition term introduced by the Joint Study Committee is a new term for Oklahoma Water Quality Standards (WQS) and has a narrow application to WQS implementation. The term instructs which water quality sample results should be utilized to evaluate the total phosphorus (TP) criterion for the purposes of water quality assessment. A technical analysis was needed to translate the committee critical condition terminology into an operational definition that could be feasibly and consistently implemented by water quality management programs across multiple agencies in both states. Moreover, the technical analysis evaluated the impact of the new critical condition term on how total phosphorus water quality conditions would be characterized within the waterbody.

The Joint Study Committee critical condition definition speaks to two endpoints 1) total flow and 2) stream ecosystem processes; therefore, independent analyses were conducted to address each endpoint. This technical memo presents an analysis conducted by OWRB staff, in consultation with Oklahoma sister environmental agencies[1], the Cherokee Nation, and Arkansas Division of Environmental Quality, to evaluate the critical condition definition endpoint of total flow.

Environmental Setting

The Illinois River watershed (Hydrologic Unit Code 11110103) (Figure 1) is located in northeastern Oklahoma and northwestern Arkansas and spans the political boundary between the two states. The watershed area is about 1,654 square miles. The mainstem of the Illinois River originates in the Boston Mountains in Washington County Arkansas. The river flows north

[1] Sister environmental agencies includes the OK Department of Environmental Quality, OK Conservation Commission, OK Department of Agriculture Food & Forestry, OK Department of Wildlife Conservation

for approximately 36 miles and turns westward at the confluence with Osage Creek; from here it flows west into Oklahoma. Flint Creek is a major tributary to the Illinois River. Flint Creek drains 127 square miles in the northwest portion of the watershed and has its confluence with the Illinois River just south of the Oklahoma state highway 59. Below this confluence the Illinois River flows southwest past the city of Tahlequah to Tenkiller Ferry Reservoir (Lake Tenkiller). Barren Fork Creek is another major tributary that has a confluence with the Illinois River just before it enters Lake Tenkiller. Barren Fork Creek drains 346 square miles in the central area of the watershed. Below the Lake Tenkiller dam the Illinois River flows 9.5 miles to its confluence with the Arkansas River.

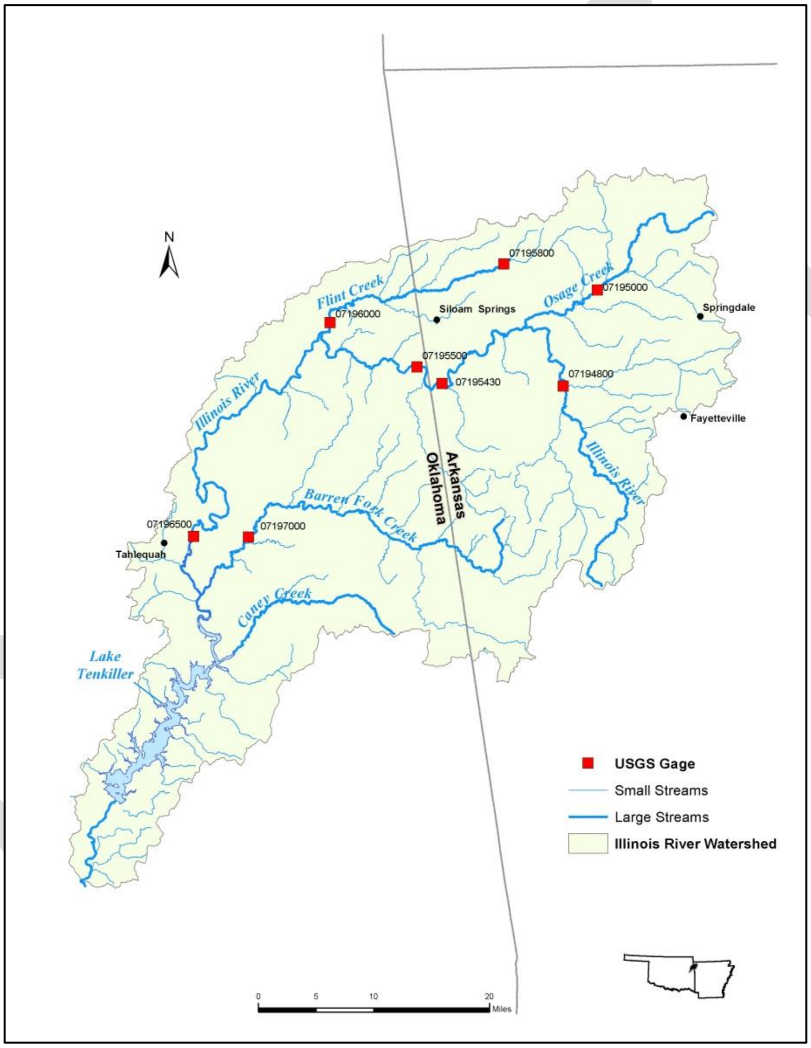


Figure 1. Illinois River Watershed map w ith USGS stream gages.

There are a number of United States Geological Service (USGS) gages in the Illinois River watershed; those listed in Table 1 were used in this analysis (Lewis et al., 2009 and Granato et al., 2017).

Table 1. USGS Stream gages relied upon

Location Name	Gage Station Number	Flow Record Used in this Analysis		Tributary Area (mi^2)	Average Daily Streamflow (cfs)	Daily Flow Years
Osage Creek near Elm Springs, AR	07195000	Jan. 2008	Dec.2018	130	123	34
Illinois River at Savoy, AR	07194800	Jan. 2008	Dec.2018	167	145	12
Illinois River at South of Siloam Springs, AR	07195430	Jan. 2008	Dec.2018	575	573	9
Illinois River near Watts, OK	07195500	Jan. 2008	Dec.2018	630	621	52
Flint Creek near Kansas, OK	07196000	Jan. 2008	Dec.2018	116	116	50
Illinois River near Tahlequah, OK	07196500	Jan. 2008	Dec.2018	950	929	72
Barren Fork at Eldon, OK	07197000	Jan. 2008	Dec.2018	312	325	59

Based on the 2016 National Land Cover Database, forty-one percent of the land use in the Illinois River watershed is classified as deciduous forest and almost forty percent is hay and pasture (Table 2, Figure 2). These two land uses alone dominate the watershed landscape. Developed areas (open space, low, medium, and high intensity) only account for about 10 percent of the watershed. The remaining ten percent of the watershed is mostly open water and grass/shrub/forest areas.

Table 2. NLDC Land Use for 2016

Land Use Class	Area (square miles)	Percentage (%)
Deciduous Forest	678.3	41.0
Hay/Pasture	655.7	39.7
Developed, Open Space	91.4	5.5
Mixed Forest	66.7	4.0
Developed, Low Intensity	46.0	2.8
Open Water	26.9	1.6
Developed, Medium Intensity	24.4	1.5
Shrub/Scrub	17.7	1.1
Herbaceous	16.7	1.0
Evergreen Forest	9.9	0.6
Developed, High Intensity	9.4	0.6
Woody Wetlands	6.5	0.4
Cultivated Crops	1.9	0.1
Barren Land	1.7	0.1
Emergent Herbaceous Wetlands	0.5	0.03
Total of classes	**1653.8**	**100.0**

DRAFT

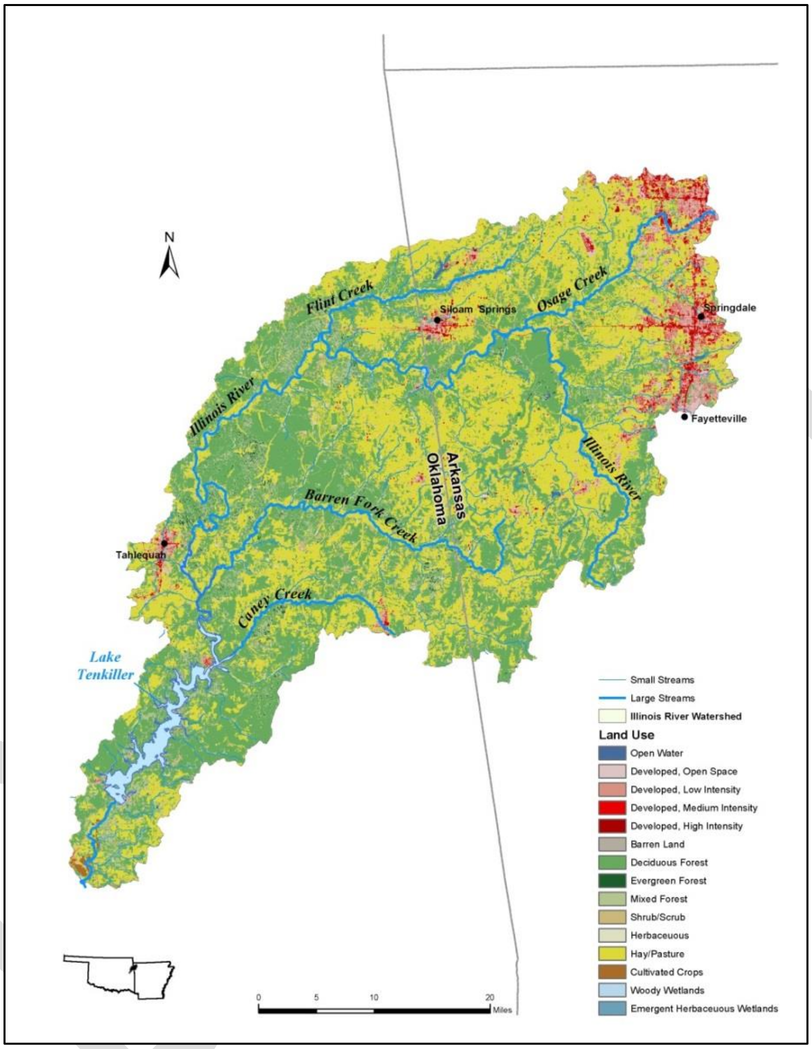


Figure 2. NLDC Land Use for 2016

Streamflow Characterization

A hydrograph is a graph of streamflow or discharge over time, typically with the units of cubic feet per second (cfs). Figure 3 presents a hydrograph for the Illinois River at Tahlequah. Streamflow is composed of a combination of baseflow (return flow from groundwater), interflow (rapid subsurface flow), and overland flow (surface flow over poorly permeable or temporarily saturated soils). Together interflow and overland flow are known as quickflow or direct runoff, which is the rapid runoff of "*new*" water into the stream channel during a rain event. Baseflow typically reaches the stream through a longer flow path and sustains streamflow during periods without rain. Baseflow can be dynamic and influenced by seasonal factors.

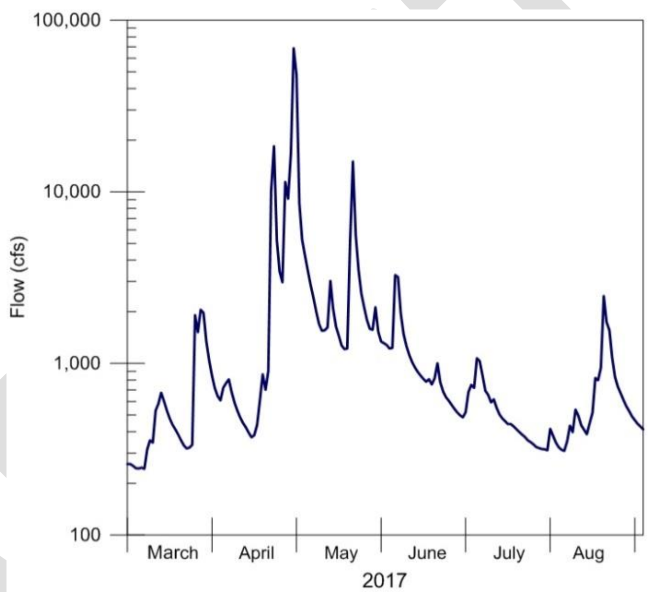


Figure 3. Hydrograph: Illinois River at Tahlequah March - August 2017

Hydrograph Separation Methods

Hydrograph separation is a procedure that partitions the hydrograph into two key component flows, baseflow and direct runoff. Figure 4 is again the hydrograph for the Illinois River at Tahlequah, but the total hydrograph has been separated to show the portion that is baseflow.

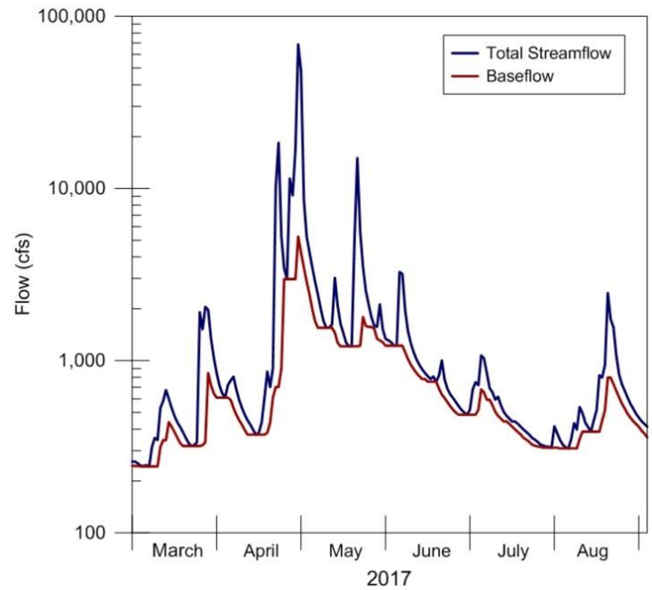


Figure 4. Illinois River at Tahlequah, hydrograph of total streamflow and baseflow (March- August 2017); baseflow according to HYSEP Sliding-Interval method.

Hydrograph separation is a tool that has long been used by Hydrologist in an effort to identify and understand the components of streamflow and runoff generation processes (i.e. source areas, pathways, retention times) (Gonzales et al., 2009). An estimation of baseflow versus direct runoff is useful to understand overall watershed hydrology, such as flood and low flow conditions and groundwater surface water interactions. Hydrograph separation methods can be divided into two major approaches 1) tracer-based methods and 2) non-tracer-based methods. Tracer-based methods employ various chemicophysical signatures of water and physical processes to differentiate the contributions of baseflow and direct runoff to total flow. Tracer-based methods will not be discussed further in this document. Non-tracer-based methods include graphical hydrograph separation methods. These methods use the hydrograph itself as a signal and utilize time as a function with the assumption that the time of a direct runoff event is much shorter than that of groundwater discharge and this time is relatively constant across rain events (Pelletier, 2019). Three USGS graphical hydrograph separation methods and one alternative method (McCarty and Haggard, 2016), termed here as the Delta 10% method were considered as part of this project.

- HySEP Local Minimum
- HySEP Sliding-interval
- PART
- Delta 10%

These methods separate a streamflow hydrograph based on a mathematical technique and the USGS Groundwater Toolbox (Barlow et al., 2015) computer program was used to ensure consistency and efficiency. The Delta 10% method was conducted in Microsoft Excel. However, it is important to note that even though the methods are formal algorithms for identifying baseflow versus total streamflow the methods are subjective and not based on physical processes as used in tracer-based methods. Listed below are several underlying assumptions applicable to these methods.

- Flow systems are driven by diffuse areal recharge uniformly disturbed over a watershed
- Single point of outflow from the basin at the gauging station of interest
- All groundwater in the basin discharges to the stream, except that lost by evapotranspiration
- Streamflow hydrograph represents water contributions from two sources: surface runoff and groundwater discharge from a single aquifer
- Groundwater and surface water drainage areas are coincident
- Regulation or diversion of flow should be minimal and groundwater pumping minimal
- Several years of record should be analyzed

The three USGS methods and the Delta 10% method are described below. A calculation of duration of surface runoff is foundational to all three USGS methods. The duration of surface runoff is calculated using the following empirical relationship.

$$N=A^{0.2}$$

N is the number of days after which surface runoff ends and A is the watershed area in square miles (Lindsley et al., 1975 and Sloto and Michele, 1996).

HYSEP Sliding-interval

The USGS HYSEP hydrograph separation methods utilize an interval of days (2N*) defined as the odd integer between 3 and 11 nearest to 2N. In the sliding-interval method, baseflow is assigned as the lowest daily discharge that occurs within the interval [0.5(2N*-1) days] before the day of interest and after the day of interest. Using Barren Fork Creek as an example, if the day of interest is May 4, 2017, the method looks back 3 days and forward 3 days to identify the lowest daily discharge and assigns that discharge to May 4th as the baseflow (Table 3). In this example the baseflow value of 511 cfs was assigned to May 4, 2017. Figure 5 shows the hydrograph of total flow and baseflow for May 2017 using the HYSEP sliding-interval method.

Table 3. Example determining baseflow value according to HYSEP Sliding-interval method

Day of Interest: May 4, 2017	
Watershed Area: 307 square miles	
Interval: 3 days	
Date	Total Streamflow (cfs)
May 1, 2017	2430
May 2, 2017	1690
May 3, 2017	1190
May 4, 2017	894
May 5, 2017	725
May 6, 2017	601
May 7, 2017	511
Baseflow assigned to May 4, 2017	511

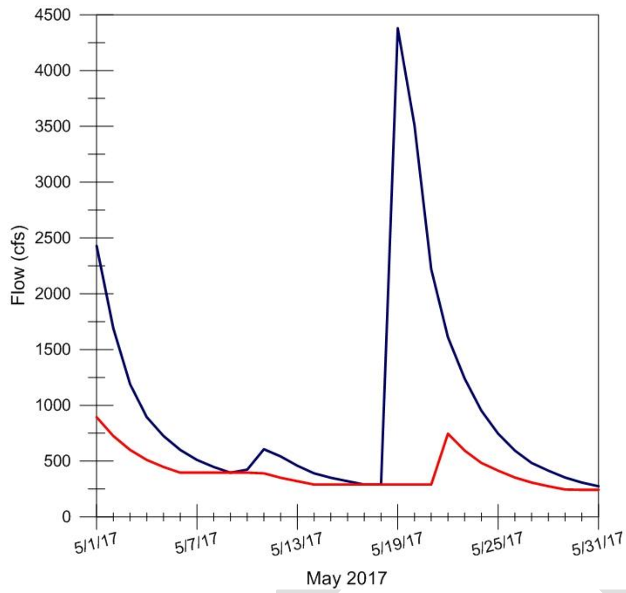


Figure 5. Barren Fork at Eldon, separated hydrograph (streamflow and baseflow) according to HYSEP Sliding-interval method

HYSEP Local minimum

The local minimum method evaluates each day to determine if it has the lowest discharge in the interval [0.5(2N*-1) days] before and after the given day. If it is the day with the lowest discharge in the total interval, then the day is a local minimum. Adjacent local minimums are connected with straight lines and baseflow values for days in between local minimums are estimated by interpolation (Table 4, and Figure 6).

Table 4. Example determining baseflow value according to HYSEP Local minimum method

Watershed Area: 307 square miles	
Interval: 3 days	
Date	Total Streamflow (cfs)
May 6, 2017	601
May 7, 2017	511
May 8, 2017	448
May 9, 2017	397 (local minimum)
May 10, 2017	424
May 11, 2017	607
May 12, 2017	542
May 13, 2017	459
May 14, 2017	391
May 15, 2017	351
May 16,2017	320
May 17, 2017	290 (local minimum)
May 18, 2017	290
May 19, 2017	4380

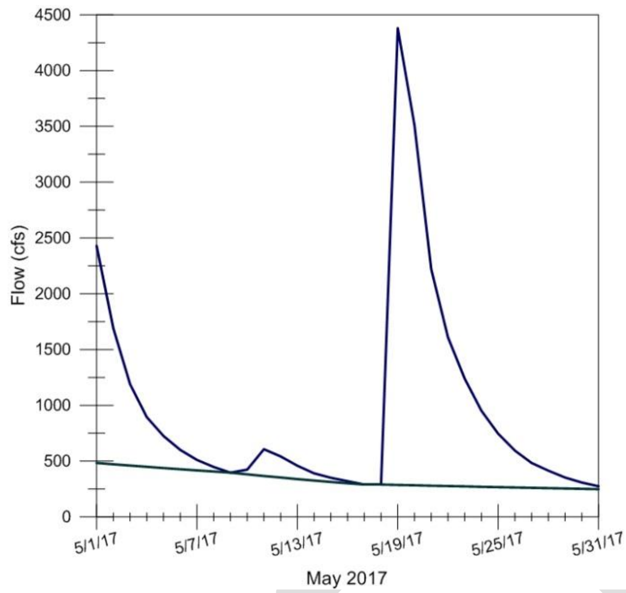


Figure 6. Barren Fork at Eldon, separated hydrograph (streamflow and baseflow) according to HYSEP Local minimum method

PART

The USGS program PART for hydrograph separation is based on antecedent streamflow recession (Barlow et al., 2015) The analysis evaluates if streamflow on N interval of days is greater than or equal to streamflow on the next day within the interval; if this is true baseflow is set equal to streamflow for the day of interest. Linear interpolation is used to assign the baseflow value for the remaining days that did not meet the antecedent recession requirement.

Table 5. Example determining baseflow value according to PART method

Day of Interest: May 9, 2017	
Watershed Area: 307 square miles	
Interval: 3 days	
Date	Total Streamflow (cfs)
May 6, 2017	601
May 7, 2017	511
May 8, 2017	448
May 9, 2017	397 (baseflow)

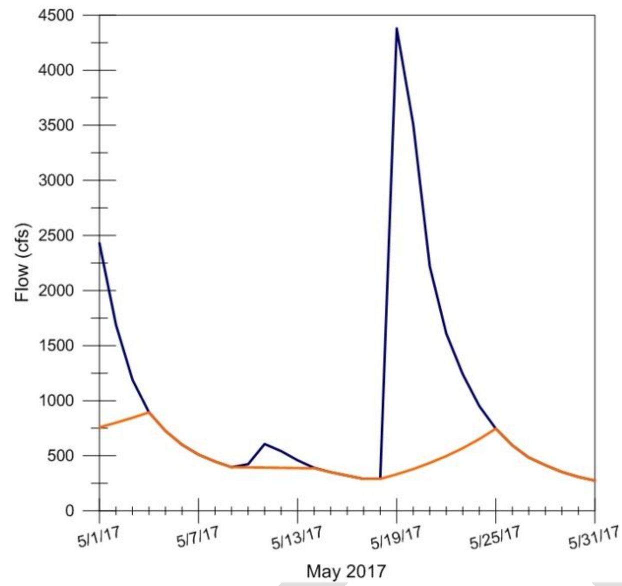


Figure 7. Barren Fork at Eldon, separated hydrograph (streamflow and baseflow) according to PART method

Figure 8 presents the comparison of all three USGS methods for Barren Fork Creek May 2017.

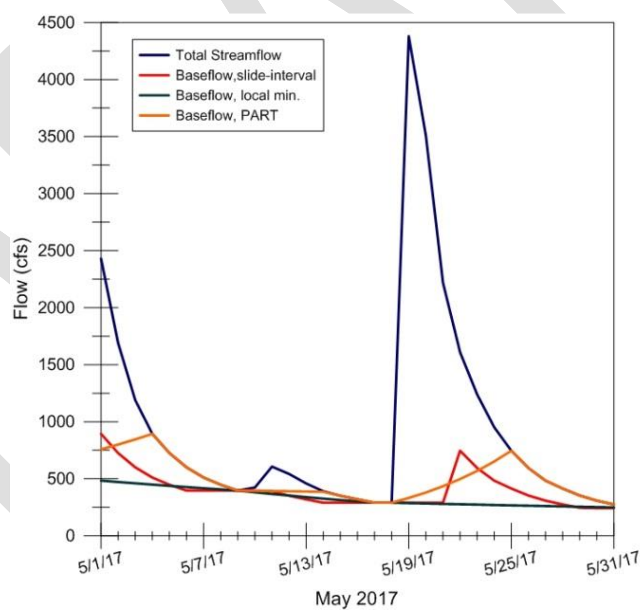


Figure 8. Barren Fork at Eldon, separated hydrograph (streamflow and baseflow) comparison of HYSEP sliding-interval, local minimum, and PART methods

Delta 10%

The final method considered in the analyses is not a hydrograph separation method, but a decision criteria approach to determine if flow conditions on the day of interest are representative of baseflow. This method was based on the approach described by McCarty and Haggard (2016) in a previous analysis in the Illinois River watershed. The Delta 10% method combined two metrics 1) a 48-hour antecedent rainfall benchmark of less than 0.01 inches and 2) a change in daily average flow of less than or equal to ± 10%. When both of these two metrics were met total flow on the day of interest was considered unaffected by direct runoff from a storm event.

Hydrograph Separation Analyses & Results

The critical condition term is defined as the condition when *"surface runoff is not the dominant influence of total flow*"; thus, a simple analysis was designed to evaluate when direct runoff (i.e. surface runoff) is *not* the dominant component of total flow. Direct runoff is not dominant when baseflow is dominant; this was interpreted as when baseflow is greater than 50% of the total flow. Increasing percentages of baseflow above 50% were considered to evaluate how a baseflow percentage threshold would impact the availability of eligible water quality sampling days and subsequently the use of associated total phosphorus data in water quality assessments. The objective of the analysis was to identify the population of days that if a sample was collected the result would qualify to assess the total phosphorus criteria.

The hydrograph separation methods described above were applied to the USGS gages in the watershed to evaluate baseflow versus direct runoff. Daily average flow from the gages listed in Table 1 were used in this analysis. The USGS program Groundwater Toolbox provides both a graphical and mapping interface for the analysis of hydrologic data and contains several hydrograph separation methods (Barlow et al., 2015). The eleven year flow records were uploaded into Groundwater Toolbox and the hydrograph separation programs for HSYEP sliding-interval, HYSEP local minimum, and PART were completed. The output for each method included the original daily average flow in cfs, baseflow in cfs calculated according to each method, and percent baseflow. Calculations for the Delta 10% method were performed in Microsoft Excel®.

The analysis was completed for seven locations in Table 1; results for the Illinois River at Tahlequah, Watts, & South Siloam Springs locations are presented below and results for remaining locations are in Appendix 1. As the baseflow percentage threshold increased, meaning baseflow was becoming more and more dominant, the number of eligible sampling days decreased because the occurrence of flow conditions deemed suitable for monitoring become more and more restricted (Figure 9). The hydrograph separation method of HYSEP sliding-interval and PART give very similar results until the baseflow percentage (BFP) was greater than 75 (Figure 9). At this point the PART method becomes more conservative, meaning a greater portion of the total flow was separated into baseflow and thus a greater percentage of eligible sampling days were retained. The Delta 10% method is a binary decision criterion and because both metrics need to be satisfied the number of eligible sampling days was considerably reduced. Additionally, the antecedent rainfall threshold was set low to assure minimal contribution from direct runoff and this worked to make the overall method fairly limiting. The results from these analyses were similar at the Watts and South Siloam Springs locations (Figure 10 and 11).

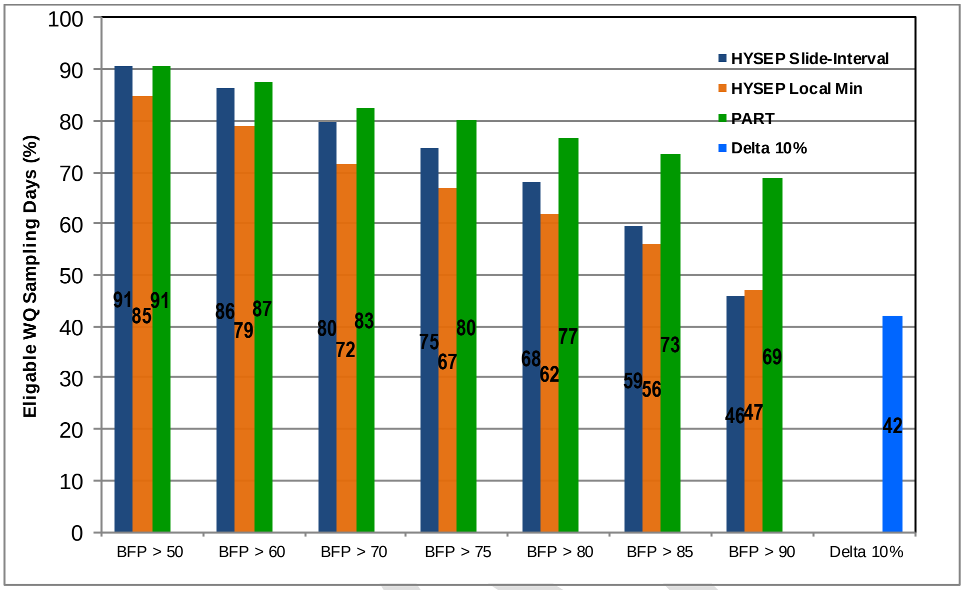


Figure 9. Tahlequah hydrograph separation analysis results; the percent of eligible sampling days decreases with increasing baseflow percent (BFP) threshold.

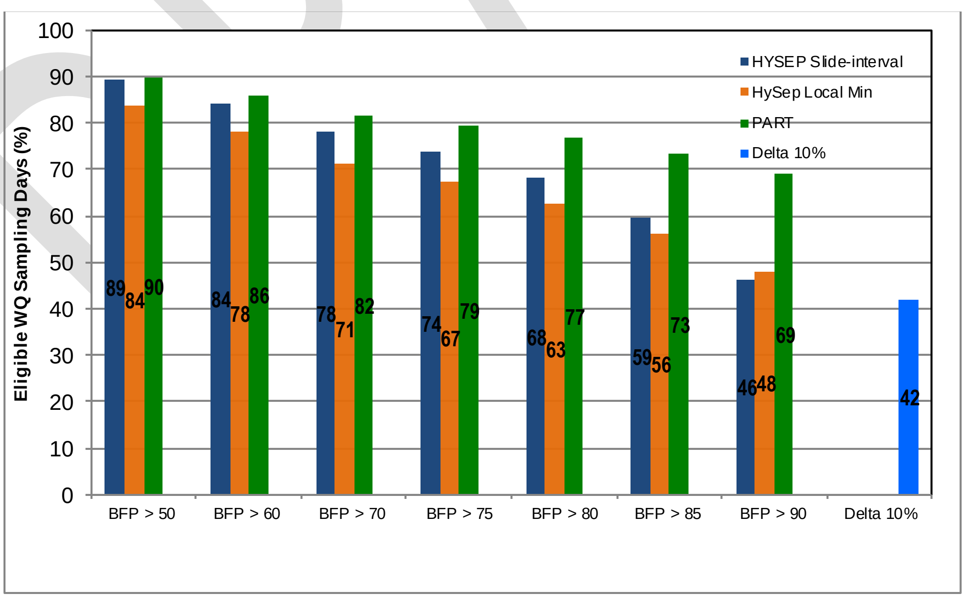


Figure 10. Watts hydrograph separation analysis results; the percent of eligible sampling days decreases with increasing baseflow percent (BFP) threshold.

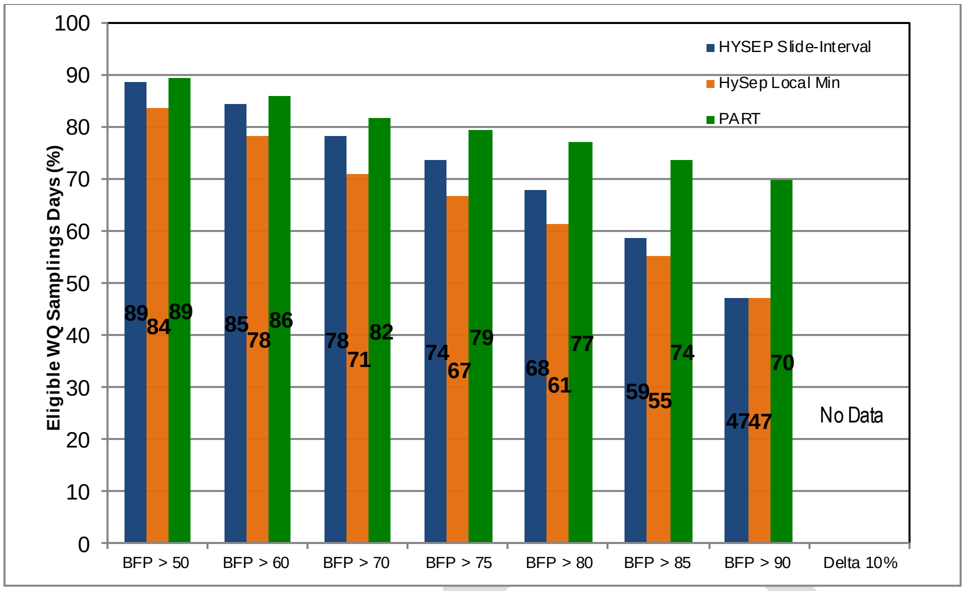


Figure 11. South Siloam Springs hydrograph separation analysis results; the percent of eligible sampling days decreases with increasing baseflow percentage (BFP) threshold.

Upon review of the three hydrograph separation methods and the Delta 10% method, HYSEP sliding-interval was selected for additional analysis. HYSEP sliding-interval was selected because it represented a reasonable compromise between the PART and HYSEP local minimum methods. Additionally, it is an established USGS method and computer programs and R code are readily available to consistently and efficiently execute the analysis in the future. The Delta 10% method was not selected because comparatively it substantially reduced the number of eligible sampling days and as a binary decision criteria and not a hydrograph separation method it does not allow for further analysis exploring the interaction between different baseflow percent thresholds and the interpretation of ambient water quality conditions. Additionally, the Delta 10% method requires rainfall data and given diverse rainfall patterns and the limited sources for rainfall data this method may prove problematic for consistent long term implementation. In further analyses on baseflow percentage thresholds and total phosphorus only baseflow from the HYSEP sliding-interval method was evaluated.

Baseflow Threshold Analysis and Results

The critical condition term describes a flow condition considered suitable for collecting data to assess the TP criterion; thus, any given day can be characterized as an eligible or ineligible sampling day based on daily average flow. As presented in Figures 9 - 11, the population of eligible versus ineligible sampling days will vary based on what one determines as a baseflow percentage threshold. The eligible and ineligible sampling days at different baseflow percentage thresholds were displayed on hydrographs for the analysis period of January 2014 through December 2017; a shorter analysis period was used to better view the hydrographs (Figures 12 – 14). This allows for visualization of how the eligible versus ineligible sampling days are represented across flows. The hydrograph is color coded blue and red to reflect the portion of the hydrograph that would be eligible for water quality sampling (blue) and the portion ineligible for water quality sampling (red). The baseflow percentage thresholds of fifty-five percent, seventy-five percent, and ninety percent for Illinois River Tahlequah, Watts, and South Siloam Springs locations are presented below (Figures 12-14). As the baseflow percentage threshold increases from 55% to 90%, the portion of the hydrograph eligible for water quality sampling (i.e. the blue portion) becomes increasingly restricted to low flow conditions. The complete series of color coded hydrographs for all locations and various baseflow percentage thresholds are provided in Appendix 1.

DRAFT

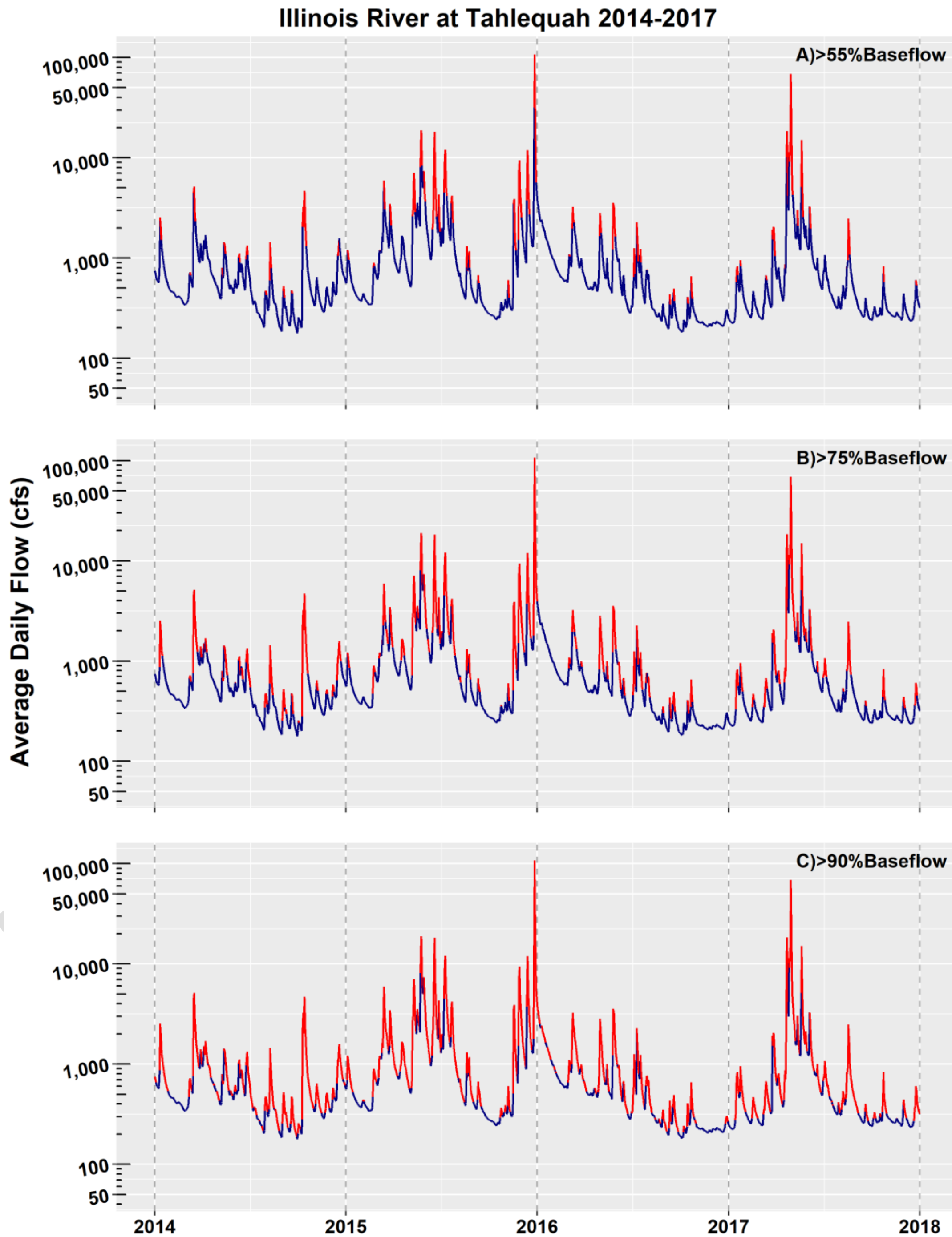


Figure 12. Illinois River at Tahlequah hydrograph (Jan. 2014- Dec. 2017), red indicates portion of hydrograph ineligible for sampling and blue represents portion eligible for sampling, based on HYSEP sliding-interval method and baseflow percentage thresholds of A) 55% or greater, B)75% or greater, and C) 90% or greater.

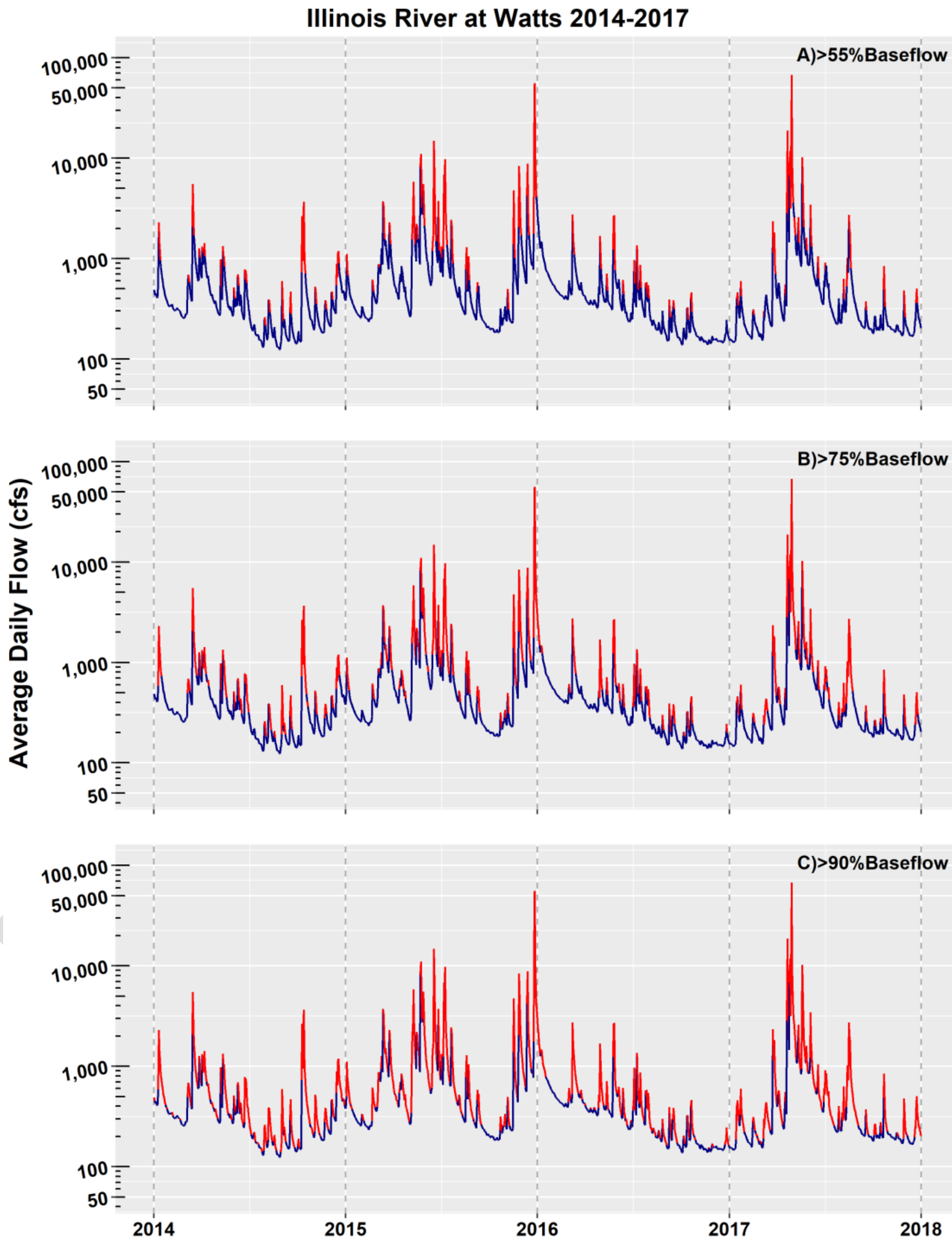


Figure 13. Illinois River at Watts hydrograph (Jan. 2014- Dec. 2017), red indicates portion of hydrograph ineligible for sampling and blue represents portion eligible for sampling, based on HYSEP sliding-interval method and baseflow percentage thresholds of A) 55% or greater, B) 75% or greater, C) 90% or greater.

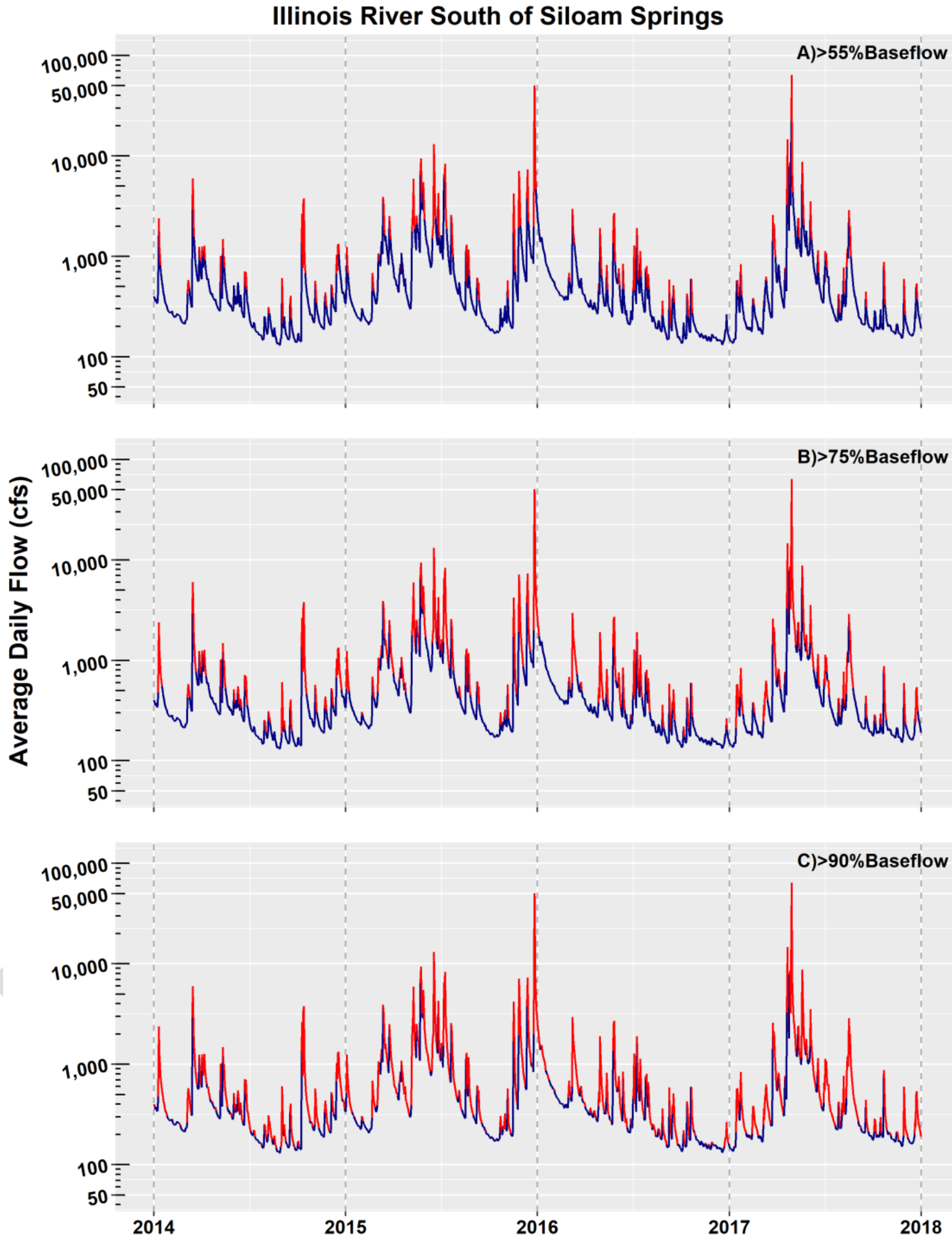


Figure 14. Illinois River at South Siloam Springs hydrograph (Jan. 2014- Dec. 2017), red indicates portion of hydrograph ineligible for sampling and blue represents portion eligible for sampling, based on HYSEP sliding-interval method and baseflow percentage thresholds of A) 55% or greater, B) 75% or greater, C) 90% or greater.

Statistical Analysis

A statistical analysis was conducted to evaluate if the number of eligible sampling days between the different baseflow percentage thresholds was statistically significant. Hypothesis testing of population proportions was conducted. This analysis posed the question: is the number of eligible sampling days at one baseflow percentage threshold significantly different from the number of eligible sampling days at another baseflow percentage threshold? For example, is the number of eligible sampling days at 50% baseflow or greater statistically different than the number of eligible sampling days at 55% baseflow or greater? Table 6 presents the results. All of the results are statistically significant at the alpha of 0.1 or less and by far the majority of results are statistically significant at the alpha of 0.01. There is a strong indication that there is a meaningful difference in the number of eligible sampling days between the various baseflow thresholds.

Table 6. Statistical analysis identifying significance between baseflow percentage thresholds

	Baseflow Percentage Thresholds							
Gaging Station	**50% vs 55%**	**55% vs 60%**	**60% vs 65%**	**65% vs 70%**	**70% vs 75%**	**75% vs 80%**	**80% vs 85%**	**85% vs 90%**
Barren Fork Creek at Eldon	**	***	***	***	***	***	***	***
Illinois River at Tahlequah	***	***	***	***	***	***	***	***
Illinois River at Watts	***	***	***	***	***	***	***	***
Illinois River at South Siloam Springs	***	***	***	***	***	***	***	***
Illinois River at Savoy	***	***	***	***	***	***	***	***
Flint Creek at Kansas	*	**	***	***	***	***	***	***
Osage Creek	*	**	***	***	***	***	***	***

*** significant at <0.01
** significant at <0.05
* significant at <0.1

Baseflow Percentage Threshold & Total Phosphorus

Regular water quality monitoring has been conducted approximately monthly in the Illinois River watershed for about twenty years. Typically, water samples have been collected at the ambient flow on the day of sampling and in accordance with OAC 785:46-15-4(b), which requires a minimum of six storm event sampling occurrences are required for assessment of Scenic Rivers total phosphorus criterion. Implementing a new approach that would only allow data collected when the critical condition was satisfied to be used for the purpose of beneficial use assessment represents a significant transition away from the longstanding Oklahoma monitoring practices and the inclusive use of data for beneficial use assessment. The influence of implementing a critical condition flow on the interpretation of instream water quality was evaluated in the context of both total phosphorus concentration and load.

The monthly total phosphorus data from January 2008 to December 2018 was used to calculate 6-month rolling averages and graphed as a time series. Figure 15 presents the 6-month rolling average total phosphorus concentration at the Tahlequah location. The blue line and triangle

DRAFT

symbol represent the 6-month average concentration based on sample values collected at any flow condition and specifically includes sampling of the six storm events. Whereas the brown, green, and orange lines represents the 6-month average TP concentration based on samples that were collected when baseflow comprised greater than 55%, 75%, and 90% of the total flow, respectively. It is clear that restricting the sample results included in the 6-month average based on a baseflow percentage threshold dramatically influences the evaluation of ambient in-stream total phosphorus conditions. The same time series of total phosphorus concentrations at the Illinois River at Watts and South Siloam Springs locations show a similar effect (Figure 16 and 17). As expected, when the baseflow percentage threshold is increased a greater number of sample results continue to be restricted from the 6-month average calculation and the outcome is a calculated lower in-stream TP concentration.

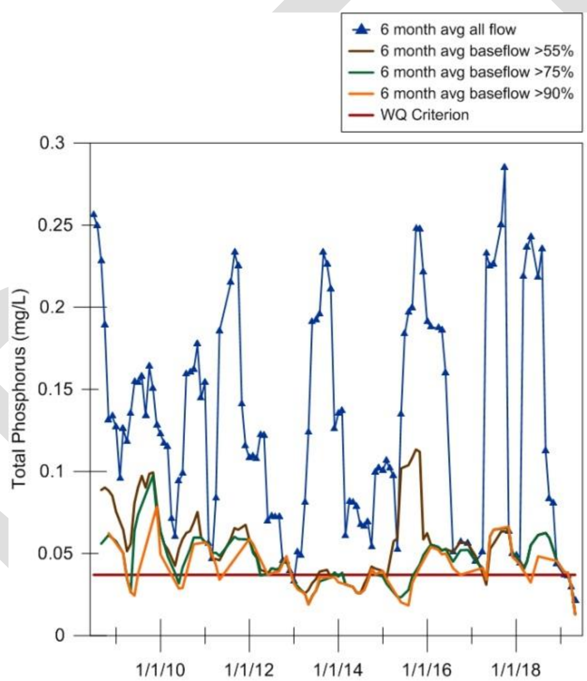


Figure 15. Tahlequah 6-month rolling average TP concentration. The blue triangle symbol represents the 6-month average TP concentration based on sample values collected at any flow condition. Brown, green, and orange lines are the 6-month average TP concentration at > 55%, 75%, and 90% baseflow percentage thresholds. The horizontal red line is the w ater quality criterion value of 0.037 mg/L.

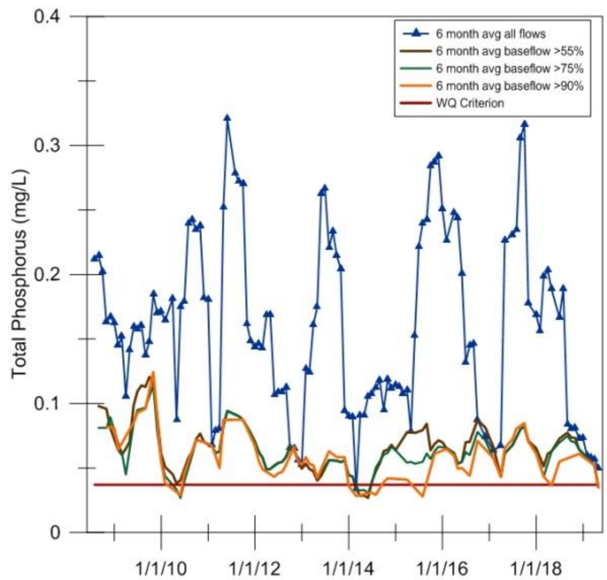


Figure 16. Watts 6-month average TP concentration at all flow s and baseflow percentage thresholds 55, 75, and 90 percent. The horizontal red line is the w ater quality criterion value of 0.037 mg/L.

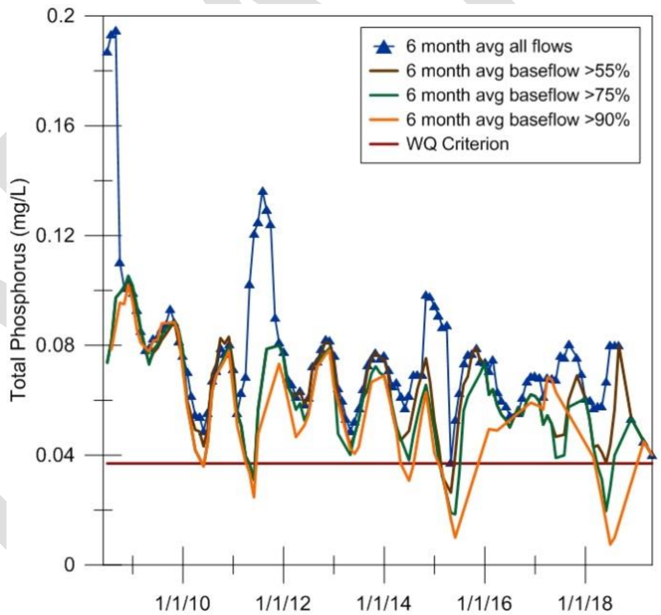


Figure 17. South Siloam Springs 6-month average TP concentration at all flow s and baseflow percentage thresholds 55, 75, and 90 percent. The horizontal red line is the w ater quality criterion value of 0.037 mg/L.

The effect is not so dramatic at the Illinois River at South Siloam Springs location because the ADEQ monitoring program does not specifically include a requirement for storm event sampling (Figure 17). This likely explains why less of a deviation was observed when sample results for the 6-month average TP calculation were restricted to only those collected when baseflow was greater than 55%, 75%, and 90% of total flow.

In-stream phosphorus concentrations are often flow dependent; during wet weather events, direct runoff carries both dissolved and particulate forms of phosphorus directly into the stream. Phosphorus data from the Illinois River watershed typically shows greater TP concentrations occurring with increased flow. Therefore, a large portion of the overall phosphorus load is delivered to the stream during wet weather events. Also the increased flow during wet weather events can activate shallow groundwater flow pathways that will release phosphorus into the stream over time (Fox et al., 2016). In contrast, during dry weather periods in-stream phosphorus concentrations are generally lower and contributions are primarily from continuous discharge sources such as, wastewater discharges. Understanding the effects of flow on total phosphorus concentration and delivery across a range of flow conditions is important to restoring beneficial uses in the Illinois River, Flint Creek and Barren Fork creek and protecting downstream waters.

The delivery of phosphorus load across flow conditions can be represented by a load duration curve. Figures 18 - 20 are load duration curves that display how TP load is delivered across the range of flows. A load duration curve is created by multiplying the streamflow by the water quality criterion and required conversion factors. The instantaneous load values in these figures reveal that failure to attain the criterion occurs across all flow conditions; although with a greater magnitude at lower percentile flows.

DRAFT

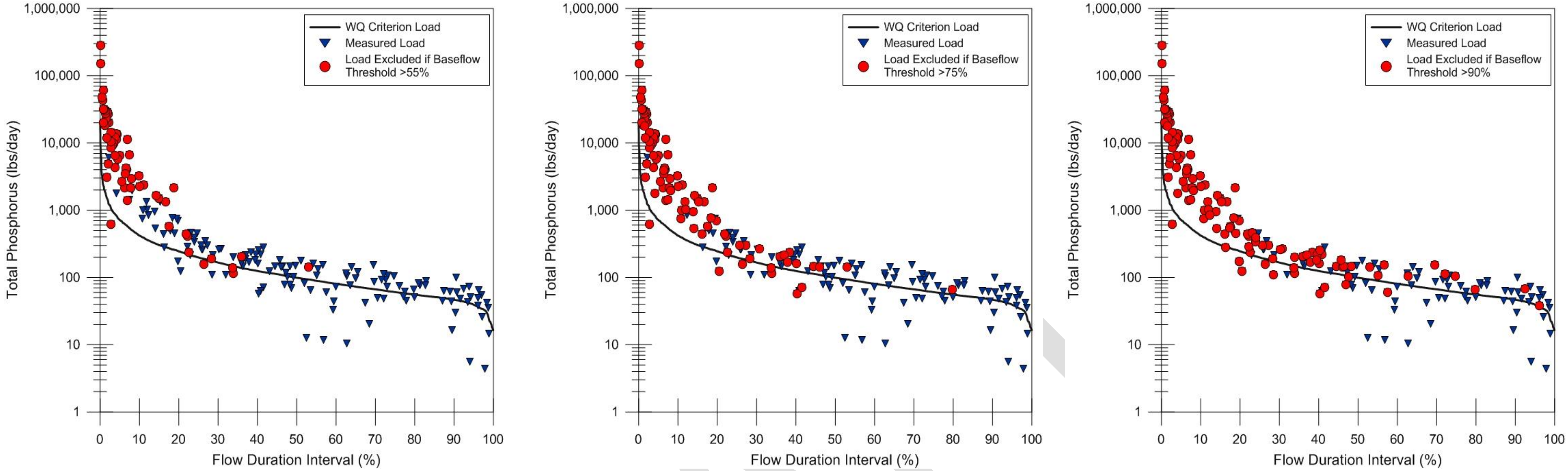


Figure 18. Illinois River at Tahlequah, load duration curve. The solid black line represents the TP load attaining the w ater quality criterion across flow intervals and the colored symbols are the instantaneous TP load, based on measured w ater quality data. Loads that plot above the curve (i.e. black line) indicate an exceedance of the w ater quality criterion. Red circle symbols indicates the TP load excluded from w ater quality assessment at the baseflow percentage thresholds of 55, 75, & 90 percent.

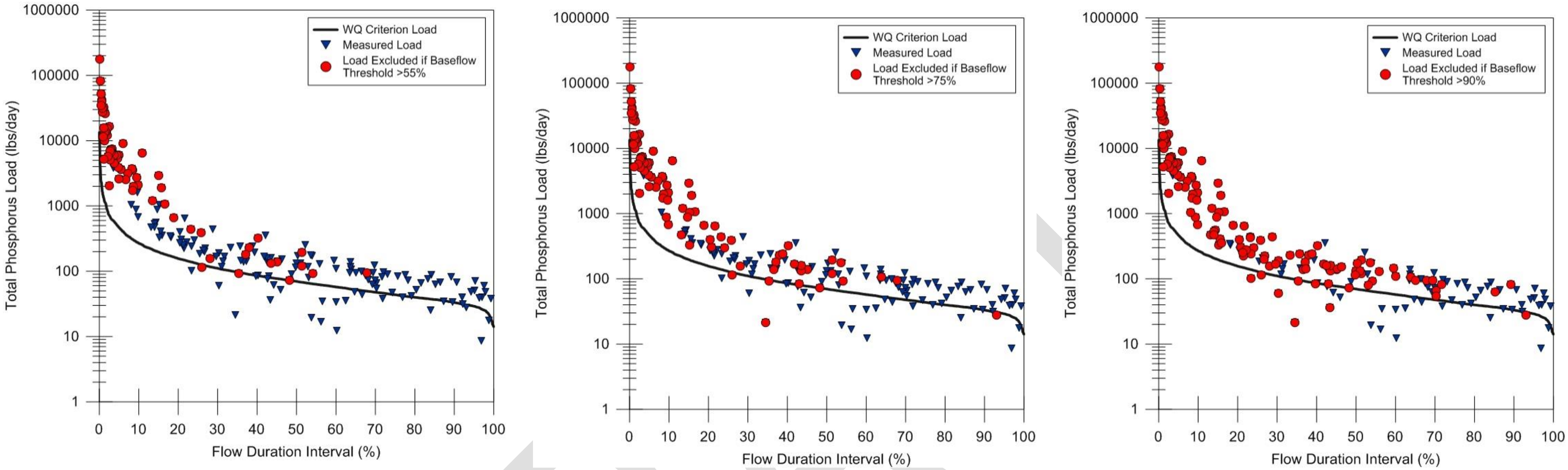


Figure 19. Illinois River at Watts, load duration curve. The solid black line represents the TP load attaining the w ater quality criterion across flow intervals and the colored symbols are the instantaneous TP load, based on measured w ater quality data. Loads that plot above the curve (i.e. black line) indicate an exceedance of the w ater quality criterion. Red circle symbols indicates the TP load excluded from w ater quality assessment at the baseflow percentage thresholds of 55, 75, & 90 percent.

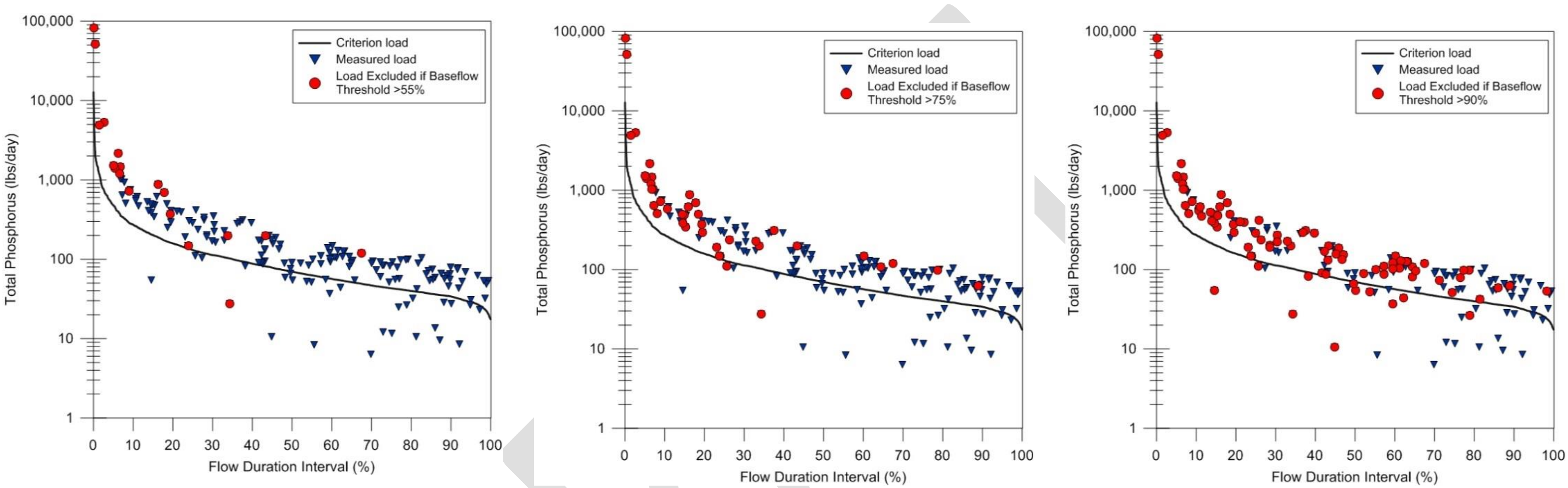


Figure 20. Illinois River at South Siloam Springs, load duration curve. The solid black line represents the TP load attaining the w ater quality criterion across flow intervals and the colored symbols are the instantaneous TP load, based on measured w ater quality data. Loads that plot above the curve (i.e. black line) indicate an exceedance of the w ater quality criterion. Red circle symbols indicates the TP load excluded from w ater quality assessment at the baseflow percentage thresholds of 55, 75, & 90 percent.

The red circle symbols represent at which baseflow percentage threshold a load would be excluded from water quality assessment. Working from the prerequisite that baseflow must be 50% or greater of total flow, a substantial amount total phosphorus loading is automatically excluded from consideration at the baseflow percentage threshold of 55% (red circles on figures). As the baseflow percentage threshold increases to 75 and 90 percent it is observed that an increasing portion of the total phosphorus load would be excluded from water quality assessment (Figures 18 - 20). The baseflow percentage threshold dictates which TP loads and consequently which TP sources are represented in a water quality assessment.

This is important because the phosphorus load delivered at different flow duration intervals often come from different sources. For example, the load delivered to the river at the 80 -100 flow duration interval represents flows of approximately 100 – 400 cfs, which are non-stormflows and predominately reflect phosphorus contributions from continuous wastewater dischargers. In contrast the load delivered in the flow duration interval of 1-10 represents flow of 1,100 – 100,000 cfs, which include stormflows and reflect phosphorus load contributions from nonpoint sources. Thus, as the baseflow percentage threshold increases greater responsibility would be focused on continuous wastewater dischargers to meet the criteria and considerable loads from nonpoint sources would be excluded from the water quality criteria assessment.

Conclusion

Water quality standards are the foundation for water quality protection under the Clean Water Act and set the benchmark for measuring success of various water quality management programs. It is essential that WQS be implementable and functional across programs. Additionally, regulatory equitability is an essential characteristic when developing a WQS because it works to promote collaborative efforts towards pollutant reduction between different sources and management programs.

The application of a baseflow percentage threshold as a means to implement the Joint Committee recommended critical condition language will limit the total phosphorus data that can be used for water quality assessment. It is clear that using flow to set a limitation around data analyses dramatically influences the appearance of ambient TP concentrations in the river and the consideration of loads delivered from the watershed. In identifying a baseflow percentage threshold OWRB staff has the objective of maintaining a WQS that is evenhanded and functional for diverse programs and to minimize artificially influencing the view of ambient TP water chemistry. Therefore, based on the considerations of 1) longstanding monitoring practice,2) influence that flow restrictions has on evaluation of ambient TP concentrations and loads, and 3) the need for evenhandedness across water quality programs OWRB staff finds that a 55% baseflow threshold would reasonably address the critical condition recommendation from Joint Committee. The 55% baseflow threshold excludes sample results when stormflow is overtly dominating the river and yet aligns with the three considerations above.

References

Barlow, P.M., Cunningham, W.L., Zhai, Tong, and Gray, Mark, 2015, U.S. Geological Survey Groundwater Toolbox, a graphical and mapping interface for analysis of hydrologic data (version 1.0) User guide for estimation of base flow, runoff, and groundwater recharge from streamflow data: U.S. Geological Survey Techniques and Methods, book 3, chapter B10

Final Report to Governors from the Joint Study Committee and Scientific Professional (2016, December 19). Retrieved from https://www.ok.gov/conservation/Agency_Divisions/Water_Quality_Division/IR_Joint_Study_Committee_Reference_Info.html

Fox, G., Purvis, R., Penn, C., 2016. Streambanks: A net source of sediment and phosphorus to streams and rivers, Journal of Environmental Management 181, 602-614

Gonzales, A.L., Nonner, J., Heijkers, J., Uhlenbrook, S. 2009. Comparison of different base flow separation methods in a lowland catchment, Hydrology and Earth System Sciences, 13, 2055-2068

Granato G.E., Ries, K.G.III and Steeves, P.A., 2017 Compilation of streamflow statistics calculated from daily mean streamflow data collected during water years 1901-2015 for selected U.S. Geological Survey streamgages: U.S. Geological Survey Open File Report 2017-1108

Lewis, JM., and Esralew, RA., 2009 Statistical Summaries of Streamflow in and near Oklahoma Through 2001: U.S. Geological Survey Scientific Investigations Report SIR 2009-5135

Linsley, R., Kohler, M., & Paulhus, J. (1975) Hydrology for Engineers (2nd ed.). McGraw-Hill

McCarty, James., Haggard, Brian., 2016 Can We Manage Nonpoint Source Pollution Using Nutrient Concentrations during Seasonal Baseflow? Agricultural Environmental Letters, Vol. 1, Issue 1, 2471:9625

Pelletier, A., Andréassian, V., Hydrograph separation: an impartial parameterization for an imperfect method, Hydrology and Earth System Sciences, 2019-503

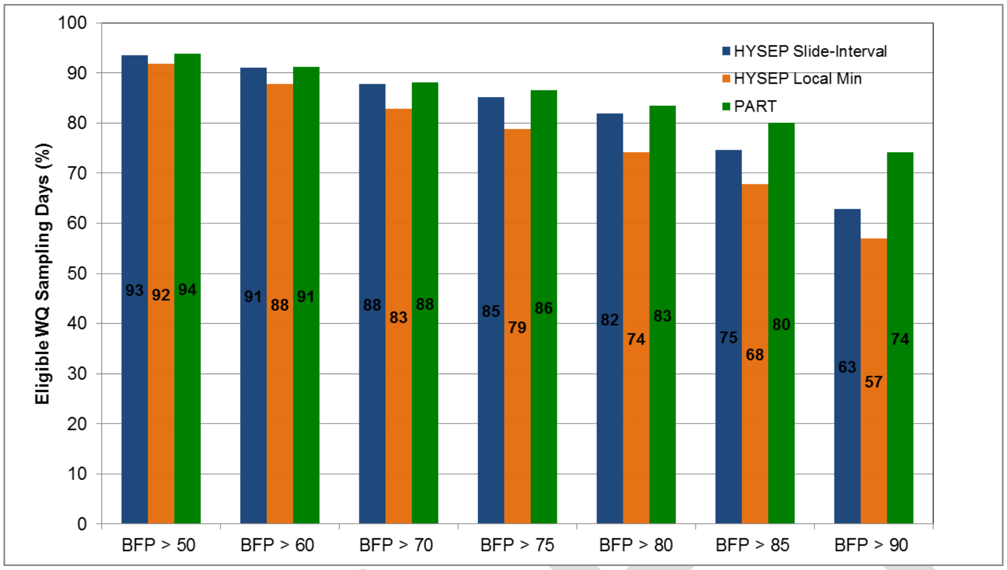
Sloto, Ronald., Crouse, Michele., 1996 HYSEP: A Computer Program for Streamflow Hydrograph Separation and Analysis. U.S. Geological Survey, Water-Resources Investigations Report 96-4040

DRAFT

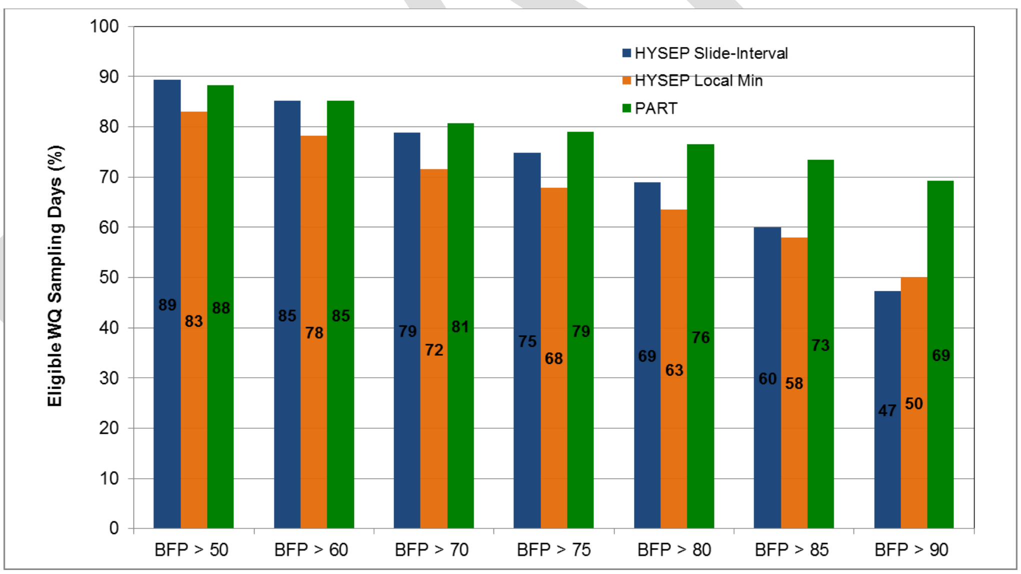
Appendix 1

DRAFT

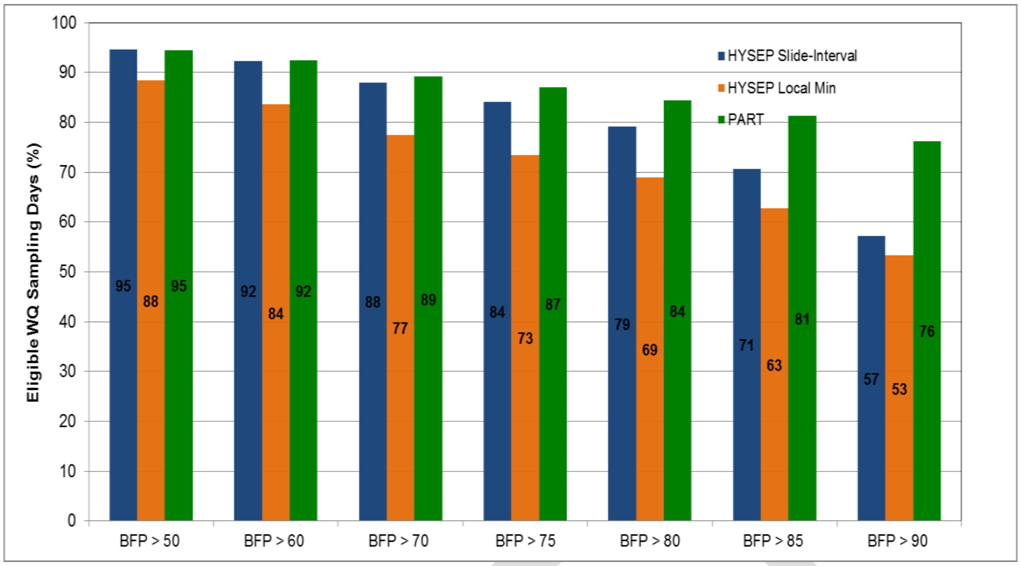
Hydrograph separation analysis results



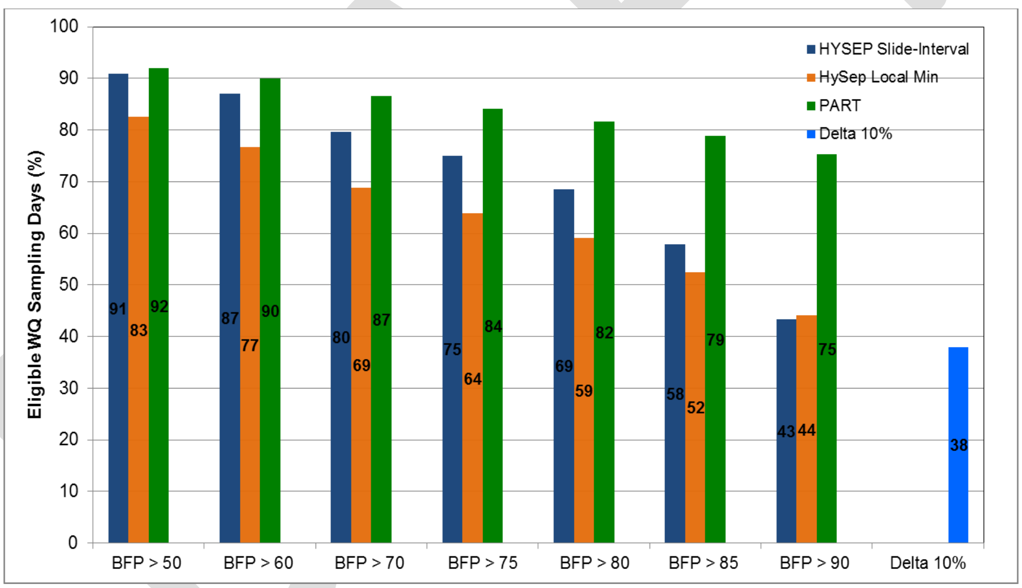
Osage Creek near Elm



Illinois River at Savoy



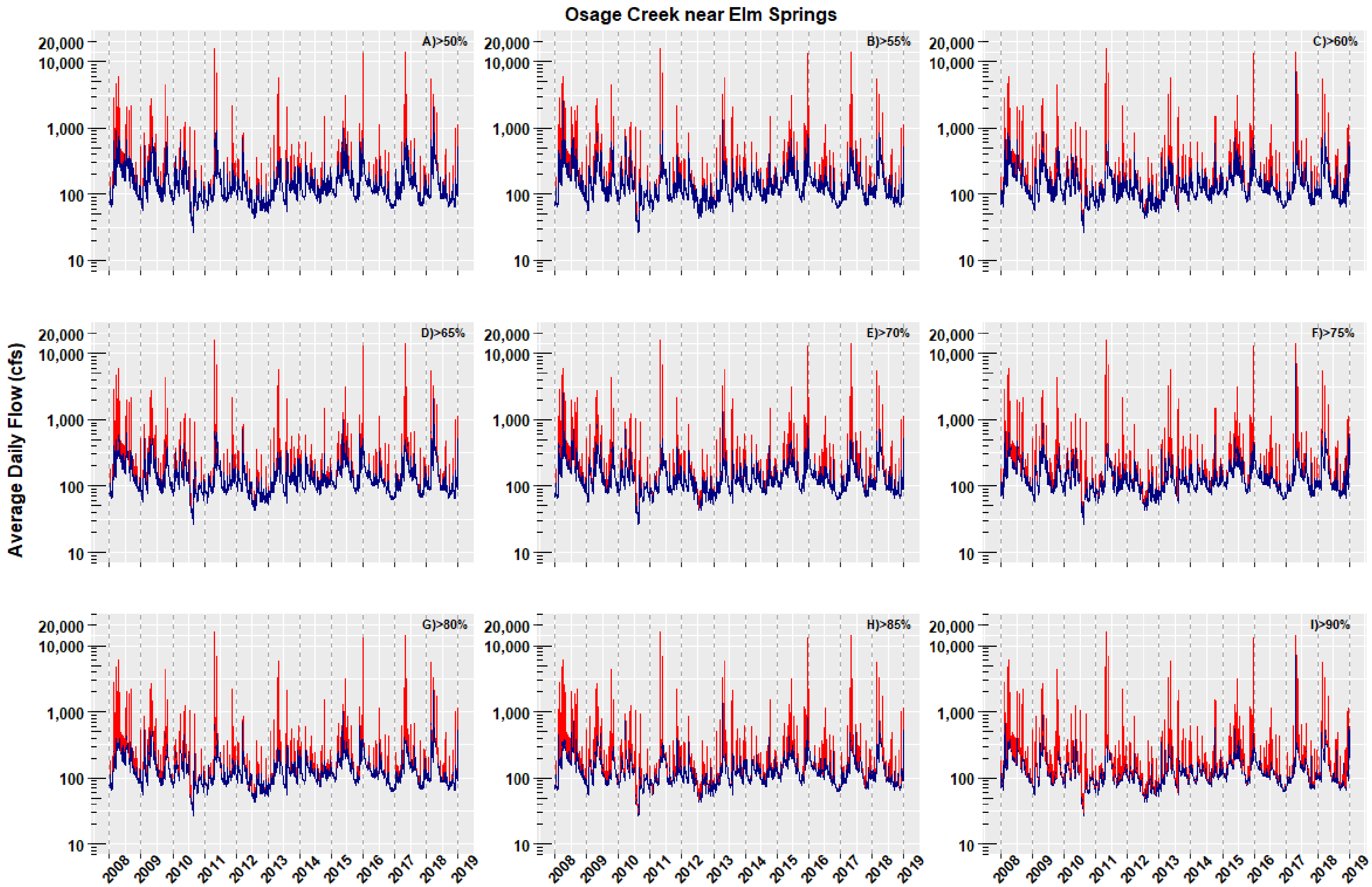
Flint Creek near Kansas

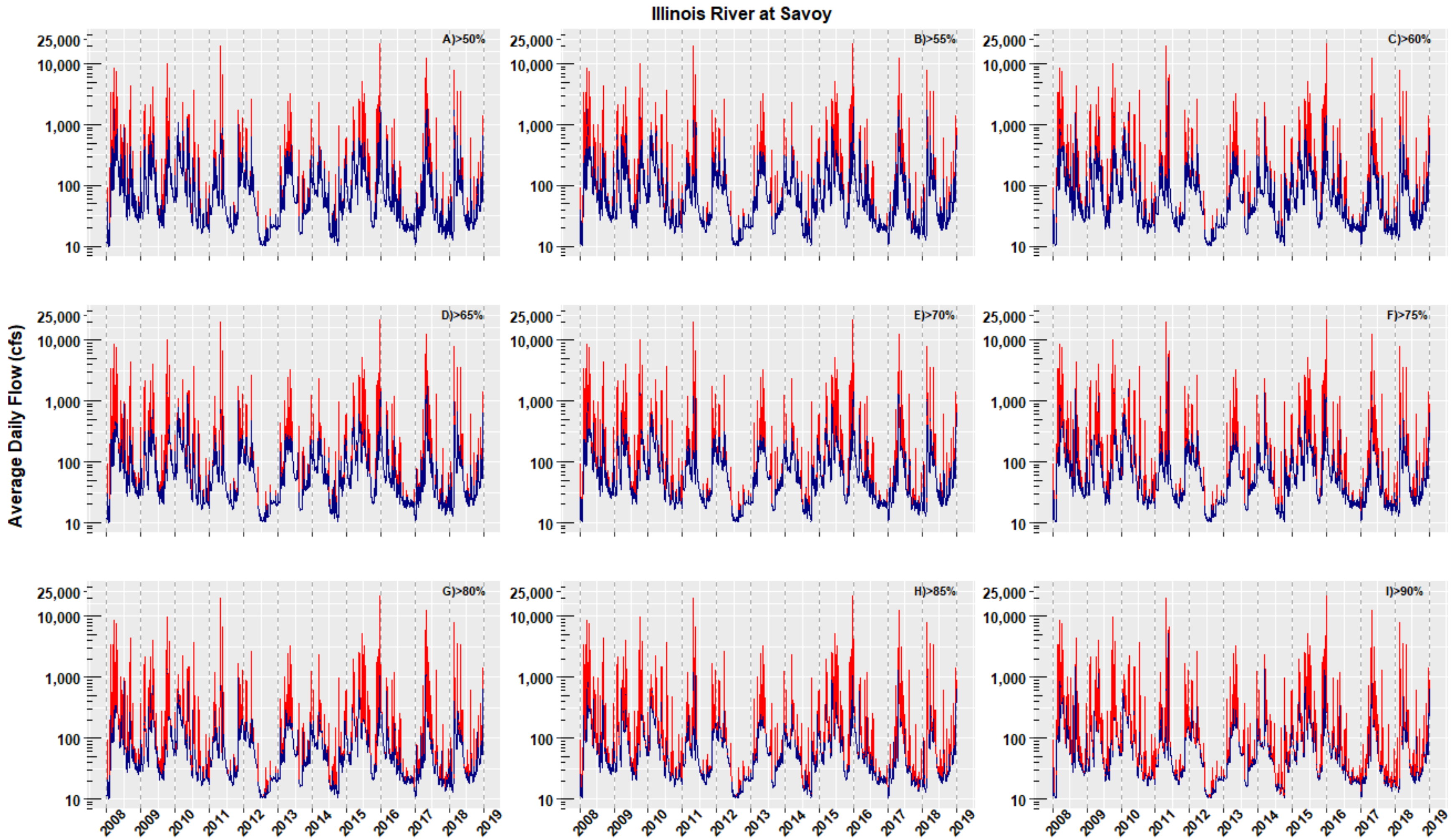


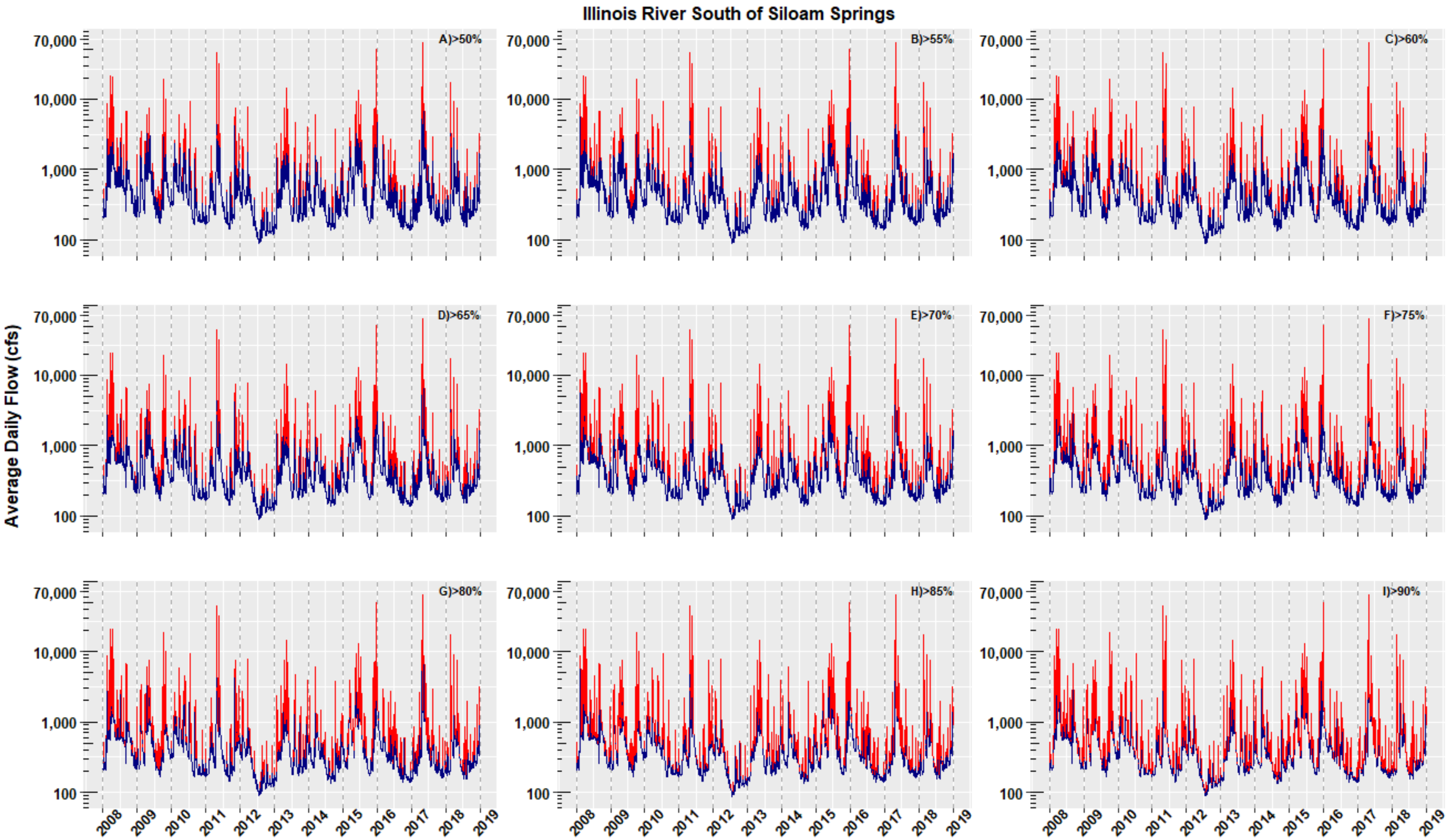
Barren Fork Creek at Eldon

Hydrographs (Jan. 2008- Dec. 2018), red indicates portion of hydrograph ineligible for sampling and blue represents portion eligible for sampling, based on HYSEP sliding-interval method and baseflow percentage thresholds of > 50% through > 90%.

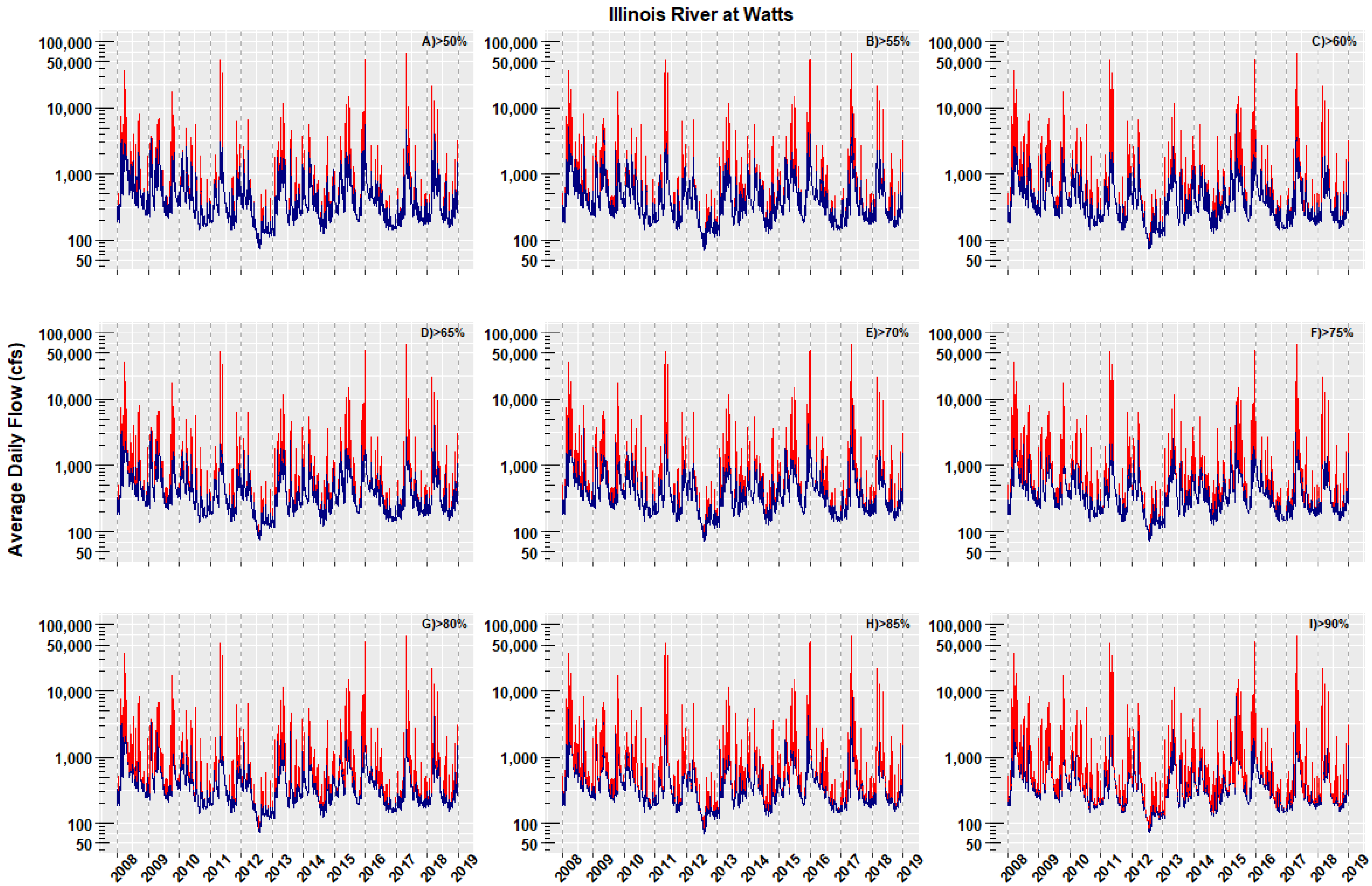
DRAFT


Osage Creek near Elm Springs
Average Daily Flow (cfs)
A)>50%
B)>55%
C)>60%
D)>65%
E)>70%
F)>75%
G)>80%
H)>85%
I)>90%
20,000
10,000
1,000
100
10
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

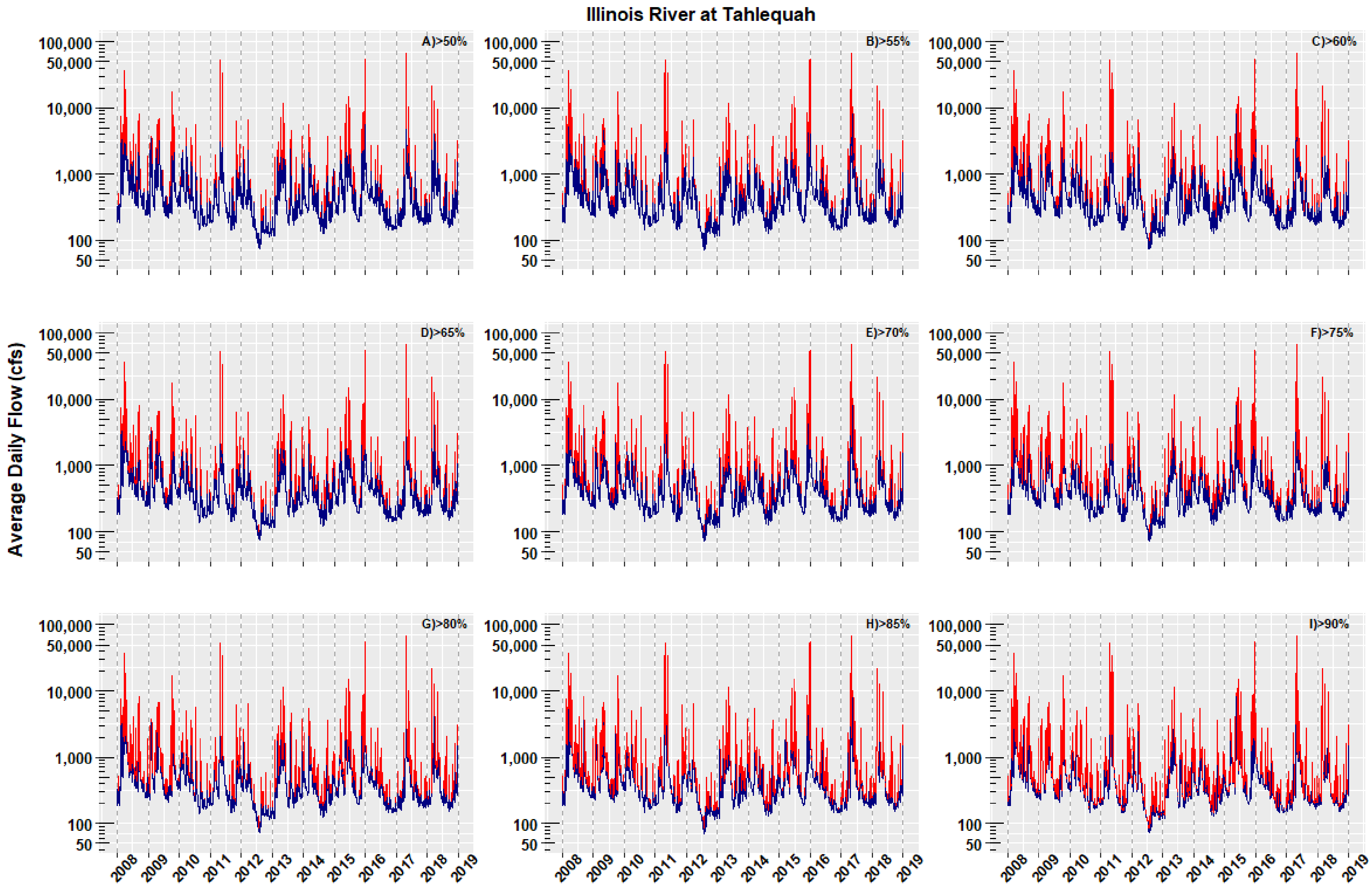

Illinois River at Savoy
Average Daily Flow (cfs)
A)>50%
B)>55%
C)>60%
D)>65%
E)>70%
F)>75%
G)>80%
H)>85%
I)>90%
25,000
10,000
1,000
100
10
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

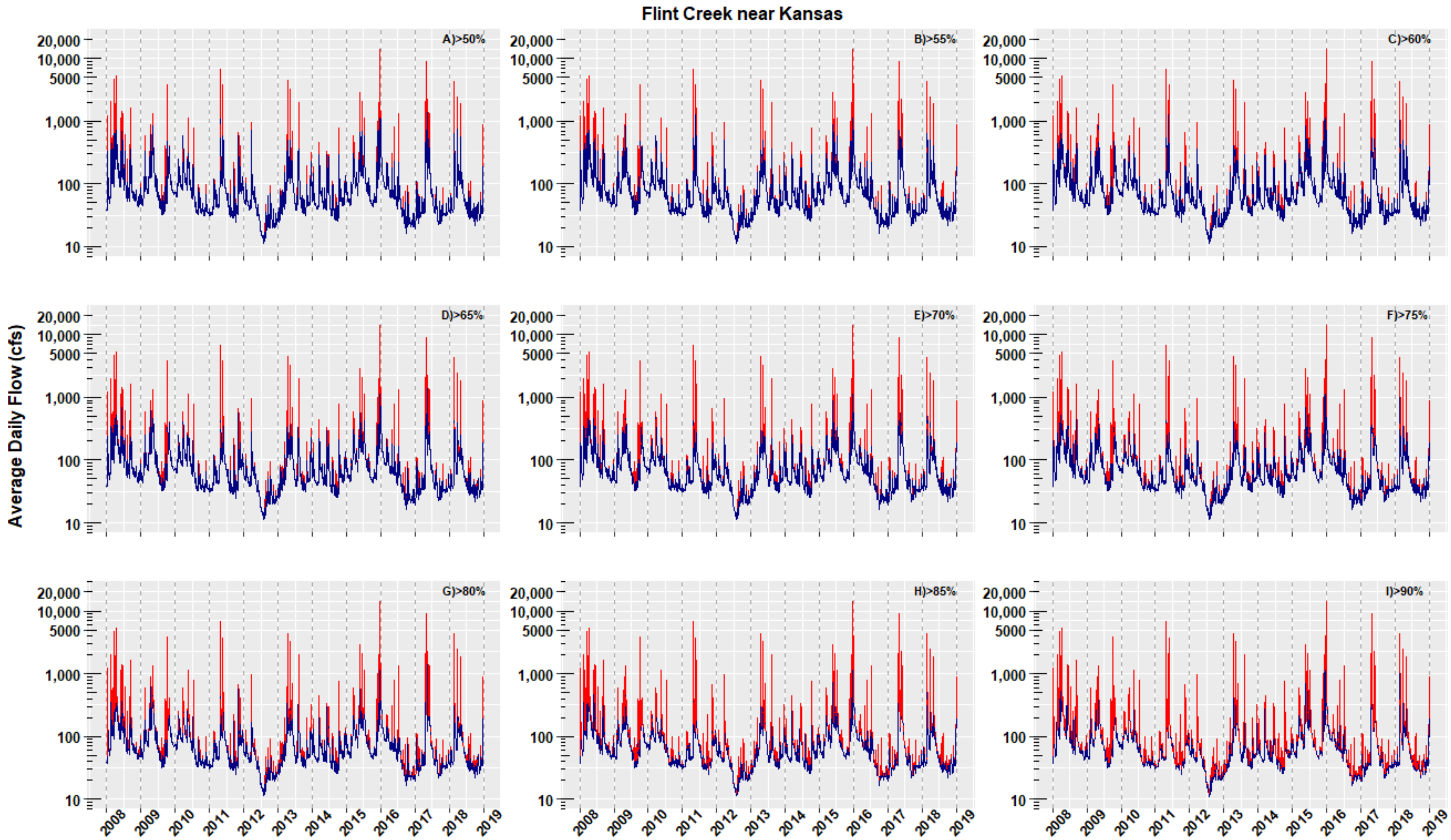


Illinois River South of Siloam Springs
Average Daily Flow (cfs)
A)>50%
B)>55%
C)>60%
D)>65%
E)>70%
F)>75%
G)>80%
H)>85%
I)>90%
70,000
10,000
1,000
100
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

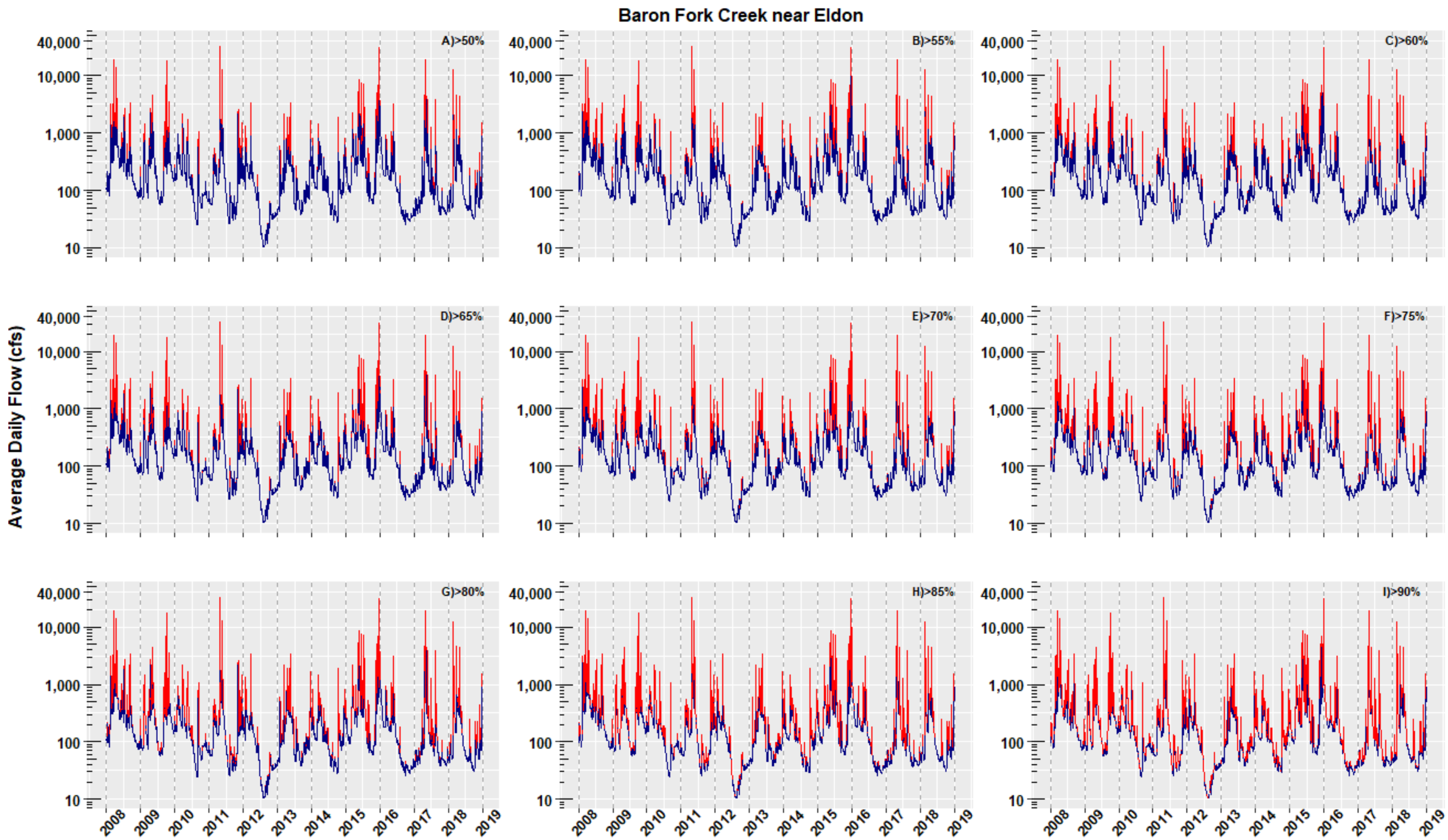


Illinois River at Watts
Average Daily Flow (cfs)
A)>50%
B)>55%
C)>60%
D)>65%
E)>70%
F)>75%
G)>80%
H)>85%
I)>90%
100,000
50,000
10,000
1,000
100
50
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


Illinois River at Tahlequah
Average Daily Flow (cfs)
A)>50%
B)>55%
C)>60%
D)>65%
E)>70%
F)>75%
G)>80%
H)>85%
I)>90%
100,000
50,000
10,000
1,000
100
50
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019



Flint Creek near Kansas
Average Daily Flow (cfs)
A)>50%
B)>55%
C)>60%
D)>65%
E)>70%
F)>75%
G)>80%
H)>85%
I)>90%
20,000
10,000
5000
1,000
100
10
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


Baron Fork Creek near Eldon
Average Daily Flow (cfs)
A)>50%
B)>55%
C)>60%
D)>65%
E)>70%
F)>75%
G)>80%
H)>85%
I)>90%
40,000
10,000
1,000
100
10
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019