# Appendix C

# Reevaluation of the Proposed Minimum Flows for the Upper Segment of the Little Manatee River, DRAFT REPORT

Prepared for
Southwest Florida Water Management District
March 5, 2018

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**Southwest Florida Water Management District**
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# Executive Summary

“Minimum flows” are defined in Florida Statute as the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area. The Southwest Florida Water Management District (District) is mandated to establish these limits based on the best information available in an effort to protect waterbodies (i.e., rivers, lakes, springs) within their jurisdiction. In 2011, the District published a document detailing draft minimum flow recommendations that could be used in District regulatory programs for the Upper Little Manatee River (Hood et al. 2011). This report (Hood et al. 2011) is subsequently referred to as the 2011 minimum flows report for the remainder of this document. The minimum flows recommended in the 2011 minimum flows report included a low-flow threshold below which no withdrawals would be allowed, as well as allowable percent reductions from a historic, non-withdrawal-impacted condition when flows were above the low-flow threshold. The evaluation was conducted based on seasonal “blocks” and resulted in recommendations that included block-specific allowable percent reductions of 9, 11 and 11 percent and a low flow threshold of 35 cfs. Together, the low-flow threshold and the allowable percent reductions were recommended as the minimum flows criteria to protect the Upper Little Manatee River in the 2011 minimum flows report. However, to date, these recommendations have not been formally adopted into District regulatory programs.

The 2011 minimum flows report was peer-reviewed in 2012 and documented in a report to the District (Powell et al. 2012). Overall, the panel of independent scientific experts found the District’s technical assumptions, ecological criteria, and analytical results used to develop the proposed minimum flows were appropriate, reasonable and minimally adequate; however, the panel strongly recommended additional study and monitoring to verify that the minimum flows are actually protecting the ecological health and productivity of the Upper Little Manatee River. In addition, the panel noted “…*that there are additional scientific methods, analyses, data integrations, and interpretations that could improve the District’s technical evaluation of minimum flows in the Little Manatee River”.*

Based on the peer review recommendations, The District decided to reevaluate the 2011 minimum flows report to address peer-review comments and conduct additional analysis deemed necessary to support establishing a minimum flows rule for the Upper Little Manatee River. As part of this reevaluation, datasets were updated as available through 2014 and analyses were conducted to increase the robustness of the methods used to:

- evaluate the “benchmark flow” period;
- define the “baseline” flow records;
- assess habitat usability criteria for fish and benthic invertebrates;
- identify protective criteria for floodplain wetland vegetation, and
- provide additional weight-of-evidence concerning potential indicators of biological integrity in the Upper Little Manatee River.

The analyses focused on addressing concerns expressed in the peer review report and including resource based assessments to establish criteria that would protect all aspects of the hydrograph for the Little Manatee River. To that end, the following models/methods were updated or included in the overall modeling framework:

- The U.S. Army Corps of Engineers Hydrologic Engineering Centers River Analysis System (HEC-RAS; U.S. Army Corps 2001) model of the river prepared by (ZFI 2010) was updated with measured cross sectional elevation data from a recently developed Surface Water Management Model (SWMM) model of the Little Manatee River (Jones Edmunds 2015).
- Systems for Environmental Flows Analysis (SEFA) was used to generalize the findings of instream habitat suitability based on a previous physical habitat simulation (PHABSIM) model reported in 2011 minimum flows report.
- Floodplain inundation analysis was conducted using HEC-GeoRAS, an extension of HEC-RAS that allows for spatial representation of the areal extent of floodplain inundation under different flow conditions.
- A new agricultural correction method was established to derive the Baseline flow condition based on a statistical relationship developed between long term trends in rainfall and streamflow.

Once the baseline flow record was established, flow reductions from baseline of between 10 and 40 percent (in 10 percent increments) were used to evaluate the effects of withdrawals on the identified water resource values. Based on the totality of information resulting from the reevaluation, the revised recommendations for minimum flows include a low-flow threshold value of 35 cfs to protect channel bottom habitats important to benthic invertebrate communities and fish passage to the upstream sections of the river. This low flow threshold is identical to that proposed in the 2011 minimum flows report, Additionally, reach-specific criteria were identified to protect hydrologic depth necessary for fish passage in upstream shoals in Reach 1 and 2 only if further consumptive use is permitted in the eastern portion of the watershed. The revised allowable percent reductions are restricted to no more than a 13.5% above the low-flow threshold to protect instream habitat suitability for fishes utilizing the river at any time with additional restrictions to protect floodplain wetland vegetation during the traditional wet season. Wet season floodplain inundation criteria include a recommended 12.8% percent allowable reduction when flows are above the 60$^{th}$ percentile value (i.e., 72 cfs) to protect baseline floodplain inundation area and frequency of occurrence throughout the system, and an 11% reduction cap when flows are above the 80$^{th}$ percentile value (i.e., 174 cfs) to protect small areas of high elevation floodplain in Reaches 2 and 5 of the River.

The revised recommendations for the proposed minimum flows for the Upper Little Manatee River remain quite similar to that proposed in the 2011 minimum flows report. The low-flow threshold is identical to that proposed in the 2011 minimum flows report. It is, of course, possible for flows to naturally fall below the low-flow threshold, however, no withdrawals would be allowed at that point. The 13.5% reduction above the low-flow threshold to the 60$^{th}$ percentile value (72 cfs) results in a maximum allowable withdrawal of approximately 10 cfs and equates to a frequency of allowable withdrawals within that window of approximately 30 percent of the days in a typical year assuming the historical time-period is representative of future conditions. This recommended criterion value to protect in-channel flows is between 2-4% higher (in terms of percent reduction) than the seasonally dependent criteria recommended in 2011 minimum flows report which was based on a very spatially limited instream habitat analysis. The differences in these thresholds results in a maximum difference in allowable withdrawal of approximately 3 cfs. Above 72 cfs, the criterion developed to protect areas of floodplain inundation is triggered resulting in a 12.8% cap on consumptive use between 72 and 174 cfs. This results in a maximum withdrawal of 22 cfs when flows are between the 60$^{th}$ to 80$^{th}$ percentile of the baseline range. Above the 80$^{th}$ percentile, the consumptive use allowance becomes more restrictive to protect higher elevation floodplains in the watershed, resulting in an 11% cap of flows above 174 cfs.

The results of this reevaluation provide additional evidence that minimum flow criteria can be developed for the Upper Little Manatee River that are both reasonable and protective. The reevaluation has incorporated a wealth of additional information based on independent peer-review and has increased the robustness of the analysis by refining the mechanistic and statistical models used in the development of the initial recommendations. The updated assessment is based on the most recent, best available information and includes an improved HEC-RAS model describing the hydrology of the freshwater portion of the Little Manatee River, a SEFA model analysis that provides a system wide assessment of the effects of flows on habitat suitability for instream channel habitats, and floodplain inundation analysis to protect the area and frequency of inundation of the floodplain wetland vegetation. These tools should serve the District well in advancing the regulatory standards for protecting the Upper Little Manatee River from significant harm due to surface water withdrawals.

# Acknowledgements

We would like to thank several current and former colleagues at the Southwest Florida Water Management District for their contributions to the development of the minimum flow recommendations presented in this report. Jason Hood, Marty Kelly, Tammy Hinkle, Michael ("Sid") Flannery, and Jonathan Morales, all formerly of the Southwest Florida Water Management District, developed the original report on proposed minimum flows for the freshwater portion of the Little Manatee River that served as the basis for this report. Much of the general language regarding statutory requirements associated with the MFLs program was taken with District permission from that report (Hood et al. 2011). We also acknowledge the authors of the peer review report: Gary Powell; Gary Grossman; and Mark Wentzel whose recommendations served as a foundation with which to proceed with this reevaluation. Kevin Flavin of Applied Technology and Management (ATM) was invaluable in his assistance in review and refinement of the HEC-RAS model for the river, which was a critical tool used for evaluating the effects of flows on the resources of concern. Bob Burleson, also of ATM was also very helpful with advice on how to export HEC-RAS model results for analysis using other software. David Jones of Jones Edmunds, Inc. provided the updated SWMM model for the Little Manatee River that was used to refine the HEC-RAS model, and we are indebted to him for sharing his time and insight to allow for the inclusion of this information in our analyses. Steve West and Jon Perry of Janicki Environmental, Inc. contributed to analysis and interpretation of the SEFA and floodplain inundation assessment, respectfully. Jennifer Brunty, Ph.D. (District Facilitated Agricultural Resource Management Systems Program i.e., FARMS Program) was helpful in describing the effect of historical flood field irrigation practices on surficial runoff to the river. Finally, Mike Heyl, formerly with the District and several current District staff, including Gabe Herrick, Natasha Mendez, Doug Leeper, XinJian Chen and Yonas Ghile, are warmly acknowledged for their collaboration and constructive comments as we have pursed the development of this product.

## 1.1 Background

Establishing regulations to protect water resources from the increasing demand for water for human uses has recently been the focus of much research. As the human need for water continues to grow, regulatory limits are necessary to ensure that rivers and streams also provide flows necessary to maintain the ecological integrity that would exist in the absence of human impact. Faced with the complexity inherent in natural systems, resource managers must define ecologically meaningful and measurable indicators that can mark progress toward ecosystem management and restoration goals (Richter et al. 1996). These “environmental flows”, of which “minimum flows” may be considered a subset, have been studied worldwide with many systems much more heavily altered than those within Florida (Herrick et al. 2017). A review of existing literature on environmental flows concluded that although the majority of studies recorded ecological changes in response to reduced flow, there are no universal responses that can be used to generalize across systems (Poff and Zimmerman 2010). The Nature Conservancy proposed that in cases where harm to habitat and resources has not been directly quantified, presumptive standards of 10% to 20% reductions in natural flows should provide high to moderate levels of protection, respectively (Richter et al. 2011). Presumptive limitations on flow assume that resources are protected when more detailed relationships between flow and resources of interest are not available. However, it was recognized that it is preferable, when possible, to explicitly link reductions in flow to critical resources.

The Southwest Florida Water Management District (District) has dedicated significant resources to perform direct evaluations of the response in identified water resource values to variations in streamflows as part of their Minimum Flows and Levels program. Minimum flows are defined in Section 372.042(1)(a), Florida Statutes or F.S., as the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area; however, no definition of significant harm is given in the statute. As part of its intention to provide goals, objectives, and guidance, Rule 62.40.473, F.A.C., within the Water Resource Implementation Rule, states that “consideration shall be given to natural seasonal fluctuations in water flows or levels, non-consumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic and wetlands ecology. There are many instances in which a critical response endpoint that represents “significant harm” is not known with certainty. For example, what reduction in catch per unit effort for a particular fish taxon would represent significant harm to the population? In cases where the response endpoint is not represented by an explicit criterion value (e.g., fish passage depth of 0.6 feet), the District has routinely used a 15% resource reduction standard as a critical threshold value to represent significant harm. This evaluation has become standard practice over time and has been implemented in many of the District MFLs that are now codified in Florida Statute. The District also typically expresses the minimum flow as a percentage of a baseline flow record which is estimated to be relatively unimpacted by human activity. This percent-of-flow approach has been used to establish minimum flows for several District rivers (Flannery et al. 2002, Heyl 2008, Heyl et al. 2010, 2012, Leeper et al. 2012) and has been supported by multiple independent peer reviews.

In 2011, the Southwest Florida Water Management District (District) published a document (Hood et al. 2011) detailing draft minimum flow recommendations for consideration in District regulatory and planning programs to prevent significant harm to the upper (or freshwater) segment of the Little Manatee River. The 2011 minimum flows report was peer-reviewed in a report to the District (Powell et al. 2012) which recommended additional scientific methods, analyses, data integrations, and interpretations that could improve the District's technical evaluation of minimum flows and levels in the Little Manatee River. These recommendations became the impetus for a reevaluation of the original analysis conducted in the 2011 minimum flows report to address peer review comments and supplement those analyses and provide additional weight of evidence from which to define minimum flows for the Upper Little Manatee River. This reevaluation is detailed within this document. The remainder of this chapter begins with a review of terms and definitions used in the establishment of minimum flows, followed by a review of the 2011 minimum flows report, and a summary of the databases that were updated in preparation for reevaluation. Following this background chapter is a chapter detailing a review of the analytical methods and tools used in development of the 2011 minimum flows report and a summary of the peer review comments on that report, a chapter detailing the analysis associated with the reevaluation, and chapters detailing the revised recommendations for minimum flows analysis and future status assessments.

## 1.2 Terms and Definitions

To aid in the understanding of information presented in this report, we find it helpful to elaborate on several flow-related definitions and concepts found herein.

- **Atlantic Multidecadal Oscillation** (AMO) – A natural multidecadal cyclic variation in large-scale atmospheric flow and ocean currents in the North Atlantic Ocean that combine to alternately increase and decrease Atlantic sea surface temperatures. The dry and wet phases last for 25-45 years at a time, with a difference of about 1F (0. 6C) between extremes.
- **Baseline Period** – a period of time when flows were recorded and withdrawal impacts were absent. A baseline period may also refer to long term tidally-filtered flows adjusted for withdrawals and/or other alterations. Rule 40D-8.021, F.A.C., defines "historic" as "a long term period when there are no measurable impacts due to withdrawals.
- **Benchmark Period** – A fixed, more or less permanent reference point in time expressed as a period of years where flows are thought to reflect conditions in the absence of withdrawals.
- **Building Block Approach –** The building block approach uses long term daily median flow statistics to identify seasonality in the flow regime and categorize the flow regime into three distinct "blocks" for which allowable flow reductions are identified.
- **Excess Flow Period** – a period of time when anthropogenic activity is expected to have influenced, and augmented, the natural expected streamflow.
- **Flow** refers to streamflow or discharge – the volume of water flowing past a point for a given unit of time. Flow is generally reported as cubic feet per second (cfs), as has been done at U.S. Geological Survey (USGS) gages which develops rating curves based on

repeated measurements of discharge and channel geometry (Buchanan and Somers 1969).

- A **flow regime** is a hydrologic regime characterized by the quantity, timing and variation of flows in a river. Rule 62-40.473, F.A.C., dictates that "minimum flows should be expressed as multiple flows defining a minimum hydrologic regime, to the extent practical and necessary to establish the limit beyond which further withdrawals would be significantly harmful as provided in Section 373.042(1), F.S." The emphasis on a flow regime, rather than a single minimum flow value, reflects the natural variation present in flowing water systems. Expressing a minimum flow as an allowable percentage of a flow addresses the intent of protecting the flow regime as allowable flow changes are proportionally-scaled to the magnitude of flow.
- **Long term** is defined in Rule 40D-8.021, F.A.C., as an evaluation period for establishing minimum flows and levels that spans the range of hydrologic conditions which can be expected to occur based upon historical records.
- **Percent of Flow Approach –** An approach used by the Southwest Florida Water Management District to establish minimum flows by assigning allowable withdrawals as a percentage of the streamflow recorded at a compliance streamflow gage in the system.
- **Prescription Flows** - a simulated historical flow record that includes a maximum withdrawal amount established by the MFL
- **Streamflow Augmentation –** human induced addition to a natural streamflow regime, usually through surface water discharges or from agricultural irrigation using groundwater that subsequently runs off into an adjacent stream.
- **Unimpacted or natural flows** - flows that occurred in the absence of withdrawal impacts.

## 1.3 Minimum Flows Proposed in 2011

The minimum flows proposed in the 2011 report were based on gaged flows at the U.S. Geological Survey (USGS) site on the Little Manatee River near Wimauma, FL (USGS 02300500). This gage is subsequently referred to for the remainder of this document as the "Wimauma gage". The 2011 proposed minimum flows included a low-flow threshold and allowable percent-of-flow reductions for seasonal blocks corresponding to periods of low, medium and high flows. Development of the proposed low- flow threshold involved assessments of fish passage and wetted perimeter (i.e., the amount of wetted river channel area) as a function of flow. Ultimately, a low-flow threshold of 35 cfs at the Wimauma gage was identified as the criterion value based on assessment of flows necessary to maintain fish passage depth at the most restrictive cross-section in the river. The allowable percent of flow reductions were based on a prescriptive flow standard requiring no more than a 15% reduction in available habitat from historic, non-withdrawal-impacted conditions. Flow reductions that limited in-channel habitat availability were based on the results of Physical Habitat Simulation (PHABSIM) modeling of instream fish habitats, and resulted in minimum flow recommendations that included allowable 9, 11 and 11 percent flow reductions associated with the seasonal "Blocks" 1, 2 and 3 that correspond with seasonal periods of low, medium and high flows, respectively

(Table 1-1). While woody habitat (i.e., snags) was also considered, the result of that analysis was not as sensitive as the PHABSIM results which therefore took precedence as the minimum flows criteria. The seasonal blocks were defined by analyzing the median daily flows for the period of record. Block 1 (a 65-day period that extends from April 18 to June 2) began when the median daily flow dropped below and stayed below the 75% exceedance flow and continued until the beginning of Block 3. Block 3 (119-day period that immediately follows the dry season (June 22 to October 18) began when the median daily flow exceeds and stays above the 50% exceedance flow. Block 2 (the remaining 181 days not included in either Block 1 or Block 3) began on October 19th and continued until April 17th.

**Table 1-1. Minimum Flows recommendation for the Upper Little Manatee River freshwater MFL (replicated from Table 8-2 of Hood et al. 2011).**

| Analysis Name | Measure/Goal | Block | Criterion |
|---|---|---|---|
| Fish Passage | Maintain depth at 0.6' across shoals | ALL | 35cfs |
| Wetted Perimeter | Maximizing inundated river channel | ALL | 30cfs |
| PHABSIM | Avoid >15% reduction in habitat for various species | 1 | 9% reduction |
| PHABSIM | Avoid >15% reduction in habitat for various species | 2 | 11% reduction |
| Snags | Avoid >15% reduction in temporal snag habitat | 2 | 16% reduction |
| Exposed Roots | Avoid >15% reduction in temporal exposed roots habitat | 2 | 14% reduction |
| PHABSIM | Avoid >15% reduction in habitat for various species | 3 | 11% reduction |

The seasonal blocks applied to the minimum flows criteria were developed using the "Building Block" approach that was originally proposed in peer review of the upper segment of the Peace River as "a way to more closely mirror original hydrologic and hydroperiodic conditions in the basin" (Gore et al. 2002). Identification of building blocks is associated with flow needs for ecosystem specific functions, biological assemblages or populations, and assembly of the blocks form a prescription, or minimum, flow (Postel and Richter 2003). As noted by the panelists comprising the Upper Peace River review panel, "assumptions behind building block techniques are based upon simple ecological theory; that organisms and communities occupying that river have evolved and adapted their life cycles to flow conditions over a long period of pre-development history (Stanford et al. 1996). Blocks were defined by analyzing the median daily flows for the long term period of record. Block 1 begins when the long term median daily flow drops below and stays below the 75% exceedance flow and continues until the beginning of Block 3. Block 3 begins when the long term median daily flow exceeds and stays above the 50% exceedance flow. Once the long term median daily flow falls below the 50% exceedance flow, Block 2 begins and continues until the beginning of Block 1.

Compliance with the proposed 2011 minimum flows was recommended to be evaluated against a simulated historical flow record that included a maximum withdrawal amount established by the proposed minimum flows (i.e., the prescription flow record). The 5 year and 10 year moving mean and medians from the prescription flow record was used to identify a minimum over the period of record and it was proposed that no 5 or 10 year moving- mean and medians from a future timeseries should fall below those values. The 2011 minimum flows report was peer reviewed by a panel of independent scientists in 2012 but has yet to be adopted into District regulatory framework or Florida Statute

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## 1.4 Peer Review of Originally Proposed Minimum Flows and Response to Peer Review

Three peer reviewers comprised the peer review panel for the 2011 minimum flows report: an aquatic ecologist [Dr. Gary Powell (chair)]; an animal ecologist (Dr. Gary Grossman, University of Georgia), and a hydraulic and hydrologic modeler (Dr. Mark Wentzel, Hydrology, Hydraulics & Modeling). Overall, the Panel reported that the District's technical assumptions, ecological criteria, and analytical results used to develop the proposed minimum flows for the Upper Little Manatee River were "…*appropriate, reasonable and minimally adequate, especially given the District's required use of a "best available data" standard (Powel et al. 2012). However, the Panel strongly recommended continued study and especially monitoring to verify that the MFL is actually protecting the ecological health and productivity of the Little Manatee River."* In addition, the Panel notes "…*that there are additional scientific methods, analyses, data integrations, and interpretations that could improve the District's technical evaluation of minimum flows and levels in the Little Manatee River."*

The Panel found that the District used generally appropriate criteria for estimating minimum flow needs and the Panel believed that the proposed minimum flows should protect the native flora and fauna associated with the river, under most conditions. They note that the "minimum flow for fish passage" criterion of 0.6 feet and the "no reduction in flow that would produce a habitat loss greater than 15% of available habitat under baseline conditions," are both suitable criteria for this purpose. However, they add that the latter criterion has a level of imprecision based on the lack of a statistically-derived relationships between flow and biologically important aquatic species or their habitats. The panel recognized that "the use of a 15% loss in habitat or species abundance as a threshold for 'significant harm' is a more or less arbitrary policy decision", but agreed that it is a reasonable approach for avoiding the most serious negative impacts on the ecosystem, and thought the subject was discussed appropriately in the 2011 proposed minimum flows report.

While the Panel recognized the District's consistent use of a seasonal building block approach for establishing minimum flows, they recommend the District consider the implementation of the proposed minimum flows for each block based upon actual flows rather than calendar date. They suggest that this would reduce unintended negative impacts when flows do not match the expected seasonal signature defined by the seasonal blocks.

The panel recognized that the development of the proposed minimum flows was based on two flow periods – a "wet flow" period from 1940 through1969 and a "dry flow" period from 1978 through 2009; however, they stated that the study could benefit from analysis of the hydrology that considers more possibilities than just the identified time period. Rather than accepting this division of the entire time period by default, the Panel recommended that additional analysis for the Little Manatee River be performed to confirm the appropriateness of this time division, or perhaps even refine it.

The panel recognized the use of Physical Habitat Simulation (PHABSIM) model as an appropriate tool for establishing relationships between habitat availability and river flows. The Panel concluded that the use of PHABSIM was appropriate given the “best available data” standard but also pointed out that the available physical data used to apply PHABSIM was very spatially limited and no evidence was presented to support the contention that the chosen sites were representative of a much larger portion of the river. The Panel emphasized that the data for this instream habitat availability study was only minimally adequate, due to a lack of direct information on aquatic species and habitats in the river. Although habitat simulations were performed for various life-history stages of Spotted Sunfish, Bluegill Sunfish, Largemouth Bass, a shallow-fast fish guild, a deep-slow fish guild, and macroinvertebrate diversity, the District’s flow reduction limit of 9% associated with the PHABSIM analyses was based on potential decreased in habitat availability for a single species (adult Spotted Sunfish) at only two “representative” sites on the entire river segment somewhat reducing scientific confidence in this criteria for development of the proposed minimum flow. The Panel also questioned why habitat suitability curves for spotted Spotted Sunfish were developed using a Delphi technique rather than from the information contained in Dutterer and Allen (2006, 2008). Given concerns that the PHABSIM modeling study sites only included portions of the river channel that may be too short to be representative of the Upper Little Manatee River, and that the number of transects used at each site may have been too few to characterize habitat within the study sites, it was recommended that that the District consider revising the PHABSIM studies at some point in the future by adding sufficient transects to be in compliance with the guidance of Bovee and Milhous (1978) and Bovee et al. (1998).

The Panel concurred with the District’s selection of a low-flow threshold of 35 cfs at the USGS stream gage near Wimauma (USGS 02300500), believing that a low-flow cutoff is both reasonable and essential for minimum flow development. Recommended future management actions included quantification of site-specific flow/habitat relationships, and that a formal plan be developed for withdrawal of river waters that will ensure that minimum flow standards will be complied with, and more importantly, that withdrawal schedules are optimized to minimize the necessity for emergency diversions during low flow periods.

## 1.5 Contract to Update Analysis and Re-Evaluate the Proposed Minimum Flows

Janicki Environmental, Inc. was tasked under contract by the District to: review the minimum flows proposed in 2011 by the District for the Upper Little Manatee River, review peer-review comments (Powell et al. 2012) on the proposed minimum flows, and complete additional analyses to address peer-review comments and provide additional information supporting minimum flow development for the Upper Little Manatee River. The contract included tasks that follow peer-review recommendations to evaluate the benchmark time period used for evaluating the effects of withdrawals on flows and environmental responses to flow changes, generalize the PHABSIM analysis by using the Systems for Environmental Flows Analysis (SEFA) software, and formally evaluate and include the effects of flow reduction scenarios on floodplain inundation as an additional minimum flows criterion. Additional analyses were conducted to increase the robustness of the analytical methods used in the derivation of the proposed minimum flows with respect to habitat usability for fish, floodplain inundation, evaluation of the benchmark and baseline flow records, and various other analyses meant to supplement the original work to provide additional weight of evidence concerning potential indicators protective of ecological integrity of the river system.

The following chapters describe efforts to update the data, supplement the analysis conducted for the 2011 minimum flows report based on peer review comments and independent review, and provide revised recommendations of minimum flows to protect the Upper Little Manatee River from significant harm. .

## 2.1 Independent Review and Data Update

One of the first tasks Janicki Environmental, Inc. accomplished as part of the reevaluation was conducting their own independent review of the 2011 minimum flows report and the peer review comments on that report. Janicki Environmental also received a data directory which was used by the District in 2011 to support the proposed minimum flows and reviewed pertinent information from that directory. Janicki subsequently performed an in-depth review of the data and models used in the derivation of the minimum flows as well a review of reports describing various aspects of the modeling framework developed to support the recommended minimum flows. During this investigation, Janicki Environmental found several issues that would benefit from additional analyses. Therefore, datasets were updated and methods and analyses reexamined where needed to inform the reevaluation and the revised recommendations for minimum flows for the Upper Little Manatee River as provided in this document. The findings from this independent review, and a description of updates to the data and methods used for reevaluation are provided in the following sub-sections along with a description of how this information is used to establish the revised recommendations for minimum flows for the Upper Little Manatee River.

## 2.2 Data Review and Update

### 2.2.1 Rainfall

The period of record for evaluation of the rainfall and hydrology for the 2011 minimum flow report was defined as 1940 to 2009. These data were updated through 2014 for the reevaluation. The National Center for Environmental Information warehouses rainfall data collected by the National Weather Service (NWS). Three long term NWS rainfall gages exist within the Little Manatee River watershed and adjacent area: Hillsborough State Park, Parrish, and Plant City. The timeseries of monthly total rainfall for these gages are presented in Figure 2-1. The line breaks in the plots represent missing data within the period of record for each gage. The Plant City rainfall gage record is relatively complete back to the early-1930s, with some missing monthly values during the 1970s.

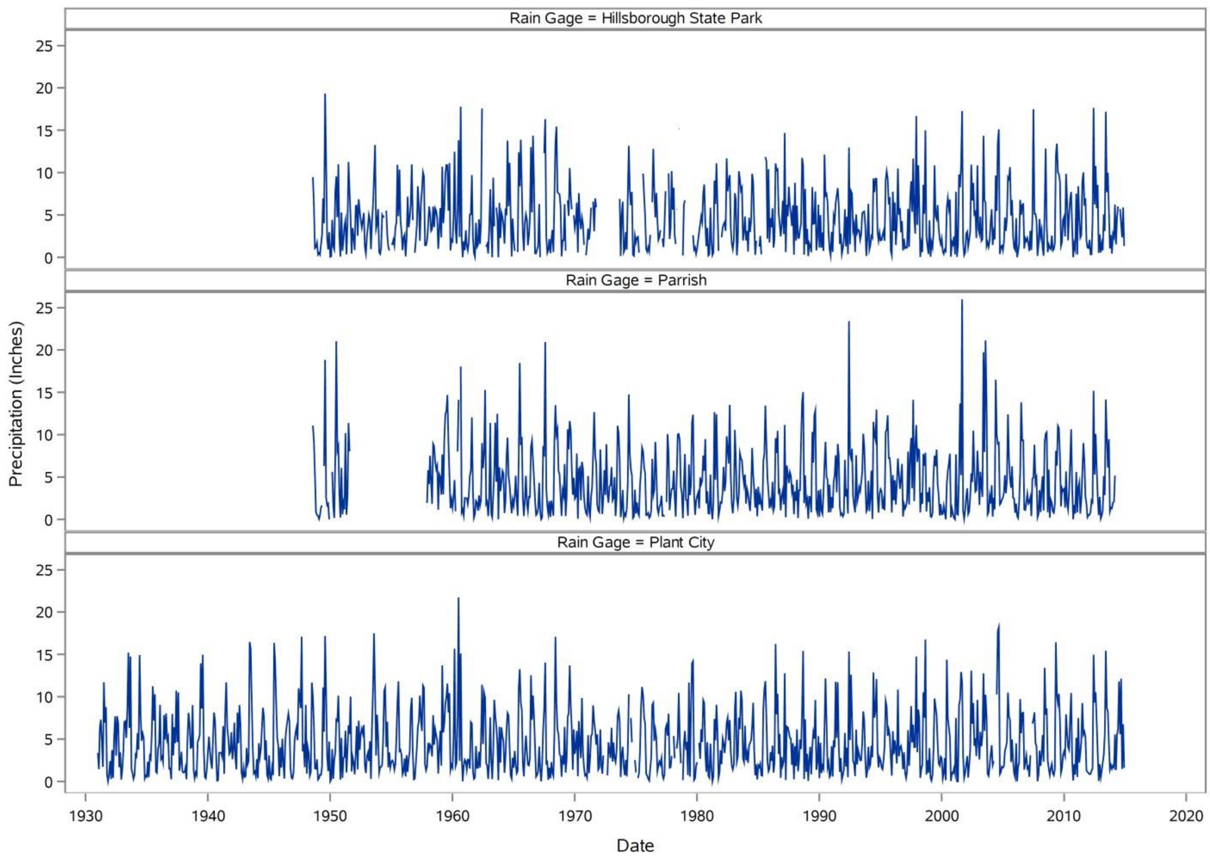



**Figure 2-1. Monthly rainfall time-series for three National Weather Service gages in the vicinity of the Little Manatee River watershed.**

Updating the rainfall data through 2014 did not change the conclusions of the 2011 minimum flows report regarding the description of the rainfall statistics or trends in rainfall over time. Annual average rainfall in the watershed is approximately 54 inches in a typical year with approximately 60 percent of the annual precipitation generated from “wet season” rains between June and September. Analysis of the Hillsborough River State Park, Parrish and Plant City rainfall records assessed for this reevaluation support the finding from the 2011 report that there were no observed trends in the monthly rainfall data over the period of record.

The 2011 minimum flows report also described a “benchmark” time period as a time when anthropogenic effects were thought to be minimized. This period was defined as the timeseries of flows prior to 1970 which was described as a breakpoint routinely used to develop minimum flows within the District. The benchmark period definition was based in part on examination of variations in the Atlantic Multidecadal Oscillation as described in other District reports (e.g. Kelly et. al. 2005a and b). As described in the peer review of the 2011 report, the choice of this breakpoint is very important and variation in the definition of the breakpoint can significantly affect the resulting analysis.

A succinct manner of displaying variability in rainfall over a long term timeseries is through the use of the Standardized Precipitation Index (SPI) (McKee et al. 1993) that standardizes rainfall to its long-term expected values. The SPI values can be integrated over various timescales to represent various antecedent conditions from one to sixty months. For example, the timeseries of the 12 month SPI values for the Parrish gage is presented in Figure 2-2. It is clear to see from Figure 2-2 that the mid to late 1970s and the early 2000s were periods of rather severe drought, while the late 1950s, early 1960s, and the mid-2000s were periods of well above average rainfall. Values over the most recent time-period suggest that the watershed recently recovered from a period of below average rainfall between 2010 and 2012.

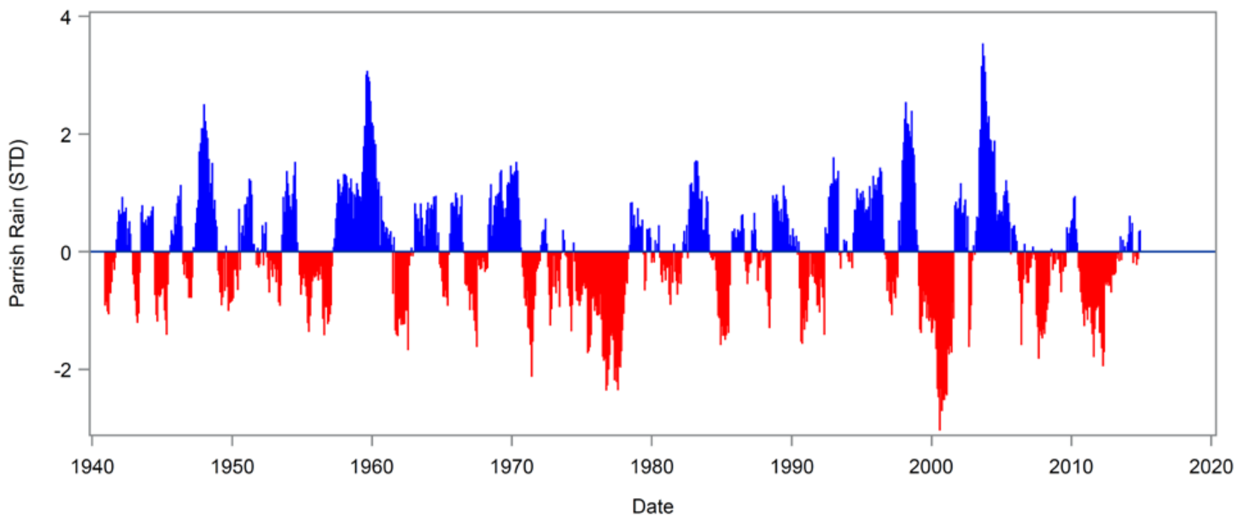



**Figure 2-2. Twelve-month Standardized Precipitation Index (SPI) values for the Parrish gage based on data from 1940 through 2014.**

These values are generated by comparing the sum of each 12 month period (e.g., January 1970 to December 1970) to the long term expected value of all periods that begin in the same window (e.g., the average of all annual sums beginning in January and ending in December of the same year). The values are then expressed as deviations from those expected values based on the gamma probability distribution and mapped to the standard normal distribution. Thereby, the y axis represents deviations from expected values according to the z statistic. The computations are performed for each month based on the moving window (e.g., 12 month) period (e.g. February to January, etc.). Values below zero indicate less than expected rainfall and values above zero represent periods of greater than expected rainfall. Droughts and surplus conditions can be categorized based on the following values (McKee et al. 1993):

- 2.0 +; extremely wet
- 1.5 to 1.99; very wet
- 1.0 to 1.49; moderately wet
- -.99 to .99; near normal
- -1.0 to -1.49; moderately dry
- -1.5 to -1.99; severely dry
- -2 and less; extremely dry

The rainfall data and the SPI are further detailed later in this document with respect to their use in reevaluating the minimum flows for the Upper Little Manatee River.

### 2.2.2 Streamflow

Streamflow is monitored by the U.S. Geological Survey (USGS) at three principal gages in the Little Manatee River. The most downstream gage (gage #1 in Figure 2-3) is located at the US Highway 301 bridge near Wimauma (USGS 02300500), which represents approximately 67% of the entire watershed. This was considered the gage of record for the 2011 minimum flows report and is the most downstream gage on the river that measures freshwater flow. This gage is also referred to in this document as the "Wimauma gage". An active USGS streamflow gage in the upper reaches of the river, with records that date back to 1963, is the Little Manatee River near Ft. Lonesome (#2: USGS 02300100) which measures flow from approximately 15% of the watershed. An active gage on the South Fork of the river (#3: USGS 02300300) has been operation since October 2000. That gage was also operated during 1987-1989, along with several other District sponsored gages (#'s 4, 5, 6) that were part of a study of the watershed that was conducted by the District and other agencies in the late 1980s.

The average daily discharge for the Wimauma gage over the period 1940 to 2014 was 168 cubic feet per second (cfs) and the median value over the same period was 61 cfs indicating that the distribution is skewed by high flow events, with daily flows recorded up to a maximum of 11,100 cfs (Figure 2-4).

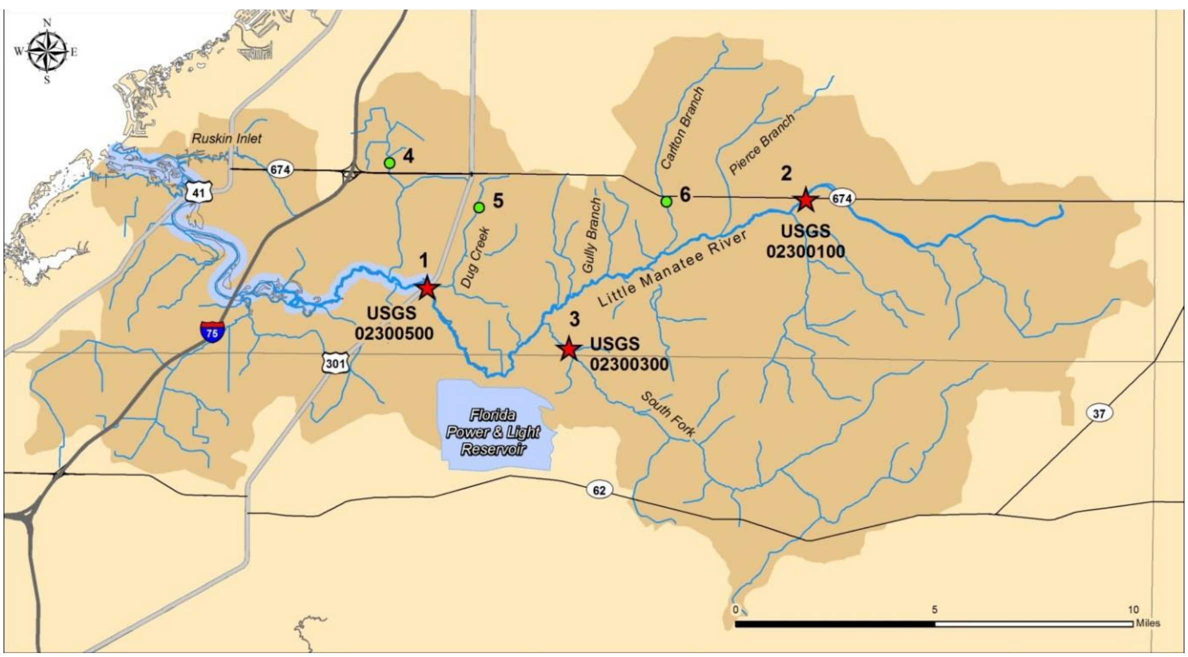



**Figure 2-3. Location of currently active (red stars) and previously operated (green circles) streamflow gages in the Little Manatee River watershed maintained by the USGS (replicated from Hood et. al., 2011).**

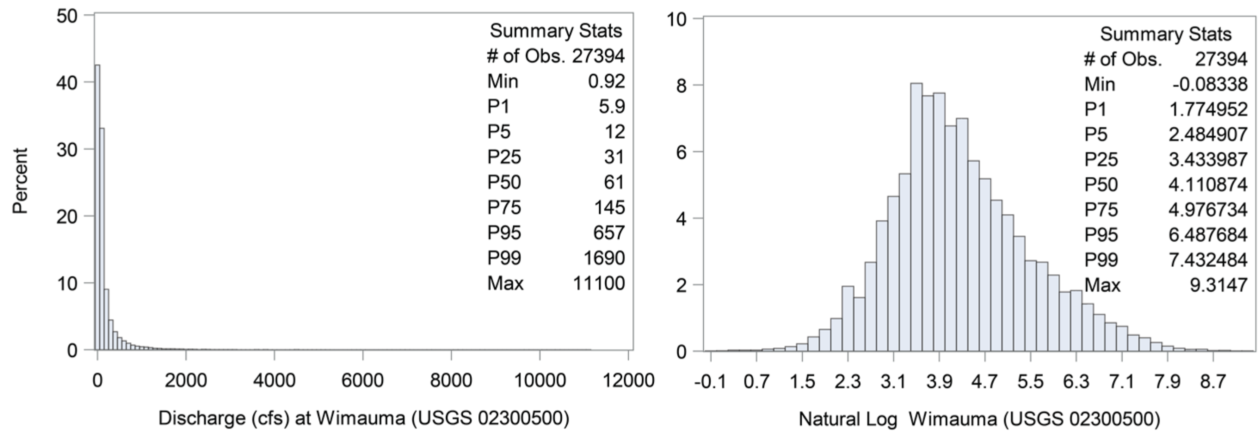



**Figure 2-4. Frequency histogram and summary statistics for discharge at USGS 02300500 – Wimauma from 1940 through 2014 on natural (left) and natural log transformed (right) scale.**

The 2011 minimum flows report found that the runoff rate for the Little Manatee River watershed was higher than either the Hillsborough River (at USGS Station 0230300, Hillsborough River near Zephyrhills, FL) or Alafia River (at USGS Station 02301500, Alafia River at Lithia, FL) which represent similar portions of their respective watershed areas. This indicates that the Little Manatee River is a relatively flashy system even though much of its watershed has remained rural.

### 2.2.3 Land Use Changes

Land use changes can affect natural stream flows and there are four principal anthropogenic influences to stream flows in the Little Manatee River: 1) development of rural or natural lands, 2) groundwater extractions, 3) surface water withdrawals, and 4) surface water discharges. These factors are all well described in the 2011 minimum flows report. Briefly, the effects of increasing groundwater withdrawals on saltwater intrusion have been particularly acute in portions of the Little Manatee River watershed and approximately half of the Little Manatee River watershed lies within the District-designated Most Impacted Area of the Southern Water Use Caution Area. As reported in Table 2-1 of the 2011 minimum flows report, while the acreage of citrus had remained relatively constant over time, large increases were reported in the acreage and irrigation quantities for tomatoes and other vegetable (row) crops in the region. Irrigation practices for row crops, particularly the “flood field” irrigation practices of the late 1970s and 1980s, were thought to contribute significantly to land-surface runoff by increasing the water table through the use of plastic underlayment that impedes infiltration, and by de-watering saturated fields to maintain constant water-table elevations. To update the analysis, the Land Use Land Cover dataset through 2011 (the most recent coverage) was acquired from the Southwest Florida Water Management District (SWFWMD 2012). These datasets include features categorized according to the Florida Land Use and Cover Classification System (FLUCCS). These features were photo-interpreted at 1:8,000 using 2010, 1 ft color infrared digital aerial photographs and include the FLUCCS Land Use code, and vegetation indicators. Since the time land-use analysis was conducted for the original freshwater MFL report, the District has revised some of the land use classifications for the 2004 data resulting in a minor discrepancy between the values reported here and those reported in the 2011 minimum flows report. In addition, the land-use classification of wetlands and water in the 1970s land-use coverage may be unreliable. The land-use information for the watershed reported in the 2011 minimum flows report was updated through 2011 and is provided in Table 2-1. It is evident that there has been an increase in developed urban land and mined lands and a decrease in rangelands over the time period. Agricultural lands peaked in 1999 and have been decreasing since while "Other Agriculture" category has continued to increase. A comparison between land use in 1990 and 2011 is provided in Figure 2-5 showing the increase in urban and mined lands within the watershed between those two time periods.

**Table 2-1. Changes in land use classification acreage over time in the Little Manatee River watershed.**

| **Land Use Type** | **Acreage by Year** | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **1974** | **1990** | **1999** | **2004** | **2007** | **2011** |
| Developed/Urban | 3,970 | 11,354 | 13,517 | 16,161 | 18,519 | 21,356 |
| Ag - Row Crop | 13,204 | 10,897 | 15,383 | 12,952 | 12,717 | 10,410 |
| Ag - Tree Crop | | 12,816 | 14,191 | 12,124 | 7,167 | 6,159 |
| Other Agriculture | 841 | 6,461 | 7,434 | 11,265 | 14,259 | 16,337 |
| Forested Uplands | 10,723 | 14,569 | 13,808 | 12,654 | 11,684 | 10,924 |
| Wetlands | 10,369 | 21,489 | 19,863 | 19,272 | 19,131 | 20,825 |
| Mines | 45 | 3,289 | 8,743 | 17,622 | 20,568 | 17,769 |
| Reclaimed Mines | . | . | . | . | . | 4,750 |
| Water | 681 | 4,997 | 5,175 | 5,236 | 5,436 | 5,609 |
| Rangeland | 102,299 | 57,659 | 44,938 | 35,810 | 33,614 | 28,956 |

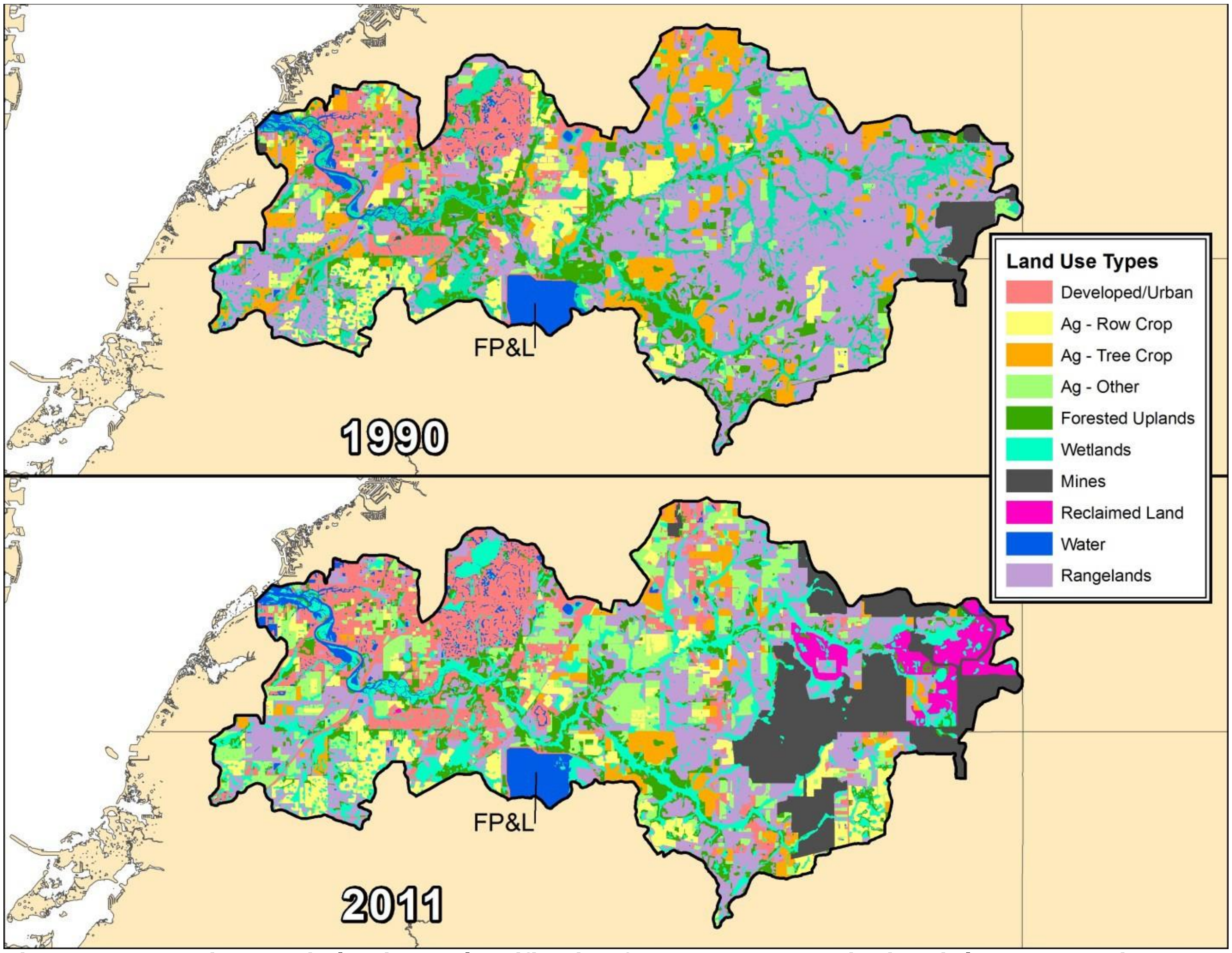



**Figure 2-5. Changes in land use classification from 1990 to 2011 in the Little Manatee River watershed. The Florida Power and Light reservoir is labeled in the center of each map.**

Developed and urban lands within the watershed have increased from 11,000 acres in 1990 to over 21,000 acres in the most recent land use survey. Mining lands increased until their peak in the 2007 land use survey. Some of the previously mined lands have recently transitioned to reclaimed mining lands. Agriculture in the Little Manatee River watershed peaked in 1999. Since 1999, the land for both row and tree crops has dropped significantly. Nearly 8,000 acres or 27% of the land which was used for tree and row crops in 1999 have been reclassified to “other open lands <rural>”. This category is defined by SWFWMD as lands that:

- Include dead or deserted crops or tree crops;
- Usually portrays a rough, uneven, shrubby texture but still portrays the appearance of agricultural processes (straight borders, old field markings, old grove lines, etc.)

The classification is predominantly used for previously farmed lands that have since not been used for cultivation suggesting that the Little Manatee River watershed is recently changing from a large agricultural area to one with less row and tree crops.

### 2.2.4 Surface Water Withdrawals and Discharges

Surface water withdrawals and direct and indirect discharges to the river can also affect flows in the Little Manatee River. Under its Water Use Permit, Florida Power and Light is permitted to withdrawal 10% of the river flow to supplement its cooling water pond when flows are above 40 cfs at the Wimauma gage. The permit also allows for an emergency diversion schedule (EDS) to be applied when water levels in the cooling pond fall below 62 feet above mean sea level under a special conditions provision. According to the conditions of the site certification, FP&L must notify the director of the Resource Regulation at the District prior to implementing the EDS. Analysis in the 2011 minimum flows report suggested that the historical range of FP&L withdrawals was between 0 to 506 cfs, averaging approximately 9 cfs, as calculated on a daily basis. Updating the withdrawal information through 2014 supported those general characterizations as portrayed in Figure 2-6 where periods of withdrawals have generally corresponded to periods of drought while little or no surface water withdrawals tend to occur during surplus conditions.

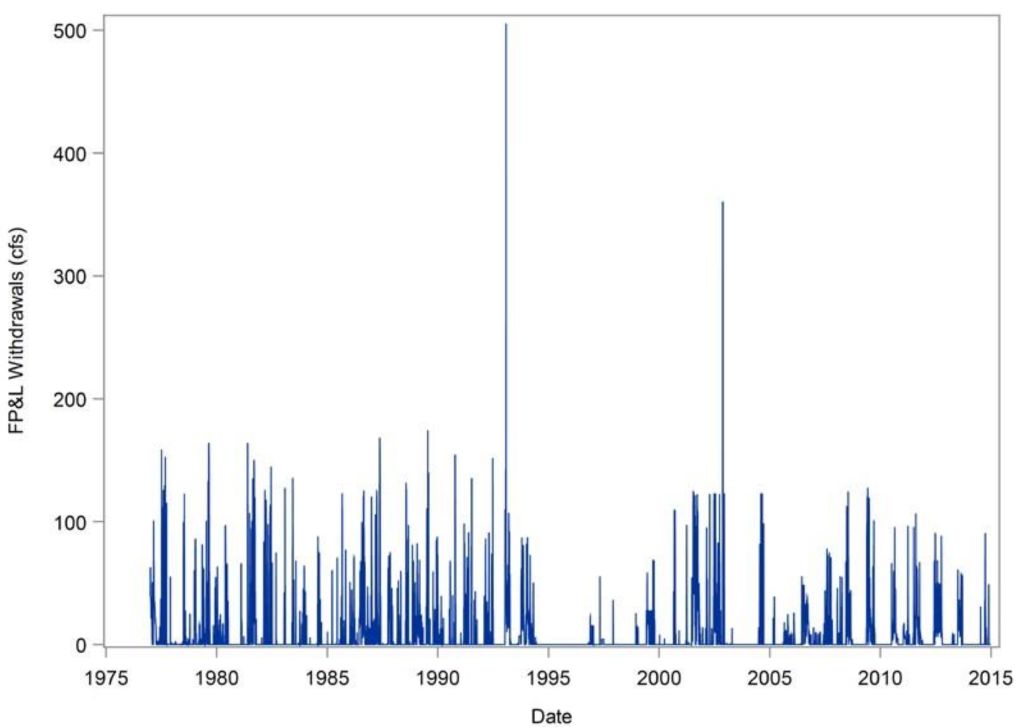



**Figure 2-6. Surface water withdrawal timeseries for the Florida Power and Light plant on the Little Manatee River.**

The Mosaic Company has a permitted surface water discharge, site D-001, that is located in the headwaters of the river on Alderman Creek. This outfall is managed under a permit issued by the Florida Department of Environmental Protection. The site is used to discharge stored surface water from mined lands during times of elevated rainfall amounts as reported by the

2011 minimum flows report. A time series plot of daily discharges reported in the 2011 minimum flows report is provided in Figure 2-7. There was no attempt in the 2011 minimum flows report to account for potential effects of mining on historical flow trends or other characteristics of the streamflow data. Daily discharge information is not available from the District after 2009. While it is clear from the land use analysis that the acreage of mined lands has increased in the watershed discharge records reported as monthly hydrologic loads through 2014 for this site suggest that there have been only a few occurrences of significant discharges since 2009 (Figure 2-8).

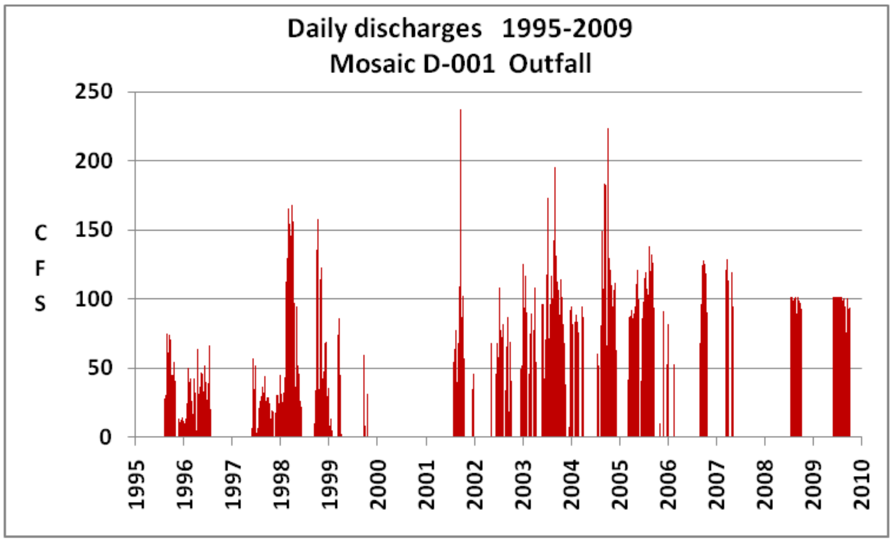



**Figure 2-7. Figure 4-16 from Hood et. al., 2011 displaying daily discharge values for the D-001 outfall through 2009.**

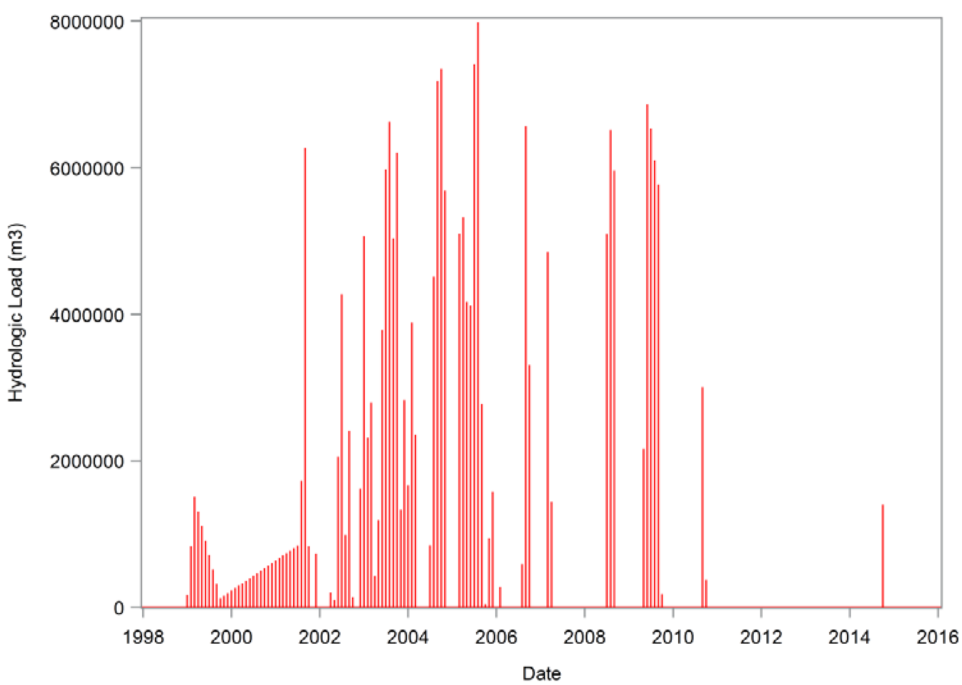



**Figure 2-8. Monthly hydrologic loads (1999-2014) for the D-001 outfall.**

Indirect discharge to the river in the form of runoff from agricultural irrigation has also been identified to have potential to affect streamflows in the Little Manatee River. The 2011 minimum flows report described the effects historical agricultural practices, which are reliant on groundwater resources, have had on stream flows. Specifically, "flood field" irrigation practices associated with row crop agriculture was identified as a principal contributing factor to higher than expected stream flows in the 1980's and 1990's. As described in the 2011 minimum flows report, the Little Manatee River lies within the District's Southern Water Use Caution Area (SWUCA) which includes portions of the Manatee, Myakka, and Peace River watersheds and approximately half of the Little Manatee River is included in the Most Impacted Area (MIA) of the SWUCA as a consequence of increased water use and saltwater intrusion in the area. The 2011 minimum flows report described historical increases in groundwater use due to an estimated ten-fold increase in row-crop agriculture between 1974 and 2004, with tomatoes being the primary crop but strawberries, cucumbers, melons, and other crops grown as well. Agricultural runoff was identified as a principal contributing factor to the observed increase in flows in the Little Manatee River. Similar increases in agricultural land use between the 1970s and 2000 have also been reported as part of establishing minimum flows and levels for the Peace and Myakka Rivers (Kelly et al. 2005a and b). Augmentation of existing flows due to agricultural practices was reported for both systems. However, no correction for excess agricultural flows was reported in the Middle Peace River minimum flows report and the agricultural correction was only used in the compliance assessment portion of the Upper Myakka River minimum flows study (Kelly et al. 2005b). No adjustments within the modeling framework were made to explicitly account for excess agricultural runoff in model calibration or verification for these systems.

The analysis conducted for the 2011 minimum flows report included multiple attempts to correct for what they considered to be the effects of agricultural runoff to the system. A flat 15 cfs quantity was first considered as part of the modeling framework for the HEC-RAS and PHABSIM analysis which was subtracted from the flow record to generate a baseline condition. Subsequently, as described in section 4.2.7 of the 2011 minimum flows report, and alternative method was considered that adjusted the flow timeseries by matching the flow duration curves of the pre-impacted or benchmark flow period identified in the 2011 report. However, it is unclear that this method was actually ever used to adjust the flow timeseries for analysis or included as part of recommended minimum flows criteria. These methods were reviewed and reevaluated in this document which is further detailed in sections 2.2 and 3.1

## 2.3 Review of Models and Analytical Methods

This section provides a detailed review of the models and analytical methods used in the 2011 minimum flow report to provide context to the reevaluation described in this document.

### 2.3.1 Benchmark Flows and Correction for Agricultural Runoff

As described in section 1.3, the peer review panel recognized that the development of the proposed minimum flows in the 2011 minimum flows report was based on two flow periods – a "wet flow" period from 1940 through1969 and a "dry flow" period from 1978 through 2009; however, they stated that the study could benefit from analysis of the hydrology that considers more than just the identified time period. Rather than accepting this division of the entire time period by default, the Panel recommended that additional analysis for the Little Manatee River be performed to confirm the appropriateness of this time division, or perhaps even refine it. As described in the peer-review report, the choice of the breakpoint is important and variation in the definition of the breakpoint can affect the resulting analysis.

The selection of the breakpoint defining the benchmark flow period also has significant implications on the calculation of the agricultural excess flow correction described in section 4.2.7 of the 2011 proposed minimum flows report. That excess flow correction relied on the benchmark flow period (i.e.,1940-1969) and derived a correction factor for excess flows for the 1978-2009 time period by adjusting the various percentiles of flow in the more recent time period to match that of the Benchmark time period. The result was that the two flow duration curves had nearly identical properties. This correction was then proposed to be assigned as the agricultural runoff correction for the more recent time-period and removed to create the baseline condition.

This adjustment was intended to be used to correct the flow record to derive a baseline condition that best represented the streamflow to the system in the absence of anthropogenic effects. However, independent review of this correction factor revealed that the agricultural correction method described in Section 4.2.7 of the 2011 minimum flows report does not appear to have been used in the model framework. Instead, the PHABSIM and HEC-RAS modeling efforts described on a non-varying 15 cfs reduction of all flows after 1977 to derive the agricultural corrected baseline flow record for use in those model estimates. In addition, the approach described in section 4.2.7 resulted in the largest flow adjustments during the dry season which is counter to findings from the Myakka River where a highly sophisticated integrated ground water – surface water model was used to estimate the influence of agricultural practices on greater than expected streamflow (Flannery et al. 2011). The MIKE SHE model was used in the Lower Myakka River report to generate estimates of the daily median flow that was thought to be due to excess agricultural runoff. The reported expected intra-annual pattern of excess flows is portrayed in Figure 2-32 and 2-33 in the Lower Myakka minimum flows document (Flannery et al. 2011). The latter of these two figures is provided as Figure 2-9 below.

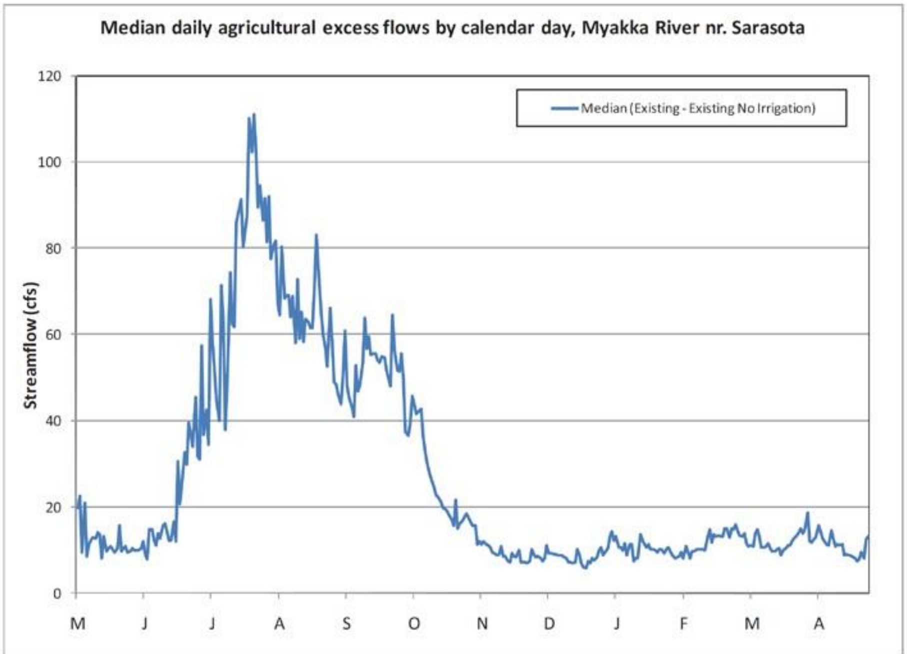



**Figure 2-9. Results of MIKE SHE application to estimate the contribution to Myakka River flows due to excess agricultural runoff as reported in Figure 2-33 of the Myakka River minimum flows report (Flannery et al. 2011).**

Based on this review, we reexamined the agricultural correction methods used in the 2011 minimum flows report and derived an alternative method described in section 3.1 of this document that more closely resembles the seasonality described for the Myakka River and is more closely aligned with known agricultural practices in the watershed.

### 2.2.2 2011 Hydrologic Engineering Centers River Analysis System (HEC-RAS) Model

The Hydrologic Engineering Centers River Analysis System (HEC-RAS) model developed for the Little Manatee River (ZFI 2010) was the single most important component of the technical analyses supporting development of the minimum flows proposed in 2011, as it was used to address fish passage, wetted perimeter, woody habitat, and hydrologic connections between the river channel and floodplain. Despite the importance of the model, there was no discussion in the peer-review report regarding a review of the HEC-RAS model framework developed by ZFI (2010) or of the adequacy of HEC-RAS modeling for minimum flows development. Therefore, we completed an in-depth review of the HEC-RAS report and the HEC-RAS model that were provided by ZFI to the District as deliverables.

There are multiple estimation routines within the HEC-RAS model framework. The estimation procedures included a Hydrologic Modeling System (HEC-HMS) to estimate the surface runoff to the channel, and the use of the HEC-RAS model to estimate river stage and velocity at various places along the river under different flows (ZFI 2010). Model calibration and validation was performed at the cross section located at the Wimauma gage which is the downstream end of the model domain. Calibration was based using select events between 2007 and 2009. The model was developed under the assumption of a steady state condition indicating that a single unique solution for elevation at each cross section would be obtained for each given flow at the Wimauma gage. As stated in ZFI (2010), the model was calibrated to the Wimauma gage with FP&L withdrawals added back in and the 15 cfs was removed through a location specific flow-stage adjustment. This adjustment process, however, was not clearly described in the report and is different from that reported as the agricultural correction method in section 4.2.7 of the 2011 minimum flows report. An in depth review of the model and report identified the following issues with the HEC-RAS model used in the 2011 minimum flows report:

- Very little, if any survey data was used in developing the cross-section geometry.
- LIDAR data were the principal data source used to derive the cross-section geometry resulting in a flat channel profile for the instream portion of the cross sections, essentially estimating the water surface elevation at the time the LIDAR was flown as the bottom channel elevation.
- The cross sections were relatively short and didn't span the entire floodplain, resulting in inadequate representation of the potential for ineffective flow areas.
- Parameterization of the expansion and contraction coefficients in the HEC-RAS model appears to be constant throughout the entire river.
- The Triangular Irregular Network (TIN) used in the model was built on a variety of data sources; the comparability of these various sources was not addressed.
- Reference is made to the problem in the conversion from a TIN to a digital elevation model (DEM) due to a "data variance" but there was no discussion as to how this problem was addressed.
- Several tributaries to the main stem of the river had identical flow characteristics for at least some, and in some cases, all of the profiles in the input model file.

Since the development of the HEC-RAS model in 2010, A Surface Water Management Model (SWMM) was completed for the Little Manatee River as part of the Hillsborough County Watershed Management Plan for the Little Manatee River (Jones Edmunds 2015). We acquired this model and used the results to compare estimated flow-stage curves from the HEC-RAS model and the SWMM model for cross sections located in very close proximity to one another in these models. It should be noted that the SWMM model is not a steady state model and therefore backwater effects can result in a distribution of predicted elevations for a particular flow since the model depends in part on the antecedent hydrograph. This evaluation suggested that the estimated flow-stage curves for these model cross-sections diverged from one another with increasing distance upstream from the Wimauma gage. For example, two locations are compared in Figure 2-8, one near the gage (left) and one far upstream of the gage (right). It was clear from this analysis that these model estimates diverged significantly in terms of both the predicted water surface elevations and the response in elevation as a function of flow. Given that the SWMM model used actual surveyed data for cross-section geometry and that the cross sections extend farther into the floodplain, the SWMM model was assumed to be the best model for representation of the general flow–stage curve relationships in the river segment..

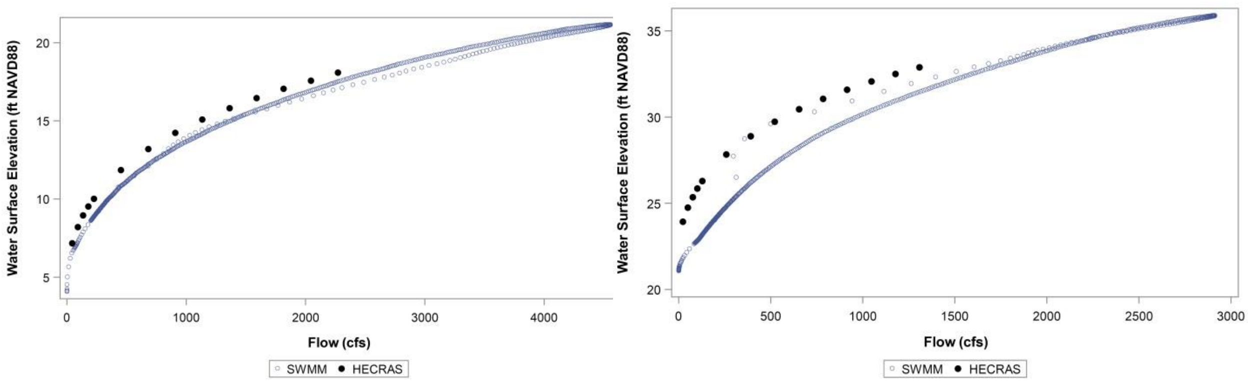



**Figure 2-10. Comparison of flow stage curves at two locations in the Little Manatee River above US 301, near the USGS gage (left) and far upstream of the gage (right). The HEC-RAS model prediction is represented by the black filled circle and SWMM model prediction represented by the blue open circles.**

The comparison between the HEC-RAS and SWMM model output, as well as the deficiencies noted above for the HEC-RAS model, resulted in a recommendation to use information from the SWMM model to refine the HEC-RAS model. Because the HEC-RAS model is used to identify threshold criteria for several resources of concern including fish passage, wetted perimeter, woody habitat, instream habitat simulation, and hydrologic connections between the river channel and floodplain, it is very important to ensure that the model is well calibrated throughout the river segment. Refining the HEC-RAS model would also help ensure that the most up-to-date, “best available information” was used for this re-evaluation. Therefore, the HEC-RAS model was refined to more closely match the general flow-stage relationship predicted by the SWMM model by importing the SWMM model geometry, including the surveyed cross sections, into the HEC-RAS model and recalibrating the HEC-RAS model. This is described in detail in section 3.2 of this document.

### 2.2.3 Physical Habitat Simulation (PHABSIM) Model

The Physical Habitat Simulation (PHABSIM) analysis used to assess the in-channel habitat suitability criterion reported in the 2011 minimum flows analysis was also reviewed. There was no formal PHABSIM report available for review, only a document describing application of the PHABSIM protocols to the Little Manatee River and a description provided in the 2011 minimum flows report. As described in the 2011 minimum flows report, Physical Habitat Simulation analyses were conducted for two representative sites on the Little Manatee River. Dry climatic period (1970-2009) and wet climatic period (1939-1969) time-series were run for each site.

Monthly discharge files were created for existing conditions, 10% monthly flow reductions, 20% monthly flow reductions, 30% monthly flow reductions, and 40% monthly flow reductions. For each set of discharge conditions, a monthly time-series was created as the amount of habitat (WUA) available for each discharge for each month. The simulated flow ranges did not encompass all low flows in the available historic available, in some instances, and did not encompass a few of the highest flows. An appropriate regression (usually first- or second-order polynomial or piece-wise linear regression) was used during time-series analysis to create WUA values for the very low and high flows. Since these flow values occurred less than 5% of the time in the historical record, they are unlikely to affect the overall estimate of MFL's at a 15% habitat loss. Duration analysis was then accomplished through the percentage of time that the average and median habitat values were met or exceeded for each month over the period of record. Comparisons to existing conditions were made to evaluate the amount of habitat gain or loss under conditions of reduced flow. Flow reductions that resulted in no more than a 15% reduction in available habitat from historic conditions were determined to be limiting factors. This was calculated by combining the WUA for all PHABSIM sites for each species, life stage, or guild. The assumption was made that the entirety of the study reach was represented equally by the selected PHABSIM sites, as was the goal during the site selection process. This calculation was made for each block. The resulting allowable percent reductions for the Wimauma gage were 9, 11 and 11 percent for Blocks 1, 2 and 3, respectively.

As pointed out in peer-review, The PHABSIM approach to quantifying fish habitat is the standard for many fish management though it only considers habitat to be comprised of physical factors: depth, velocity, and substrate. However, analysis was limited to only two sites in the lower portion of the Upper Little Manatee River resulting in peer review to question the representativeness of those sites to generalize the result for the entire segment of the river. In addition, independent review noted that, while the PHABSIM results were used to set criteria for Block 3, it was noted that the simulations for high flows in both locations were said to be unreliable for at least one transect. As part of the reevaluation of the 2011 report, the District contracted for the development of additional analysis on instream habitat suitability using the System for Environmental Flows Analysis (SEFA: Aquatic Habitat Analysts, Inc. 2012) to address peer-review comments on the PHABSIM analysis specifically with respect to generalizing the inference of PHABSIM to be more representative of the Upper Little Manatee River. The results of reevaluation of the PHABSIM results using SEFA are further discussed in section 3.5.

### 2.2.4 Wetted Perimeter and Fish Passage

As described in the 2011 minimum flows report, wetted perimeter and fish passage are techniques employed to evaluate the low flow threshold typically associated with minimum flows criteria recommendations. Wetted perimeter is defined as the cross-sectional area of the streambed from wetted edge to wetted edge (Heinz and Woodard 2013) while the fish passage criterion was defined as the flow which allow 0.6 feet of hydrologic depth over the most sensitive cross section. Studies on streams in the southeast United States have demonstrated that the greatest amount of macroinvertebrate biomass per unit reach of stream occurs on the stream bottom (e.g., Benke et al. 1985). Although production on a unit area basis may be greater on snag and root habitat, the greater area of stream bottom along a reach makes it the most productive habitat under low flow conditions (Heinz and Woodard 2013). By plotting the response of wetted perimeter to incremental changes in discharge, an inflection can be identified in the resulting curve where small decreases in flow result in increasingly greater decreases in wetted perimeter. This inflection point on the curve represents a flow at which the water surface recedes from stream banks and habitat is lost at an accelerated rate (Stalnaker et al. 1995). According to Heinz and Woodard (2013), the wetted perimeter - discharge curve can then be used to identify the lowest breakpoint, which defines the threshold below which aquatic habitat conditions for benthic invertebrates rapidly decline. An example is provided in Figure 2-11 (reproduced from Heinz and Woodard 2013) where multiple inflection points are determined from the hydrograph and the "breakpoint" was identified as the lowest inflection point. Riffle sites are typically selected because they are typically shallow, depth-sensitive areas of a stream that are most impacted by changes in flow, and they are critical habitats for benthic macroinvertebrates that fish eat (Heinz and Woodard 2013).

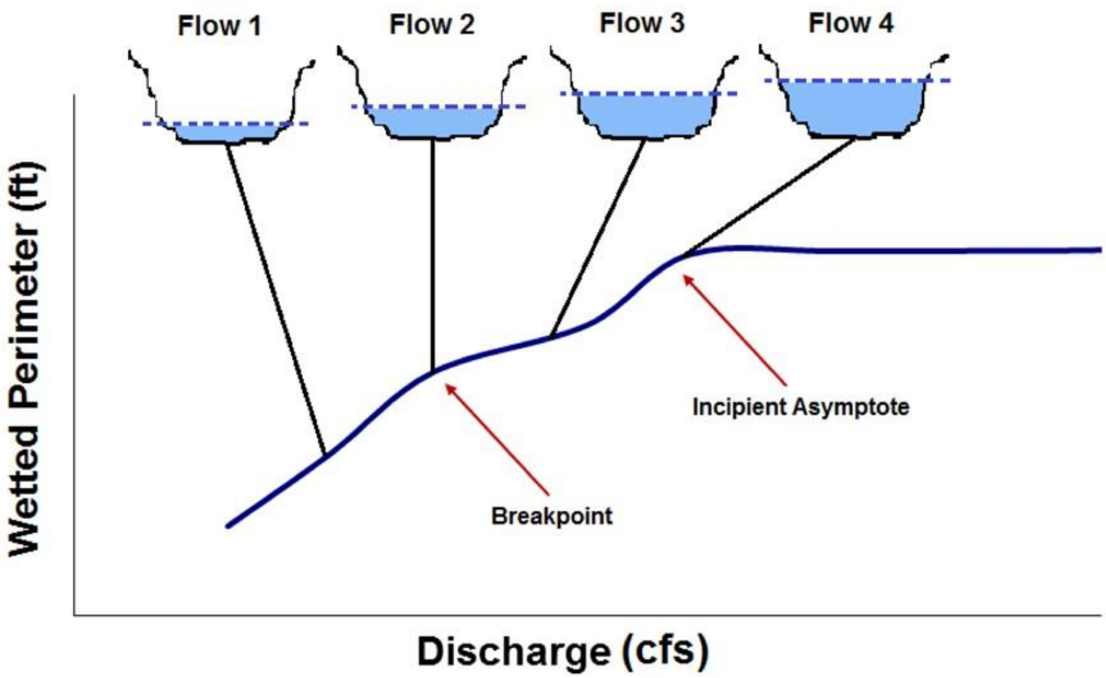



**Figure 2-11. Inflection point definitions as described in Figure 2 of Heinz and Woodard 2013.**

This point is defined as the "lowest wetted perimeter inflection point" (LWPIP) in District terminology. It should be noted that the Upper Little Manatee River has few locations that would be traditionally considered "riffle" habitats. The river is generally well incised, shallow, with silty sand bottom and few rocky areas throughout. The 2011 minimum flows report identified 30 cfs wetted perimeter criterion and a 35 cfs fish passage criterion which was subsequently recommended as the low flow threshold, below which no withdrawals would be allowed.

Ensuring sufficient flows to support the longitudinal connectivity for the natural passage or movement of fishes along a river is an important component of the development of minimum flows. As described in the 2011 minimum flows report, maintenance of these "fish passage" flows is expected to promote natural patterns of continuous flow within the channel or river segment, allow for recreational navigation (e. g., canoeing), improve aesthetics, and avoid or lessen potential negative effects associated with pool isolation (e. g., high water temperatures, low dissolved oxygen concentrations, localized phytoplankton blooms, and increased predatory pressure resulting from loss of habitat/cover). To secure the benefits associated with connectivity and sustained low-flows, a 0.6-ft fish-passage criterion was used to develop a low-flow metric for the Upper Little Manatee River. This fish-passage criterion is routinely used by the District for minimum flows development and was considered acceptable by the panel that reviewed the recommended Upper Peace River minimum flows report (Gore et al. 2002) as well as subsequent District minimum flows peer review panels convened to review minimum flows for freshwater lotic systems. For example, Shaw et al. (2005) note “the 0.6-ft standard represents best available information and is reasonable”.

Because the HEC-RAS model was revised as part of the reevaluation, the wetted perimeter and fish passage analysis were reevaluated as part of developing the revised minimum flows recommendations in section 3.3 and 3.4.

## 3.1 Reevaluation of Proposed Minimum Flows

The following sections detail analytical work to enhance the model framework used in establishing the proposed minimum flows for the Upper Little Manatee River. The efforts included:

- a new derivation of the excess flows observed in the historical flow time series at the USGS Little Manatee River near Wimauma, FL gage (02300500);
- improvements to the HEC-RAS model to estimate river stage throughout the river segment over the range of observed flows;
- revised analysis of wetted perimeter and fish passage criteria using the revised HEC-RAS output;
- SEFA analysis to generalize the results of the previous PHABSIM analysis to the entire main stem of the Upper Little Manatee River to evaluate instream habitat suitability requirements for common fish species utilizing the system, and
- floodplain inundation analysis to evaluate the effects of flow reductions on the frequency and extent of floodplain inundation to protect floodplain wetland vegetation and biogeochemical processes.
- An alternative to the calendar-date-based “building block” approach that links seasonality in flows with resourced-based flow requirements which are seasonally dependent (e.g., floodplain inundation requirements and wet season flood flows).

## 3.2 Benchmark and Excess Flows

This section describes evaluation of the benchmark Flow periods in response to peer-review comments and an investigation into alternative ways to formulate the correction for anthropogenic contributions to historical excess flows as described in the 2011 proposed minimum flows report.

### 3.2.1 Benchmark Flows

There are three principal concerns with the derivation of the benchmark flow period based on review of the 2011 minimum flows report. Namely:

- The comparison did not consider potential differences in rainfall between the two periods.
- The 1970 to 1977 period, which was an extremely dry period, was removed from the analysis.
- The choice of alternative benchmark periods may have a significant impact on the results.

To address peer-review comments, and account for the effects of rainfall in the selection of the breakpoint defining the two time-periods, we used permutation based change-point analysis described by Hothorn et al. (2006). The change-point analysis method uses a model-based recursive partitioning algorithm to build linear regression models that are partitioned based on an explanatory variable (in this case year). The algorithm conducts many binary splits of the time periods and chooses the breakpoint as the value (year) that maximize the difference in the relationship between any two time-periods. In this way, the method provides a statistically-based, objective selection of the historical benchmark time period that is based on statistically sound methods and also describes variations in the rainfall-flow relationship that may be useful in assigning the agricultural correction values.

Statistical analysis was conducted by relating monthly average streamflow records for the Wimauma gage to a 2-month Standardized Precipitation Index (SPI) based on long-term rainfall data from the NWS Plant City rainfall gage. The flows at were corrected for FP&L withdrawals, natural log transformed, and standardized against a normal distribution creating a standardized index for streamflow as well as rainfall. Change-point analysis was then conducted using these data and recursive partitioning based on linear regression described above. Once the first change-point in this relationship was identified, the algorithm repeated within each subset until stopping criteria based on statistical inference were met, at which point the recursive algorithm stopped.

The results of the change-point analysis are provided in Figure 3-1. The first breakpoint occurs in 1977 suggesting that the relationship between flows and rainfall are different after 1976. The results support the Districts selection of the 1970s as a decade where the rainfall-flow relationship may have changed due to anthropogenic effects though there were short term droughts and surplus rainfall events throughout the time-period. These results provide additional evidence to support the previous definition of the benchmark flow time-period and improve the analysis by:

- including the 1970s time-period,
- accounting for the effects of rainfall in the evaluation of the flow time series, and
- allowing for an objective, statistically sound method to identify the point that maximizes the difference between the two time-periods.

Additional splits within each of the principal time periods (i.e., before and after 1976) are more likely due to short-term climatic events and were ignored for the purposes of this analysis.

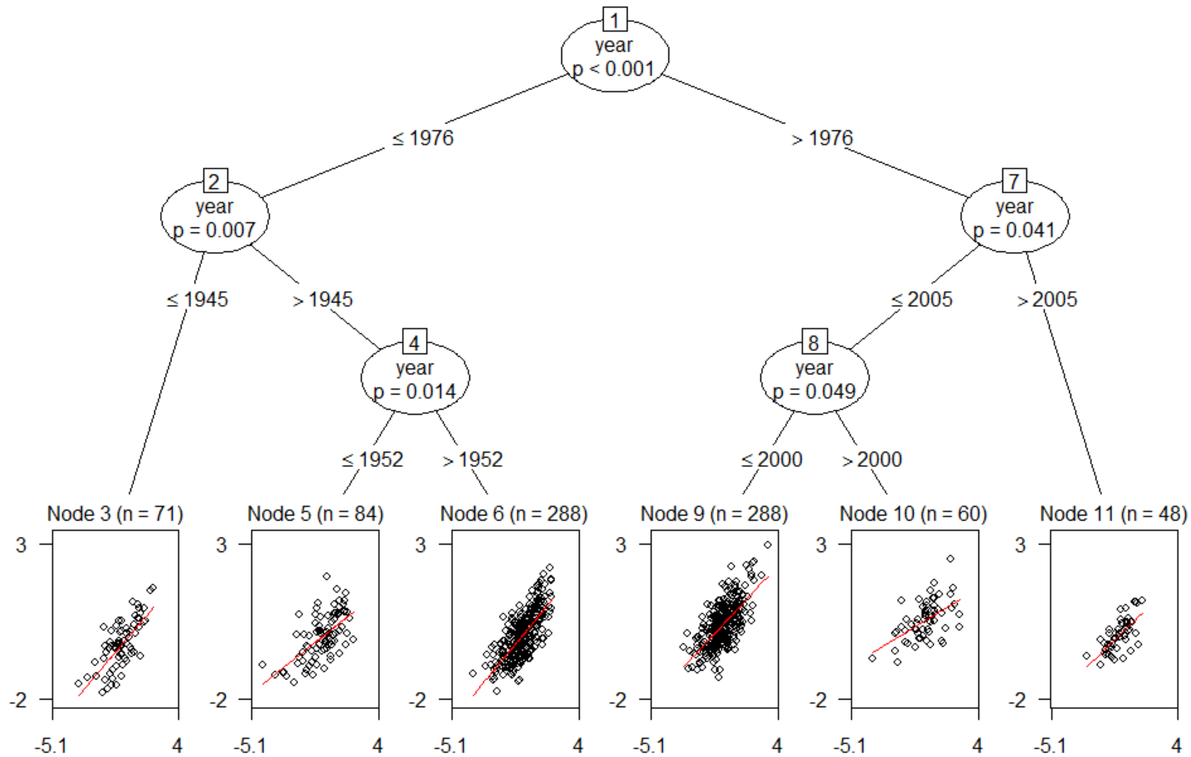



**Figure 3-1. Results of model based recursive partitioning of the rainfall flow relationship using the standardized precipitation index (x axis) and standardize monthly average flow (y axis) partitioned based on time (year).**

The result of the benchmark period analysis is important in that it identifies a period of time assumed to be relatively free of anthropogenic effects in the watershed, and land-use analysis supports that indeed the period of time prior to 1977 was comparatively free from the effects of mining, surface water withdrawals and large scale row crop agriculture. However, it is also important to remember that both time periods included significant periods of drought and surplus conditions without any strong evidence that the different periods represent opposing long term “wet” and “dry” periods associated with the Atlantic Multidecadal Oscillation as expressed in the 2011 proposed minimum flows report. This revised benchmark flow time period was subsequently used to investigate an alternative method to account for the potential excess flows in the freshwater segment of the Little Manatee River as further described below.

### 3.2.2 Excess Flows

Excess flow from agricultural runoff was identified in the 2011 minimum flows report as a principal source of excess flows to the Upper Little Manatee River. The excess flows were attributed to historical flood-field irrigation practices in which ridges and furrows are constructed and the fields flooded to control water table depths. To better describe the effects of these historical practices, we reached out to Jennifer Brunty, Ph.D. (District Facilitated Agricultural Resource Management Systems Program i.e., FARMS Program) to better understand local agricultural practices including timing of intensive water uses and causes of excess runoff due to these practices. Dr. Brunty suggested that bed preparation, crop establishment, and freeze protection were the most intensive water uses for typical flood field row-crops (strawberries and tomatoes). Bed preparation, including building of ridges and furrows and requires the saturation of the sandy soils which are dominant in the Little Manatee River watershed. Bed preparation generally starts sometime in July depending on how many acres and how many pieces of equipment a farmer has available. Bed preparation also includes laying plastic underlayment. Together, the artificially-raised water tables and the plastic underlayment in the fallow fields in the summer can increase summer runoff even though summer is a relatively unproductive time for row crop agriculture. Strawberry harvest can last until April and tomato harvest can last into June depending mostly on the market prices which can be influenced by international trade as well as local supplies. Controlling water table depths is an important part of cultivation throughout the growing season. However, it should also be noted that seasonality and inter-annual variation in row-crop agricultural water use in southwest Florida is affected by many factors over time including crop type, irrigation type, changes in antecedent rainfall deficit, and economic forces affecting crop market prices.

Given the results of the benchmark period analysis, the benchmark time period was used to develop a rainfall streamflow relationship that would define the expected amount of flow given rainfall in the watershed. Given that streamflow is a resultant combination of localized flows occurring close in time to the streamflow measurement as well as antecedent effects of rainfall at larger spatial and temporal scales. Therefore, statistical analysis was conducted using a linear regression approach to estimate the rainfall-flow relationship of the revised benchmark period (i.e., pre-1977). The regression related deviations from long term averages in both rainfall and flows prior to 1977. The SPI index values for plant City and Parrish rain gages between 1 and 12 months were used to predict deviations from monthly natural log average flows over the time period based on measurements at the Wimauma gage.

The resulting regression included four independent terms; the 1, and 4 month SPI values based on the Parrish gage, which represents the near field effects of rainfall, and the 2 and 12 month SPI values from the Plant City gage which represent the far field effects of rainfall on streamflows in the Little Manatee River. A seasonal term was included to account for the potential for different rainfall - flow relationships as a function of season. The resulting $R^2$ was 0.66. All rainfall coefficients were positive and highly significant while the seasonal term was marginally significant (p=0.03). A season-rainfall interaction term was explored but was found to not significantly contribute to variation in streamflows.

A partial plot displaying the relationship between the 2-month SPI index and the standardized flows is provided in Figure 3-2. The fit diagnostics for this regression are presented in Figure 3-3 and indicate that the regression generally meets the assumptions of linearity, normality, independence (Durbin Watson=1.39, VIF < 3), and homoscedasticity, despite the fact that a significant amount of variation remains unexplained by this model. Further details of the regression, including the ANOVA table, parameter estimates, residual diagnostics and tests for serial correlation and multicollinearity (i.e., VIF) and plots of the predicted relationship as a function of the independent terms are provided in Appendix A.

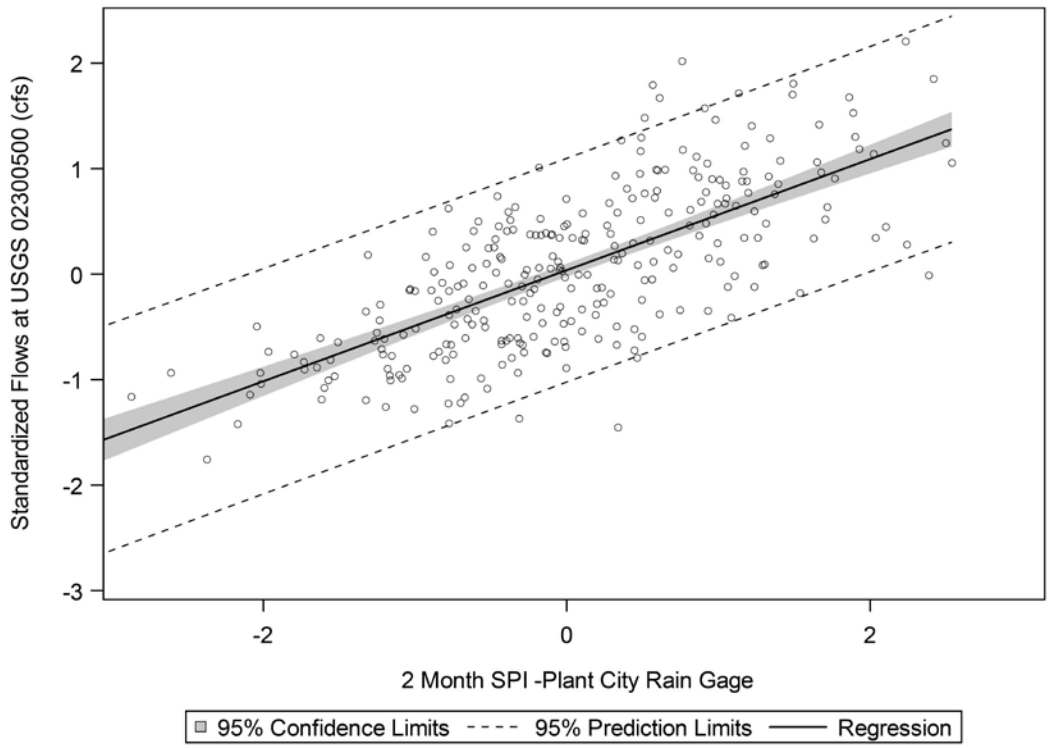



**Figure 3-2.** **Partial plot displaying linear relationship between the 2-month standardized precipitation index for Plant City rain gage and standardized monthly flows at the USGS gage 02300500-Wimauma.**

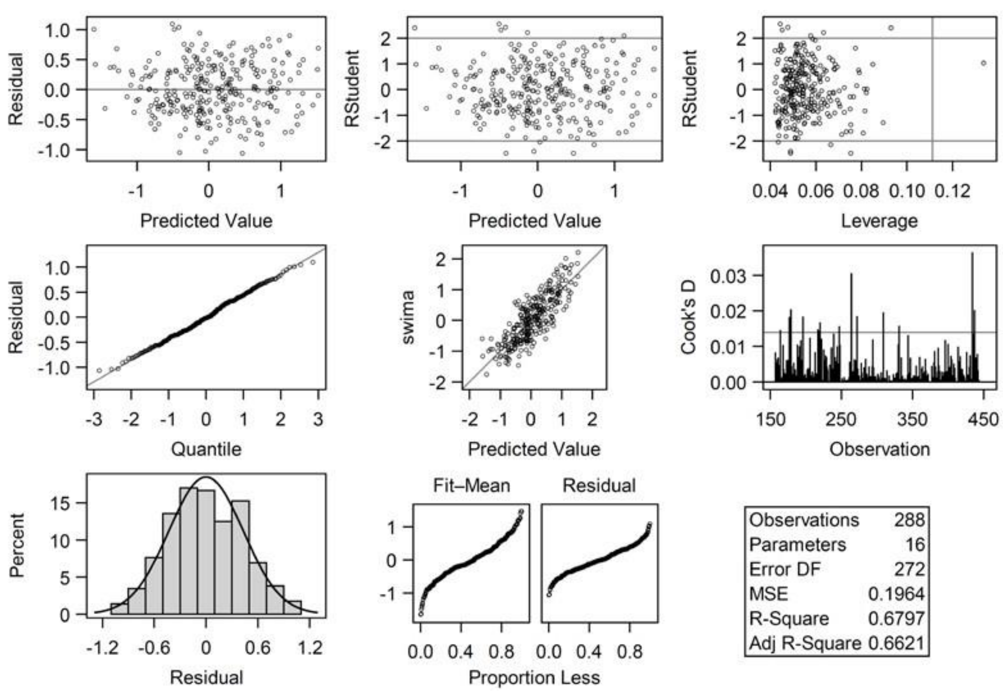



**Figure 3-3.** **Fit diagnostics for the rainfall streamflow regression using SPI values and standardized monthly flows at the USGS gage 02300500-Wimauma.**

The predictive regression equation developed on the pre-1977 relationship was then used to predict streamflows post 1976 based on the independent terms in the regression model. Any bias in the residuals between the predicted and observed flows post 1976 was attributed to and became the estimate of anthropogenic effects on the rainfall - flow relationship. The residuals of the regression are plotted as a time series in Figure 3-4. The residuals are calculated as the result of subtracting the observed values from the predicted values. Therefore, a negative residual indicates that there is more streamflow than expected based on the predicted relationship.  Beginning in 1977, there is a noticeable trend in the residuals suggesting systematic bias due to excess flow compared to that expected based on the regression for the pre-1977 period. There is also a noticeable trend in the residuals back towards zero after 2000 which corresponds to the updated land-use information showing increases in conservation lands and decreases in active agricultural lands in the watershed as well as implementation of agricultural best management practices. There are two residual trend lines in Figure 3-4 ; a smooth curve representing the monthly trend and another smooth curve representing the long term trend in residuals over time.

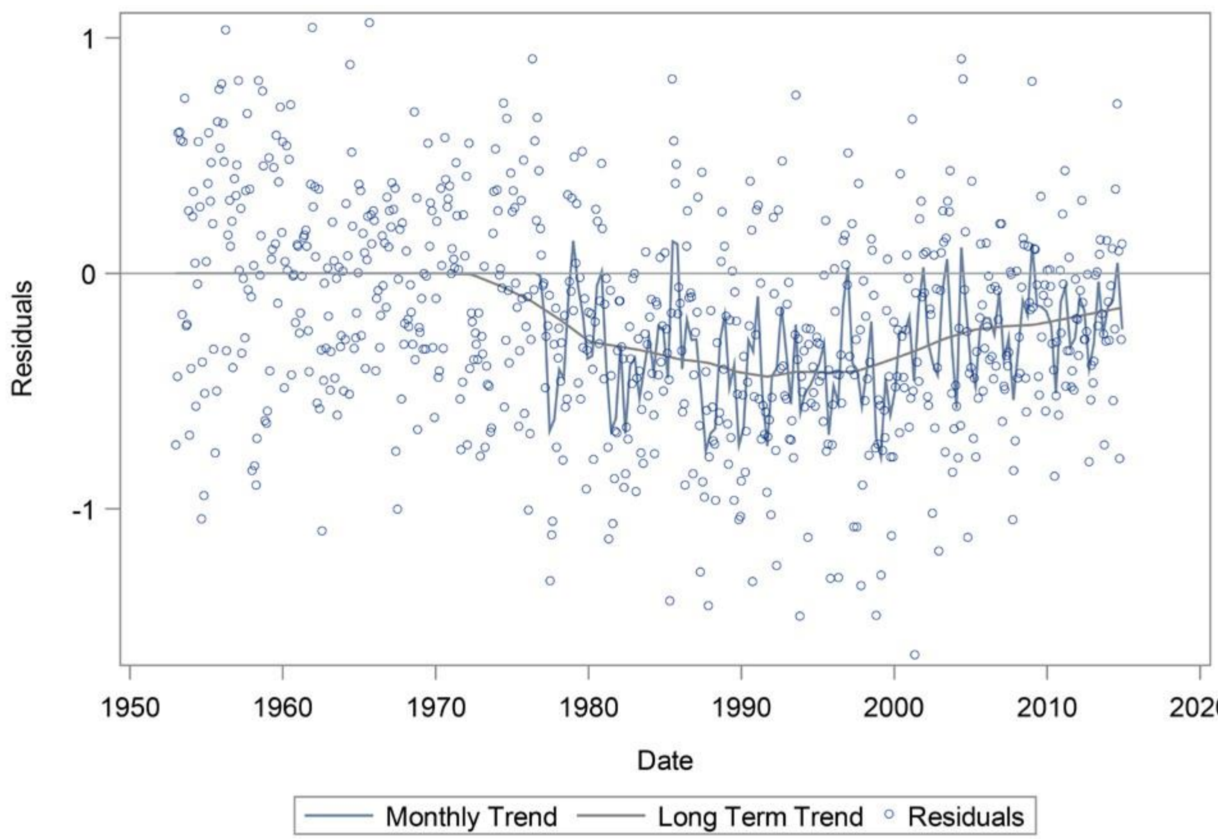



**Figure 3-4.** **Time series of residuals with LOESS curve of monthly and long term trend in residuals post 1976.**

LOESS regression (PROC LOESS: SAS V9.4) of the residuals was used to derive a correction factor to estimate the anthropogenic effects to streamflow using the same logic presented in the 2011 minimum flows report. The difference from zero for each monthly LOESS estimate was calculated and back transformed to represent a monthly deviation in units of cfs.  The monthly predictions also needed to be mapped to the daily flow record which was accomplished using the cumulative probability distribution for the daily flows. In this way the adjustment was scaled to the deviations in flows from their long term monthly average. For example, when flows were average, the correction was based on the LOESS curve trend line which represents the average expected adjustment due to anthropogenic influence. When the daily flows were at their 70% percentile of the cumulative probability distribution, the correction was 1.7 times the LOESS estimated average estimated by the trend line. The adjustment was capped such that it never exceeded twice the LOESS predicted average correction for anthropogenic effects. The resulting correction factor is provided as an intra-annual distribution in Figure 3-5 to compare to the estimates of excess flow from the MIKE-SHE model for the Myakka River (inset) (Flannery et al. 2011. The same seasonal order represented for the results of the MIKE-SHE model in the Myakka River was used to compare these plots. The results of the correction described above for the Little Manatee River are strikingly similar to that described by the MIKE-SHE model in terms of both, timing and magnitude, with higher excess agricultural flows predicted during the summer wet season in both models.

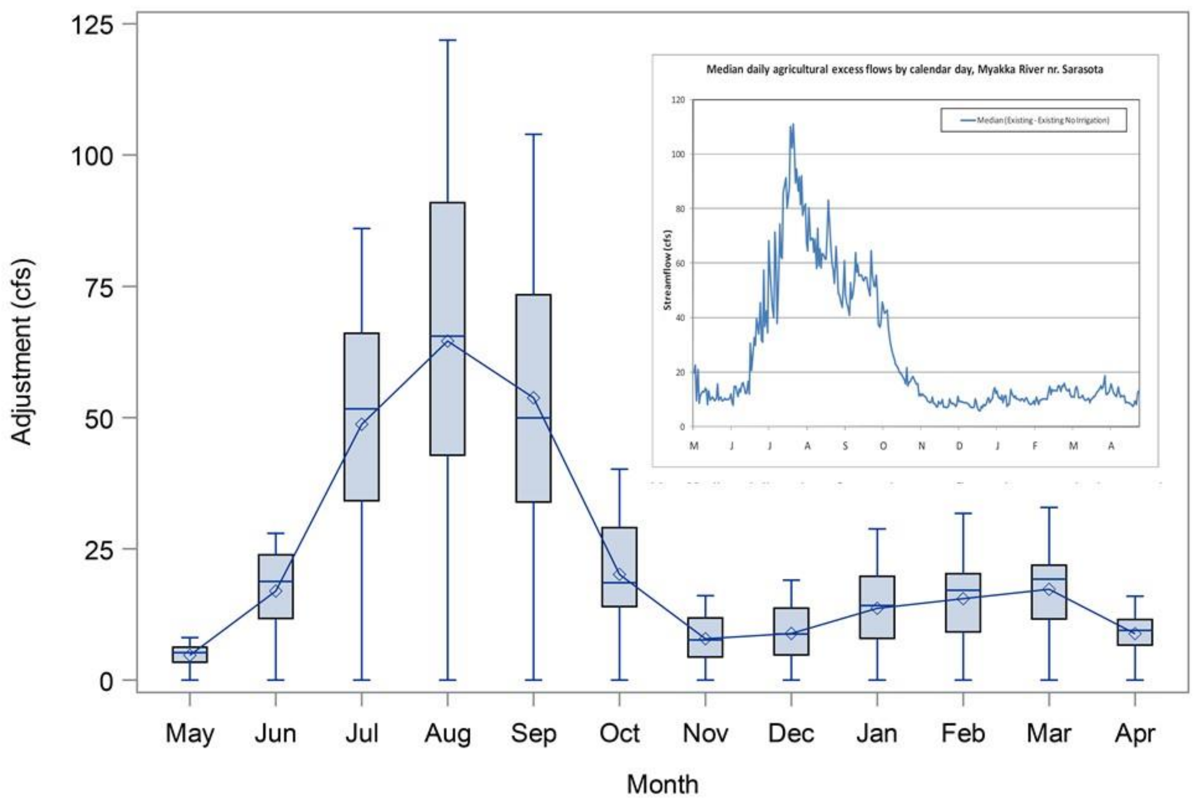



**Figure 3-5. Seasonal distribution of estimated excess flows in the Upper Little Manatee River post-1976 with an inset plot of the seasonal distribution of estimated excess flows in the Myakka River (from Flannery et al. 2011) for comparison.**

The analysis above suggested that the District has appropriately identified significant historical streamflow augmentation to the Little Manatee River and has appropriately identified a general period when the streamflow augmentation seems to have begun. The issue of accounting for excess flows in the establishment of minimum flows recommendations is not a simple one as several anthropogenic influences may have affected streamflows in the system. Historical agricultural practices were identified in the 2011 minimum flows report as the principal influence of anthropogenic effects to streamflow and this is consistent with other studies in District rivers. Historical records for agricultural well-pumping during the period when flood-field irrigation practices for row crop agriculture were dominant in the watershed (i.e., 1970s and 1980s) are lacking. The estimated excess flows identified by this analysis reflect average expectations that will very likely not reflect event-specific variability in excess flows due to historical agricultural practices or potential discharges from historical mining activities. The long term trend in LOESS predictions of the residuals suggest that these historical excess flows have been trending towards zero since 2000 and the excess flow correction proposed for the revised minimum flow recommendations addresses this artifact as well. The District's FARMS program has implemented programs to improve irrigation efficiencies in the watershed, mining practices have improved reuse of process water, and Hillsborough County has been active in acquiring conservation lands that were previous in agricultural or ranchlands. The adjustment for excess flows described above was used to define a baseline flow condition to evaluate the effects of the flow reduction scenarios against a time series of flows assumed to be relatively unaffected by anthropogenic activity.

The District previously considered two alternative methods for developing a correction for excess flows due to agriculture during the development of minimum flows for the Upper Little Manatee River. The daily 15 cfs withdrawal appears to be chronologically the first correction considered and that is the method described in the HEC-RAS report and presumably used in the PHABSIM analysis as described in the summary in Chapter 2. The second method, utilizing the difference in percentile flow values between the two benchmark flow periods was well described in section 4.2.7 of the 2011 minimum flows report, but based on review of the model framework, does not appear to have actually been used for development of the proposed minimum flows. Other District minimum flows reports (Kelly et al. 2005a and b, Flannery et al. 2011) have described augmentation of streamflow due to historical agricultural practices but have not explicitly accounted for this flow augmentation within the modeling framework used for minimum flows establishment. Instead, they considered those excess flows as a scenario or adjustment to the baseline scenario as part of the flow reduction scenario evaluation process. As with other District minimum flows, the adjustment proposed in this section was not integrated into the modeling framework but simply used to establish the baseline condition from which flow reductions could be evaluated for their potential for significant harm. This revised method incorporates the effects of rainfall and the rainfall-flow relationship in the estimation of the excess flow correction, incorporating comments from peer review into the updated analysis. The next section of this report describes refinements to the HEC-RAS model that was subsequently used for evaluating the wetted perimeter, fish passage, in-channel habitat suitability, and floodplain inundation criteria.

## 3.3 HEC-RAS Modeling

As described in Section 2.2.3 of this report, since the development of the HEC-RAS model, a SWMM model update was performed as part of the Hillsborough County Watershed Management Plan for the Little Manatee River (Jones Edmunds 2015). We acquired this model, ran a one in ten year storm event for the period of August 21 2011 through September 11 2011 and used the results to compare the flow-stage curves between the HEC-RAS model and the SWMM model for cross sections located in very close proximity to one another. The evaluation suggested that the estimated flow-stage curves for these models diverged from one another with increasing distance upstream from the calibration gage (both models were calibrated to the Wimauma gage). Because the SWMM model was based on actual survey data, and given the other underlying issues with the HEC-RAS model, the SWMM model was assumed to provide the best available information on the flow–stage curve relationships at various cross sections in the Upper Little Manatee River.

The SWMM model geometric data was imported into HEC-RAS and used, along with the SWMM model output, to reconstruct and recalibrate the HEC-RAS model.. The reaches included in the HEC-RAS model are identified in Figure 3-6 along with the location of USGS streamflow gages and the withdrawal point for the principal surface-water user in the watershed [Florida Power and Light (FP&L)]. Note that the FP& L withdrawal point is in the lower reach of the upper river, near the downstream domain of the model. Also note that the USGS gage near Wimauma is at the downstream end of the model domain.

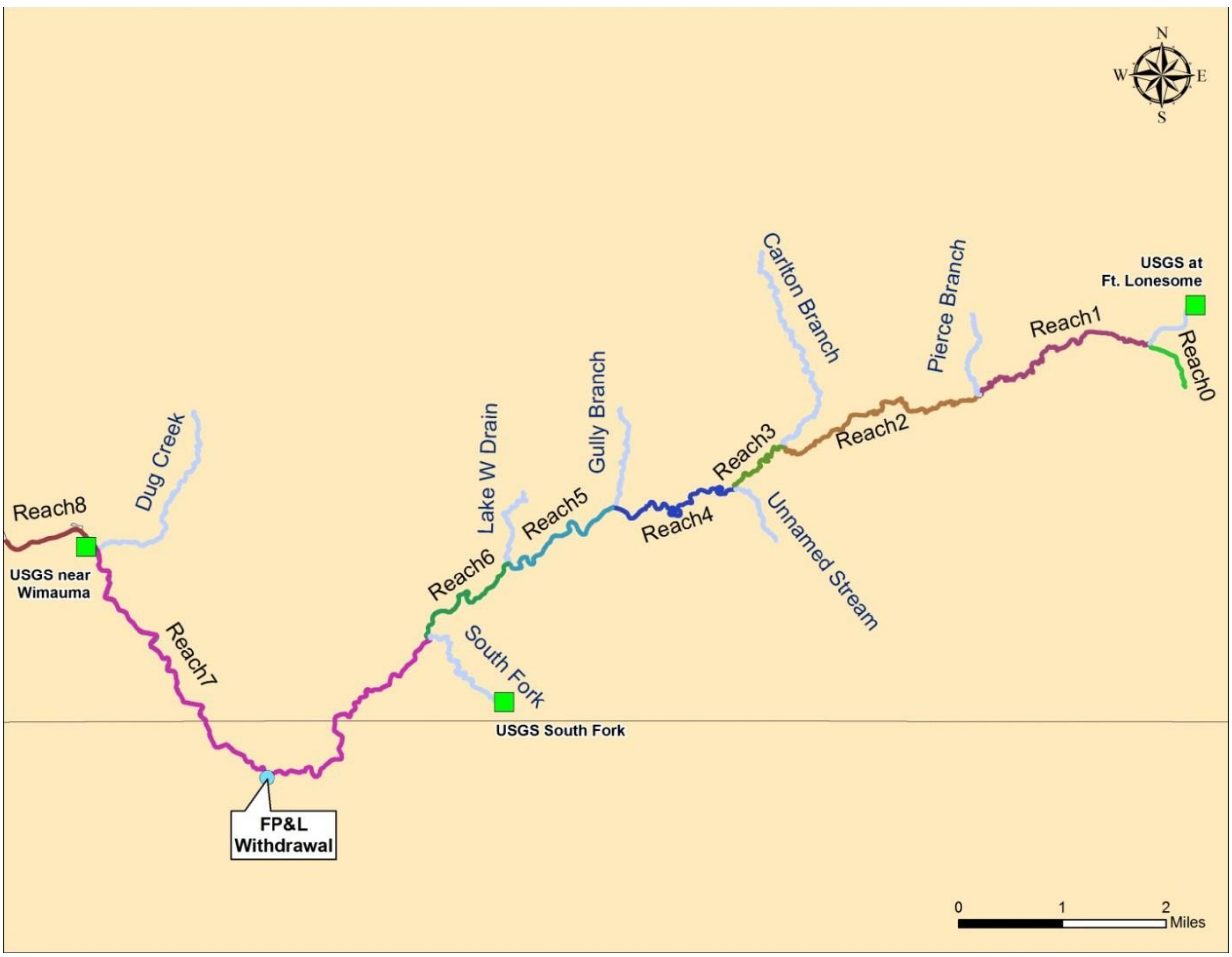



**Figure 3-6. HEC-RAS model reaches, USGS gages and principal utility with a surface water withdrawal permit in the Upper Little Manatee River.**

The original (ZFI 2010) HEC-RAS cross sections are displayed in Figure 3-7.

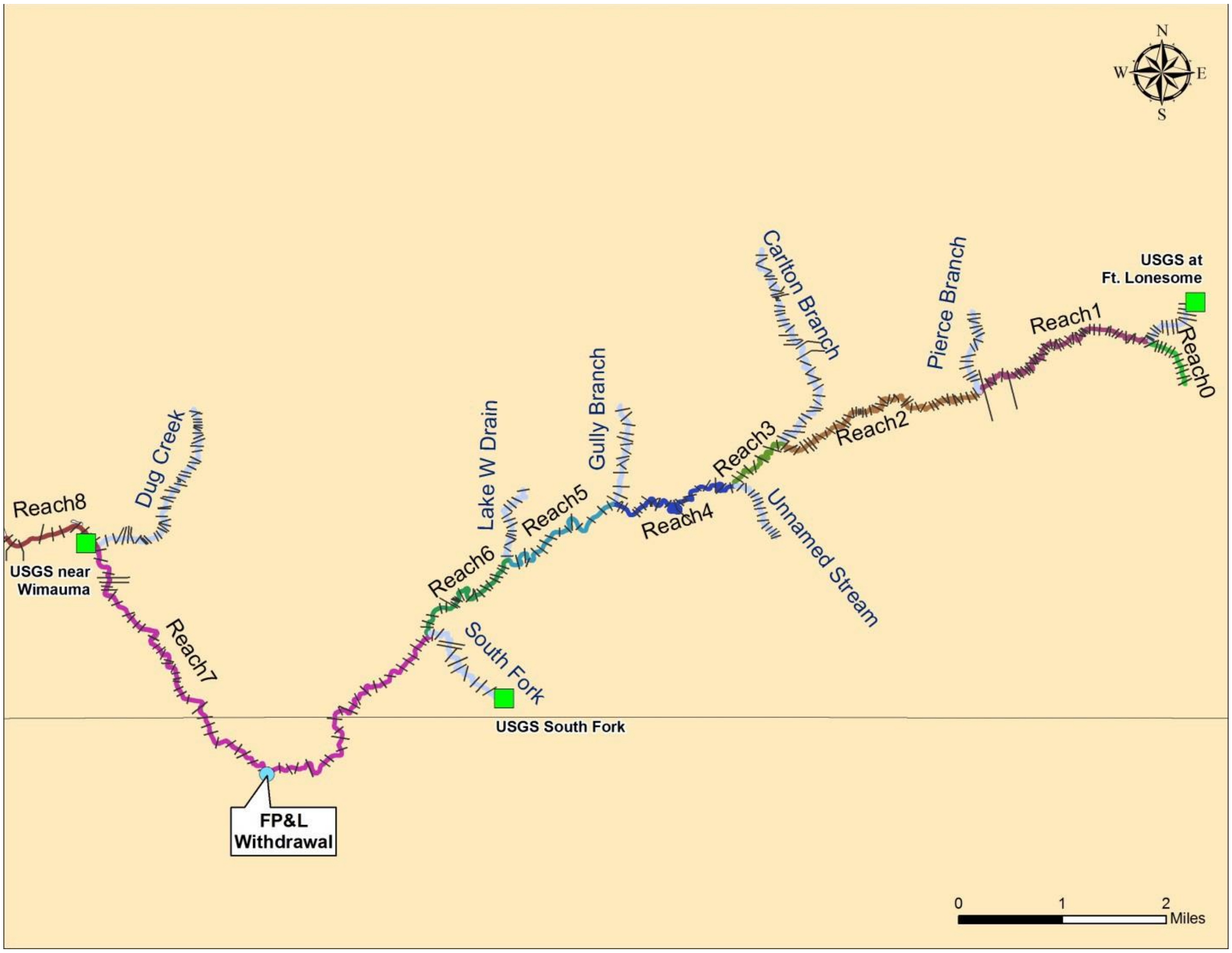



**Figure 3-7. Original HEC-RAS cross sections.**

The SWMM model cross section overlaid on the HEC-RAS model cross sections are provided in Figure 3-8 along with the 15 SWMM model cross sections used to recalibrate the new HEC-RAS model cross sections. The 15 cross-sections (termed “calibration cross sections”) were selected to be: in close proximity to the old HEC-RAS cross sections; representative of the upstream portion of the system, and correlate with known critical analysis points from the existing vegetation and PHABSIM analysis performed by District staff for the 2011 minimum flows report.

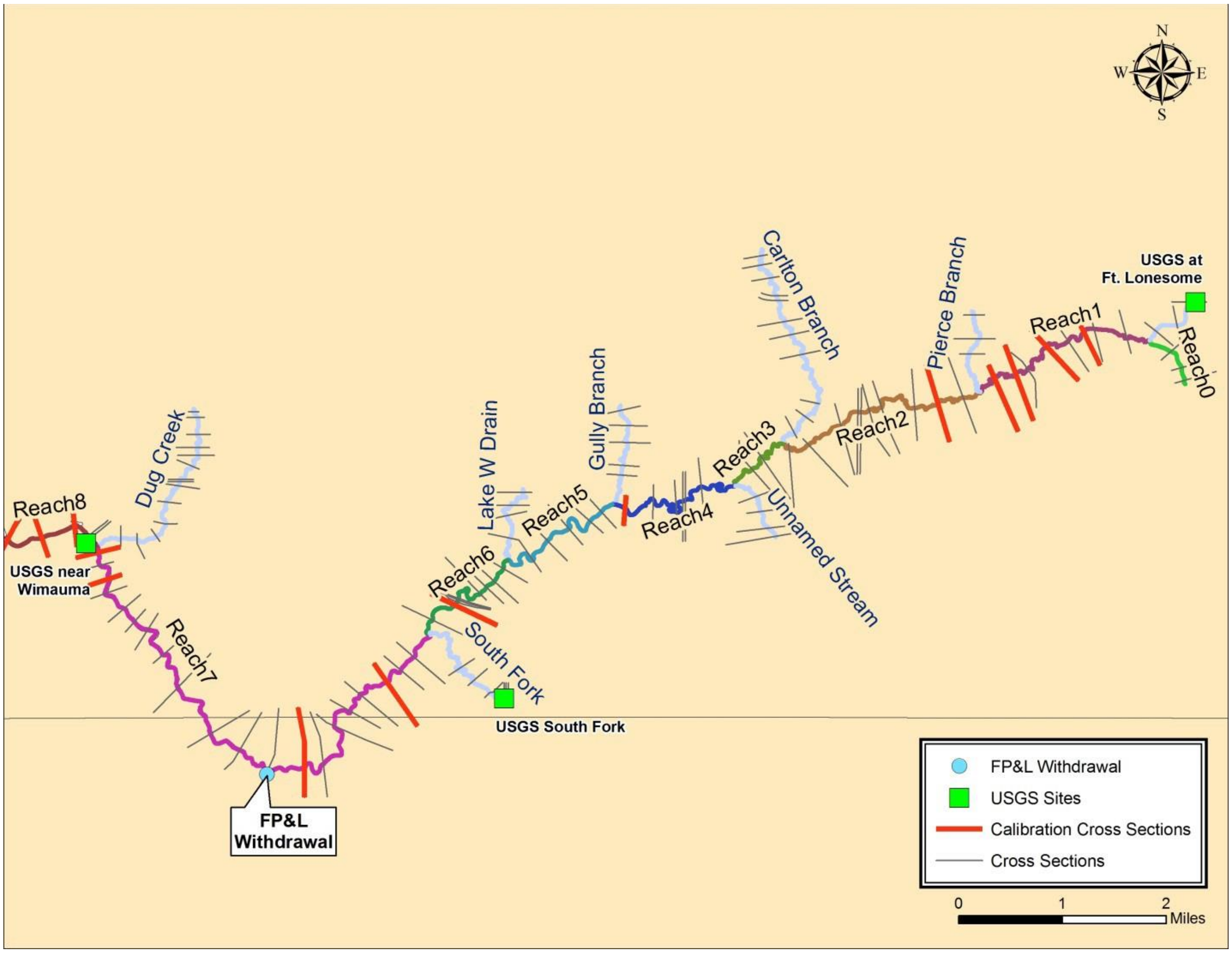



**Figure 3-8.** **SWMM model cross sections imported into HEC-RAS for model update for the Upper Little Manatee River. The red lines indicate the 15 SWMM calibration cross sections used to recalibrate the HEC-RAS model.**

The HEC-RAS model was then recalibrated to the SWMM cross section flow-stage relationship. Results for 3 representative cross sections are displayed in Figure 3-9. The plots on the left are the original HEC-RAS model flow-stage curves (black filled circles) overlaid on the SWMM model predictions (open blue circles) and the curves on the right display the recalibrated comparison. The curves are presented from downstream (top) to upstream (bottom) and show that the recalibrated model more closely matches the SWMM model prediction both at the downstream boundary (top set of figures) and farther upstream. In particular, the recalibrated HEC-RAS model now matches the proper elevations better at the low flows because actual surveyed data was used instead of LIDAR data that defined the channel bottom elevation in the original model.

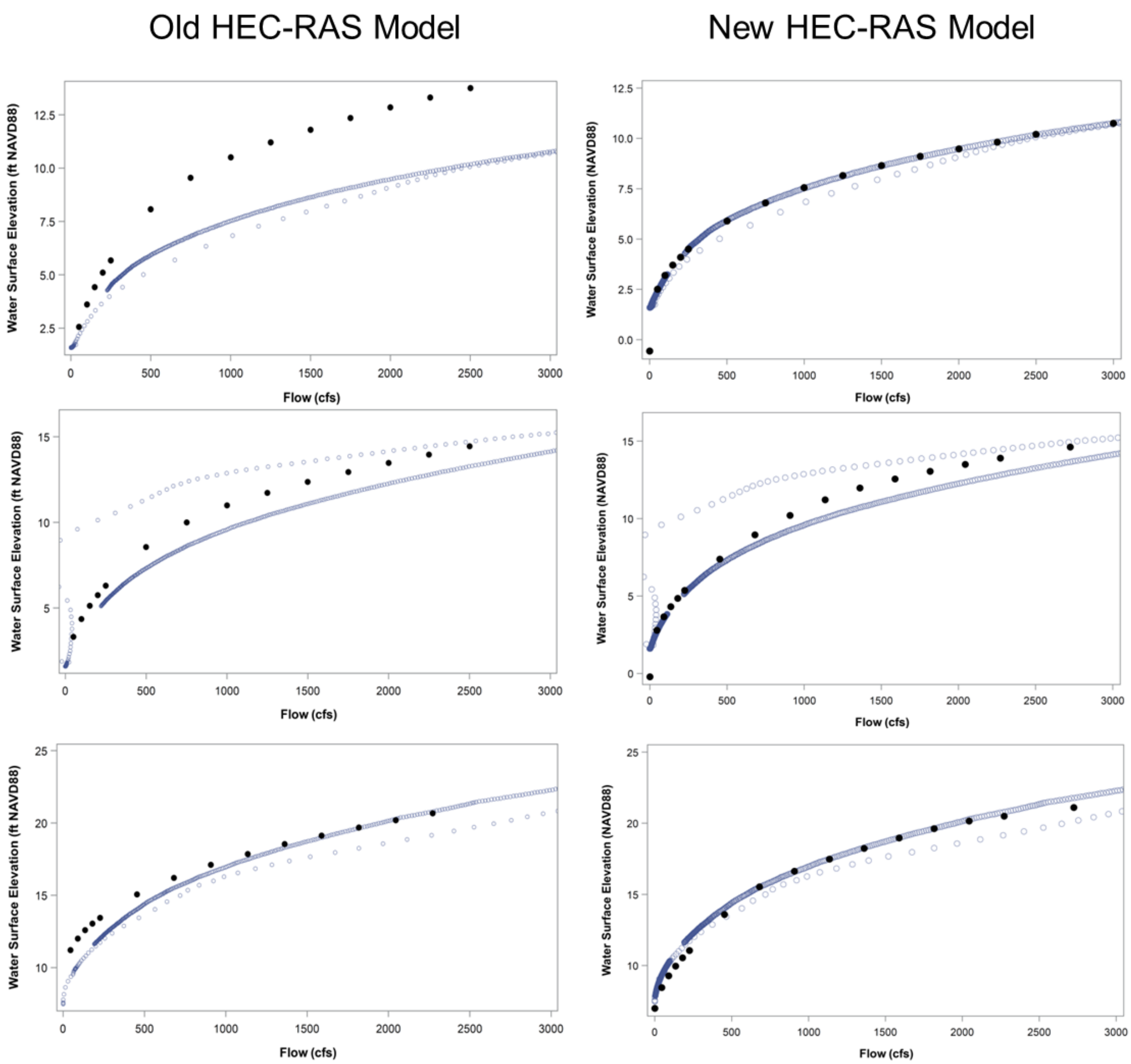



**Figure 3-9.** **HEC-RAS and SWMM model comparisons for the original Upper Little Manatee HEC-RAS model (left) and recalibrated HEC-RAS model (right) at three representative cross sections.**

It is important to note that it was necessary to maintain some assumptions of the original HEC-RAS model for this work. Principally, the flow apportionment by reach developed by ZFI (2010) was accepted. This determines the relative quantities of flow for each reach based on the downstream Wimauma gaged flow. The flow apportionment for each reach is provided in Figure 3-10. Note that:

- The South Fork (SOFKLM) contributes approximately 30% to the total flow at the Wimauma gage,
- the relative contribution of the Ft. Lonesome branch (USGS 02300100, Little Manatee River near Ft. Lonesome, FL gage) changes as a function of flow, and

- several tributaries have the same apportionment (e.g., Dug Creek and Carlton Branch).

In fact, Dug Creek, Carlton Branch, Pierce Branch and Unnamed Stream (see Figure 3-6 for reference) all have identical flow characteristics expressed in the model (Figure 3-10). Gully Branch and LakeWDrain have identical flow characteristics as well. The Ft. Lonesome curve suggests that the contribution from the watershed upstream of the gage site is considerably variable at flows below the 90th percentile.

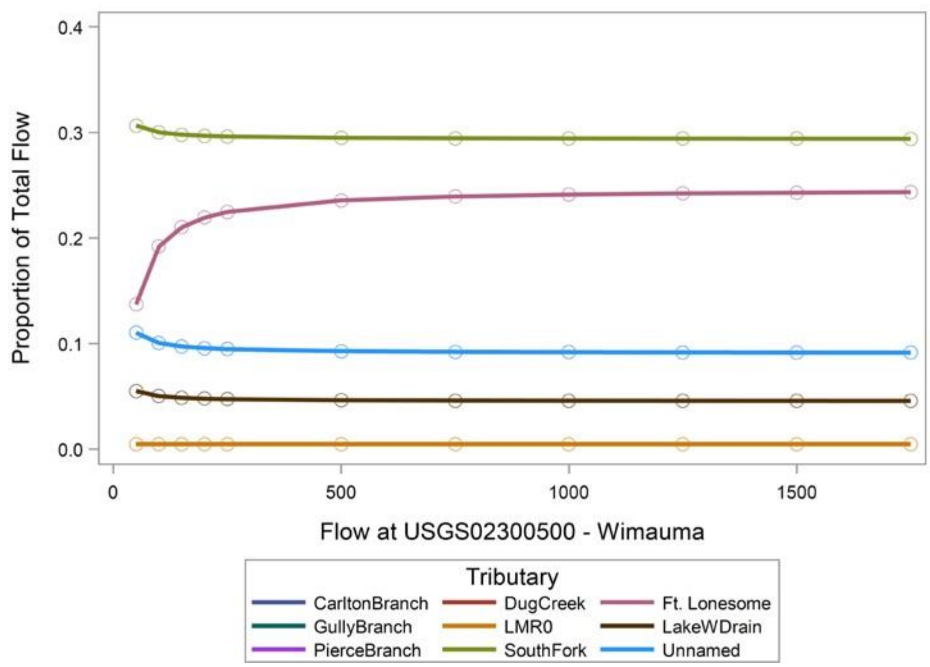



**Figure 3-10. HEC-RAS flow apportionment by Reach for the Upper Little Manatee River.**

An independent assessment of the general relationship between flows at the Wimauma gage and the flows at South Fork and Ft. Lonesome, using the daily median values across years when both gages were active, confirms the general finding that the Ft. Lonesome contribution is low and seasonally dependent (Figure 3-11). However, the assessment also suggests that on any given day the flows can vary appreciably and may be as high, or even higher on occasion, than the same-day flow at the near Wimauma gage. This observation can complicate compliance with a low flow cutoff established solely based on the Wimauma gage as further described in Chapter 6. In summary, the new HEC-RAS model, while retaining some aspects of the previous effort, is improved because it: utilizes the best currently available information on the river morphology; incorporates surveyed cross sections into the model; accounts for more of the floodplain that may contribute to ineffective flow areas driving the flow stage relationships, and more closely matches the SWMM model profiles considered the most accurate representation of the floodplain of the Little Manatee River. The application of the HEC-RAS model for assessment of the wetted perimeter, fish passage, SEFA, and floodplain inundation is described in the following sections.

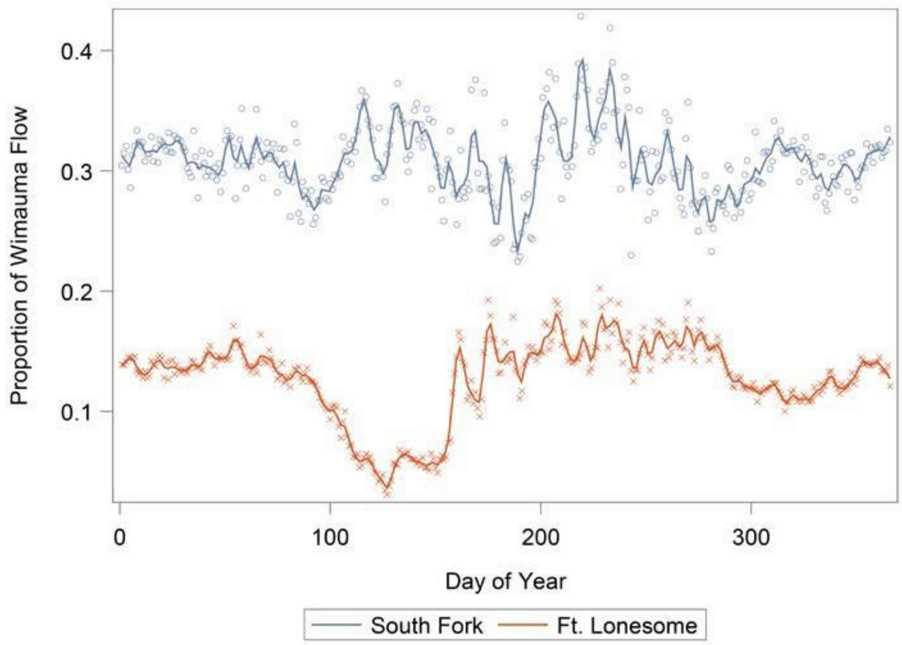



**Figure 3-11. Proportion of South Fork and Ft. Lonesome to the total flow at Wimauma.**

## 3.4 Wetted Perimeter Analysis

The wetted perimeter analysis was reevaluated using the recalibrated HEC-RAS model. The HEC-RAS output produces corresponding estimates of the wetted area of the cross section for each value of flow and each percentile value of flow (considered a "profile" in HEC-RAS terminology) from the long term distribution of the baseline flow record for the Wimauma gage was used to evaluate the flow - wetted area relationship for each cross section. The inflection point (LWPIP) was then identified and the most sensitive cross section was identified from which the low flow threshold criterion value would be proposed.

The District most recently used the LWPIP approach for the Pithlachascotee River (Leeper et al. 2016) where HEC-RAS model output was used to generate wetted perimeter versus flow plots. Plots were visually examined for the lowest wetted perimeter inflection point at each cross section and used along with calculated changes in wetted perimeter on a per cfs basis to identify flow at the Pithlachascotee River near New Port Richey gage that were associated with relatively large changes in wetted perimeter within the river channel. Leeper et al. (2016) found most cross sections did not exhibit apparent inflection points for wetted perimeter at elevations within the channel. For cross sections that displayed no distinct inflection point or where the majority of the in-channel wetted perimeter was inundated at the lowest modeled flow, the lowest wetted perimeter inflection point was established at the lowest modeled flow.

For this reevaluation, the process of selecting the LWPIP was automated by calculating the slope of the line connecting each percentile value and the selecting the highest slope value as the inflection point in the flow wetted area curve which defined the LWPIP. In addition, because the analysis was geared towards low flow conditions and riffle type habitats, inclusion criteria were established such that only flows below the 40th percentile value at the Wimauma gage (i.e., below 40 cfs) were considered for identifying the inflection point. In addition, the LWPIP was only considered if the hydrologic depth (that is, the depth of the stream when flows are at the inflection point) was less than 1 ft and above the 1st percentile of flow. The fish passage hydrologic depth criterion of 0.6 ft, and the SEFA analysis described in the next sections are more specifically designed to evaluate the instream flow requirements for species-specific habitats of fish utilization in the Upper Little Manatee River.

## 3.5 Fish Passage

The revised HEC-RAS model output was used to assess flow-related water depths at each of the HEC-RAS cross-sections on the main-stem of the river. Flows at the Wimauma gage were associated with flows at each cross-section that resulted in at least 0.6 feet of water in the deepest part of the channel. These cross-section specific fish-passage depths were then evaluated to identify the most sensitive cross sections to support development of a minimum low-flow threshold for Upper Little Manatee River.

## 3.6 SEFA Analysis

The Systems for Environmental Flows Analysis software (SEFA: Aquatic Habitat Analysts, Inc. 2012.) is an instream flow methodology (IFIM) and a generalization of Physical Habitat Simulation model (PHABSIM) that uses HEC-RAS model output to calculate a suitability index (“area weighted suitability” or AWS) for all cross sections in the model domain. The SEFA relies on HEC-RAS cross sectional estimates of both the area of inundated channel at a particular cross section as well as velocities at specific channel locations across the channel, to derive a single index value for each date in a time series. SEFA analysis was not conducted for the 2011 minimum flows report; however, the method can be considered a generalization of the *in situ* based PHABSIM model used in the 2011 report (Jowett et al 2014; Milhous and Waddle 2001). Since no additional *in situ* data were collected for the SEFA analysis, substrate index codes were absent in the final calculation of the area weighted suitability for each species and life stage, though a site visit, as well as descriptions in the 2011 minimum flows report, suggests that the section of river is generally monotypic silty sand throughout.

The HEC-RAS flow-stage curves were exported from the HEC-RAS model using the report generator function, transposed into a usable format, and input into the SEFA program. Each species or group has a suitability profile for both velocity and depth as exemplified in Figure 3-12 for Spotted Sunfish (*Lepomis punctatus*). Habitat suitability curves for forty species life stages or species groups (Table 3-1) were incorporated into the instream habitat model and the timeseries library in SEFA was used to calculate a value representing the extent of suitable area throughout the river for each date in the timeseries. The AWS was calculated for each date in the time series of flows and for each flow reduction scenario.

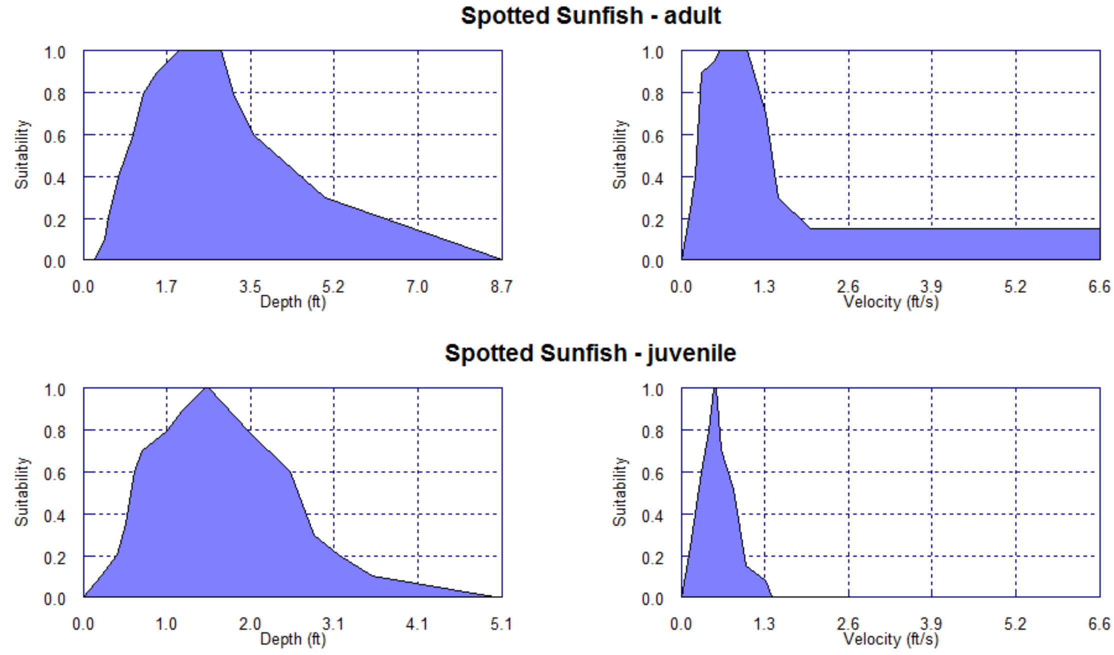



**Figure 3-12.** **Suitability index for the Spotted Sunfish adults (top) and juveniles (bottom) indicating suitability as a function of depth (left) and velocity (right).**

**Table 3-1.** **Species/life stages or species groups used for in-channel habitat suitability analysis for the upper Little Manatee River.**

| Species or Group | Life Stage |
|---|---|
| Suwannee Bass | Adult, Juvenile |
| Redbreast Sunfish | Adult, Juvenile, Spawning, Fry |
| Habitat Guilds | Shallow/Slow, Shallow/Fast, Deep/Slow, Deep/Fast |
| Channel Catfish | Adult, Juvenile, Juvenile (spring, summer, fall, warmwater), Spawning, Fry |
| Darters | Generic, Blackbanded |
| Macroinvertebrates | Ephemeroptera, Plecoptera, Trichoptera, EPT Total, *Pseudocloeon ephippiatum*, Hydropsychidae - Total, *Tvetenia vitracies* |
| Largemouth Bass | Adult, Juvenile, Spawning, Fry |
| Bluegill | Adult, Juvenile, Spawning, Fry |
| Spotted Sunfish | Adult, Juvenile, Spawning, Fry |
| Cyprinidae | Adult |

The difference from the baseline estimates was then evaluated by calculating the average difference expressed as a percentage of the baseline average which is equivalent to analysis of the difference in the normalized area under the suitability curve. The results of SEFA analysis as applied to the MFL flow reduction scenarios are provided in Chapter 4.

## 3.7 Floodplain Inundation

Minimum flows are established not only to protect low flows but also to establish protective limits that guard against significant harm to the biological integrity of floodplain habitats that are intermittently inundated during flooding events. While the wetted perimeter and fish passage criteria were used to support development of a minimum low flow threshold, and PHABSIM and SEFA analysis were used to identified instream or in-channel flow thresholds, floodplain inundation criteria were developed to protect intermittent high flows that supply the necessary requirements for the wetland vegetation and biogeochemical processes and habitat values associated with the floodplain of the Upper Little Manatee River. A prescriptive standard allowing up to a 15% change in floodplain inundation from the baseline condition was adopted to define the limit beyond which further withdrawals would result in significant harm. While the 2011 minimum flows report suggested that the Upper Little Manatee River is generally considered well-incised without extensive floodplain area that is common in many other southwest Florida rivers, we found several areas of wetland floodplain within the boundaries of the SWMM model that necessitated the evaluation of this resource in support of establishing minimum flows for the Upper Little Manatee River.

The refined HEC-RAS model included SWMM model transects that extended farther into floodplain areas then the old HEC-RAS model. The revised model was used to evaluate the level of floodplain inundation as a function of flows measured at the USGS gage near Wimauma. HEC-GeoRAS, a geo-processing accessory to HEC-RAS that incorporates a digital elevation layer, was used to import the HEC-RAS model water surface profile simulation data into ArcGIS for spatial mapping of the extent of floodplain inundation for each percentile value of flow identified for the baseline flow condition. The inundation levels for each percentile were then intersected with the District Land Use Land Cover layer for the 2011 mapping event which was used to characterize the extent of floodplain wetland vegetation within the floodplain of the model domain. All floodplain wetland vegetation in the Upper Little Manatee River was categorized as a single District FLUCCSCODE (Bottom Land Hardwood Swamp; FLUCCSCODE 6150). The model domain (black line) and the existing wetland vegetation within the model domain (brown polygons) are identified in Figure 3-13.

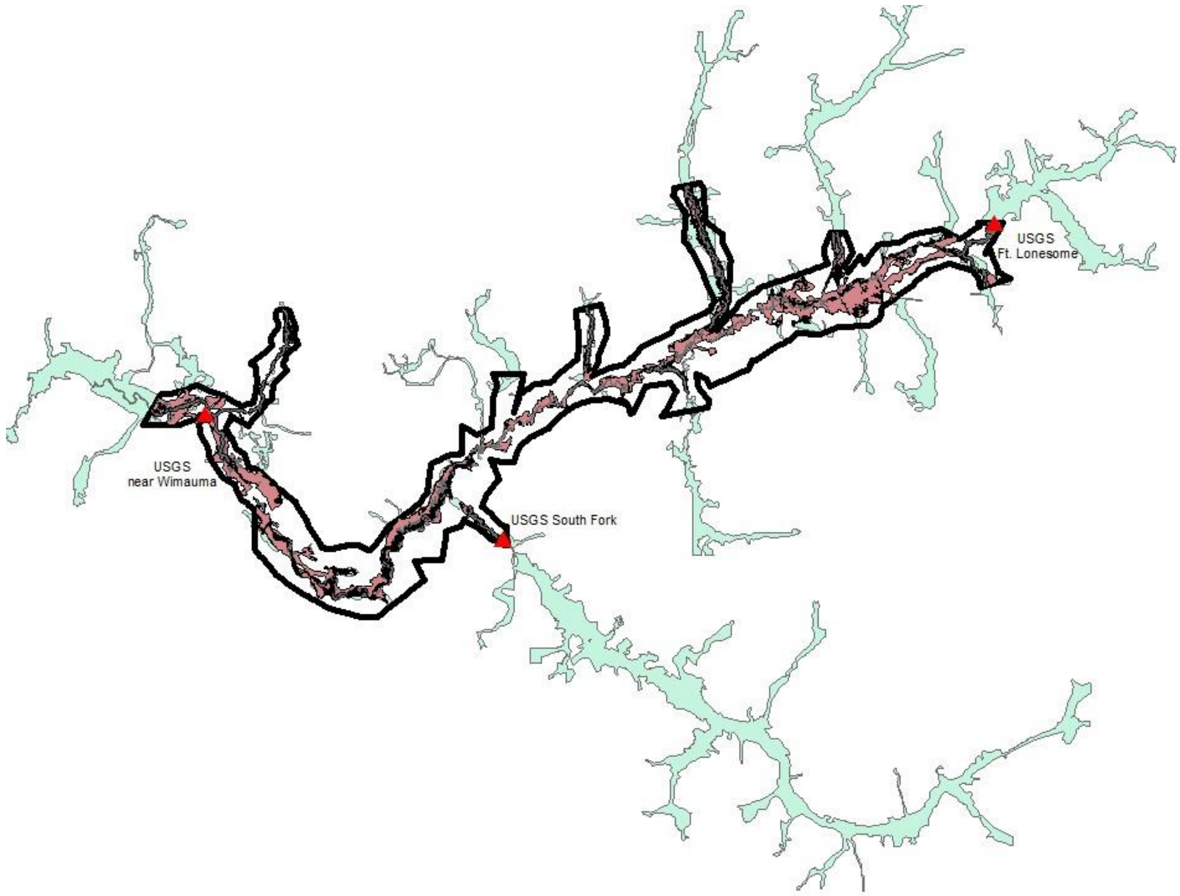



**Figure 3-13. HEC-RAS model boundary for the Upper Little Manatee River (black outline) with wetland vegetation throughout the floodplain of the Little Manatee River (green polygons) and within the model domain (brown polygons). All Wetlands were categorized as a single type in the Little Manatee River ( FLUCCSCODE 6150: Bottom land Hardwood Swamp).**

The intersections of floodplain vegetation and inundated area were completed for each 1 percentile interval between the 50$^{th}$ and 100$^{th}$ percentile values of the baseline flow condition calculated over the full period of record as well as the 0, 10$^{th}$, 20$^{th}$, 30$^{th}$, and 40$^{th}$ percentile to capture any, though unlikely, potential for floodplain inundation at lower flow conditions. The flow percentiles and the associated flow values for each half decile are provided for reference in Table 3-2.

A curve of the percentage of floodplain wetland acreage inundated as a function of flow percentile for Reach 7 (the lowest reach above the Wimauma gage in the HEC-RAS model domain; see Figure 3-8) is provided in Figure 3-14 and an example of the area of inundated vegetation in Reach 7 associated with flow percentiles of 0, 60, 70, 80, 90, and 100 percent is provided in (Figure 3-15). This example demonstrates that the floodplain generally does not become inundated until flows are above the 70$^{th}$ percentile (i.e., 110 cfs) in Reach 7 though small pockets of wetlands are inundated with flows as low as the 60$^{th}$ percentile (72 cfs).

**Table 3-2. Baseline flow percentiles for the USGS 02300500, Little Manatee River near Wimauma, FL gage calculated based on full period of record.**

| Low Flow Percentiles | Flow Values (cfs) | High Flow Percentiles | Flow Values (cfs) |
|---|---|---|---|
| p5 | 11.00 | p55 | 61.74 |
| p10 | 16.96 | p60 | 72.00 |
| p15 | 21.00 | p65 | 85.97 |
| p20 | 24.82 | p70 | 105.45 |
| p25 | 28.11 | p75 | 133.00 |
| p30 | 32.00 | p80 | 173.93 |
| p35 | 36.00 | p85 | 241.45 |
| p40 | 40.26 | p90 | 366.00 |
| p45 | 46.00 | p95 | 646.65 |
| p50 | 52.87 | p100 | 11100.00 |

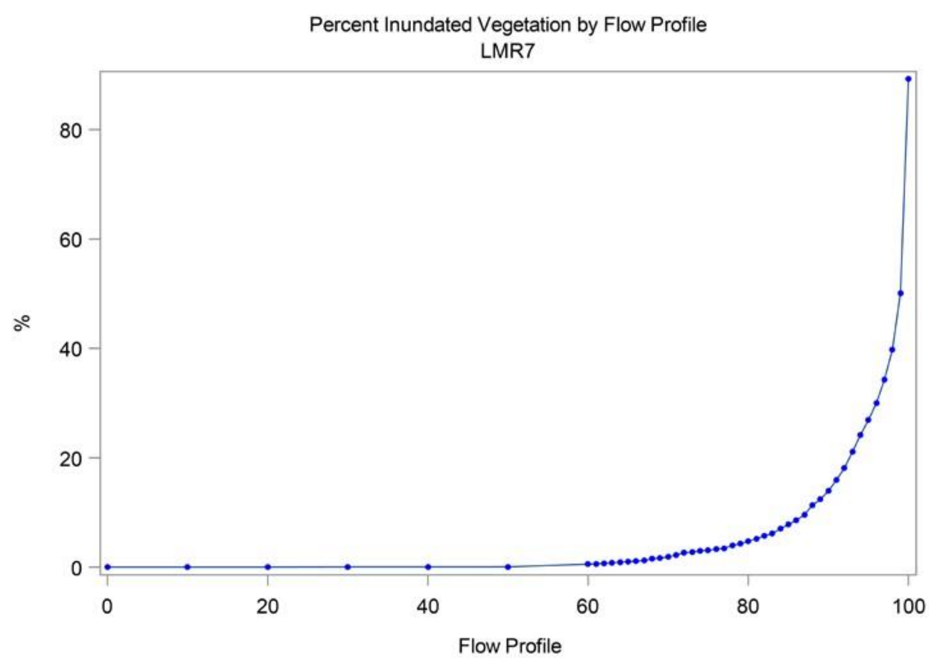



**Figure 3-14. Percentage of inundated vegetation in Reach 7 (see Figure 3-8 above for location of Reach 7) as a function of baseline flow percentile.**

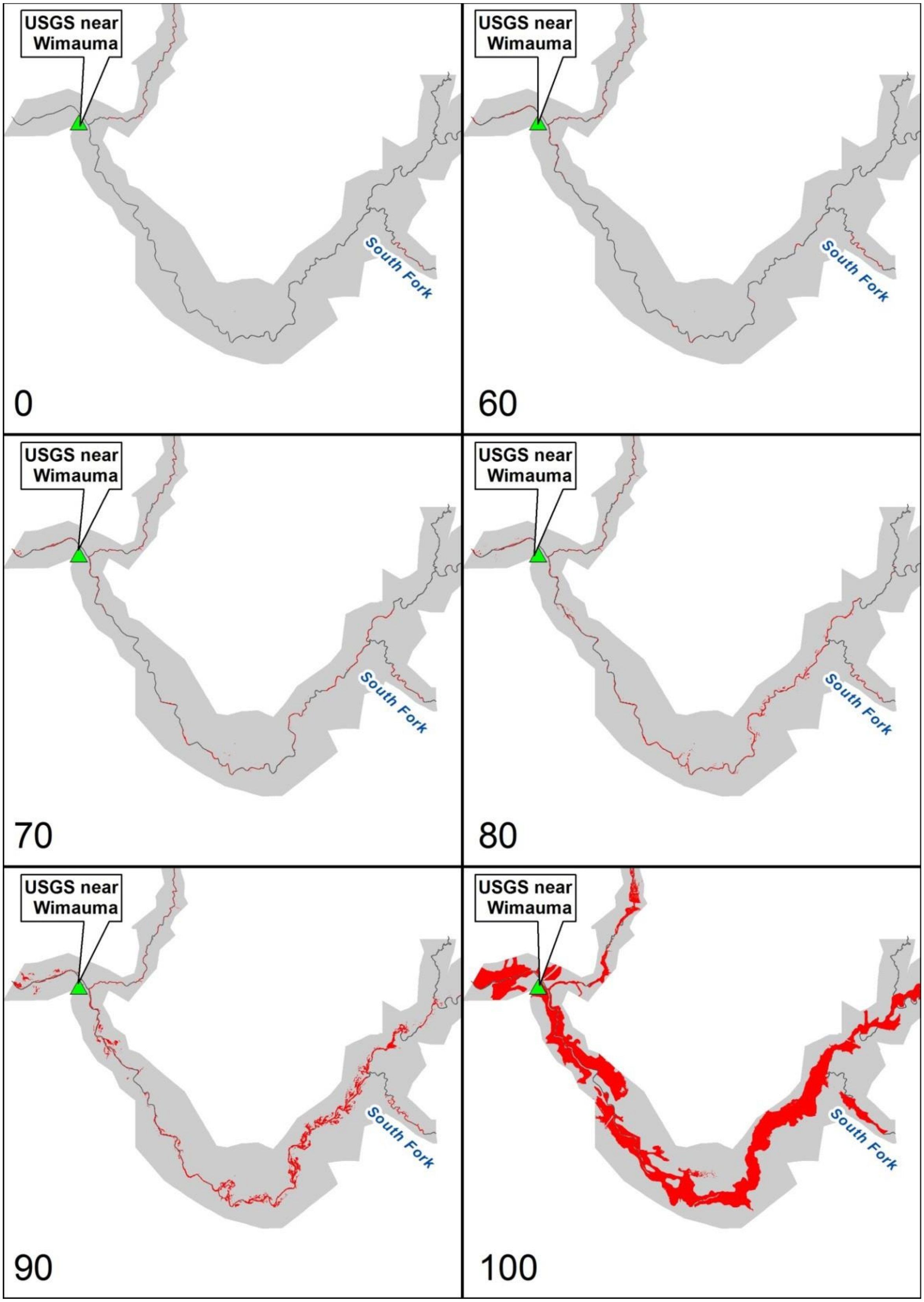



**Figure 3-15.** **Area of inundated vegetation (red) in Reach 7 as a function of the percentile of flow at USGS 02300500, Little Manatee River near Wimauma, FL (green triangle).**

The inundated acreage for each flow percentile value was exported from ArcGIS, read into SAS software (SAS Institute, Inc. 2014) and a weighted least-squares regression (PROC LOESS: SAS/STAT V14.1) was used to predict the acreage inundated for any flow value within the domain of the baseline flow percentiles. This was necessary to evaluate the effects of flow reductions on the area and frequency of inundation of the floodplain wetlands. The LOESS fit included an automated procedure to identify the smoothing parameter that minimized the Akaike Information Criteria value with a constraint to ensure that the algorithm identified a global minimum as the best model fit. Separate LOESS models were developed for each of the 8 reaches of the mainstem of the river. An example of the LOESS model predictions for Reach is provided in Figure 3-16. Note that the flow axis is plotted on the natural log scale expanded in this figure as the LOESS regression was carried out with flow on the natural log scale.

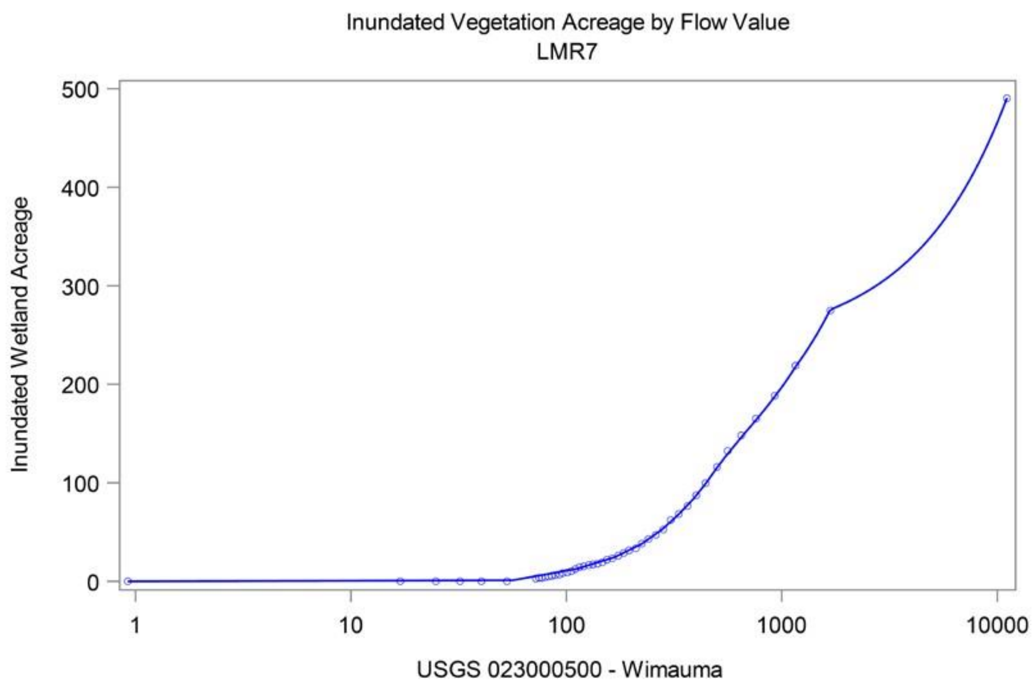



**Figure 3-16. LOESS model fit (solid line) to the inundated wetland acreage estimates for Reach 7 as a function of flow percentile value from the HEC-RAS model output.**

Once the LOESS models were developed, they were then used to predict the acreage of inundated wetland vegetation for each date in the timeseries for the baseline condition and for the flow reduction scenarios used to evaluate the effects of flow reductions on water resource values. The average inundated acreage was then calculated for various temporal and spatial scales including: by reach and year, by reach across years, and across reaches and years.

# 4.1 Model Applications

This chapter reports on the results of the modeling efforts described in Chapter 3 to evaluate the resources of concern in the Little Manatee River in support of establishing the freshwater MFL.

# 4.2 HEC-RAS Modeling of Wetted Perimeter and Fish Passage

### 4.1.1 Wetted Perimeter

Application of the HEC-RAS model to identify a potential minimum low-flow threshold protective of benthic invertebrate habitat was developed by identifying the LWPIP using the slope method described in Section 3.3. The largest slope was identified as the inflection point for that particular cross-section. An example of the results using the full flow range is provided in Figure 4-1. The top figure (Reach 1 - cross section 80368.77) represents the most common outcome where the lowest percentile values had the highest inflection point and were therefore identified as the protective criteria for that cross section. The lowest percentiles represent cross sections with a steep channel morphology such that as the stream bed is inundated, the inclusion of the bank as inundated area triggers the inflection point in the curve. This can be seen in the inset of the top graph showing a close-up of the cross-section center profile (bottom right). The red dots in the profile represent top full bank. The middle figure represents the results for a wider stream section in Reach 2 (76341.48). This channel geometry has the effect of increasing the flow necessary to incorporate a substantive portion of the channel banks which then triggers the LWPIP. The bottom graph represents a cross section in Reach 6 (39256.93) where the inflection is triggered as the water surface elevation approaches the top of bank and the side channel of the cross section begins to become inundated. The top two graphics in Figure 4-1 represent the appropriate use of the wetted perimeter assessment while the lowest graph represents a case where other water resource values are better criteria for high flow situations. As described in Section 3-3, the wetted perimeter analysis was restricted to inflection points identified below the 40$^{th}$ percentile value of the flow at the USGS gage near Wimauma and where the hydrologic depth at the inflection point was less than 1 foot.

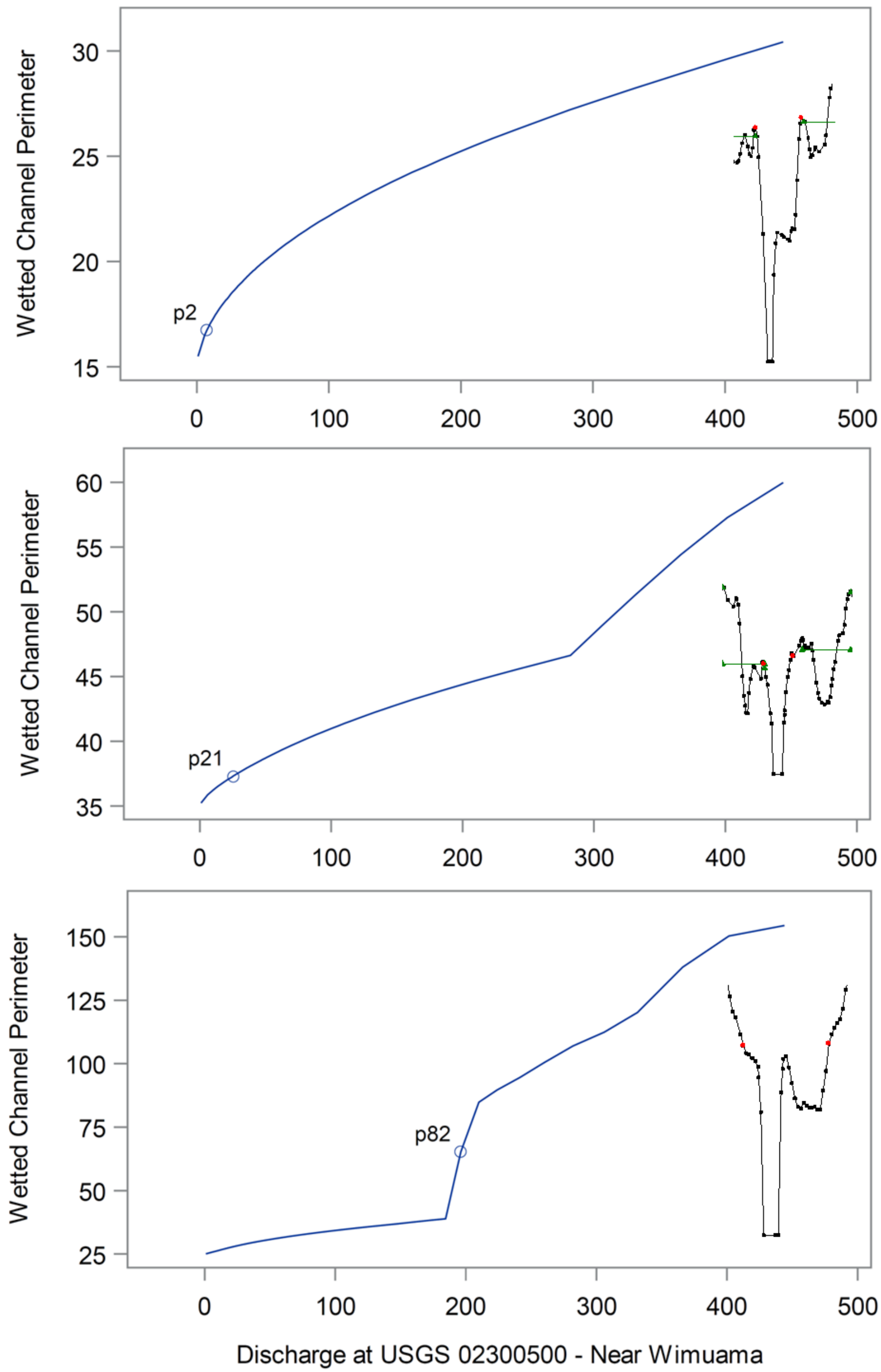



**Figure 4-1.** **Wetted-perimeter curves as a function of flow at the USGS02300500, Little Manatee River near Wimauma, FL gage. Insets are entire cross section (lower right) and expanded view of channel center geometry (upper left).**

Application of the LWPIP approach to the HEC-RAS model results suggested that most of the wetted perimeter inflection points were near the lowest flows considered (i.e., 7 cfs, the second percentile). All cross section curves are provided in Appendix B. Several cross sections in the most downstream reaches had inflection points associated with flow values near 48 cfs (Figure 4-2) but had hydrologic depths at that critical flow value greater than 1 foot (Table 4-1) and were therefore excluded from consideration. An example of those downstream cross sections excluded from consideration based on hydrologic depth is provided in Figure 4-3 for cross section 115.66 in Reach 8 where the hydrologic depth at the inflection point was 3.07 feet. At this cross section the channel widens appreciably, providing an inflection point in the cross-sectional area inundated. The next most sensitive cross section was located in Reach 6 with a critical flow value at the LWPIP of 30.18 cfs (cross section 41919.80: Table 4-1). It should be noted that the reach specific flow at this inflection point is 18.29 cfs (the critical flow value of 30.18 is as-measured at the Wimauma gage). Contributions to the total flow at the Wimauma gage from the South Fork are assumed to make up the difference between the reach specific estimate and the downstream gage though it is extremely likely that on any given day any reach could disproportionately contribute to the total flow at the Wimauma gage. Because this cross section is relatively close to the Wimauma gage and because the contribution to the Wimauma gage record from the South Fork is relatively constant, the critical flow threshold based on the Wimauma gage flow of 30.18 cfs was accepted as the wetted perimeter low-flow threshold criterion. Note that this value is associated with a hydrologic depth of 0.48 which is insufficient for fish passage according to the 0.6 foot fish passage criterion value.

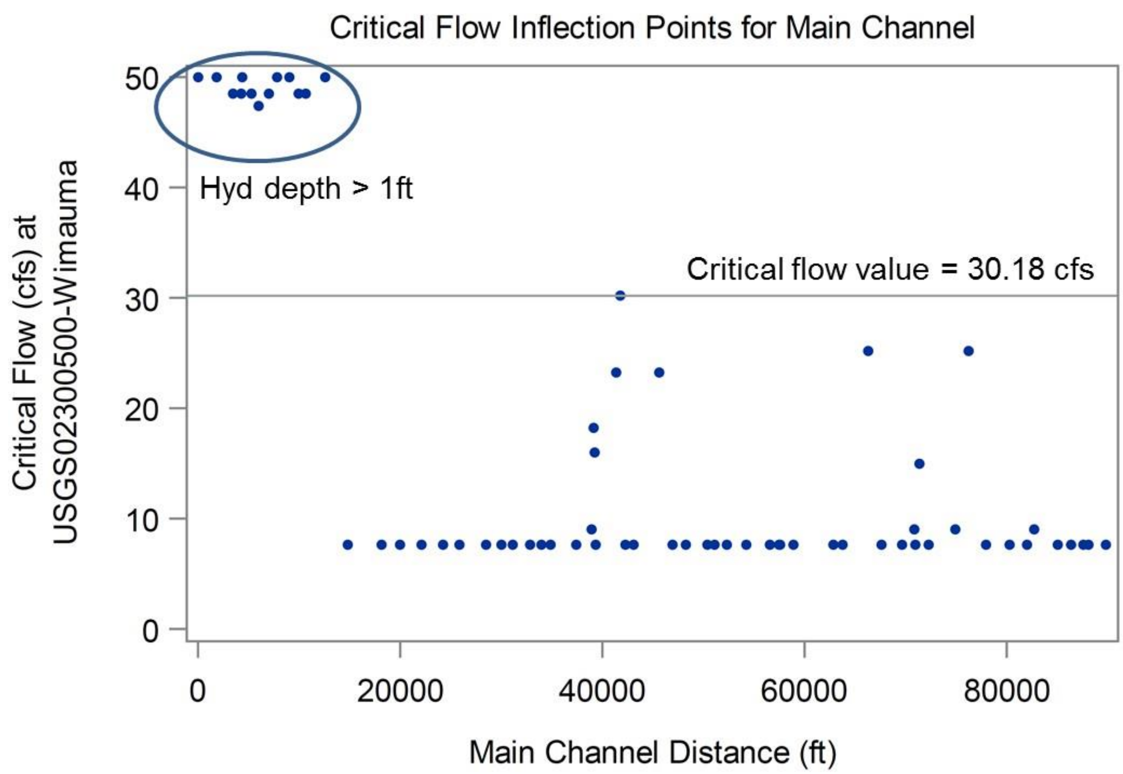



**Figure 4-2.** **Critical flow for each HEC-RAS cross section (y axis) as a function of distance from the downstream flow gage (USGS02300500).**

**Table 4-1. Critical flow values and hydrologic depth for wetter perimeter inflection point analysis in the Little Manatee River. Shaded portion of column represents hydrologic depths greater than 1 foot. Shaded row represents inflection point of most sensitive cross section.**

| HEC-RAS Cross Section | Reach | Reach Flow (cfs) | Critical Flow (cfs) | Percentile Value | Hydrologic Depth (ft) |
|---|---|---|---|---|---|
| 12702.82 | 7 | 45.17 | 50.00 | p48 | 1.94 |
| 7915.02 | 7 | 45.17 | 50.00 | p48 | 4.32 |
| 9181.31 | 7 | 45.17 | 50.00 | p48 | 4.70 |
| 115.66 | 8 | 50.00 | 50.00 | p48 | 3.07 |
| 1941.75 | 8 | 50.00 | 50.00 | p48 | 2.55 |
| 4528.87 | 8 | 50.00 | 50.00 | p48 | 3.00 |
| 10034.60 | 7 | 43.84 | 48.53 | p47 | 4.43 |
| 10789.23 | 7 | 43.84 | 48.53 | p47 | 4.23 |
| 5364.85 | 7 | 43.84 | 48.53 | p47 | 2.94 |
| 7101.67 | 7 | 43.84 | 48.53 | p47 | 3.88 |
| 3562.29 | 8 | 48.53 | 48.53 | p47 | 1.84 |
| 4402.72 | 8 | 48.53 | 48.53 | p47 | 2.92 |
| 6064.80 | 7 | 42.80 | 47.37 | p46 | 3.69 |
| 41919.80 | 6 | 18.29 | 30.18 | p28 | 0.48 |
| 66439.73 | 2 | 7.96 | 25.16 | p21 | 0.75 |
| 76341.48 | 2 | 7.96 | 25.16 | p21 | 0.59 |
| 45765.16 | 5 | 12.96 | 23.23 | p18 | 0.74 |
| 41462.90 | 6 | 14.08 | 23.23 | p18 | 0.72 |
| 39256.93 | 6 | 11.03 | 18.20 | p12 | 1.00 |
| 3766.85 | 9 | 5.41 | 18.20 | p12 | 0.16 |
| 39368.45 | 6 | 9.70 | 16.00 | p9 | 0.93 |
| 71518.59 | 2 | 4.75 | 15.00 | p8 | 0.37 |

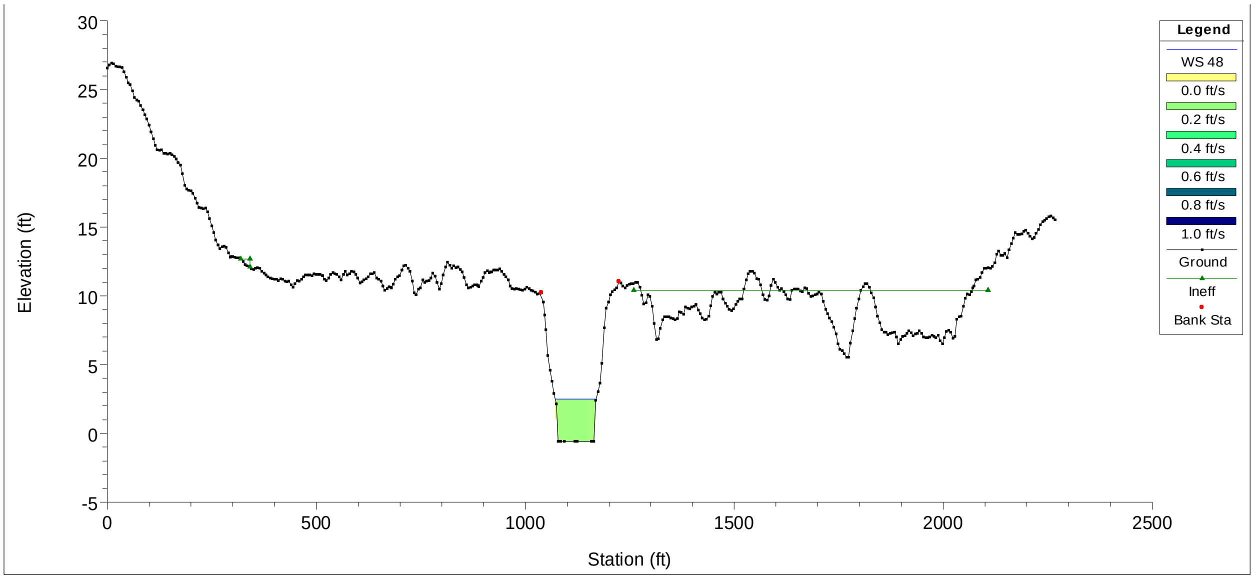



**Figure 4-3. Example cross-section (115.66) in the upper Little Manatee River where the inflection point was associated with a relatively deep channel water depth (i.e., 3.07 feet).**

These wetted perimeter criteria are considered in Chapter 5 along with an evaluation of the fish passage criterion (discussed in the next section), to support the establishment of a low-flow threshold for the Upper Little Manatee River.

### 4.1.2 Fish Passage

The fish passage analysis was very straightforward. To assess the water surface elevation requirements for fish passage, the HEC-RAS output and water surface profiles associated with each model cross section and flow percentile value, the lowest percentile flow value that resulted in 0.6 ft. of hydrologic depth at each cross section was identified. The results representing reach-specific flow values associated with maintaining the depth requirement for fish passage for each cross section are presented in Figure 4-4. The highest values in the plot are located in Reaches 1, 2 ,4, and 6. A reach specific flow of 15 cfs is required in Reach 1; a reach specific flow of 27 cfs is required in Reach 2, a reach specific flow of 24 cfs is required in Reach 4, and a reach specific flow of 21 cfs is required in Reach 6. Therefore, the reach specific flow requirement of Reach 2 would also be protective of all other downstream reaches. A display of the water surface profile of the mainstem of the river illustrating the locations of shoals restrictive to fish passage is displayed in Figure 4-4.

Translating the reach specific criteria to a critical flow at the compliance (i.e., Wimauma) gage is problematic because the flow at the Wimauma gage can be derived by several combinations of inputs from downstream tributaries including the South Fork which contributes a significant portion of the total flow to the river. For example, the Reach 2 flow of 27 cfs translates to an estimated flow at the Wimauma gage of 85 cfs which is well above the long term median flow. This is further discussed with respect to establishing low flow threshold recommendations in Chapter 5.

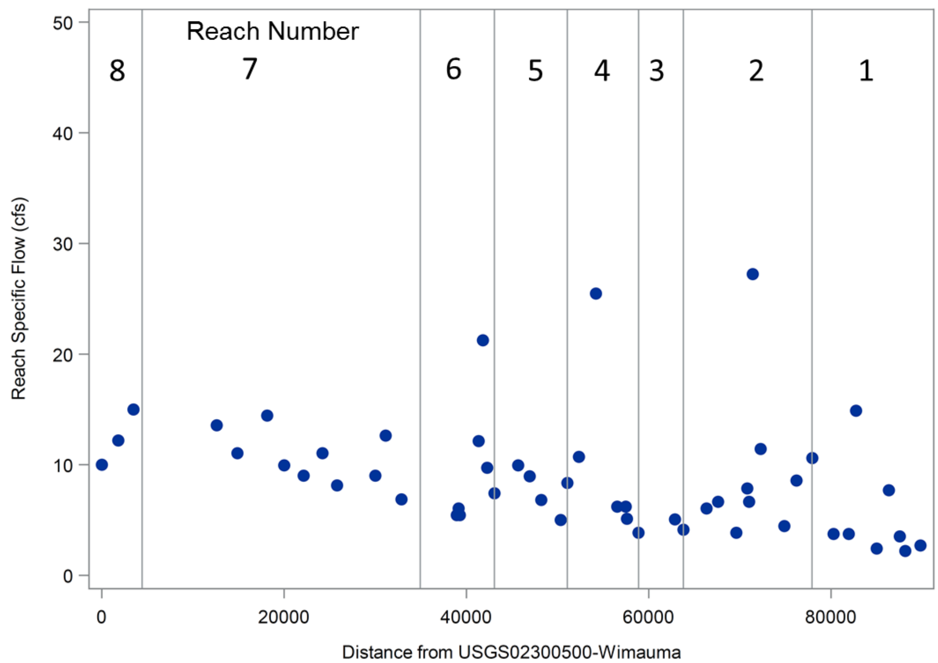



**Figure 4-4.** **Reach specific critical flow values associated with a 0.6-foot hydrologic depth for fish passage in the Upper Little Manatee River. See Figure 3-9 for river reach delineations.**

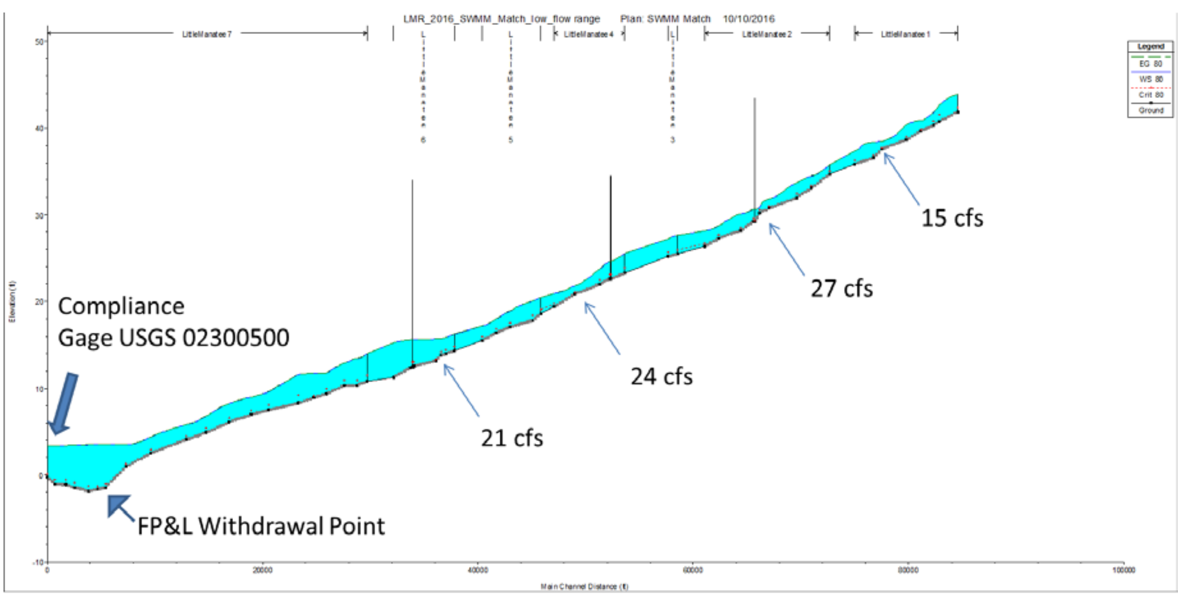



**Figure 4-5.** **Water-surface profile of the main stem of the Little Manatee River with critical shoals for fish passage denoted by arrows and labeled with reach specific flow requirements necessary to maintain hydrologic depth of 0.6 feet.**

## 4.2 SEFA Analysis for Instream Habitat Protection

The assessment of wetted perimeter and fish passage criteria are steady state evaluations. That is, there is a single unique solution to determining the criterion value associated with wetted perimeter or fish passage low flow thresholds which only depend on the wetted area or hydrologic depth of the water. Therefore, those criteria do not require evaluation of a timeseries of data. However, the SEFA analysis does require comparisons of timeseries of simulated flow reduction scenarios against a baseline timeseries of flows. This allows for the calculation of the change in species-specific suitable habitat for instream biota. This “reduction from baseline” approach is used to assess the potential for significant harm to biotic habitat suitability requirements based on percentage reductions in flow from the baseline scenario. Significant harm was identified as more than a 15% reduction in suitable habitat from the baseline flow record. Again, the baseline condition was defined as the excess flow corrected time series with the addition of any withdrawals by FP&L.

An example of the typical response in AWS as a function of season is provided for Spotted Sunfish in Figure 4-6. In this figure, the long term daily median flow is used to portray the long term median response in AWS to flow for each date. These curves for all taxonomic groups considered for analysis are provided in Appendix C.

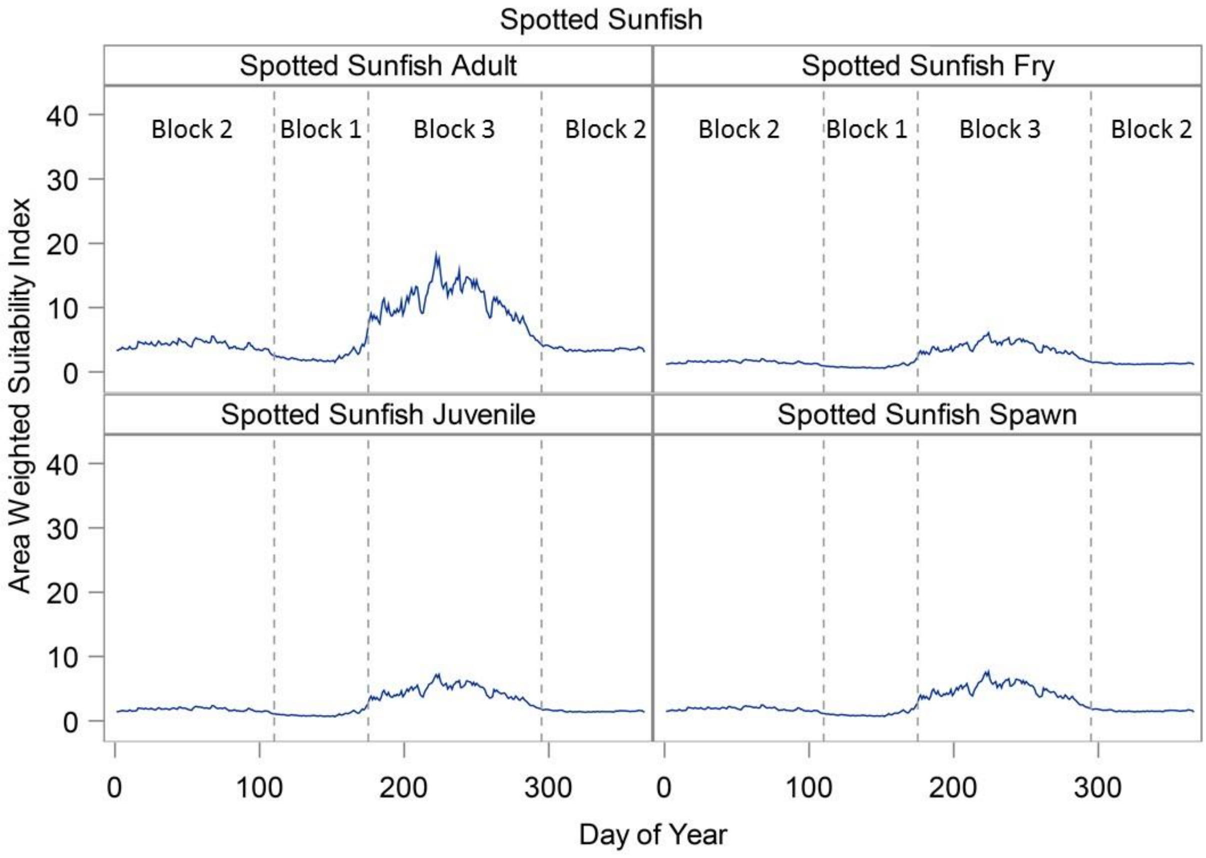



**Figure 4-6. Response in Area Weighted Suitability as a function of day of the typical year based on long term median flows at the Wimauma gage.**

The response curves for all species considered peaked in the high flow summer season (i.e., Block 3) which is due to the fact that the potential habitat area is inundated, and therefore maximized, during higher flows until velocity becomes restrictive. Because the analysis was intended to describe in channel habitat suitability and because reductions in habitat are more sensitive to lower flows, the SEFA analysis was restricted to Blocks 1 and 2 for the reevaluation. The floodplain inundation evaluation represents events that typically occur in Block 3 and therefore are most representative of the effects of flow reductions during that time. Flow reduction scenario evaluations were performed both within and across the two time periods identified as the benchmark and excess flow corrected time period. This was done to compare the results between the benchmark and excess flow corrected time periods.

The results of SEFA suggest that the percent reduction in AWS was generally linearly related to the percent reduction in flows. Because percent reductions in flow result in nonlinear decreases in the actual discharge values, the relationship between AWS and flow is exponential. Based on evaluation of the percent change in mean AWS values, the most sensitive taxa include specific life stages of the Largemouth Bass, Bluegill, Redbreast Sunfish, and Channel Catfish as well as the insect families Plecoptera, and Trichoptera (Table 4-2). By linearly interpolating between the results of the 10% and 20% flow reduction scenarios for the most sensitive species/life stage (Largemouth Bass fry), the results suggest that no more than a 13.5% reduction in flow would be allowed before triggering the significant harm criterion for instream habitat suitability. The percent reductions were almost identical when considering the benchmark and excess flow corrected time periods or when considering each block separately (Appendix C). These results support the method to account for excess flows in the system after 1976 and suggest that, after accounting for those excess flows, the benchmark and excess flow corrected time periods were similar to one another overall and it was not necessary to analyze these time periods separately for the remaining analysis.

**Table 4-2. Results of SEFA analysis reporting percent reduction in area weighted suitability for the 10 most sensitive species/life stages or groups as a function of percent flow reductions for two time periods within the full period of record.**

| | 1940-1976 | | | | | | 1977-2014 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Taxon/Group | Flow Reductions (%) | | | | | Taxon/Group | Flow Reductions (%) | | | |
| | 10% | 20% | 30% | 40% | | | 10% | 20% | 30% | 40% |
| Largemouth Bass Fry | -11.2 | -22.4 | -33.5 | -44.2 | | Largemouth Bass Fry | -11.1 | -22.1 | -32.9 | -43.8 |
| Largemouth Bass Adult | -9.8 | -19.6 | -29.6 | -39.7 | | Largemouth Bass Adult | -9.9 | -19.9 | -30.0 | -40.2 |
| Bluegill Fry | -9.7 | -19.3 | -29.2 | -39.2 | | Bluegill Fry | -9.7 | -19.5 | -29.5 | -39.8 |
| Redbreast Sunfish Fry | -9.0 | -18.2 | -27.6 | -37.4 | | Redbreast Sunfish Fry | -9.3 | -18.8 | -28.5 | -38.4 |
| Channel Catfish Adult | -8.8 | -17.9 | -27.2 | -36.7 | | Bluegill Adult | -9.2 | -18.5 | -28.0 | -37.8 |
| Bluegill Adult | -8.8 | -17.9 | -27.2 | -36.8 | | Channel Catfish Adult | -9.0 | -18.2 | -27.6 | -37.1 |
| Largemouth Bass Juvenile | -8.7 | -17.5 | -26.6 | -36.0 | | Largemouth Bass Juvenile | -8.8 | -17.9 | -27.3 | -37.0 |
| Largemouth Bass Spawn | -8.6 | -17.5 | -26.6 | -35.9 | | Largemouth Bass Spawn | -8.8 | -17.8 | -27.0 | -36.6 |
| Plecoptera | -8.4 | -17.0 | -25.9 | -35.1 | | Plecoptera | -8.6 | -17.4 | -26.4 | -35.8 |
| Trichoptera | -8.2 | -16.8 | -25.6 | -34.7 | | Trichoptera | -8.5 | -17.2 | -26.1 | -35.4 |

## 4.3 Floodplain Inundation for Protection of Bottomland Hardwood Swamp

The floodplain inundation analysis was based on the relationship between flow percentiles and the area of inundated floodplain vegetation as described in Chapter 3. A predictive model relating flows and floodplain inundation was used to predict whether or not the floodplain would be inundated on a particular date based on the critical elevation; and, the total area of the inundated floodplain for that date. The overall average inundated area for each reach and flow scenario over the period of record evaluated, as well as the inundation frequency based on at least 0.5 acres being inundated, were used as the metrics for evaluation. Based on outcomes of the SEFA analysis that demonstrated that the benchmark and excess flow corrected time series resulted in similar response profiles to flow reduction scenarios, only the time period between 1977 and 2014 was assessed for this analysis.

The 15% criterion value for both area and inundation frequency was not exceeded until flow reductions were above the 10% flow reduction scenario for all individual reaches along the main stem of the Upper Little Manatee River (Table 4-3). The overall reduction in inundated area for each flow scenario is provided in the last row of Table 4-3. Because this value was calculated across individual reaches that had different potential acreages of inundation, the result represents the best estimate of the overall average effect of flow reductions on the system. Linear interpolation between the results of the 10 and 20 percent reductions was used to determine the flow reduction resulting in a 15% reduction in area and frequency of inundation. The inference analysis suggests that a minimum flows criterion to protect the area of floodplain vegetation from significant harm would restrict withdrawals to no more than a 12.8% reduction in flows when flows are above the 60th percentile (the floodplain is not inundated until the 60th percentile of flow (72 cfs). The calculation of the proportion of days when the floodplain would be inundated varied in very similar fashion to the average acreage indicating that the floodplain elevations are relatively homogeneous The floodplain wetland vegetation in Reach 2 and Reach 5 were most sensitive to reductions in flow and represent a small area of higher elevation floodplain within the system. The criterion value resulting in no more than a 15% loss in area of inundated floodplain for these Reaches (that don't become inundated until the 80th percentile of flow), would require no more than an 11% withdrawal when flows were above the 80th percentile (i.e., 174 cfs).

**Table 4-3. Reach-specific and total percent change in average inundated area and proportion of days inundated in the Upper Little Manatee River as a function of flow reduction scenario from baseline.**

| | Reduction in Average Inundated Area | | | | Reduction in Days Inundated | | | |
|---|---|---|---|---|---|---|---|---|
| | Flow Reduction Scenario | | | | Flow Reduction Scenario | | | |
| Reach | 10% | 20% | 30% | 40% | 10% | 20% | 30% | 40% |
| LMR1 | -12.31 | -24.47 | -36.38 | -47.98 | -9.03 | -18.14 | -27.07 | -36.36 |
| LMR2 | -13.65 | -27.00 | -39.94 | -52.40 | -10.34 | -19.57 | -29.98 | -40.14 |
| LMR3 | -11.55 | -23.03 | -34.47 | -45.81 | -8.98 | -18.02 | -26.89 | -37.48 |
| LMR4 | -10.60 | -21.36 | -32.21 | -43.11 | -6.96 | -14.51 | -22.72 | -30.89 |
| LMR5 | -13.40 | -26.56 | -39.46 | -51.98 | -10.67 | -21.01 | -31.43 | -42.18 |
| LMR6 | -11.34 | -22.75 | -34.23 | -45.70 | -8.94 | -17.95 | -27.49 | -36.51 |
| LMR7 | -11.45 | -22.94 | -34.47 | -45.94 | -7.90 | -15.39 | -24.42 | -33.60 |
| LMR8 | -11.37 | -22.86 | -34.46 | -46.15 | -6.27 | -13.43 | -21.45 | -30.17 |
| Total | -11.72 | -23.43 | -35.12 | -46.70 | -7.99 | -16.16 | -24.99 | -34.14 |

# 5.1 Recommendations for Establishing Minimum Flows for the Upper Little Manatee River

## 5.2 Minimum Low-Flow Threshold

### 5.2.1 Wetted Perimeter

Application of the LWPIP approach suggested that most of the wetted perimeter inflection points were near the lowest flows considered (i.e., 7 cfs, the second percentile). After application of the exclusion criteria associated with the LWPIP approach, which restricted analysis to flows less than the 40$^{th}$ percentile and depths below 1 foot, the most sensitive cross section was located in Reach 6 (cross section 41919.80) where a reach specific critical flow of just over 18 cfs (i.e.,18.29) was identified as the LWPIP. This flow corresponds to a critical flow value at the Wimauma gage of 30.2 cfs. Reach 6 is relatively close to the Wimauma gage but is located above the South Fork junction where a substantial proportion of the total flow at the Wimauma gage is derived. Therefore, it is entirely possible for the critical flow value at Wimauma to be met while the reach specific flow is not, or vice versa. However, given that the cross section is close to the Wimauma gage and that this is the best information currently available from which to estimate low flow threshold values to protect the system from significant harm, 31 cfs was identified as the wetted perimeter criterion value for consideration as the low-flow threshold for the Upper Little Manatee River. It was noted that the hydrologic depth associated with the critical flow at that cross section was estimated to be 0.48 feet which would be insufficient as a fish passage criterion value.

### 5.2.2 Fish Passage

The fish passage criterion requires 0.6 feet of hydrologic depth at the most sensitive cross section. Using the logic considered for the wetted perimeter recommendation, the flow requirement to provide 0.6 feet hydrologic depth to the same Reach 6 cross section identified in the wetted perimeter analysis would require a reach specific flow of 22 cfs and a flow at Wimauma gage of 35 cfs. However, the same issues regarding the translation of reach specific flows to flows at the Wimauma gage affect both the wetted perimeter and the fish passage results.

The flow at Wimauma gage associated with the most sensitive cross section (Reach 2) would require 86 cfs, which is well above the long term median flow in the system. Since there is no way for downstream withdrawals to affect the upstream Reach 2 cross-section, and because a flow of 86 cfs at the gage near Wimauma can be achieved by multiple combinations of reach flows (in particular the substantial flows from the South Fork of the river), identifying a single criterion for fish passage represented by a flow at the Wimauma gage seemed impractical. In addition, it should be noted that currently the only significant surface water withdrawal is downstream of the most sensitive cross sections. Therefore, To be conservative and consistent with the logic of the LWPIP approach, a 35 cfs low-flow threshold is recommended for fish passage based on the flow requirements at the Wimauma gage for the same Reach 6 cross section that was identified for the wetted perimeter assessment and in addition, reach-specific criteria are also recommended to protect the eastern portion of the river if additional consumptive use is requested in the upstream portion of this watershed. The proposed fish passage criteria are 15 cfs at Reach 1 and 27 cfs at Reach 2 would protect upstream resources and because the Reach 2 flow is higher than any other downstream reach, would be protective of all other reaches to maintain a 0.6-foot hydrologic depth. That is, when flows in Reach 2 are 27 cfs, hydrologic depths are greater than 0.6ft in all other downstream cross sections. Again, these reach specific cross sections would only apply if further consumptive use was requested in the upstream watershed and a compliance assessment point would need to be implemented in order to evaluate compliance with these criteria.

## 5.3 Protection of Instream Flow Needs –SEFA

The results of SEFA suggest that the percent reduction in Area Weighted Suitability was generally linearly related to the percent reduction in flows, indicating an exponential relationship between AWS and flow. The results suggest that no more than a 13.5% reduction in flow would be allowed before triggering the significant harm criteria for the most sensitive taxa and life history stages (Largemouth Bass). Woody habitat analysis was conducted in the 2011 MFL report but no additional information was available from which to update these analyses. The results of the woody habitat analysis from the 2011 are still relevant but are less restrictive (in terms of percent reduction requirements) than the SEFA results presented here and therefore the woody habitat criteria are not further considered as minimum flows criteria.

## 5.4 Protecting High Flows for Floodplain Inundation

The inference from the floodplain inundation analysis suggests that an MFL to protect high flows would result in no more than an 11% reduction in those high flows that result in floodplain inundation to protect the most sensitive reaches (i.e., above the 80$^{th}$ flow percentile in Reach 2 and Reach 5) and no more than a 12.8% reduction in high flows (i.e., above the 60$^{th}$ percentile) to protect the entire system on average. The floodplains are not typically inundated by flows lower than the 60$^{th}$ percentile and not inundated in the most sensitive reaches until flows are above the 80$^{th}$ flow percentile.

## 5.5 Recommended Revised Minimum Flows

A summary of the results is provided in Table 5 1. Based on the totality of information resulting from the analysis described above, the recommended minimum flow for the freshwater portion of the MFL is a low flow cutoff value of 35 cfs to protect fish passage and wetted perimeter with additional reach specific criteria to protect upstream shoals in Reach 1 and 2 if further consumptive use is permitted in the eastern portion of the watershed. In addition, no more than a 13.5% reduction in flows above the low flow threshold is allowed anytime and no more than a 12.8% and 11% reduction is allowed when flows are above their 60$^{th}$ and 80$^{th}$ percentile values, respectively.

**Table 5-1. Table of results of MFL evaluation for resources of concern.**

| Analysis Name | Measure/Goal | Block | Criterion Values |
|---|---|---|---|
| Fish Passage | Maintain depth of 0.6 ft. at shoals at historical inundation frequency | All | Reach 1= 15 cfs, Reach 2= 27 cfs Wimauma = 35 cfs |
| Wetted Perimeter | Maximize inundation of stream bottom for benthic invertebrates | All | 31 cfs |
| SEFA | Avoid > 15% reduction in habitat for various instream species | All | No more than 13.5% |
| Floodplain | Avoid > 15% reduction of floodplain inundation frequency and areal extent | Flow greater than 60$^{th}$ and 80$^{th}$ percentile | No more than 12.8% when flows are above 60$^{th}$ percentile (i.e.,72 cfs) and 11% when flows are above the 80th percentile (174 cfs). |

The flow duration curves for the Baseline and Prescription flows are displayed in (Figure 5-1).

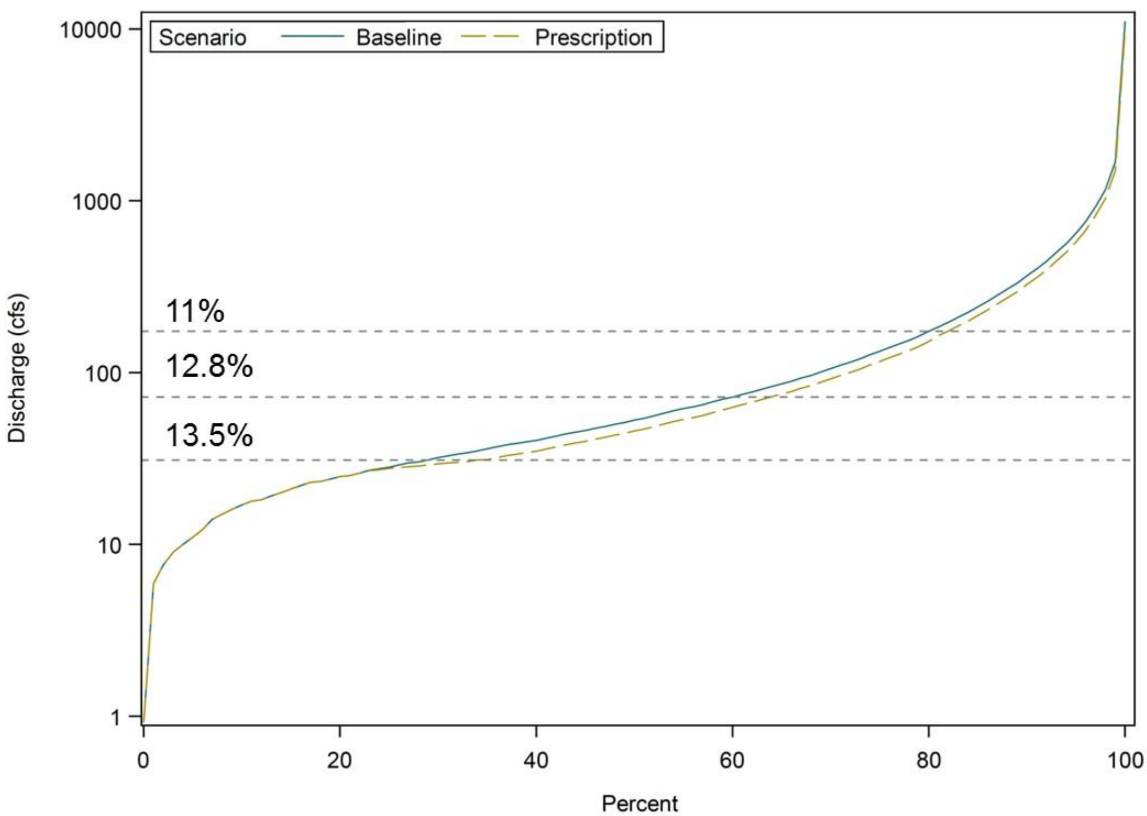



**Figure 5-1. Baseline and Prescription flow distribution with allowable consumptive use located on the hydrograph.**

The minimum flows (i.e., “prescription flows”) described above are based on specific habitat requirements associated with the protection of ecological resources in the system. While the calendar based blocks were considered as part of the analysis, blocks were not specifically used in the establishment of the recommended criteria because the natural resource requirements evaluated encompassed the range of flows described by the blocks. That is, the natural resource requirements of the system are inherently related to seasonality and the results of the analysis over the various water resource values supported a “flow based” or “resource based” approach to establishing the minimum flows. A comparison of the baseline and recommended prescription flows based on long term daily median values over the period of record is presented in Figure 5-2. This plot illustrates the relationship between a flow based MFL and one based on the “Building Block” approach. The plotted time series suggests that the allowable withdrawals are still tied to the calendar based blocks but have the advantage of being resource dependent irrespective of block. This helps address the issue brought up during peer review (Powell et al. 2012), regarding how a specific date may trigger an increase in allowable withdrawals even when flows for a specific calendar date are well below the long term median flow used to establish the block.

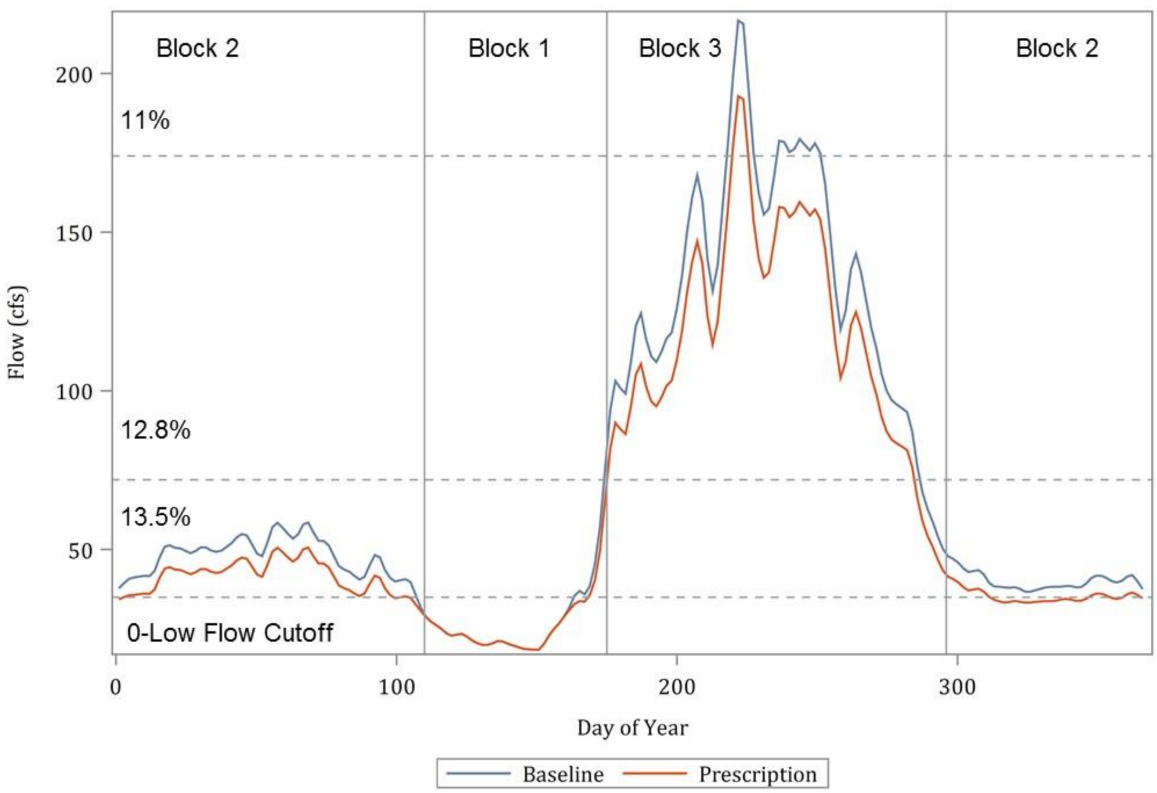



**Figure 5-2. Median flows under Baseline and Prescription scenario for each day of the year illustrating seasonal distribution of expected maximum difference in flows allowed under MFL.**

These recommendations based on reevaluation using the most recent data available resulted in generally very similar findings to those described in the 2011 minimum flow report. The currently proposed minimum low flow threshold is identical to that recommended in 2011. The 13.5% reduction between 35 cfs and the 60th percentile value (72 cfs) results in an allowable maximum flow reduction of approximately 10 cfs. This window for withdrawals equates to a frequency of approximately 30 percent of the days in a typical year assuming the historic time-period is representative of future conditions. The recommended criterion value for in-channel flows is between 2-4% higher (in terms of percent reduction) than that proposed in 2011, which was based on spatially restricted PHABSIM results. The differences in these thresholds results in a maximum difference in allowable withdrawal of approximately 3 cfs. Above 72 cfs, the criterion developed to protect small areas of floodplain inundation is implemented resulting in a 12.8% cap on consumptive use when flows are between 72 cfs and 174 cfs. This percentage flow reduction corresponds with a maximum withdrawal of 22 cfs when flows are between the 60$^{th}$ to 80$^{th}$ percentile. Above the 80$^{th}$ percentile, the consumptive use allowance becomes more restrictive to protect higher elevation floodplains in the watershed, resulting in an 11% cap of flows above 174 cfs. There is currently no high flow cap included in the recommendations; however, a high flow cap for withdrawals could be implemented as part of any future consumptive use permit.

The District has benefited from this reevaluation in several ways. The results lend further weight of evidence that the proposed MFL for the freshwater portion of the Little Manatee River is both reasonable and protective and addresses peer-review comments. The District now has an updated evaluation based on the most recent, best available data; has an improved HEC-RAS model for the Little Manatee River as well as an associated SWMM model from another project in the watershed; has an improved estimate of historical influences resulting in excess flows to the system, and has included SEFA and floodplain analyses into consideration when establishing the MFL. These attributes should serve the District well in advancing the regulatory standards for protecting the Upper Little Manatee River from significant harm. Because changes in the watershed such as future structural alterations and climatic change could potentially affect surface water or groundwater flow characteristics and because additional information relevant to minimum flows development may become available, the District is committed to periodic reevaluation and if necessary, revision of minimum flows for this priority water body that will presumably be incorporated into Chapter 40D-8, F.A.C., The complexity of the reach-specific low-flow threshold is an issue that will only require additional efforts on the part of the District in the event that additional consumptive use is permitted in the eastern portion of the watershed because currently the only significant surface water withdrawal is downstream of the most sensitive cross sections. This, and other issues associated with regulatory aspects of future water supply planning in the Little Manatee River are discussed further in the next Chapter on compliance and future status assessments

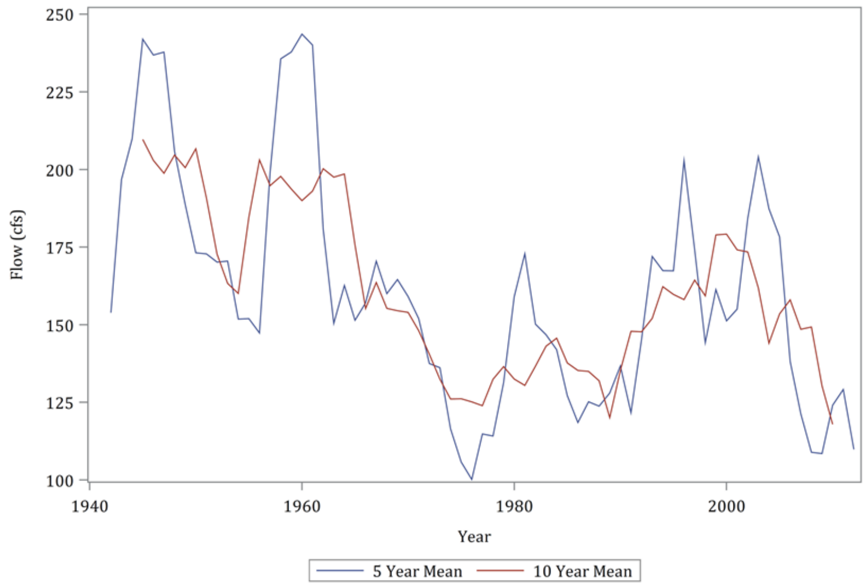
# 6.0 Minimum Flows Status Assessments

As reported in the 2011 minimum flows report, minimum five-year and ten-year moving annual average (mean) values were set forth as a tool to assess whether flows to the Little Manatee River remained above the proposed minimum flows. Yearly means and medians are computed for January 1 through December 31 of each year. Therefore, the means and medians are hydrologic statistics that represent the flows that will be met or exceeded if compliance with the proposed minimum flows is maintained. The hydrologic statistics are generated by simulating the maximum allowable withdrawal (as determined by the minimum flows criteria) being withdrawn from the daily flows for the period of record flows. Five- and ten-year running annual means and medians are then calculated for the period of record, and the minimum value of any 5 or 10 year mean and median values are designated as the threshold values.

For the revised recommended minimum flows described within, the minimum values used for compliance are presented in Table 6-1. It is notable that 3 of the 4 metrics evaluated resulted in threshold values that occurred within the historical time period considered to be relatively free of anthropogenic inputs. The time series of mean and medians over the various time windows are plotted in Figure 6-1 and illustrate the sensitivity of these values over time and the dramatic effects of a prolonged drought in the mid 1970's. Interestingly, the early 1940's displayed extremely high variability resulting in rather dramatic difference between the mean and median values, indicating some potential for the early portion of the time series to be of questionable reliability.

**Table 6-1. Minimum Five-Year and Ten-Year Moving Mean and Median Flows for the USGS Little Manatee River near Wimauma, FL gage with the application of the proposed minimum flows based on the flow record from 1940 through 2014.**

| Hydrologic Statistic | Flow (cfs) | Time Period of Minimum Value |
|---|---|---|
| 10- year mean | 105 | 2005–2014 |
| 10- year median | 34 | 1941–1950 |
| 5- year mean | 90 | 1974–1978 |
| 5- year median | 31 | 1942–1946 |



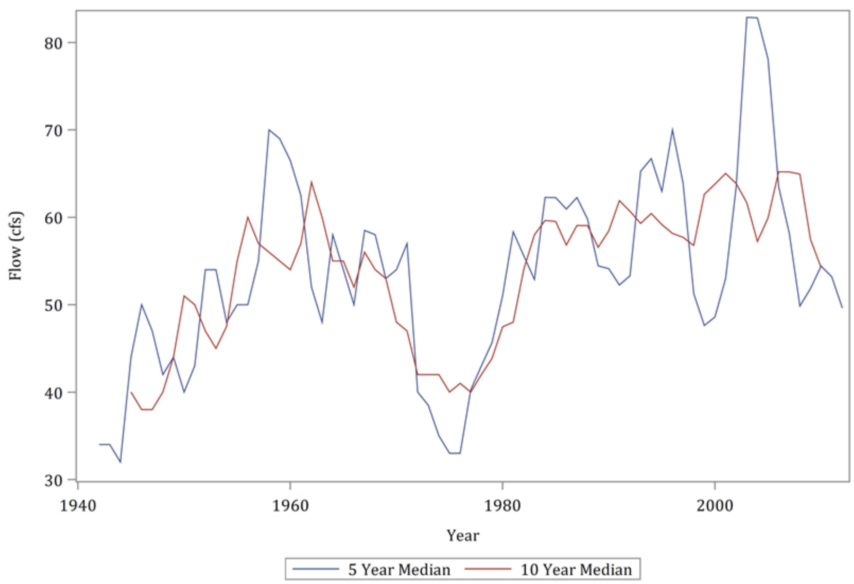




**Figure 6-1. Hydrologic statistics associated with a flow regime that would meet the recommended minimum flows for the Upper Little Manatee River. Statistics include five and 10-year arithmetic averages (top) and median values (bottom).**

While the compliance assessment described above has been used as standard methodology for several of the District MFLs, the methodology, if used as the sole evaluation metric may be insufficient to be protective of the proposed MFL. The arithmetic average is, even when taken over 5 and 10 year intervals, susceptible to influence by the presence (or absence) of peak flooding or drought events. The median values are more robust to the effects of large deviations due to single events but only reflect typical conditions in the system and are not directly tied to the endpoints identified as protective of the resource of concern. Future efforts should be directed towards developing a compliance framework that considers more than simply the long term hydrologic statistics as compliance points.

Fortunately, the Little Manatee River is currently one of the more pristine tidal river systems in the Tampa Bay area, if not the entire District. There is limited permitted consumptive use, much of the river bank is unarmored (i.e., not hardened with seawalls or rip-rap) and undeveloped, the Florida DEP considers the Little Manatee River a reference site based on its landscape development index score, and Hillsborough County has recently been active in acquiring conservation lands in the watershed to protect riparian buffer and other natural habitats in the watershed. Despite these important attributes, the Little Manatee River also appears to be quite sensitive to anthropogenic disturbance. As noted in the 2011 minimum flows report, the Little Manatee River is a flashy system with high runoff coefficients despite much of the watershed being rural. Both mining and agricultural practices have historically influenced stream flows. This was evident in the observation that stream flows were greater than could be expected by rainfall alone for a large portion of the time series and particularly in the 1980s and early 1990s. Fortunately, these trends appear to be dissipating as agricultural BMPs are implemented in the watershed, conservation lands are acquired, and mining practices improve efficiencies with respect to consumptive use and discharge.

As recommended by peer-review (Powell et al. 2012), the District would be well served to support additional studies in the Upper Little Manatee River to strengthen the evidence-based assessments used to support minimum flows implementation. In particular, a comparison of the several existing ungagged runoff modules associated with the modeling framework (SWMM, HEC-RAS, HSPF) of this system could yield additional insights into the relatively high flashiness of the system relative to other similar rivers in southwest Florida with more urban development and impervious surface. This effort would also yield more information from which it may be possible to partition the observed excess flows by source, including agriculture as well as other potential influences including mining activities. In addition, establishing another calibration point upstream of the Wimauma gage would likely improve the HEC-RAS model for future use.

There have been very few biological studies conducted in the Upper Little Manatee River despite the use of biological indicators as key metrics for thresholds indicative of significant harm. Dutterer (2006) conducted an electrofishing study to identify habitat selection and potential effects of flow reductions on Spotted Sunfish in the Little Manatee River. This study has been used by the District in support of establishing habitat suitability criteria for this species for evaluating the effects of flow reductions. The study makes an important contribution to the knowledge base of habitat flow interactions for a species of a family of fishes that are common and important ecological elements in many freshwater systems. However, the study has several limitations which further studies might support. The study was conducted downstream of the US Highway 301 bridge across the river and therefore outside the defined boundary for the Upper river minimum flows. The sampling locations were tidally influenced with a reported average effect of 0.3 meters change in stage due to tide though salinities were reported as generally less than 5 ppt salinity. Further study in more upstream areas (i.e., above US Highway 301) would help support the reported finding that a relatively minor change in stage (0.3 meters) corresponded to a 20% loss in habitat availability for Spotted Sunfish in areas where tidal influence is negligible. The SEFA analysis conducted for this report suggested that Spotted Sunfish area weighted suitability response to changes in flow was more muted than other species such as the Largemouth Bass, also commonly found in the Little Manatee River. More recently the Florida Fish and Wildlife Conservation Commission (FWC) has been conducting electrofishing sampling in the same areas sampled by Dutterer to target habitat associations of the Common Snook (*Centropomus undecimalis*) in oligohaline portions of the Little Manatee River (Alexis Trotter, personal communication). Snook are an economically important popular game fish in Florida and are thought to move from open estuarine and coastal marine habits in Florida into rivers during colder months to overwinter (Blewett et al 2009). Blewett et al. (2009) documented relatively high abundance of Snook in three southwest Florida rivers during all seasons. They also found that Snook abundance in the tidal freshwater portions of all three rivers was high in spring and summer, and then doubled in the fall. Preliminary results from the FWC study in the Little Manatee River (Alexis Trotter unpublished data) indicate that Snook utilize the Little Manatee River year-round and that seasonal differences may vary by year. Captured Snook ranged in size from young of the year juveniles to sexually mature adults indicating that the Little Manatee River is an important resource for multiple life stages of this highly prized gamefish species. More study, further upstream of the Little Manatee River would be beneficial not only to refine Spotted Sunfish habitat assessments but to confirm the utilization of the freshwater portion of the Little Manatee River by the Common Snook.

The Little Manatee River is a complex system with a significant portion of the flow measured at the Wimauma gage derived from the South Fork of the river which drains portions of Manatee County. Given the nature of thunderstorm activity in Southwest Florida during the wet season, it is possible if not likely that on any given day the flow measured at the Wimauma gage may have been disproportionately derived from any of the individual reaches in the system despite the HEC-RAS model's flow apportionment routine. This factor complicates the inference when establishing flow threshold criteria for a compliance gage on the downstream end of a complex river system. The recommendation of additional reach specific low-flow threshold criteria in the eastern portion of the watershed are proposed to help ensure that critical areas, such as the shallow cross section in Reach 2, maintain adequate water-surface elevations representative of historic conditions in the watershed. If additional consumptive use is permitted in the eastern portion of the watershed, it would be worthwhile to conduct a survey of this area and perhaps develop a rating curve that could be used to establish an additional future compliance point for this section of the river.

In summary, the District now has recommended minimum flows for the Upper Little Manatee River that are based on an internally consistent model framework and use current information to derive protective limits for consumptive use. A companion document to this report is currently being developed to evaluate the effects of flow reductions on the lower (estuarine) portion of the Little Manatee River. That report includes description of the relationship between flows and estuarine biota, including additional analysis of flow reductions on fish habitat suitability as well as an evaluation of the potential effects of sea level rise on the proposed minimum flows criteria. Together, these documents and the resultant minimum flow rules based on recommendations included in these documents will provide a benchmark from which water use permitting, water supply planning, and adaptive management strategies can be utilized for the proper stewardship of these critical ecosystem values in the Little Manatee River.

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# APPENDIX A

Regression results used for excess flow correction

# Rainfall Streamflow Regression

## The GLM Procedure

| Class Level Information | | |
|---|---|---|
| **Class** | **Levels** | **Values** |
| **month** | 12 | 1 2 3 4 5 6 7 8 9 10 11 12 |

| | |
|---|---|
| **Number of Observations Read** | 900 |
| **Number of Observations Used** | 288 |

## The GLM Procedure

### Dependent Variable: swima

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **Model** | 15 | 113.3490490 | 7.5566033 | 38.48 | <.0001 |
| **Error** | 272 | 53.4088244 | 0.1963560 | | |
| **Corrected Total** | 287 | 166.7578734 | | | |

| R-Square | Coeff Var | Root MSE | swima Mean |
|---|---|---|---|
| 0.679722 | 833.9599 | 0.443121 | 0.053135 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **Parrish1** | 1 | 62.93883157 | 62.93883157 | 320.53 | <.0001 |
| **Parrish4** | 1 | 32.51227760 | 32.51227760 | 165.58 | <.0001 |
| **Plant2** | 1 | 10.99979559 | 10.99979559 | 56.02 | <.0001 |
| **Plant12** | 1 | 2.61845743 | 2.61845743 | 13.34 | 0.0003 |
| **month** | 11 | 4.27968683 | 0.38906244 | 1.98 | 0.0303 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| **Parrish1** | 1 | 5.59725358 | 5.59725358 | 28.51 | <.0001 |
| **Parrish4** | 1 | 8.33100776 | 8.33100776 | 42.43 | <.0001 |
| **Plant2** | 1 | 7.89003377 | 7.89003377 | 40.18 | <.0001 |
| **Plant12** | 1 | 2.58572748 | 2.58572748 | 13.17 | 0.0003 |
| **month** | 11 | 4.27968683 | 0.38906244 | 1.98 | 0.0303 |

| Parameter | Estimate | | Standard Error | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| **Intercept** | 0.0862785403 | B | 0.09047008 | 0.95 | 0.3411 |
| **Parrish1** | 0.1858406770 | | 0.03480770 | 5.34 | <.0001 |
| **Parrish4** | 0.2470131159 | | 0.03792218 | 6.51 | <.0001 |
| **Plant2** | 0.2327662182 | | 0.03671999 | 6.34 | <.0001 |

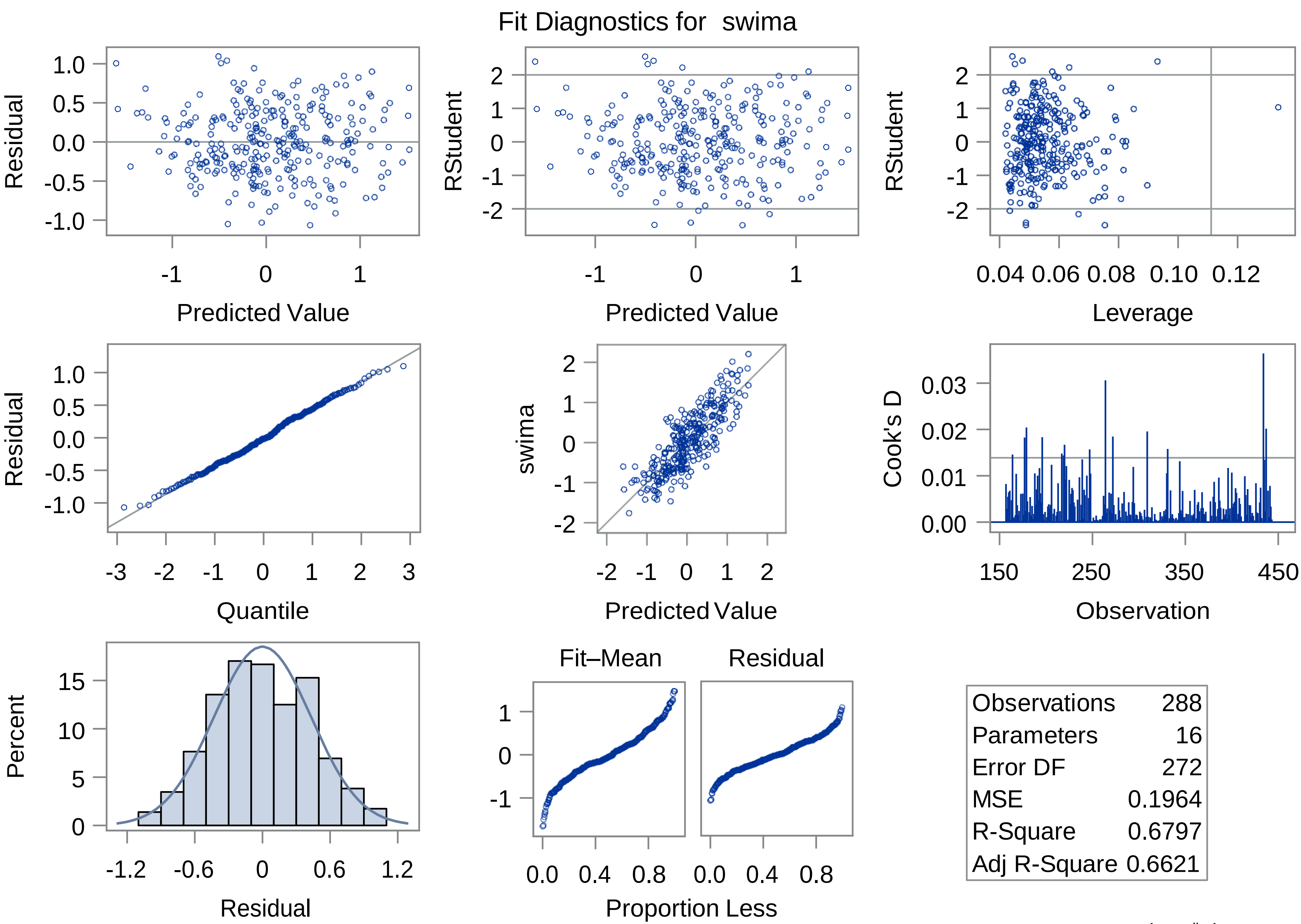
## The GLM Procedure

## Dependent Variable: swima

| Parameter | Estimate | | Standard Error | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Plant12 | 0.0973265176 | | 0.02682019 | 3.63 | 0.0003 |
| month 1 | 0.0595559323 | B | 0.12802757 | 0.47 | 0.6422 |
| month 2 | 0.0166762905 | B | 0.12807194 | 0.13 | 0.8965 |
| month 3 | -.0097851190 | B | 0.12816512 | -0.08 | 0.9392 |
| month 4 | 0.1085113405 | B | 0.12823369 | 0.85 | 0.3982 |
| month 5 | 0.0564814085 | B | 0.12808271 | 0.44 | 0.6596 |
| month 6 | 0.0140079782 | B | 0.12800641 | 0.11 | 0.9129 |
| month 7 | -.2345775087 | B | 0.12795460 | -1.83 | 0.0679 |
| month 8 | -.2837294070 | B | 0.12795518 | -2.22 | 0.0274 |
| month 9 | -.1777934897 | B | 0.12792706 | -1.39 | 0.1657 |
| month 10 | -.1612932427 | B | 0.12795229 | -1.26 | 0.2085 |
| month 11 | -.0416825498 | B | 0.12804021 | -0.33 | 0.7450 |
| month 12 | 0.0000000000 | B | . | . | . |

**Note:** The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

Dependent Variable: swima




| | |
|---|---|
| Observations | 288 |
| Parameters | 16 |
| Error DF | 272 |
| MSE | 0.1964 |
| R-Square | 0.6797 |
| Adj R-Square | 0.6621 |

# Residual Diagnostics on Rainfall Streamflow Regression

# Diagnostics Test for Autocorrelation and multicolinearity in Residuals

## The REG Procedure Model: MODEL1 Dependent Variable: swima

| | |
|---|---|
| **Number of Observations Read** | 900 |
| **Number of Observations Used** | 288 |
| **Number of Observations with Missing Values** | 612 |

| Analysis of Variance | | | | | |
|---|---|---|---|---|---|
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 4 | 109.06936 | 27.26734 | 133.76 | <.0001 |
| **Error** | 283 | 57.68851 | 0.20385 | | |
| **Corrected Total** | 287 | 166.75787 | | | |

| | | | |
|---|---|---|---|
| **Root MSE** | 0.45149 | **R-Square** | 0.6541 |
| **Dependent Mean** | 0.05313 | **Adj R-Sq** | 0.6492 |
| **Coeff Var** | 849.71753 | | |

| Parameter Estimates | | | | | | |
|---|---|---|---|---|---|---|
| **Variable** | **DF** | **Parameter Estimate** | **Standard Error** | **t Value** | **Pr > \|t\|** | **Variance Inflation** |
| **Intercept** | 1 | 0.03182 | 0.02665 | 1.19 | 0.2335 | 0 |
| **Parrish1** | 1 | 0.18412 | 0.03507 | 5.25 | <.0001 | 1.65523 |
| **Parrish4** | 1 | 0.24566 | 0.03857 | 6.37 | <.0001 | 1.91138 |
| **Plant2** | 1 | 0.23342 | 0.03721 | 6.27 | <.0001 | 2.05818 |
| **Plant12** | 1 | 0.09782 | 0.02729 | 3.58 | 0.0004 | 1.37635 |

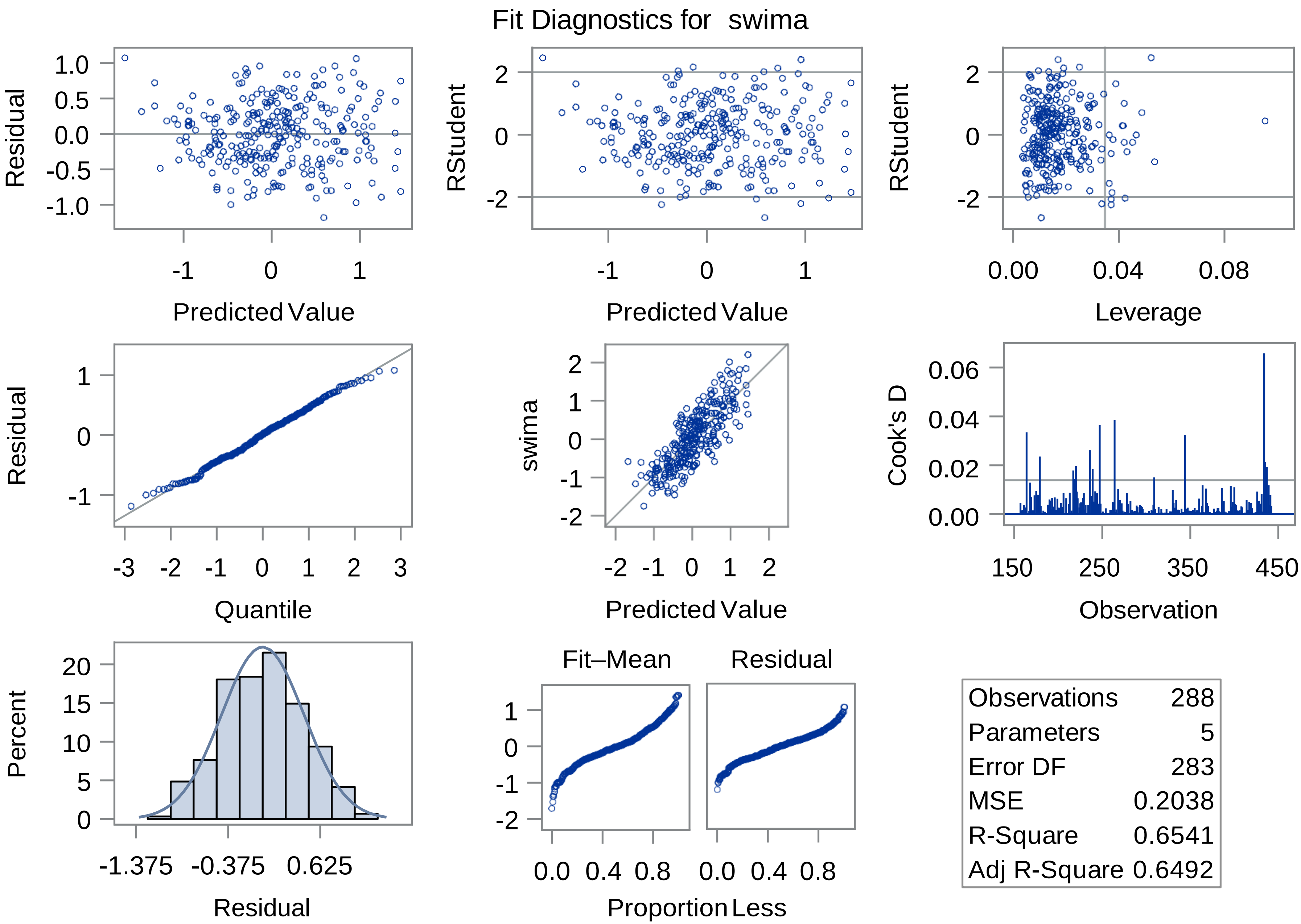
# Diagnostics Test for Autocorrelation and multicolinearity in Residuals

## The REG Procedure Model: MODEL1 Dependent Variable: swima

| | |
|---|---|
| **Durbin-Watson D** | 1.399 |
| **Number of Observations** | 288 |
| **1st Order Autocorrelation** | 0.294 |

**Diagnostics Test for Autocorrelation and multicolinearity in Residuals**

**The REG Procedure Model:**
**MODEL1 Dependent**
**Variable: swima**

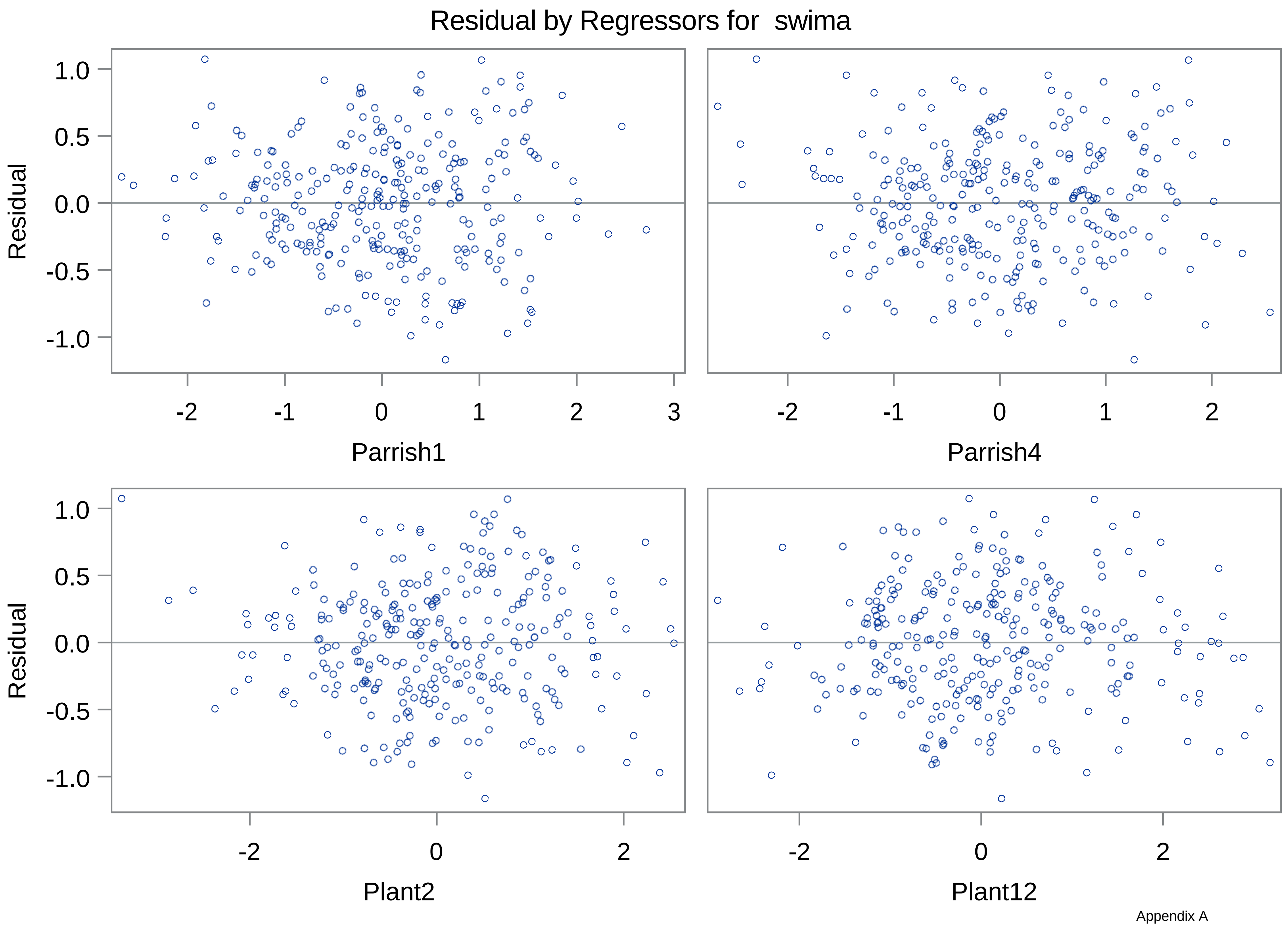



Appendix A

## Diagnostics Test for Autocorrelation and multicolinearity in Residuals

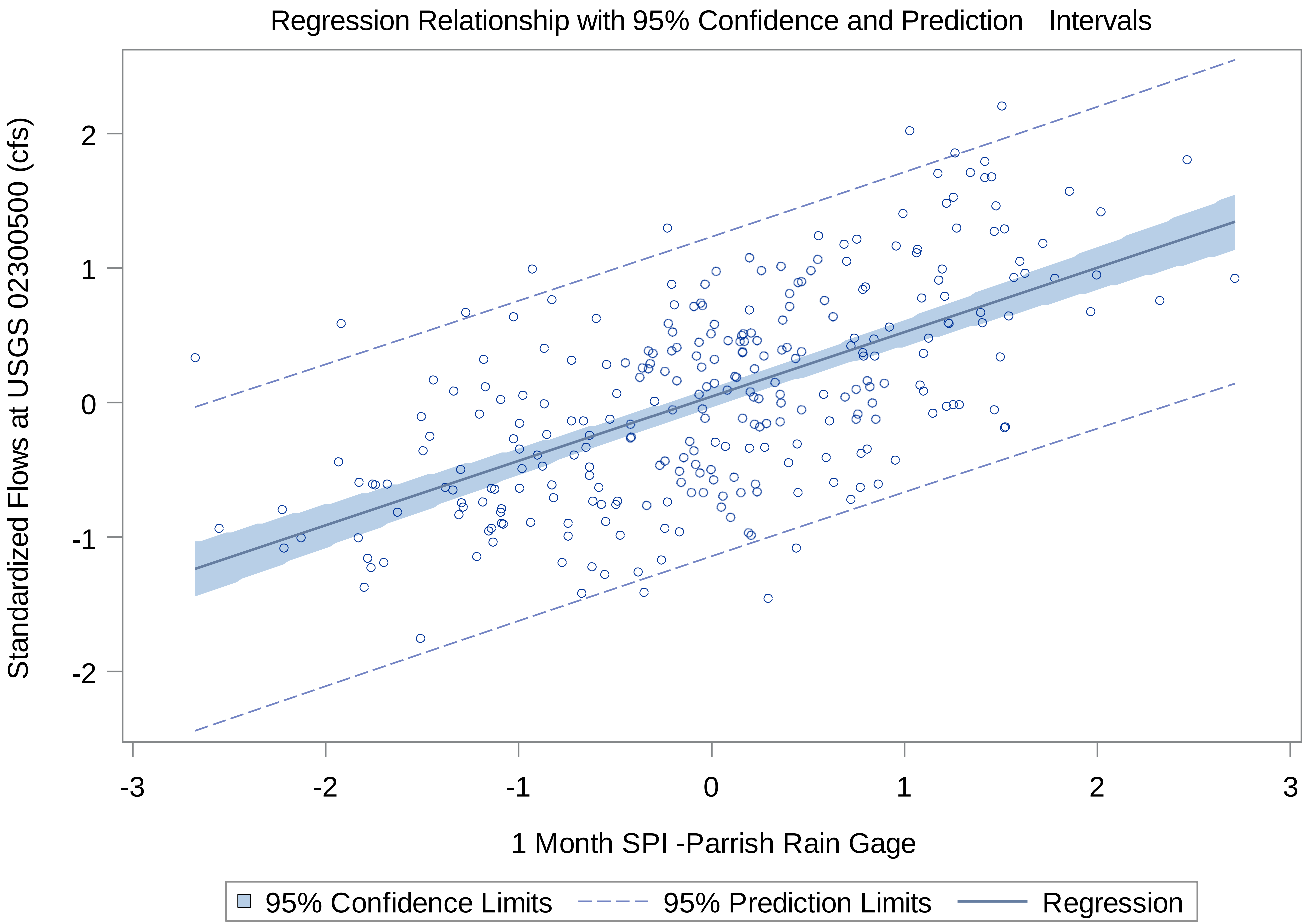
**The REG Procedure Model:**
**MODEL1 Dependent**
**Variable: swima**

Appendix A


Residual by Regressors for swima
Residual
1.0
0.5
0.0
-0.5
-1.0
-2
-1
0
1
2
3
Parrish1
Parrish4
Plant2
Plant12

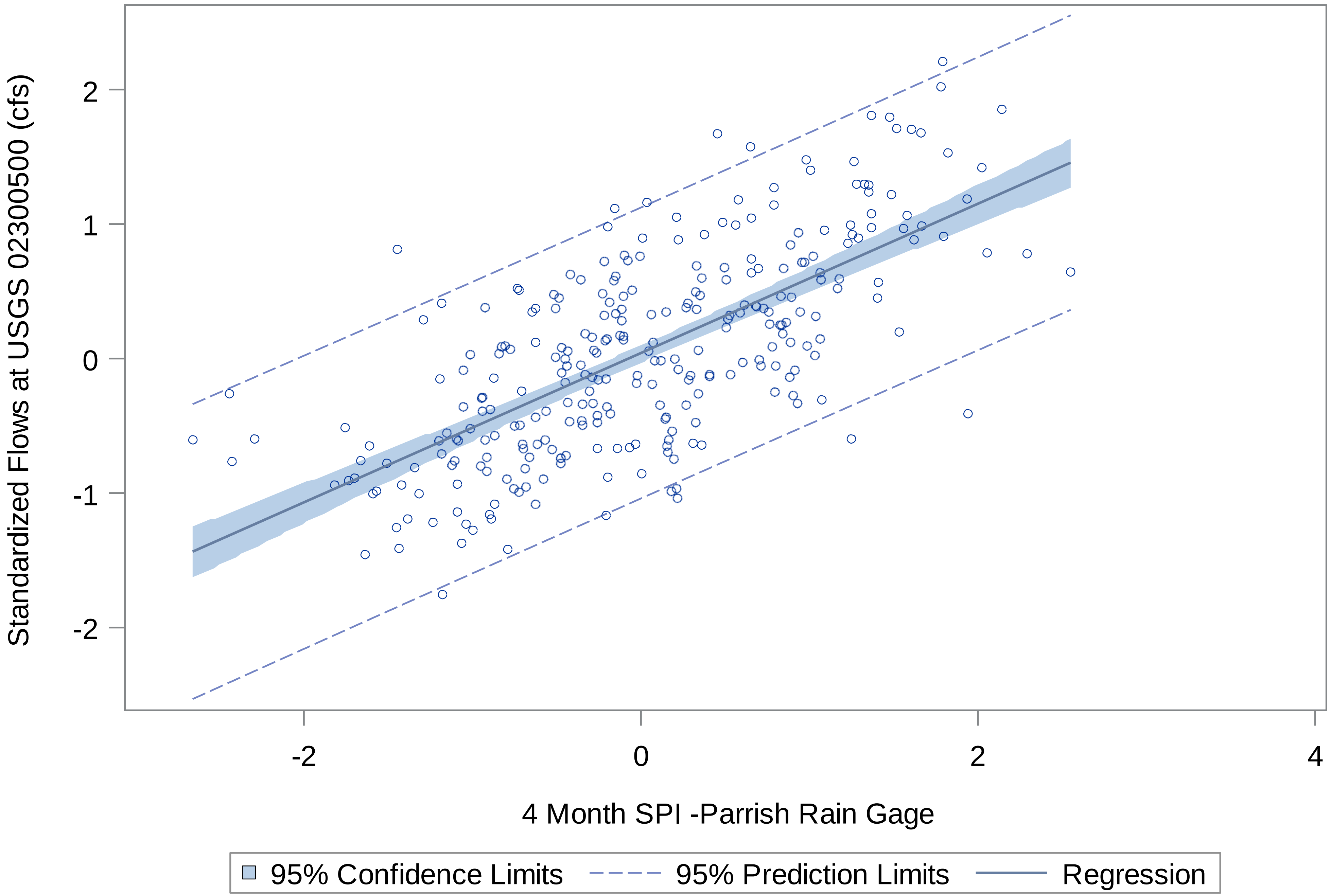
Appendix A

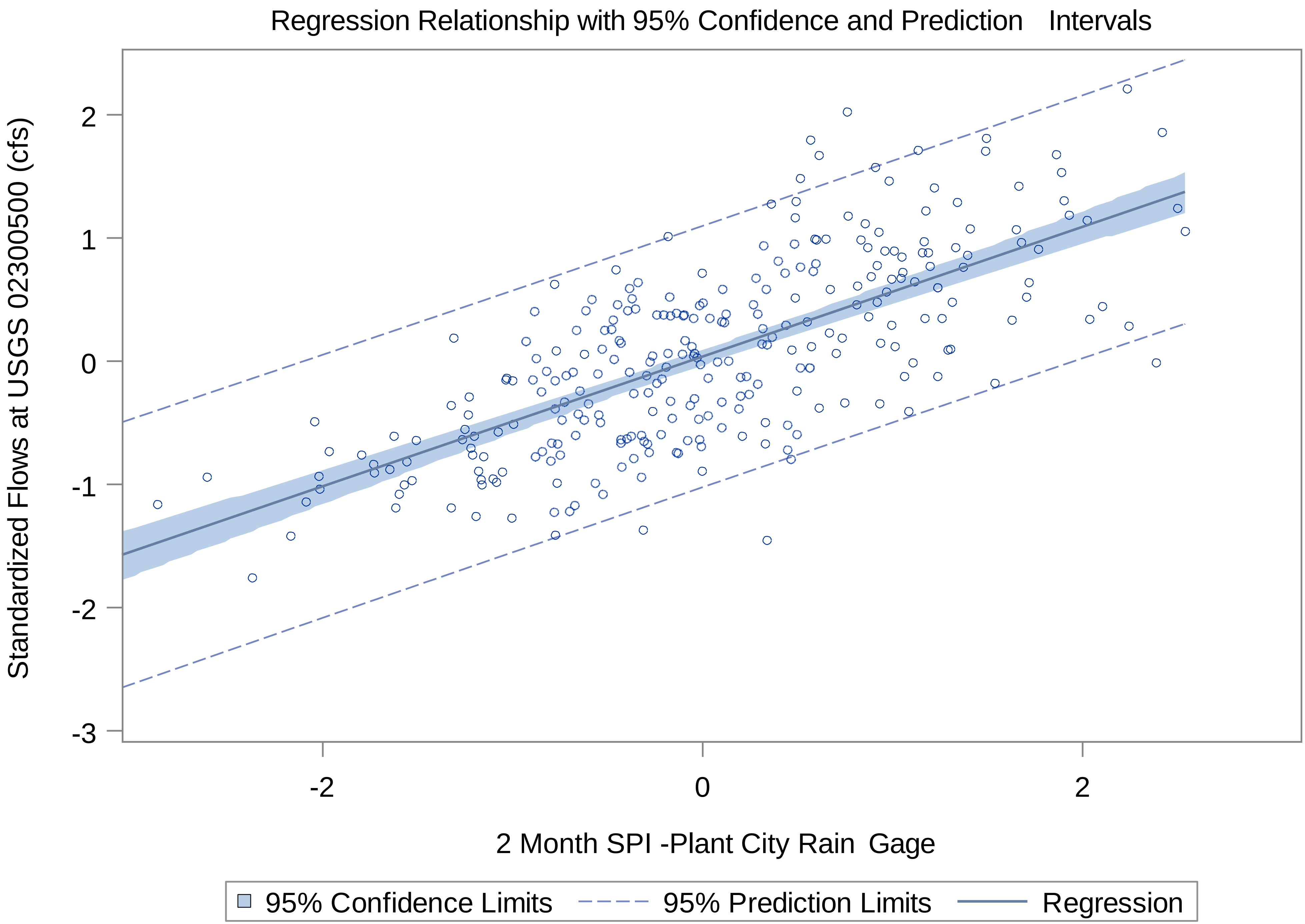
# Partial Prediction Plots

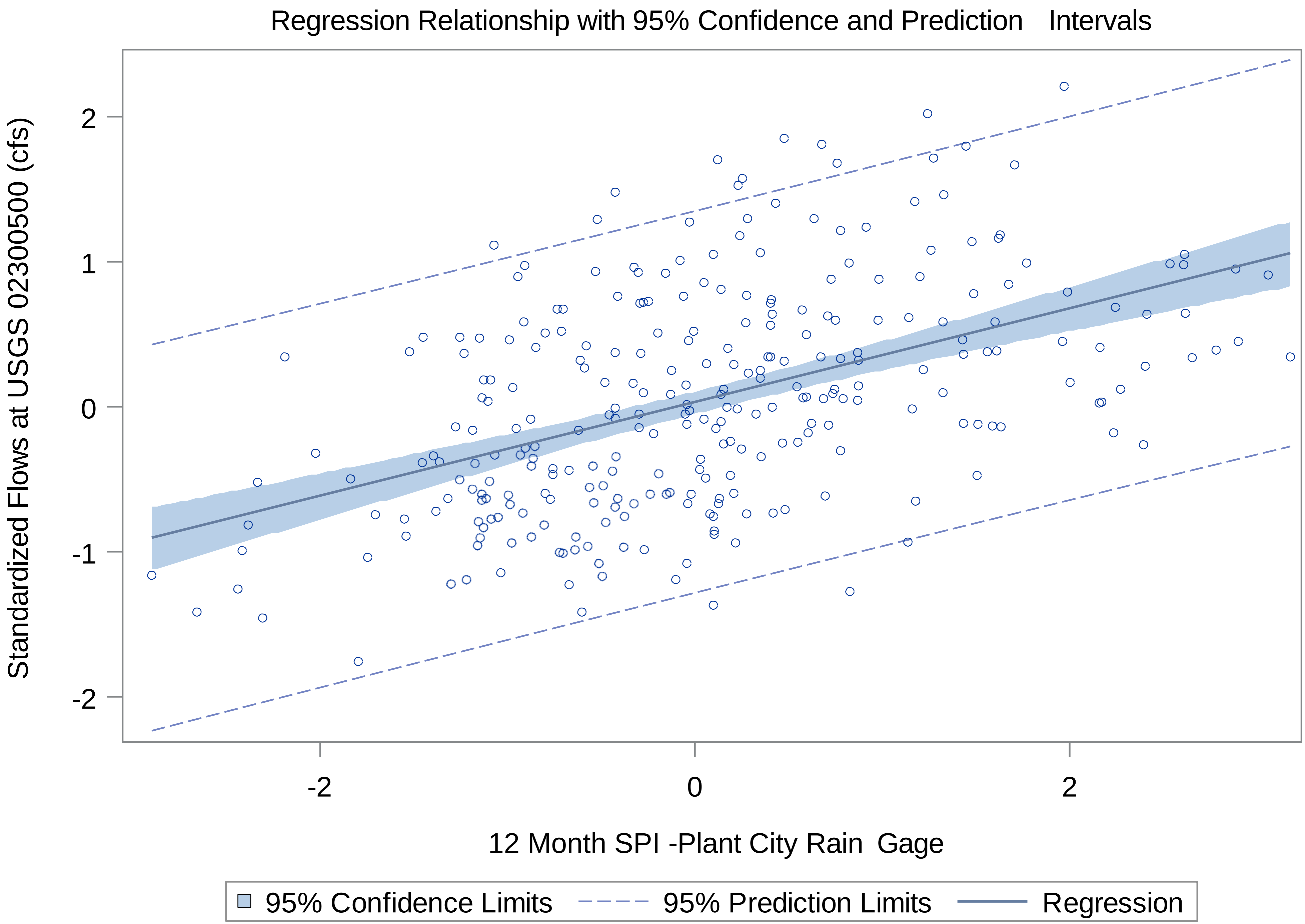

Regression Relationship with 95% Confidence and Prediction Intervals
Standardized Flows at USGS 02300500 (cfs)
2
1
0
-1
-2
-3
-2
-1
0
1
2
3
1 Month SPI -Parrish Rain Gage
95% Confidence Limits
95% Prediction Limits
Regression

Appendix A

Regression Relationship with 95% Confidence and Prediction Intervals




Regression Relationship with 95% Confidence and Prediction Intervals
Standardized Flows at USGS 02300500 (cfs)
2
1
0
-1
-2
-3
-2
0
2
2 Month SPI -Plant City Rain Gage
95% Confidence Limits
95% Prediction Limits
Regression


Regression Relationship with 95% Confidence and Prediction Intervals
Standardized Flows at USGS 02300500 (cfs)
2
1
0
-1
-2
-2
0
2
12 Month SPI -Plant City Rain Gage
95% Confidence Limits
95% Prediction Limits
Regression

# LOESS Regression Through the Residuals to Predict Excess Flows

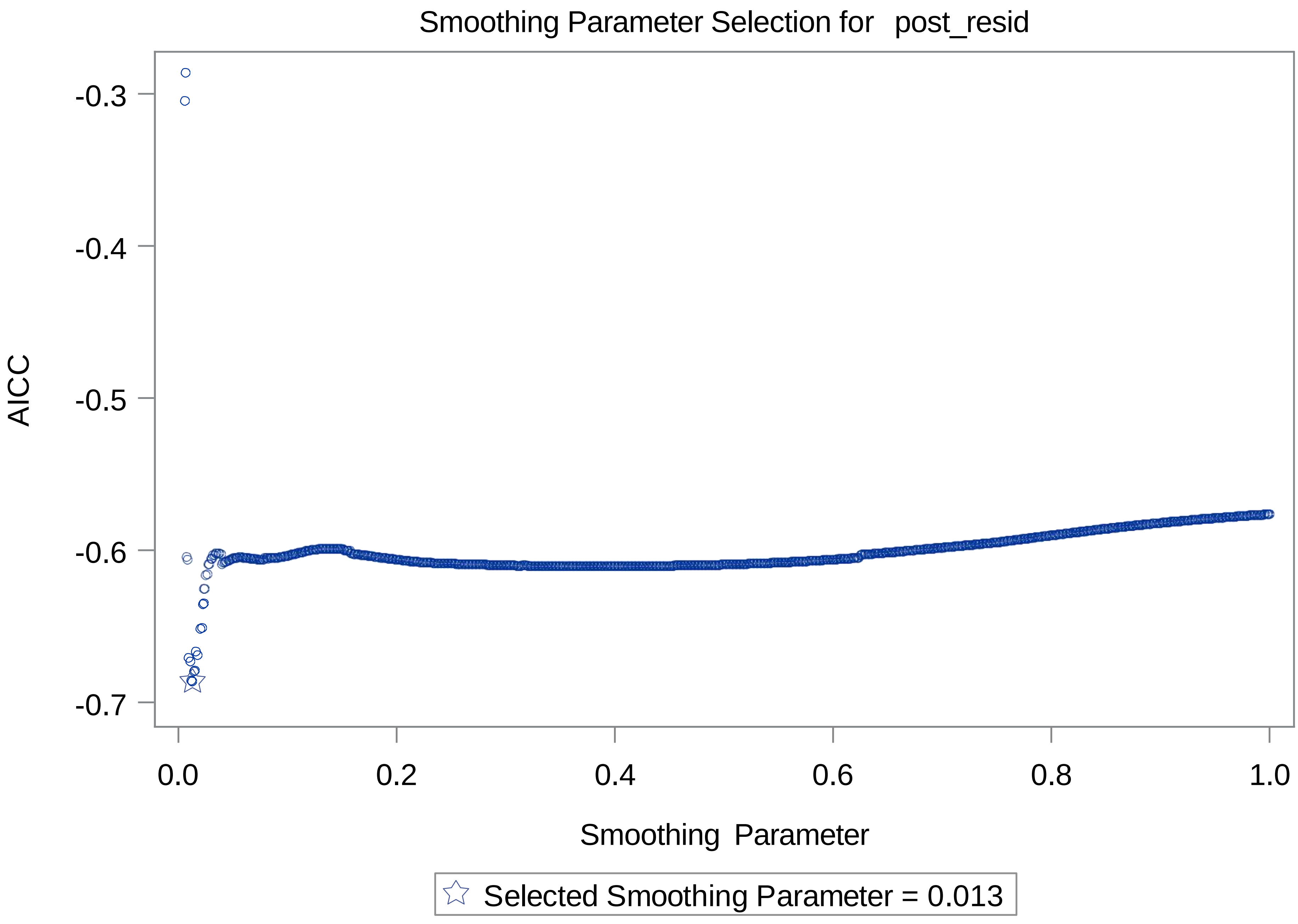
# LOESS Regression For Calculation of Excess Flows

## The LOESS Procedure

| Independent Variable Scaling | |
|---|---|
| Scaling applied: None | |
| Statistic | date |
| Minimum Value | 01DEC40 |
| Maximum Value | 01DEC14 |

**LOESS Regression For Calculation of Excess Flows**

**The LOESS Procedure**
**Dependent Variable: post_resid**




Appendix A

# LOESS Regression For Calculation of Excess Flows

## The LOESS Procedure
## Dependent Variable: post_resid

| Optimal Smoothing Criterion | |
| --- | --- |
| AICC | Smoothing Parameter |
| -0.68610 | 0.01294 |

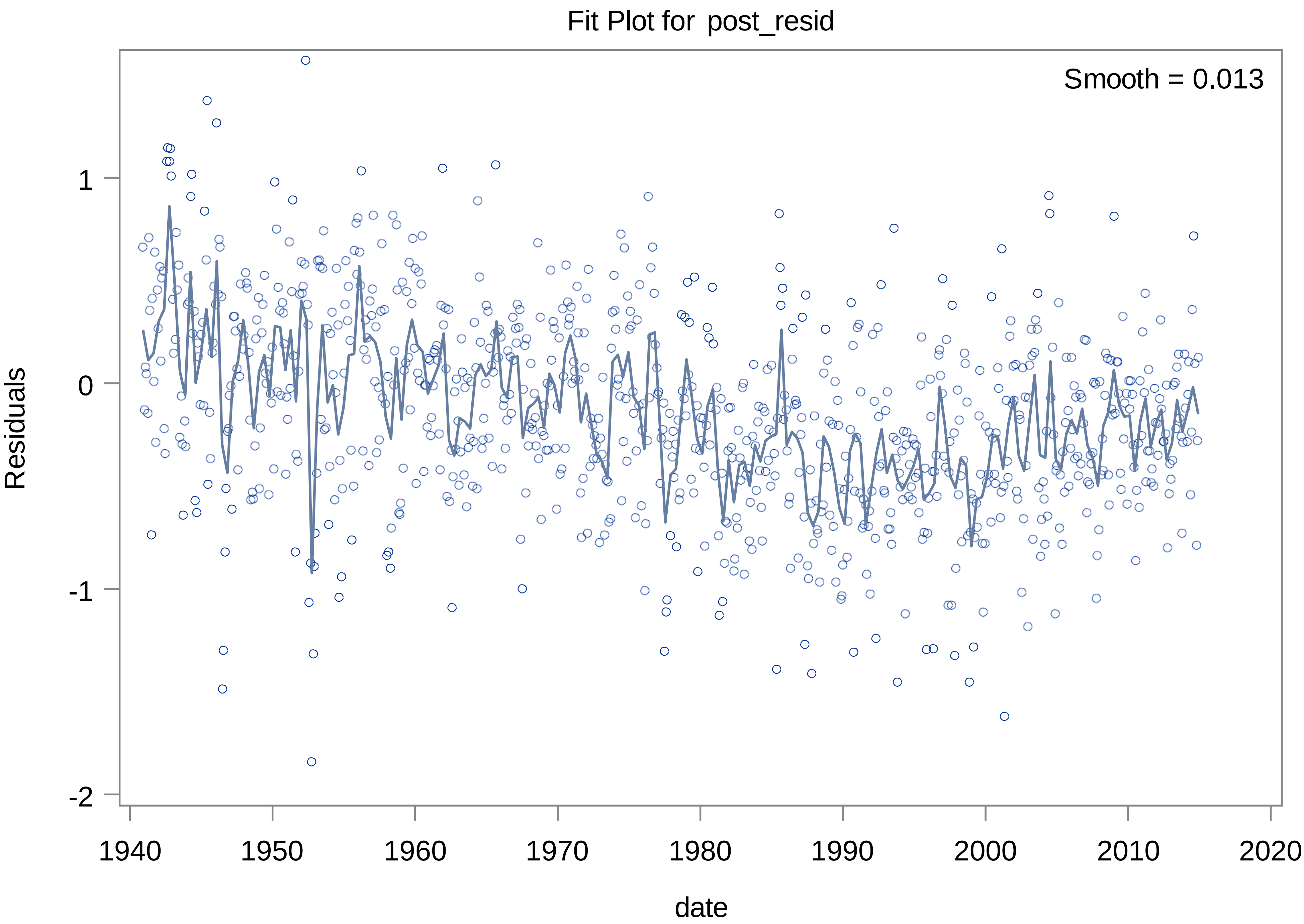
# LOESS Regression For Calculation of Excess Flows

## The LOESS Procedure
## Selected Smoothing Parameter: 0.013
## Dependent Variable: post_resid

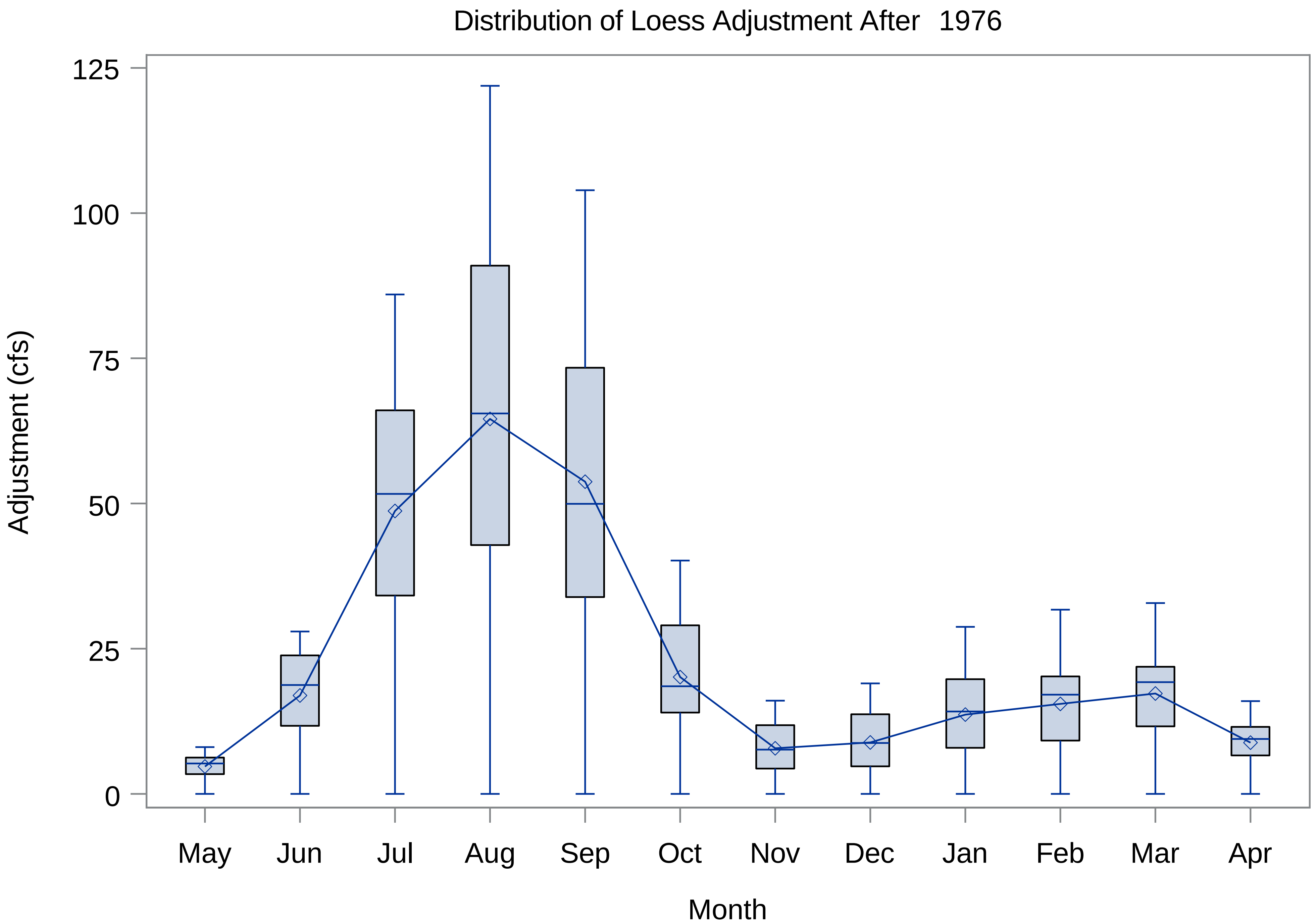
| Fit Summary | |
|---|---|
| **Fit Method** | kd Tree |
| **Blending** | Linear |
| **Number of Observations** | 889 |
| **Number of Fitting Points** | 513 |
| **kd Tree Bucket Size** | 2 |
| **Degree of Local Polynomials** | 1 |
| **Smoothing Parameter** | 0.01294 |
| **Points in Local Neighborhood** | 11 |
| **Residual Sum of Squares** | 108.62205 |
| **Trace[L]** | 151.93901 |
| **GCV** | 0.00019995 |
| **AICC** | -0.68610 |

## LOESS Regression For Calculation of Excess Flows

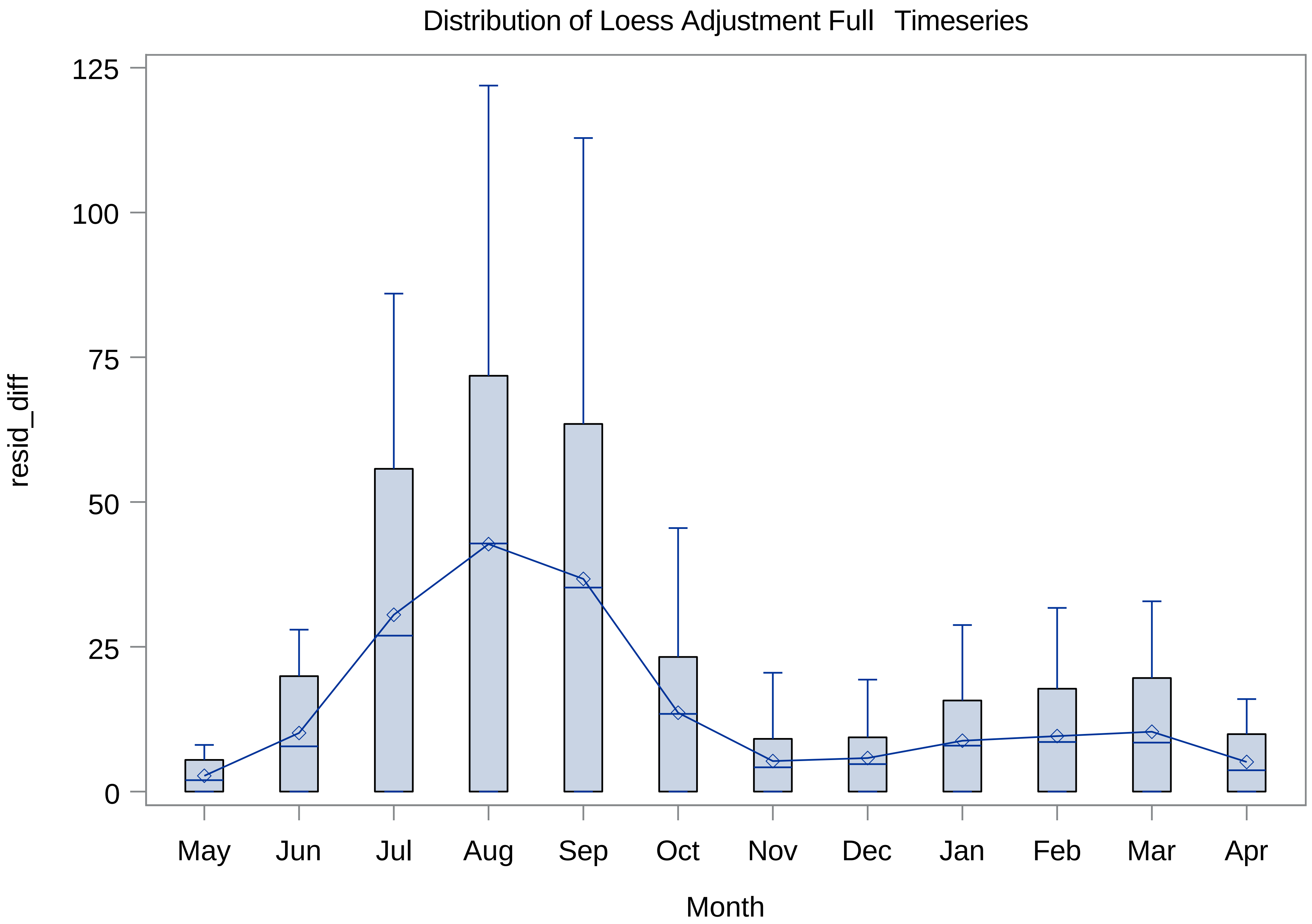
**The LOESS Procedure**
**Selected Smoothing Parameter: 0.013**
**Dependent Variable: post_resid**


Fit Plot for post_resid
Smooth = 0.013
Residuals
1
0
-1
-2
1940
1950
1960
1970
1980
1990
2000
2010
2020
date

# Distribution Plots of Excess Flow Correction


Distribution of Loess Adjustment After 1976
Adjustment (cfs)
125
100
75
50
25
0
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Month

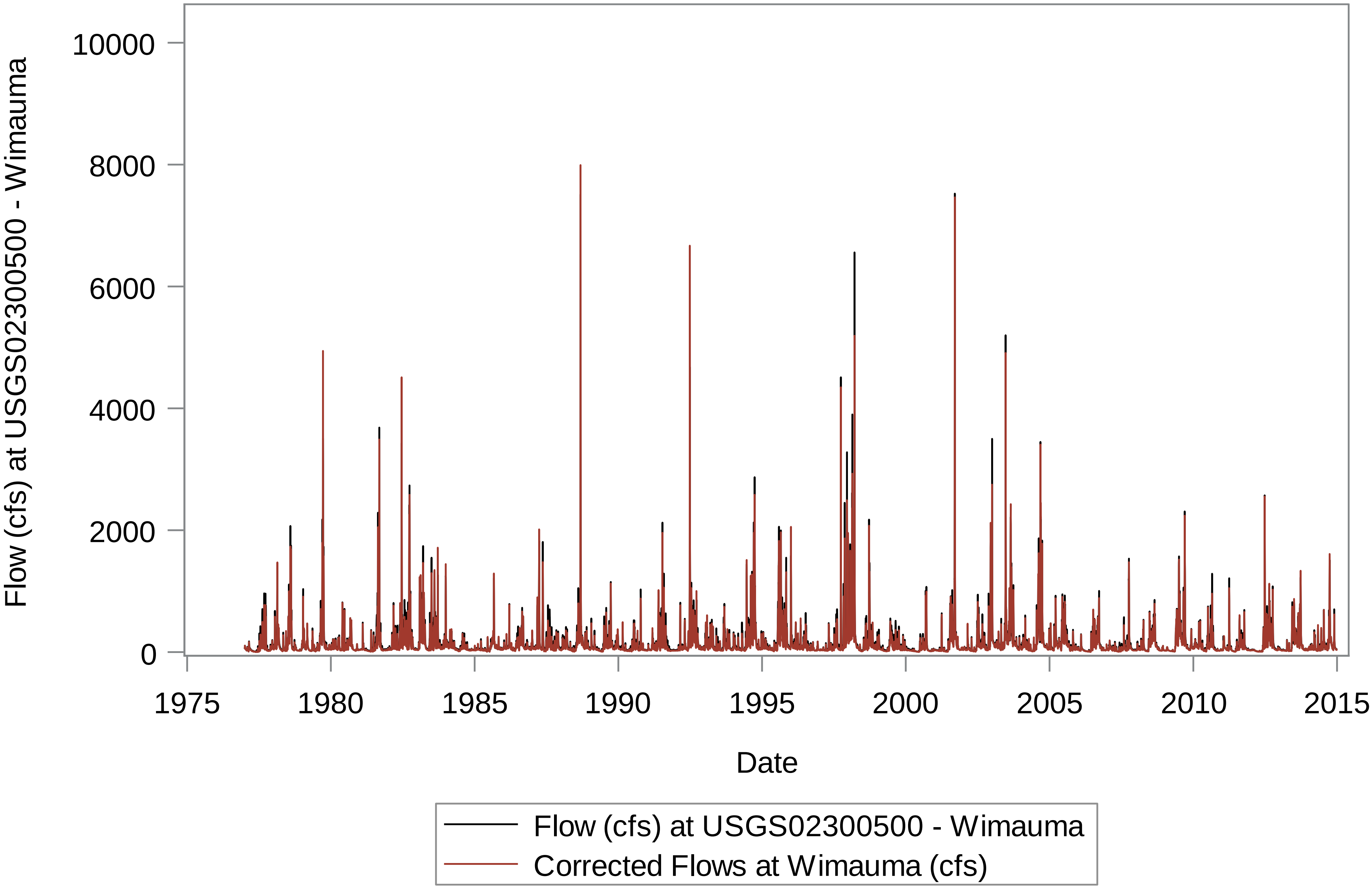
Appendix A



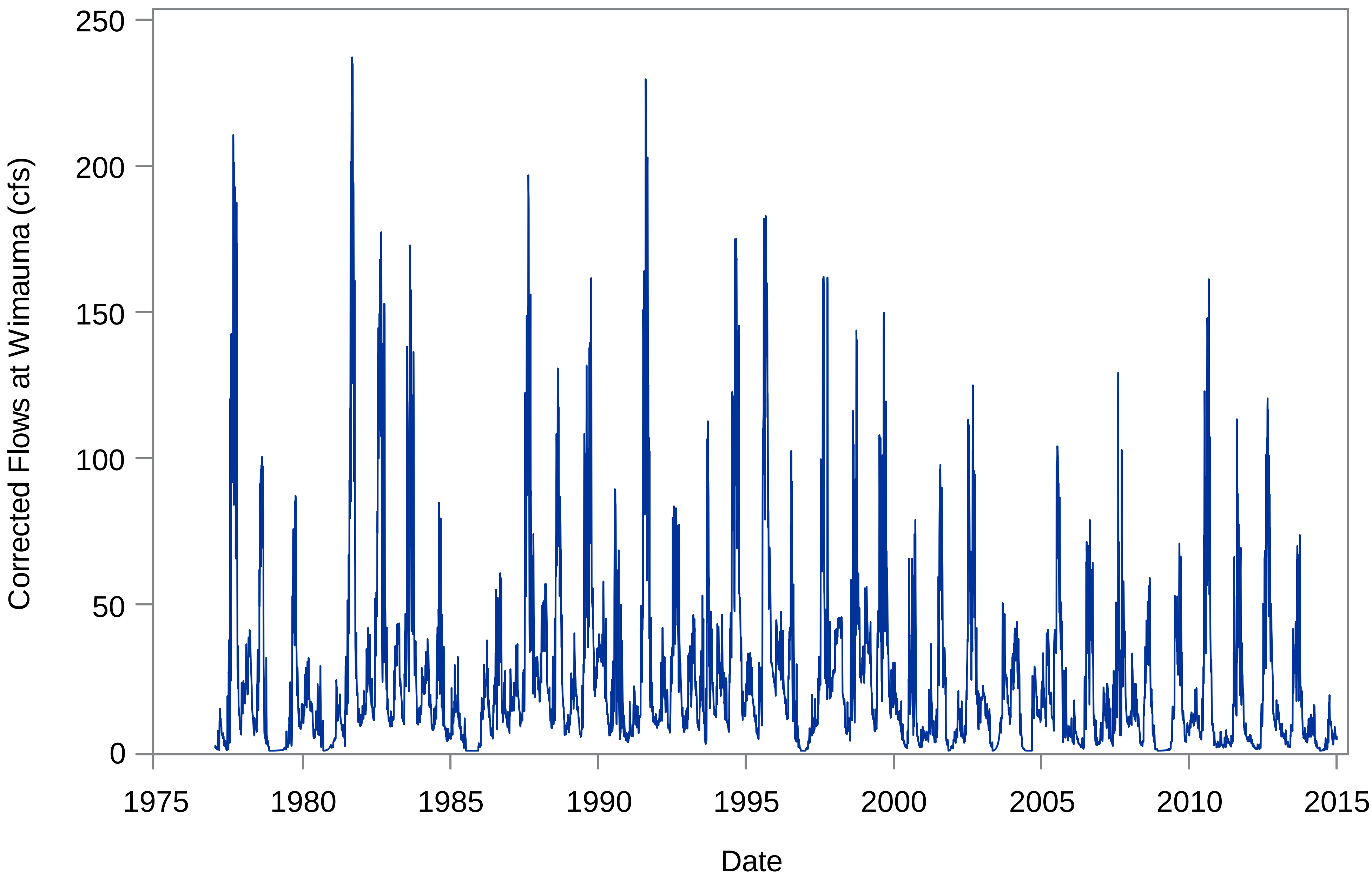
Distribution of Loess Adjustment Full Timeseries
resid_diff
125
100
75
50
25
0
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Month


Appendix A

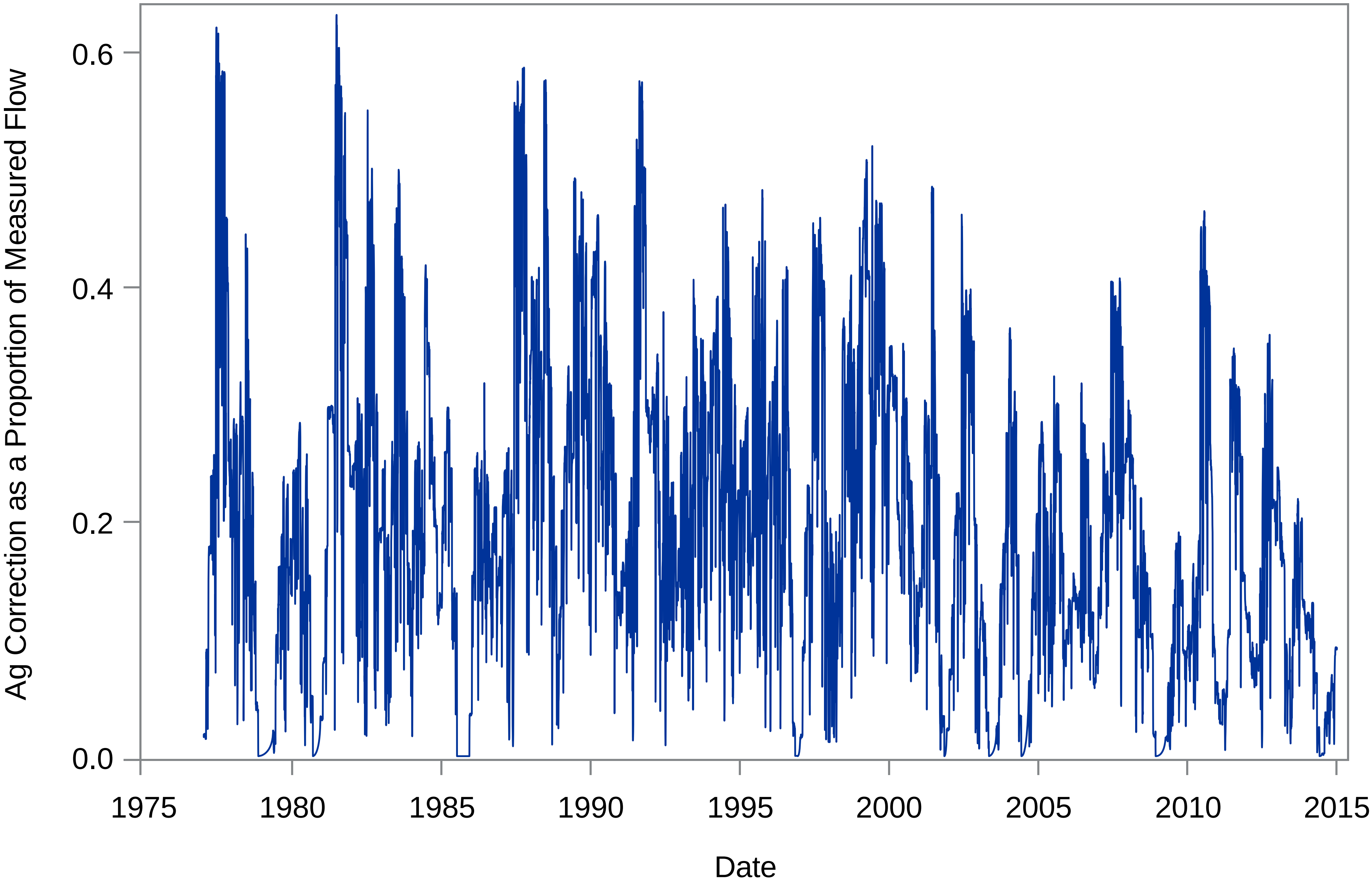
Comparison of Recorded and Agricultural Corrected Flows at the Wimauma Gage for the Period of Record



Time Series of the Difference in Recorded and Agricultural Corrected Flows at the Wimauma Gage between 1977 and 2014



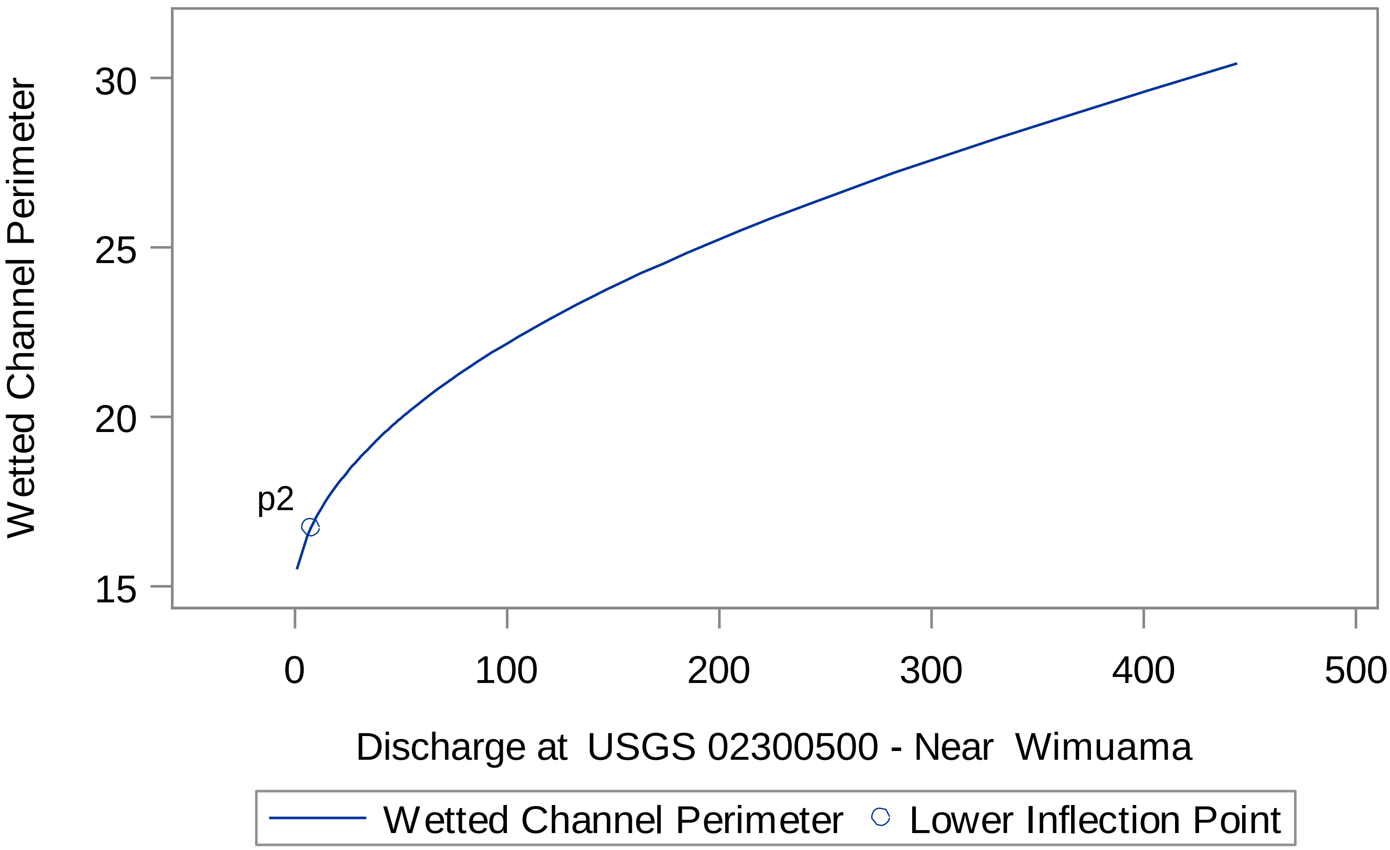
Time Series of the Difference (expressed as a proportion) in Recorded and Agricultural Corrected Flowsat the Wimauma Gage between 1977 and 2014



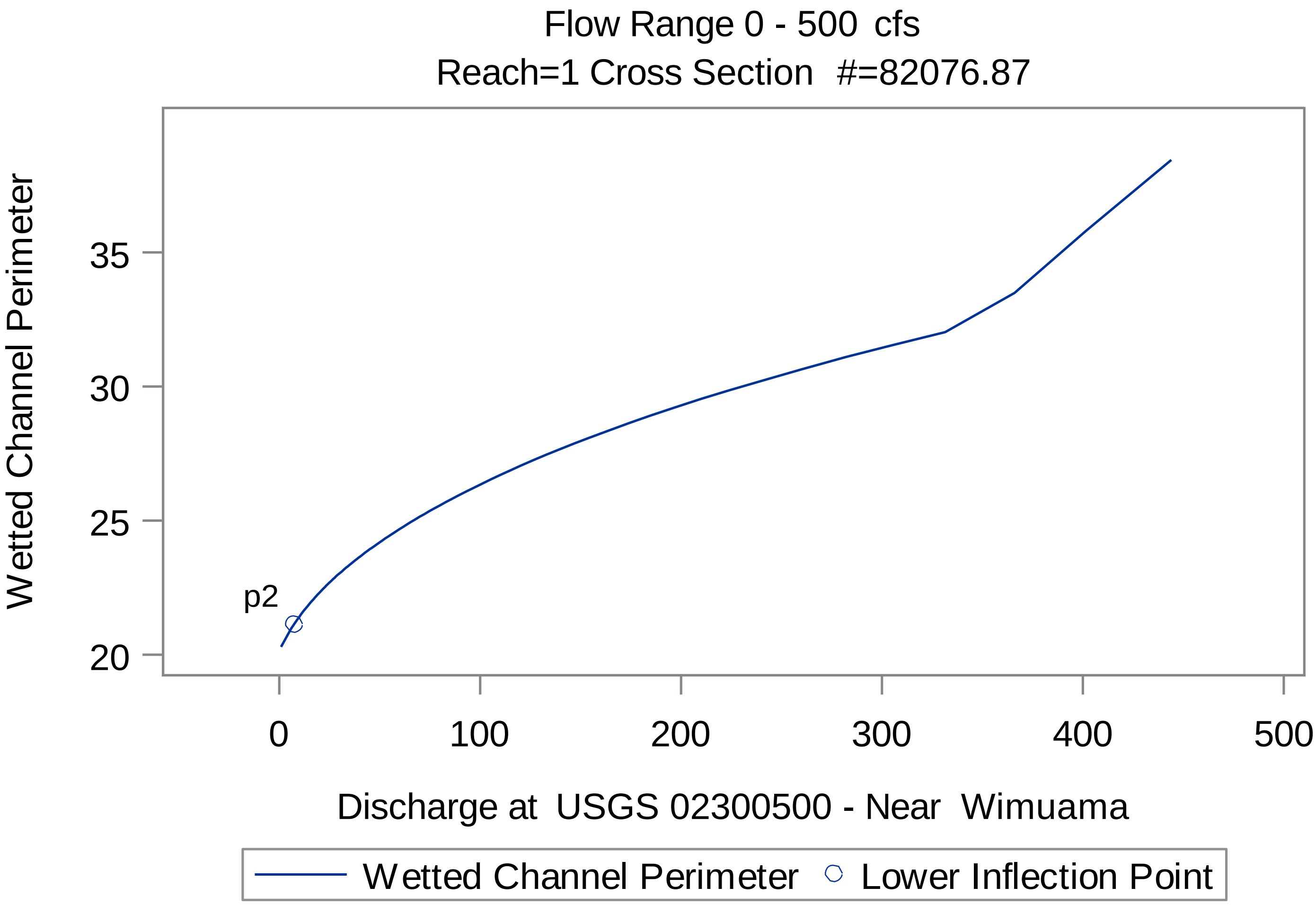
# APPENDIX B

Perimeter inflection points for all cross sections

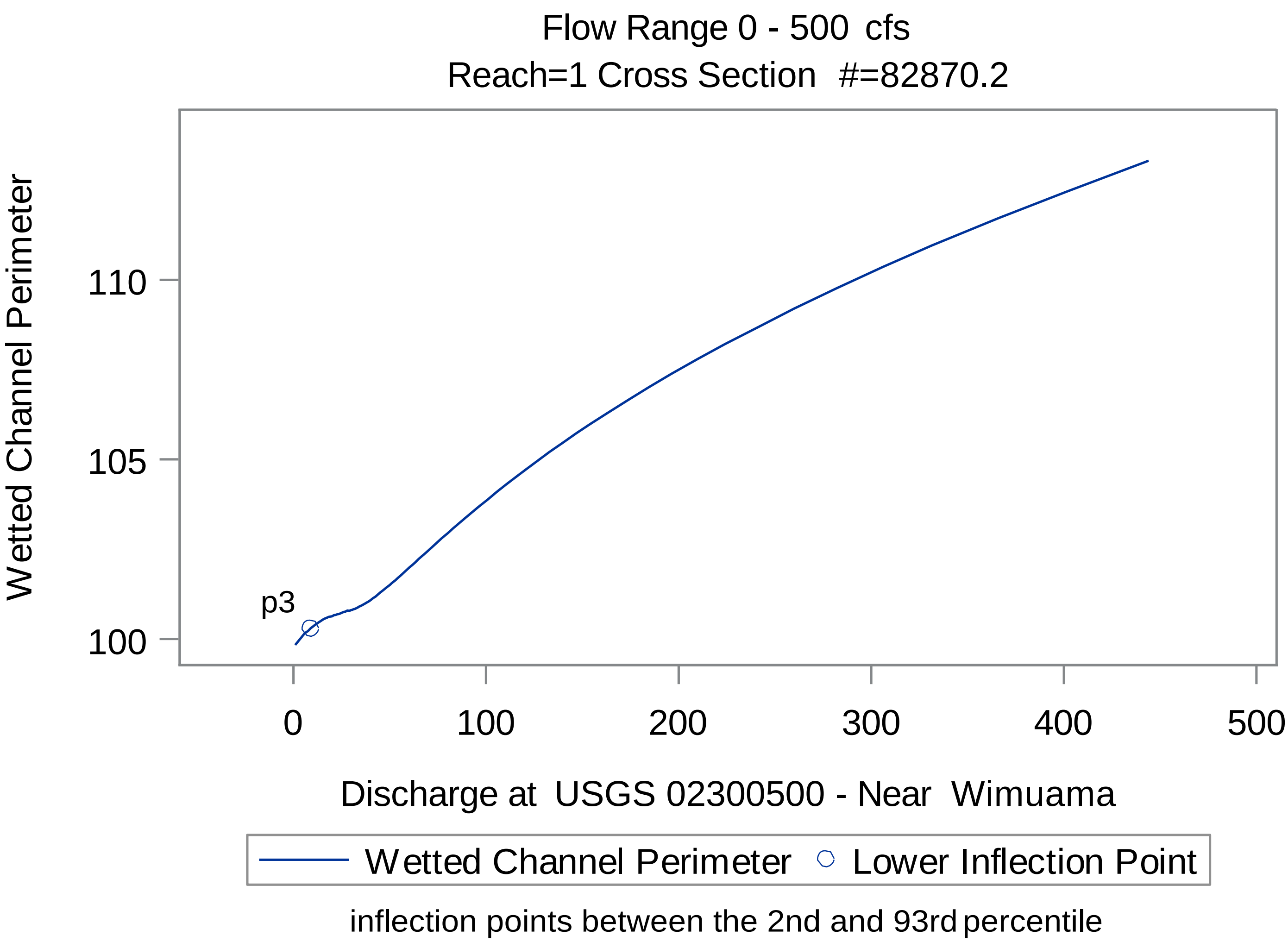
Flow Range 0 - 500 cfs
Reach=1 Cross Section #=80368.77



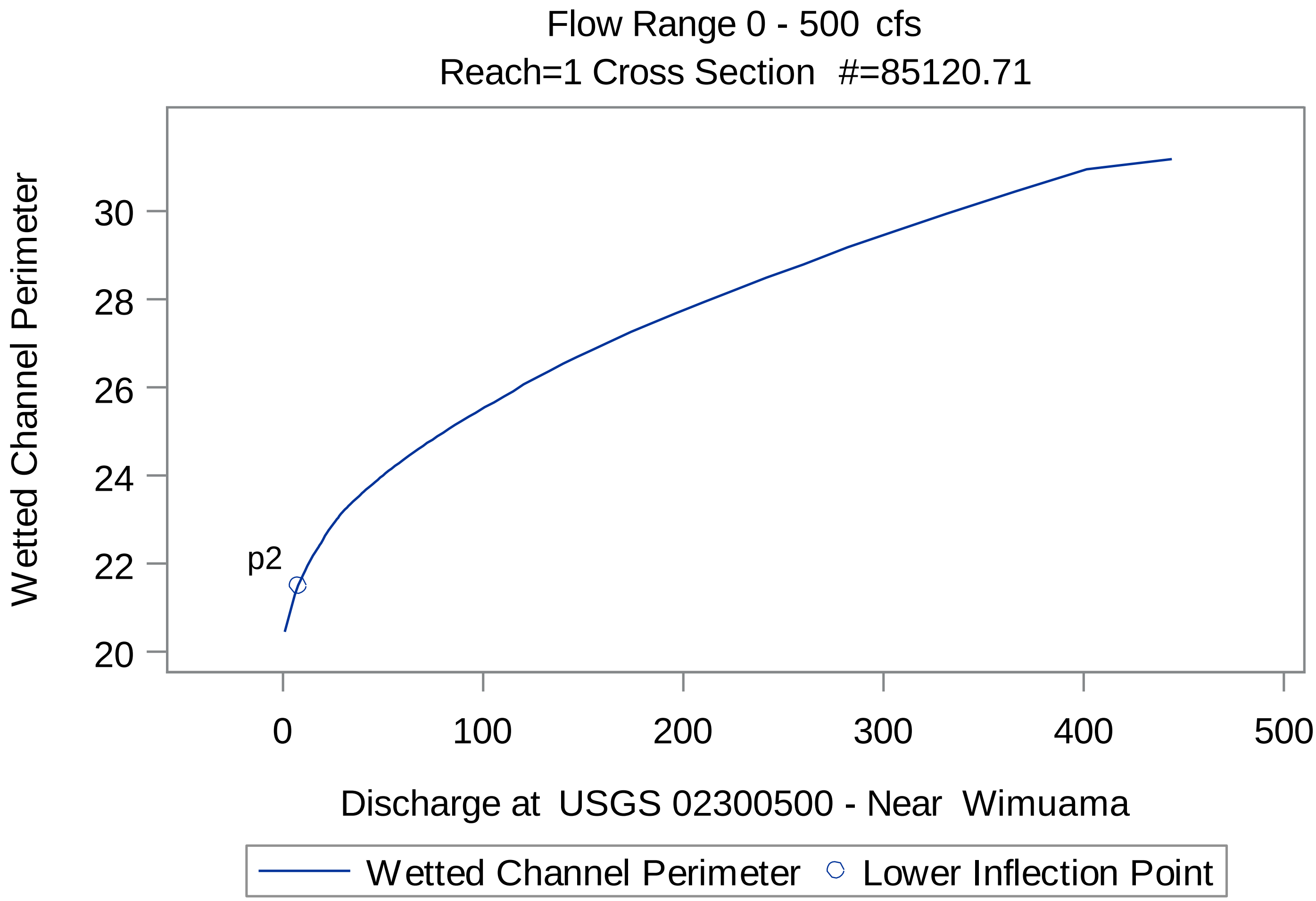

inflection points between the 2nd and 93rd percentile



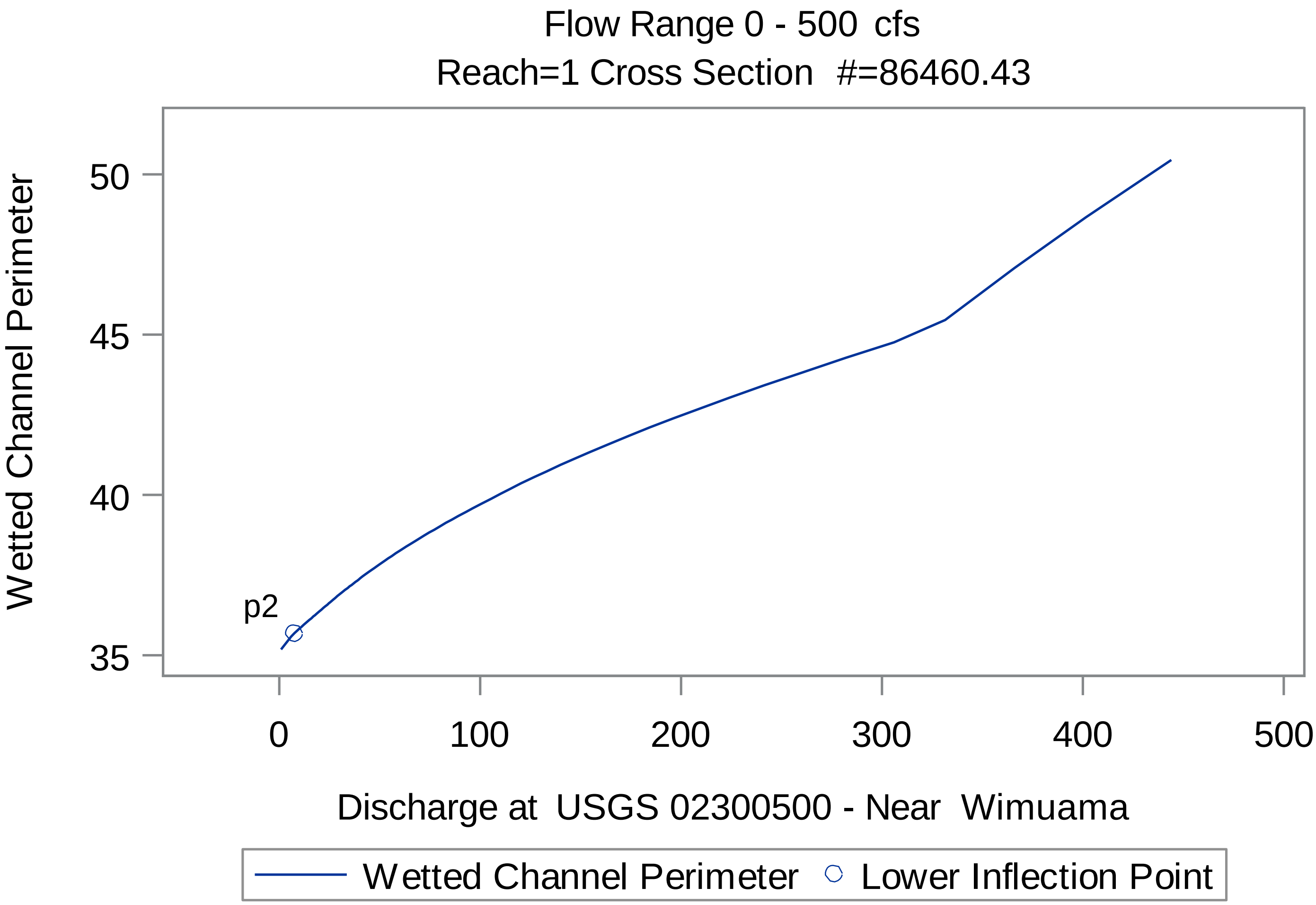

inflection points between the 2nd and 93rd percentile



Flow Range 0 - 500 cfs
Reach=1 Cross Section #=82870.2
Wetted Channel Perimeter
110
105
100
p3
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

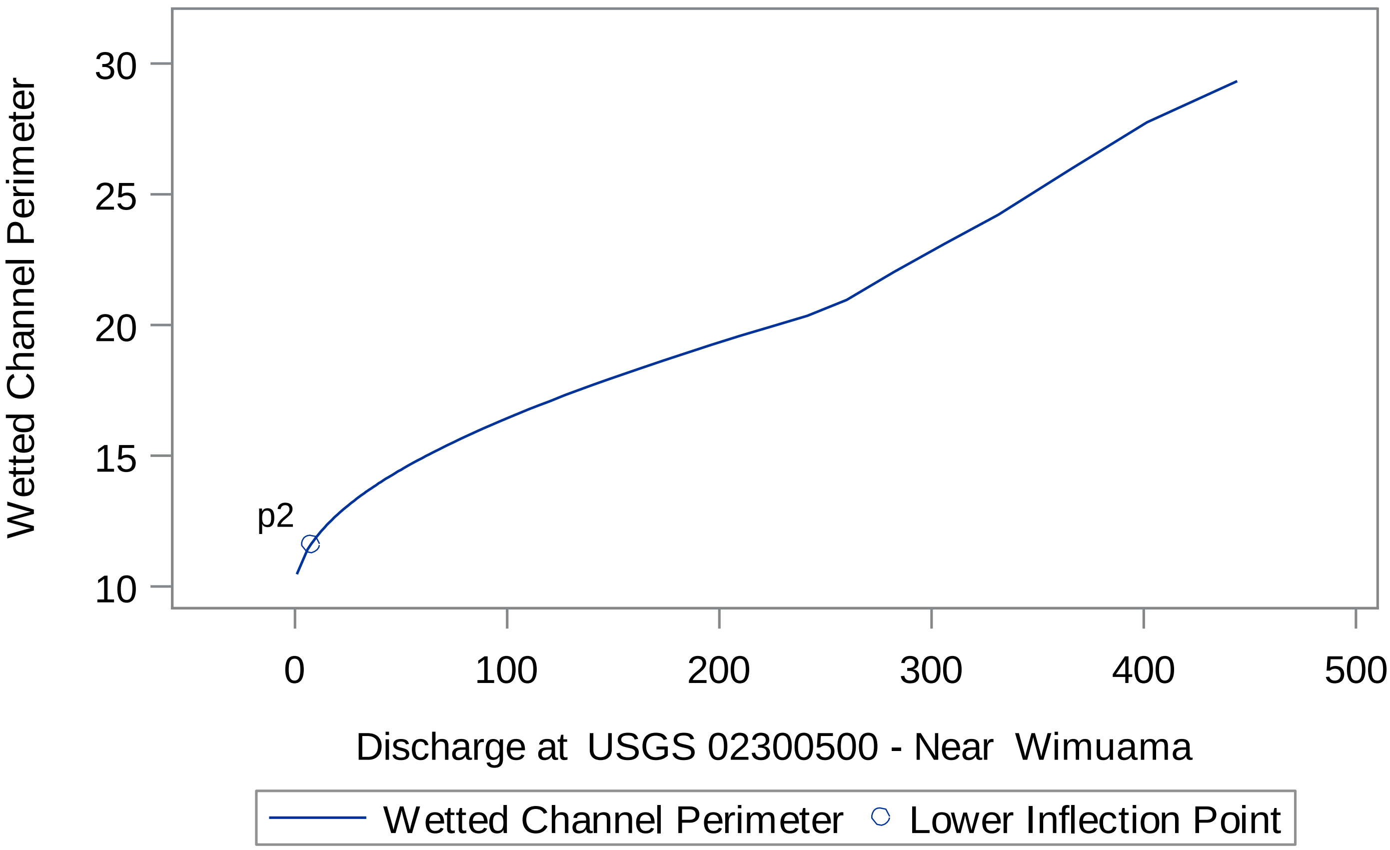



inflection points between the 2nd and 93rd percentile



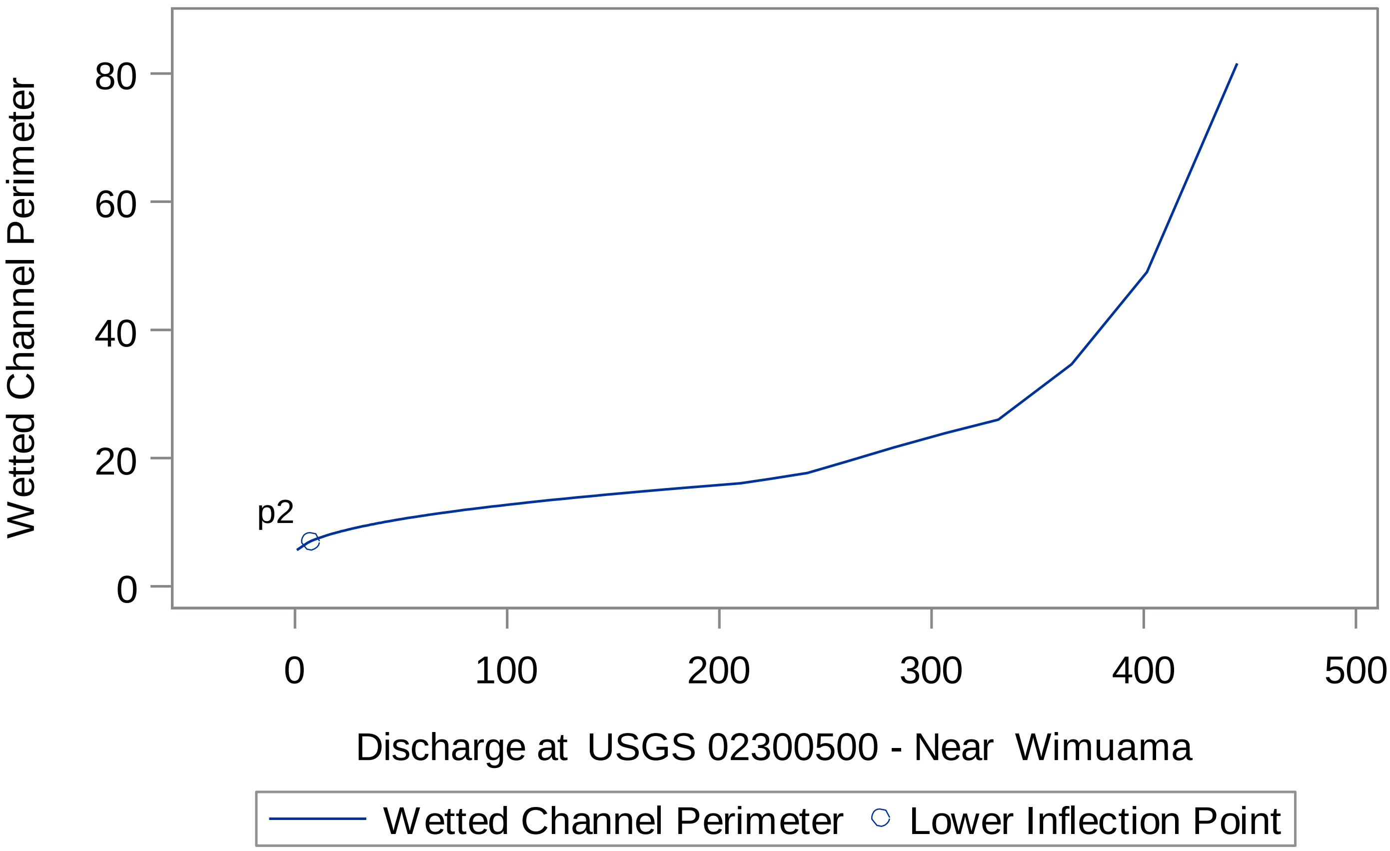

inflection points between the 2nd and 93rd percentile

Flow Range 0 - 500 cfs
Reach=1 Cross Section #=87667.32

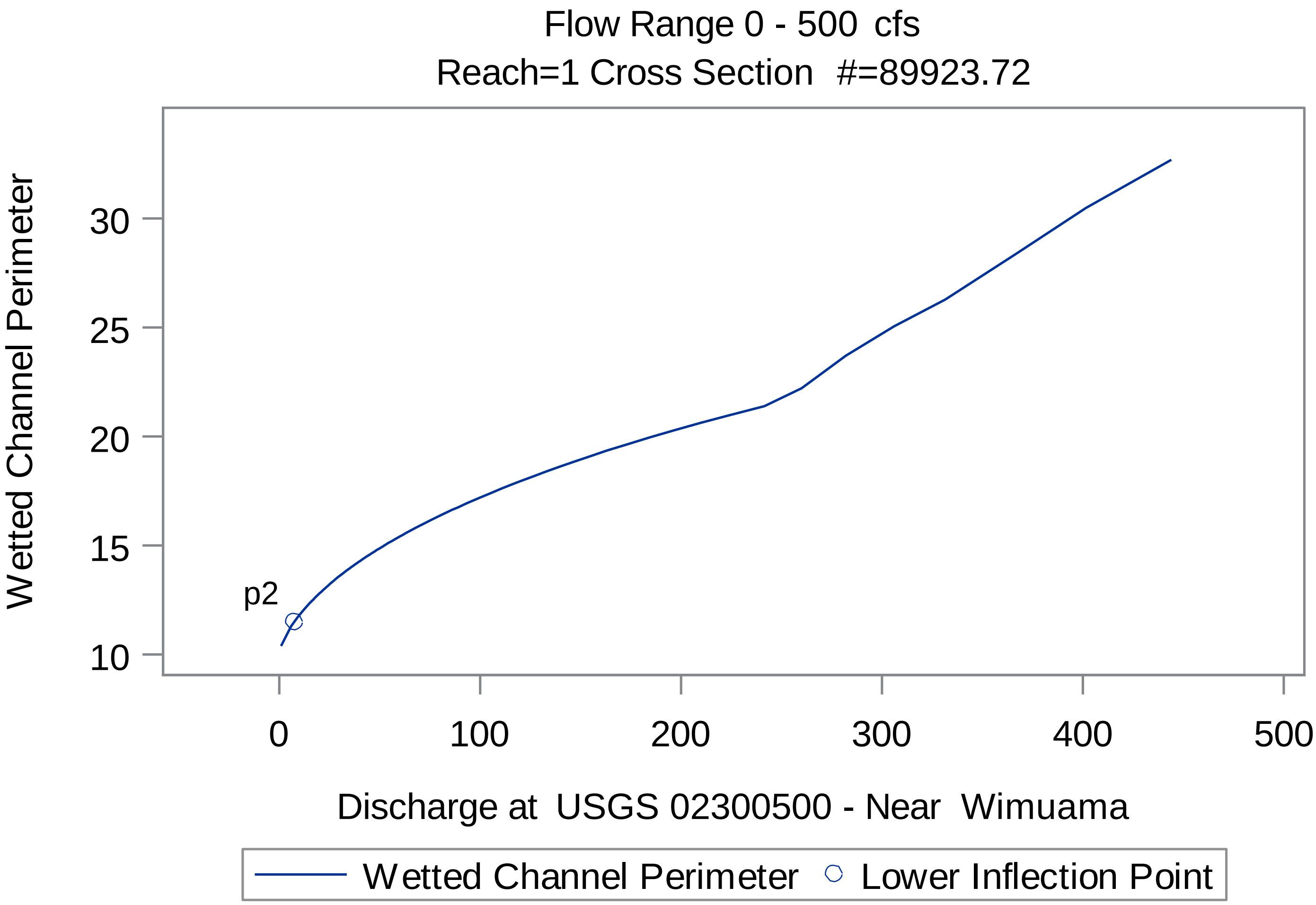



inflection points between the 2nd and 93rd percentile

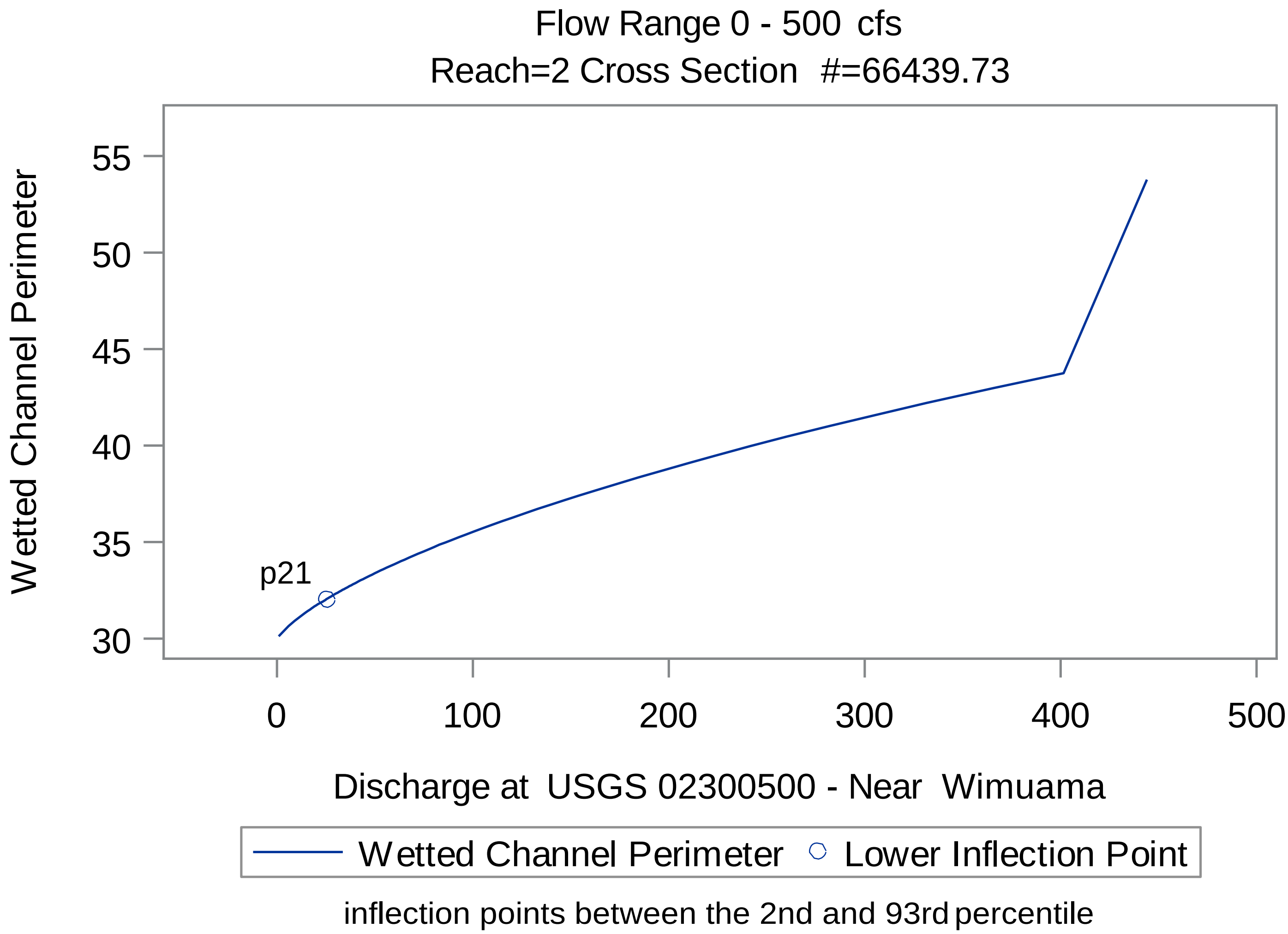
Flow Range 0 - 500 cfs
Reach=1 Cross Section #=88225.55




inflection points between the 2nd and 93rd percentile

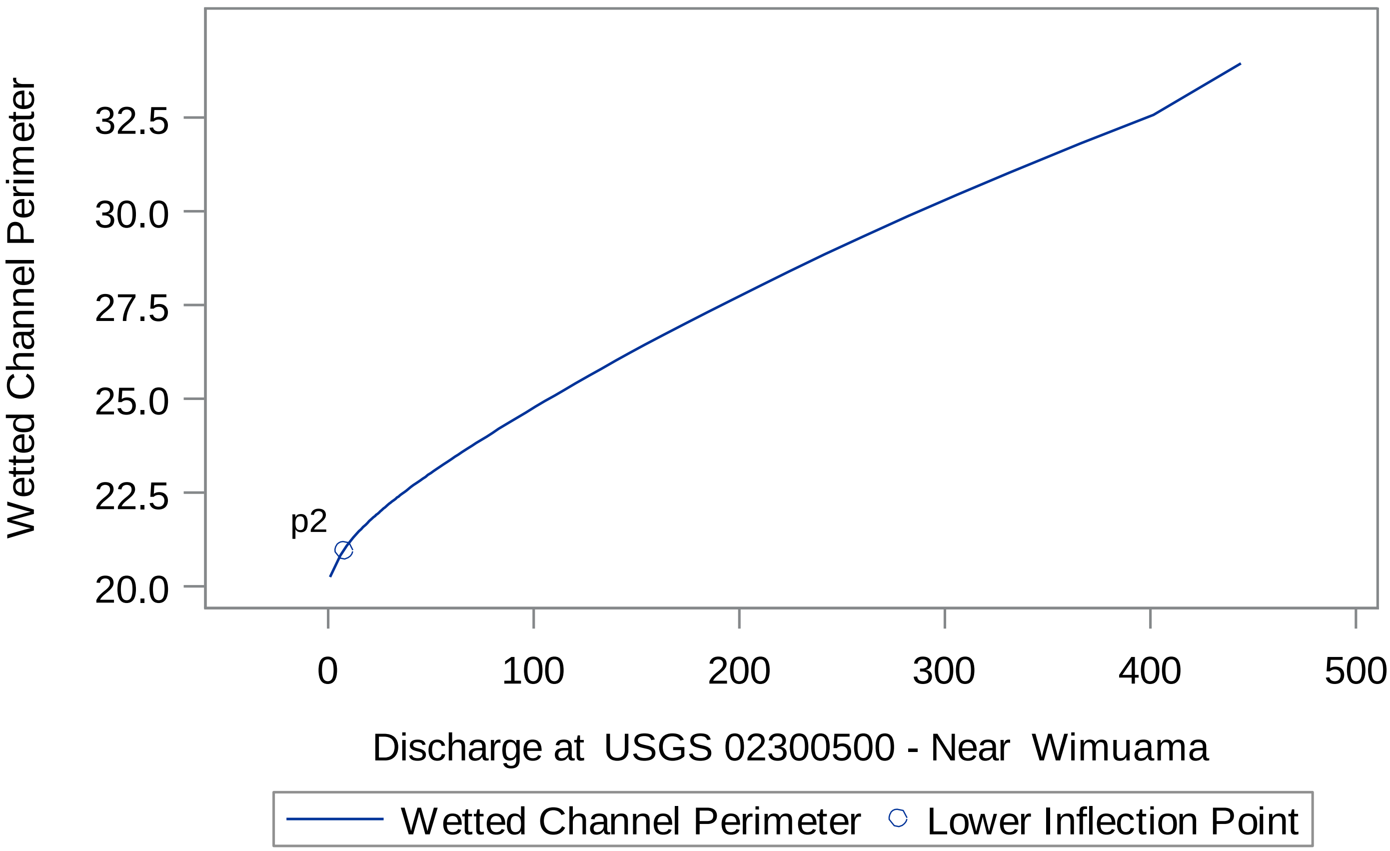



inflection points between the 2nd and 93rd percentile

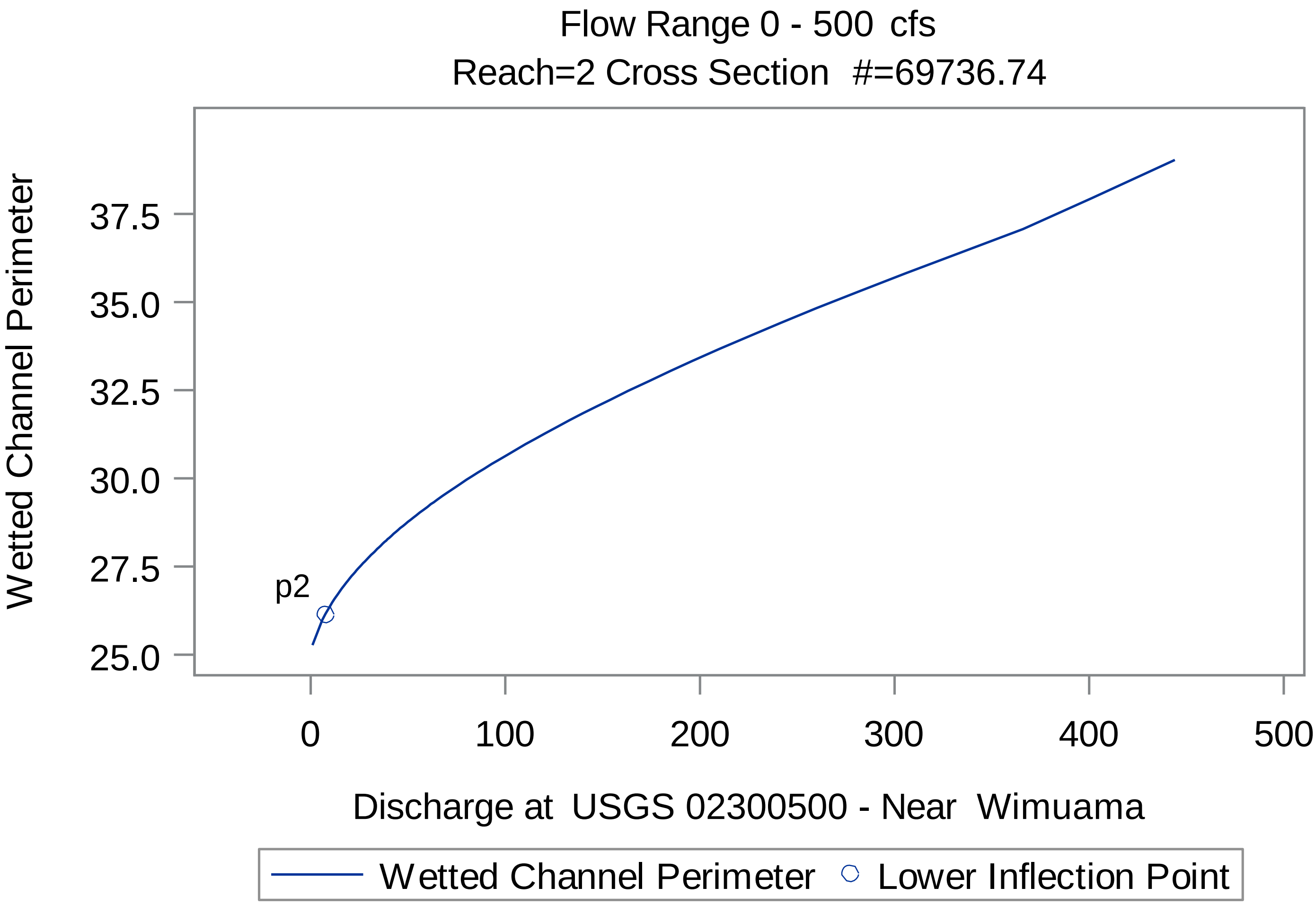


Flow Range 0 - 500 cfs
Reach=2 Cross Section #=66439.73
Wetted Channel Perimeter
55
50
45
40
35
30
p21
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

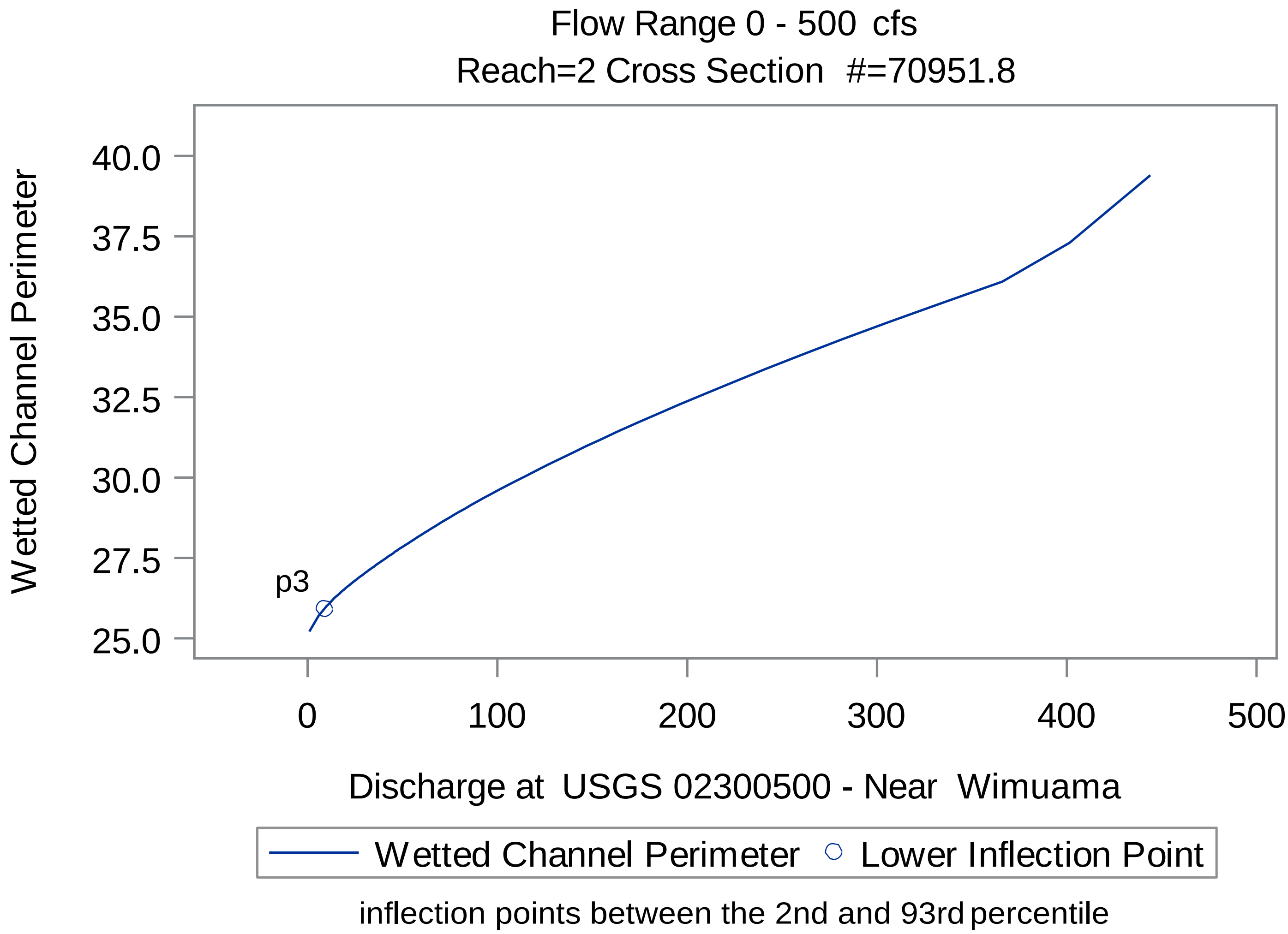
Flow Range 0 - 500 cfs
Reach=2 Cross Section #=67727.98




inflection points between the 2nd and 93rd percentile



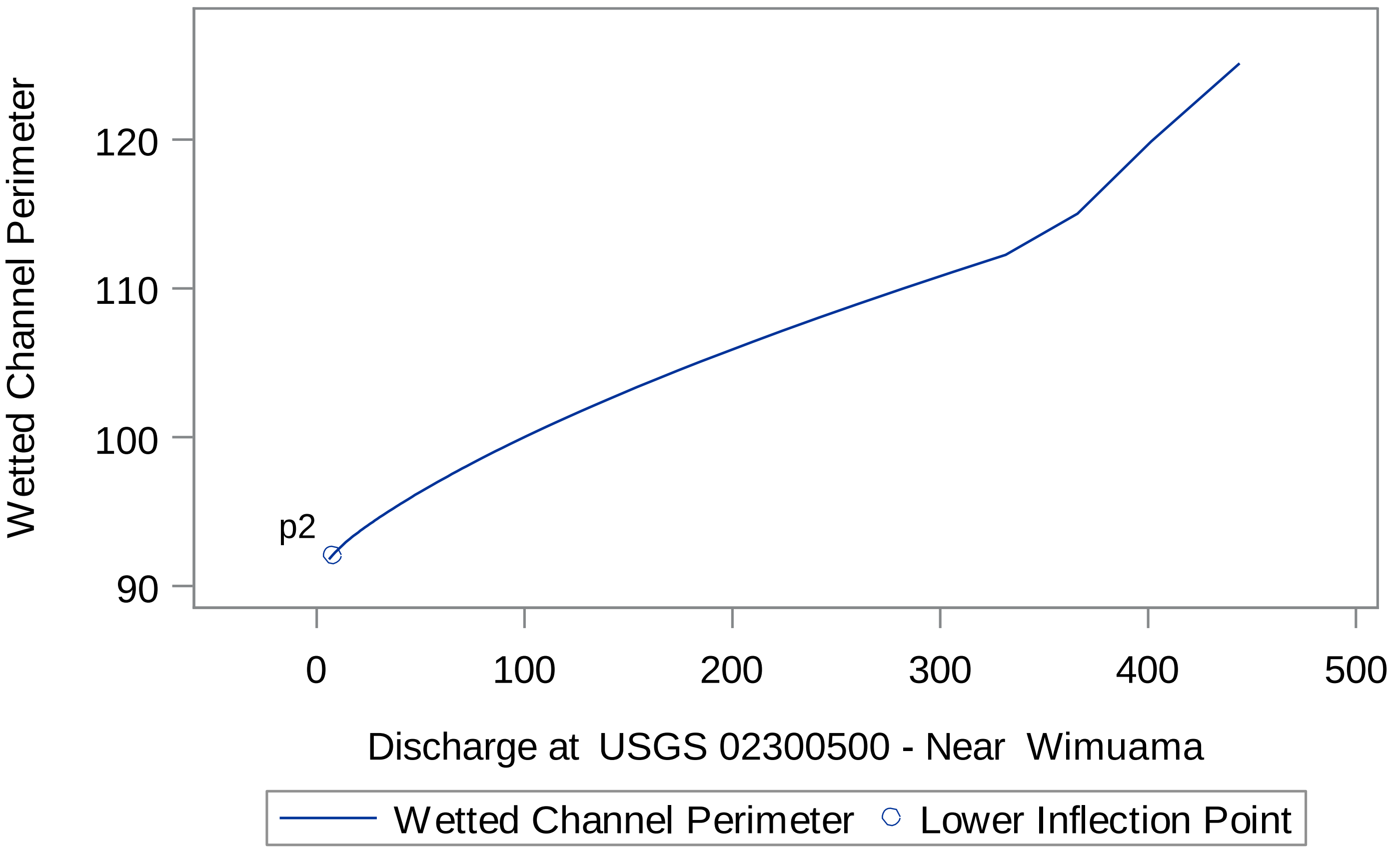

inflection points between the 2nd and 93rd percentile


Flow Range 0 - 500 cfs
Reach=2 Cross Section #=70951.8
Wetted Channel Perimeter
40.0
37.5
35.0
32.5
30.0
27.5
25.0
p3
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

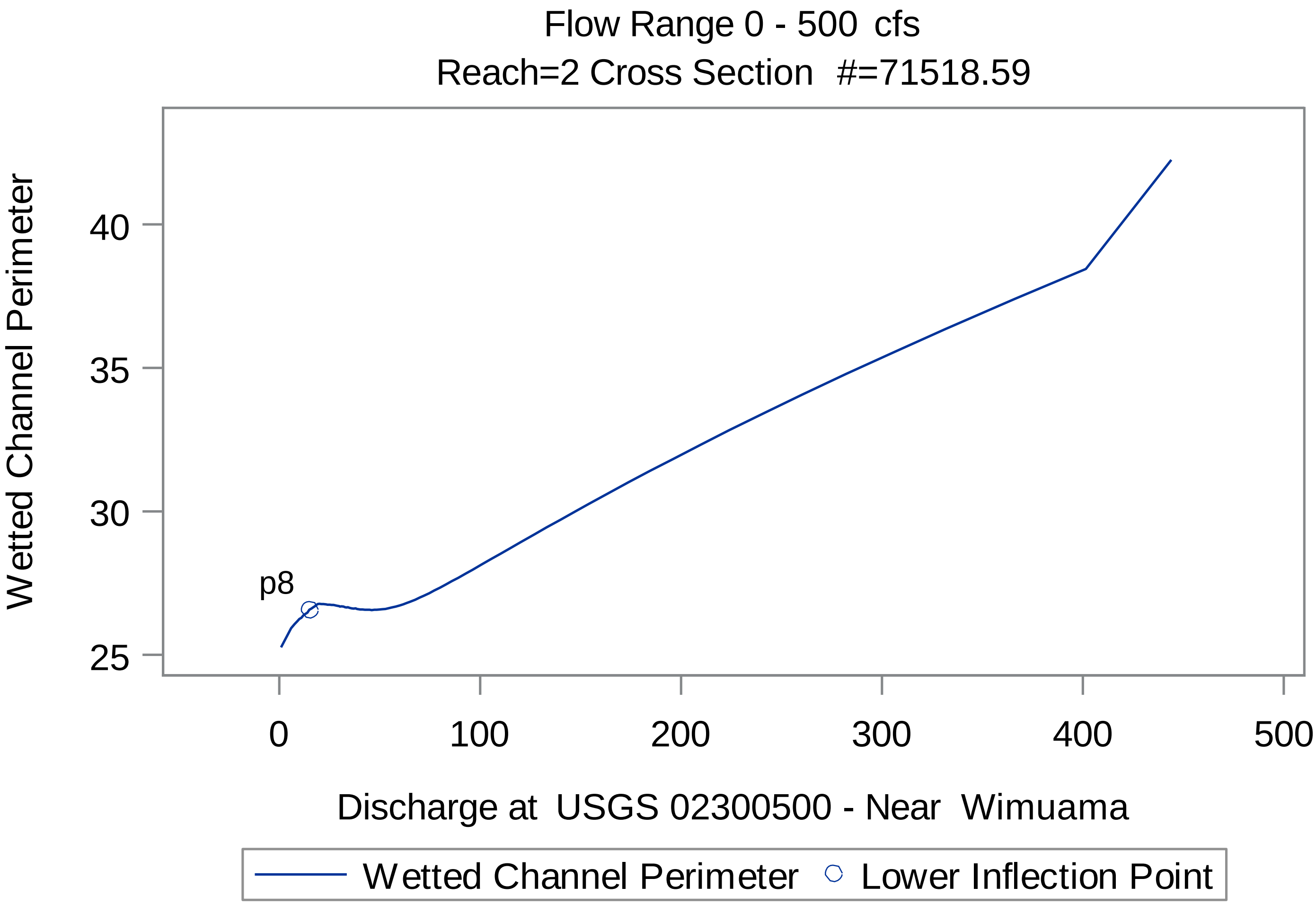
Flow Range 0 - 500 cfs
Reach=2 Cross Section #=71030.16

inflection points between the 2nd and 93rd percentile

Flow Range 0 - 500 cfs
Reach=2 Cross Section #=71094.04

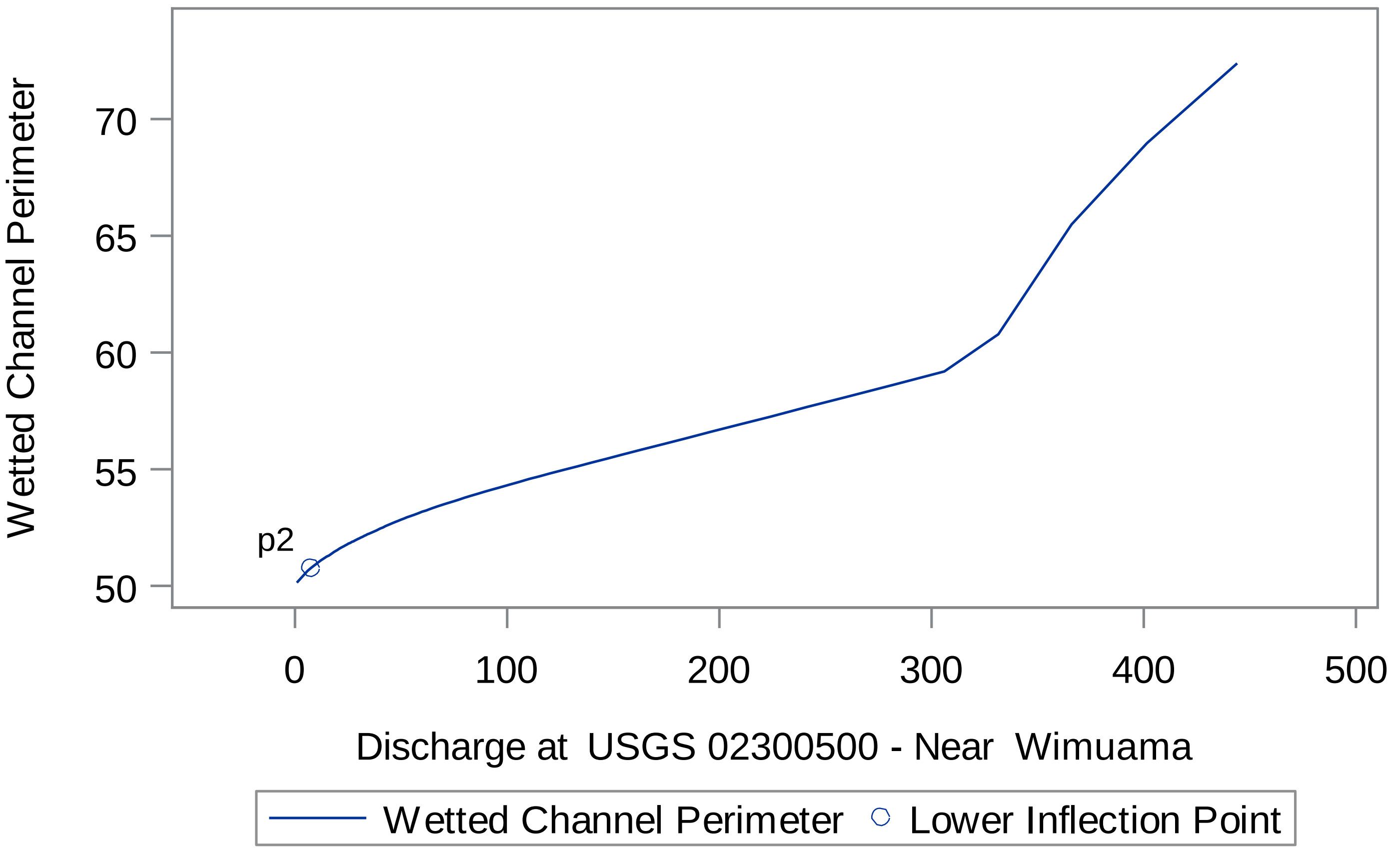



inflection points between the 2nd and 93rd percentile



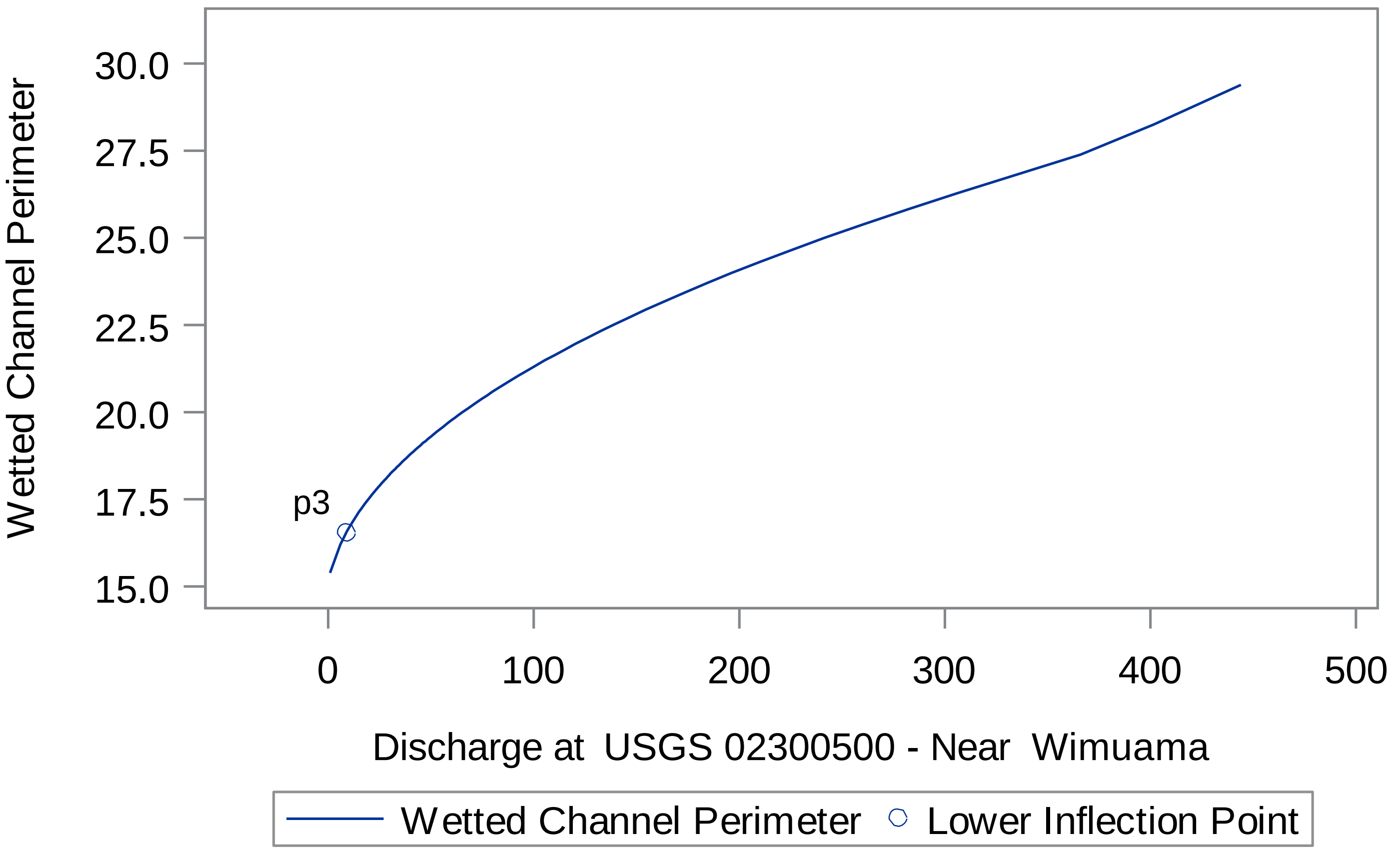

inflection points between the 2nd and 93rd percentile

Flow Range 0 - 500 cfs
Reach=2 Cross Section #=72409.5

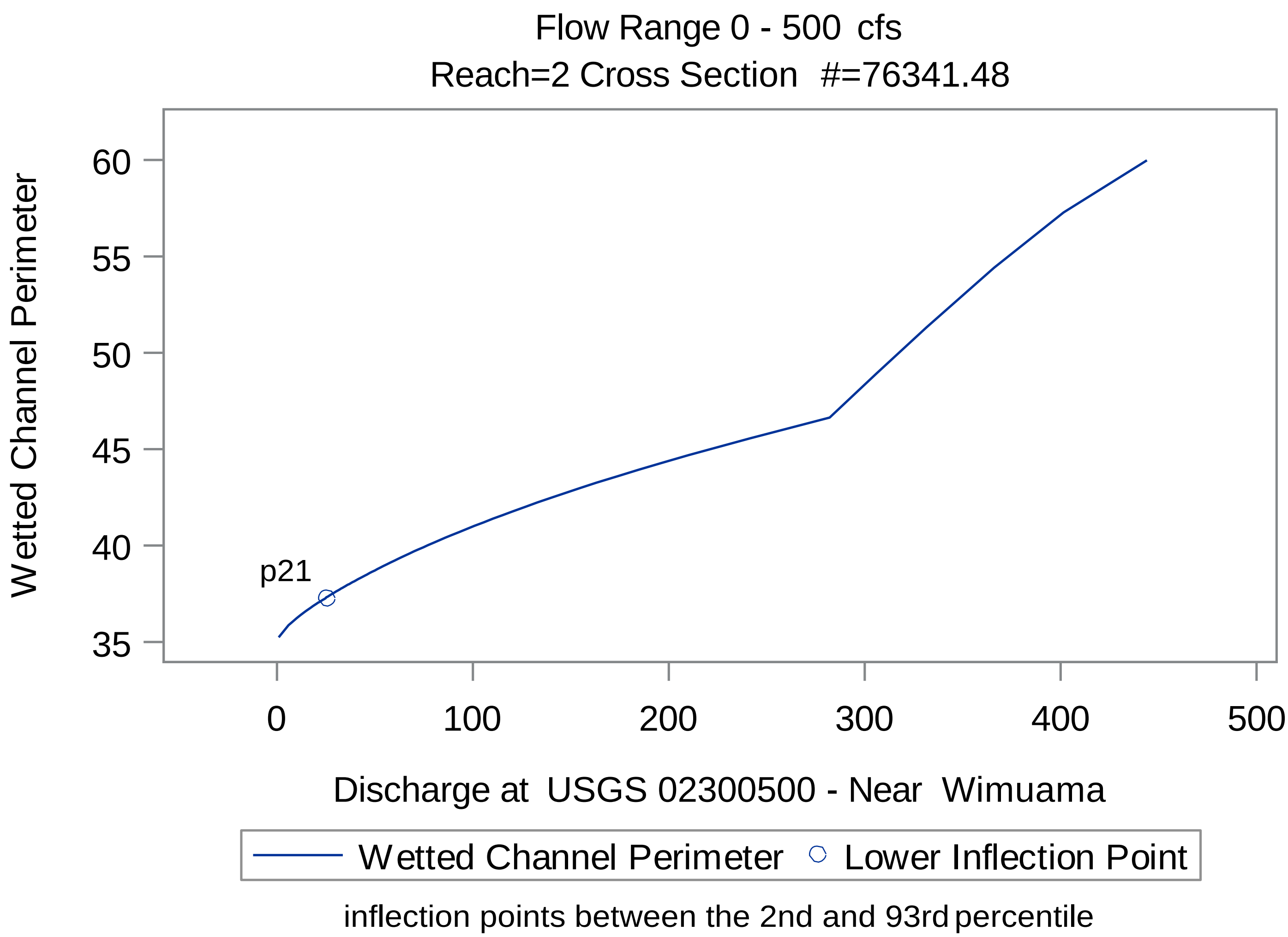



inflection points between the 2nd and 93rd percentile

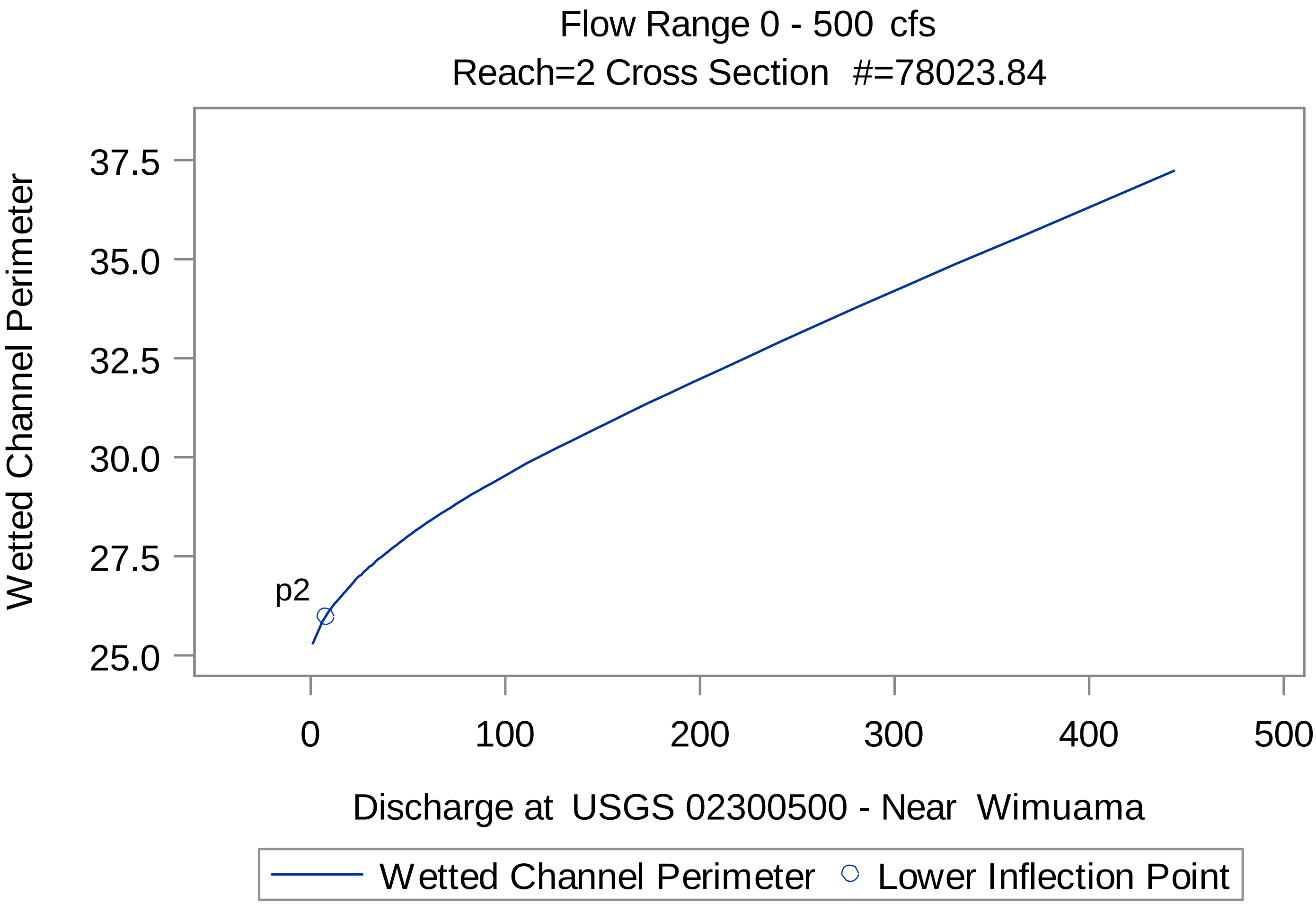
Flow Range 0 - 500 cfs
Reach=2 Cross Section #=74988.78




inflection points between the 2nd and 93rd percentile

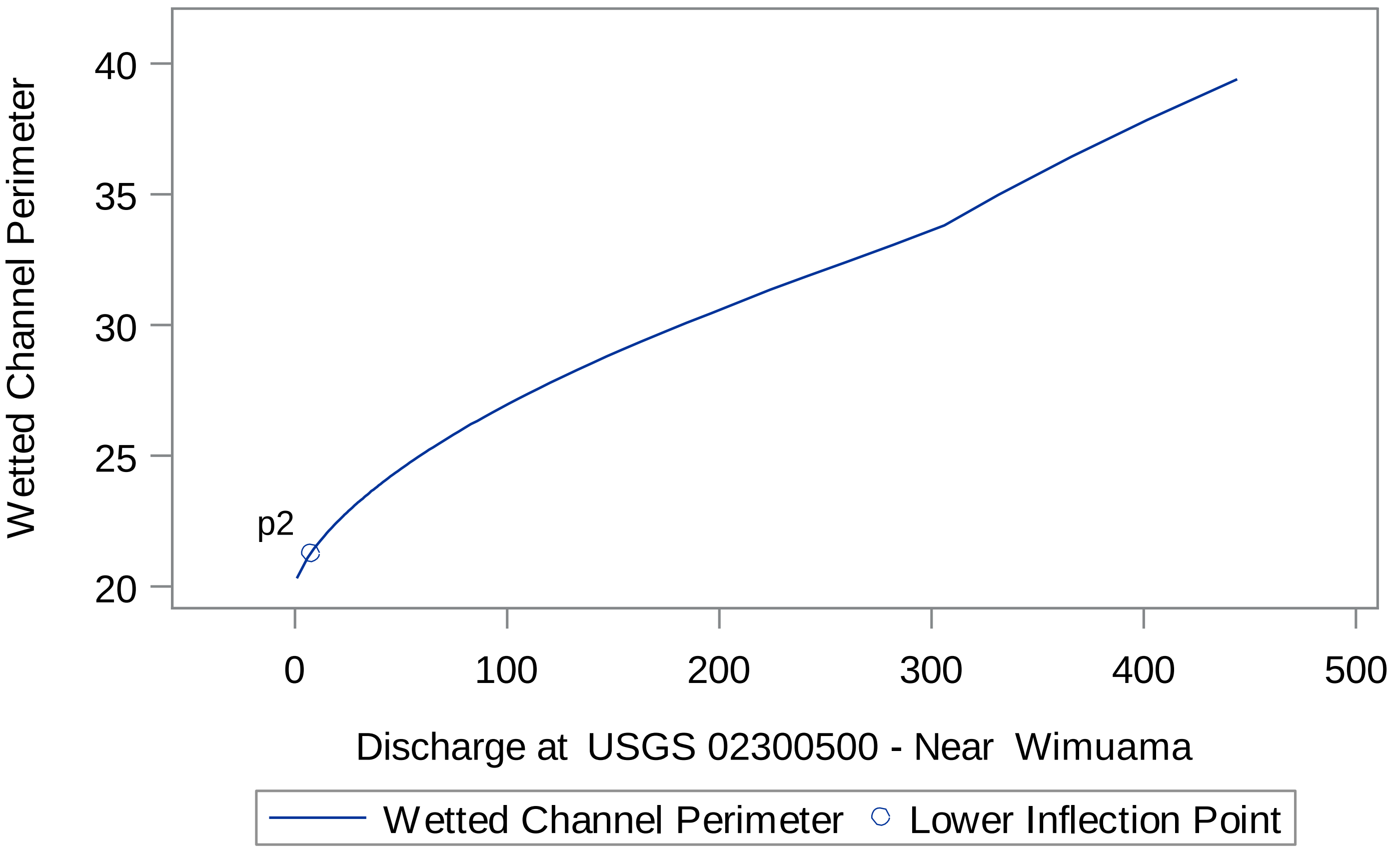


Flow Range 0 - 500 cfs
Reach=2 Cross Section #=76341.48
Wetted Channel Perimeter
60
55
50
45
40
35
p21
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile




inflection points between the 2nd and 93rd percentile

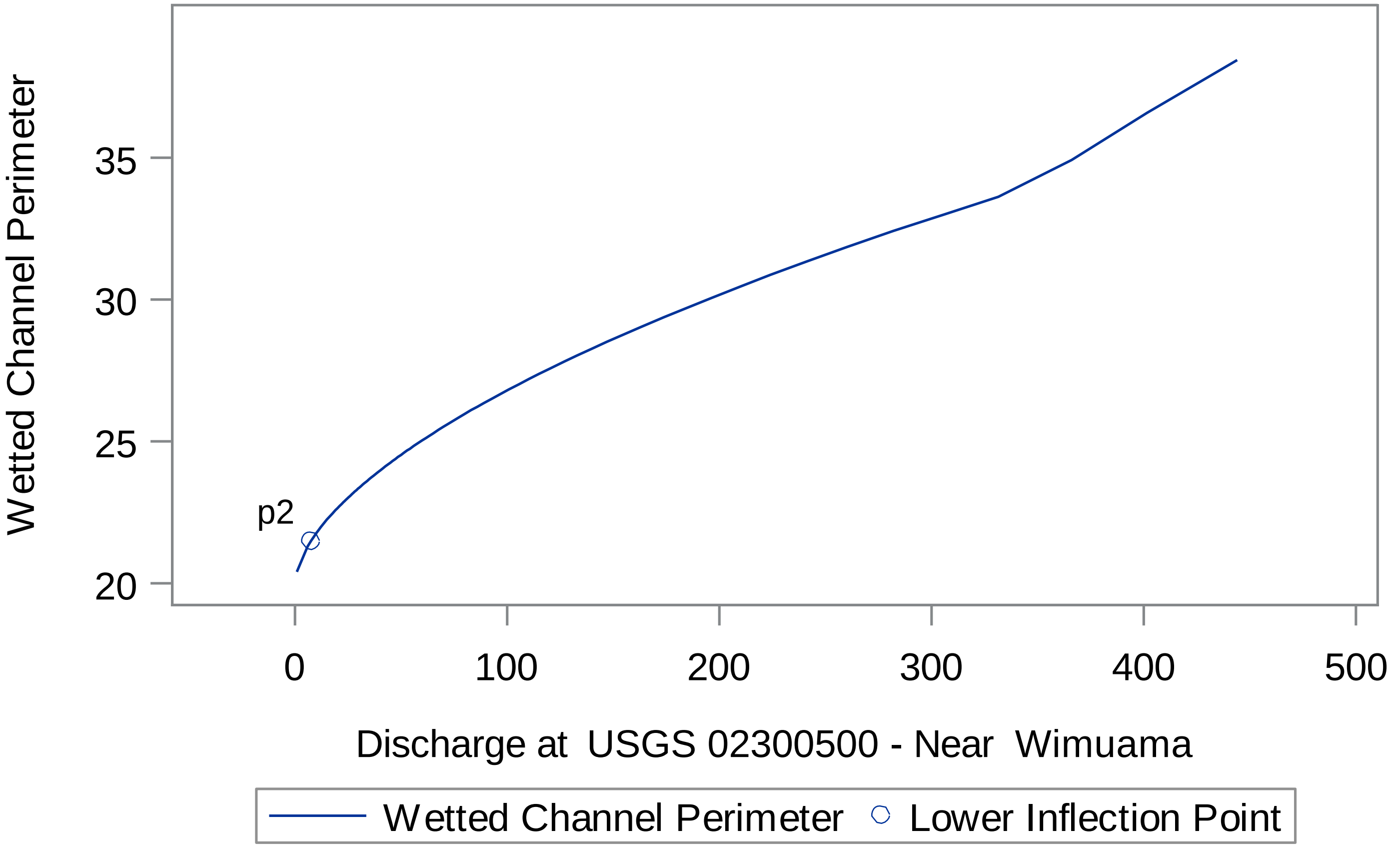
Flow Range 0 - 500 cfs
Reach=3 Cross Section #=63008.19



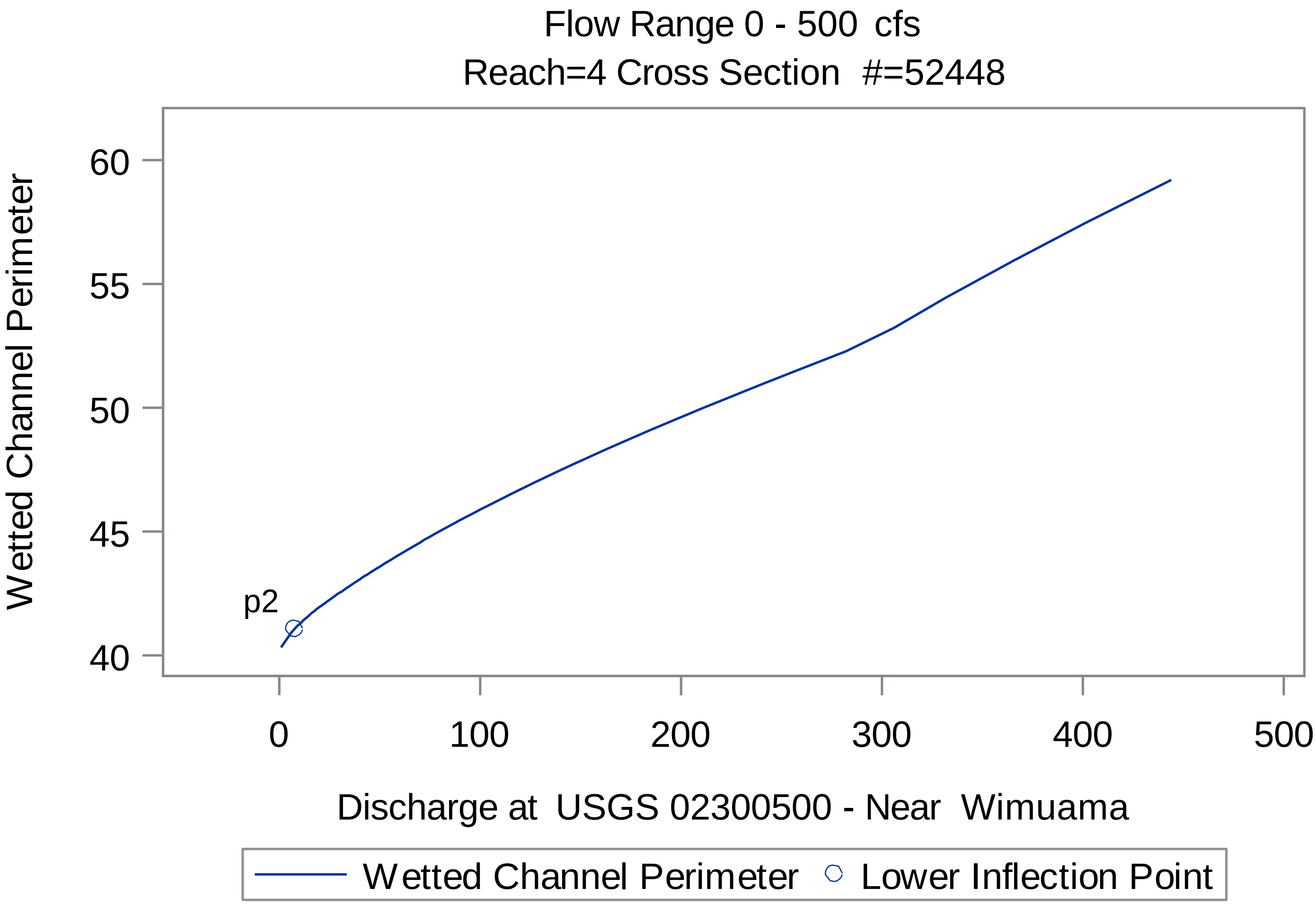

inflection points between the 2nd and 93rd percentile

Flow Range 0 - 500 cfs

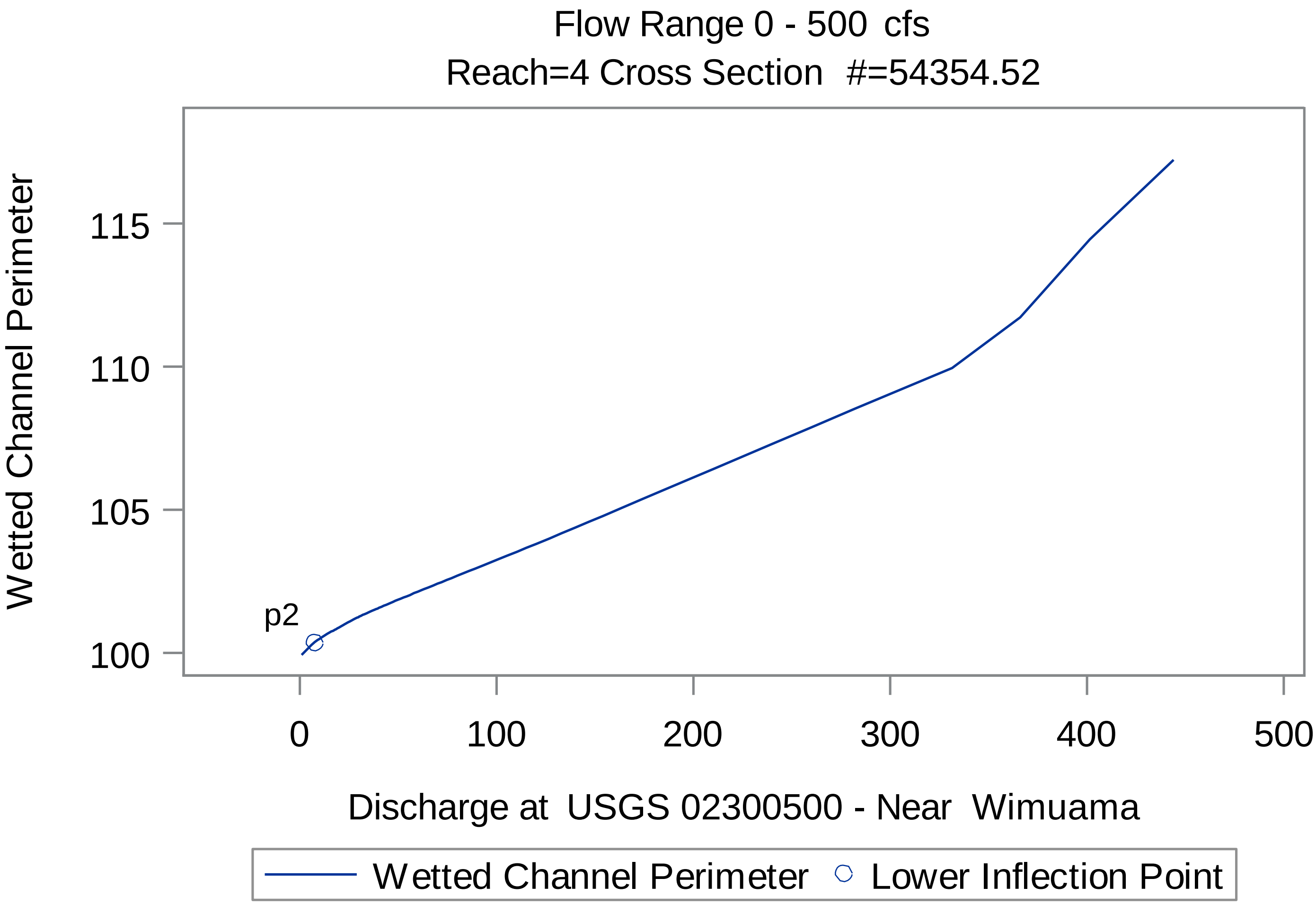
Reach=3 Cross Section #=63911.24



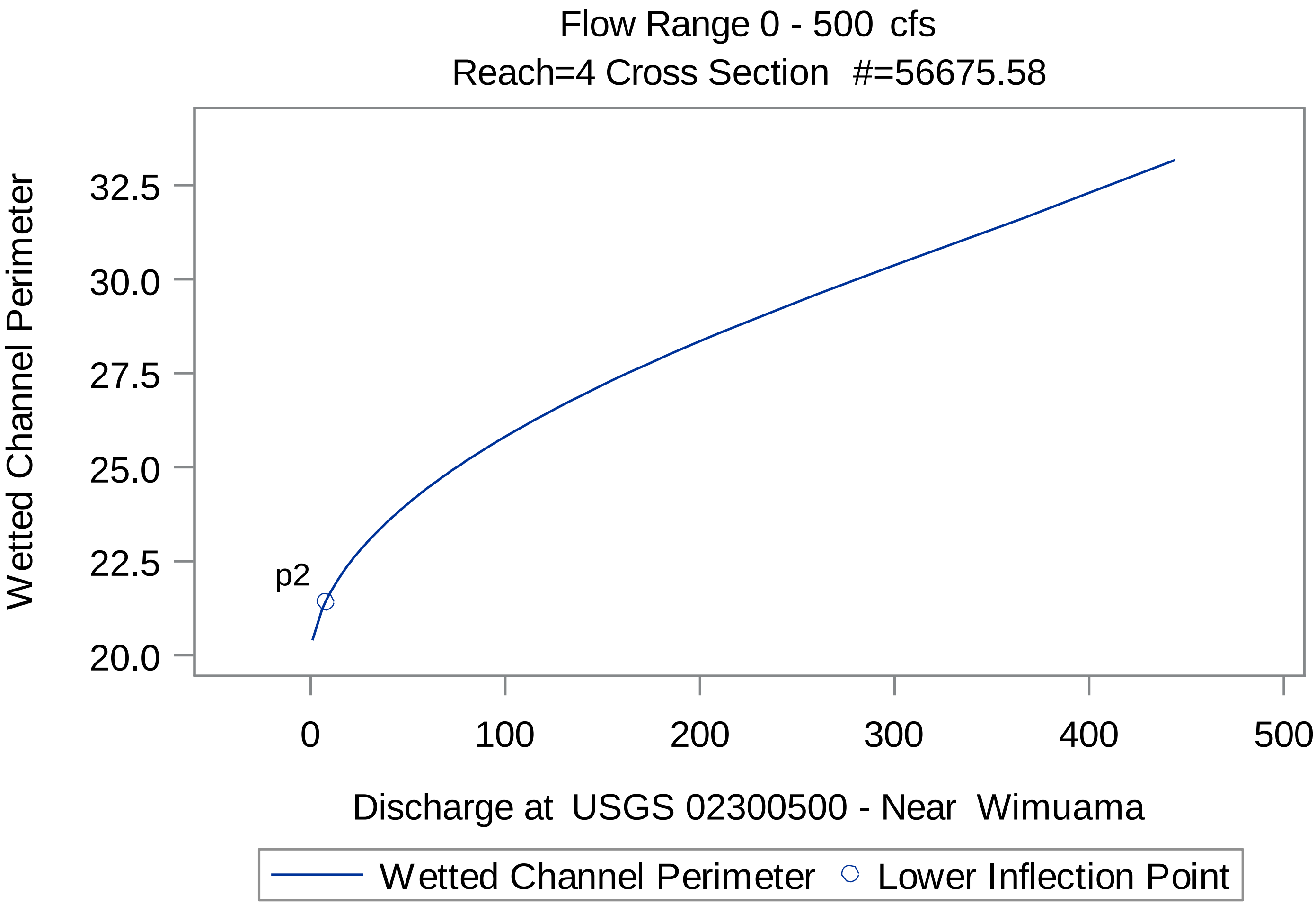

inflection points between the 2nd and 93rd percentile




inflection points between the 2nd and 93rd percentile

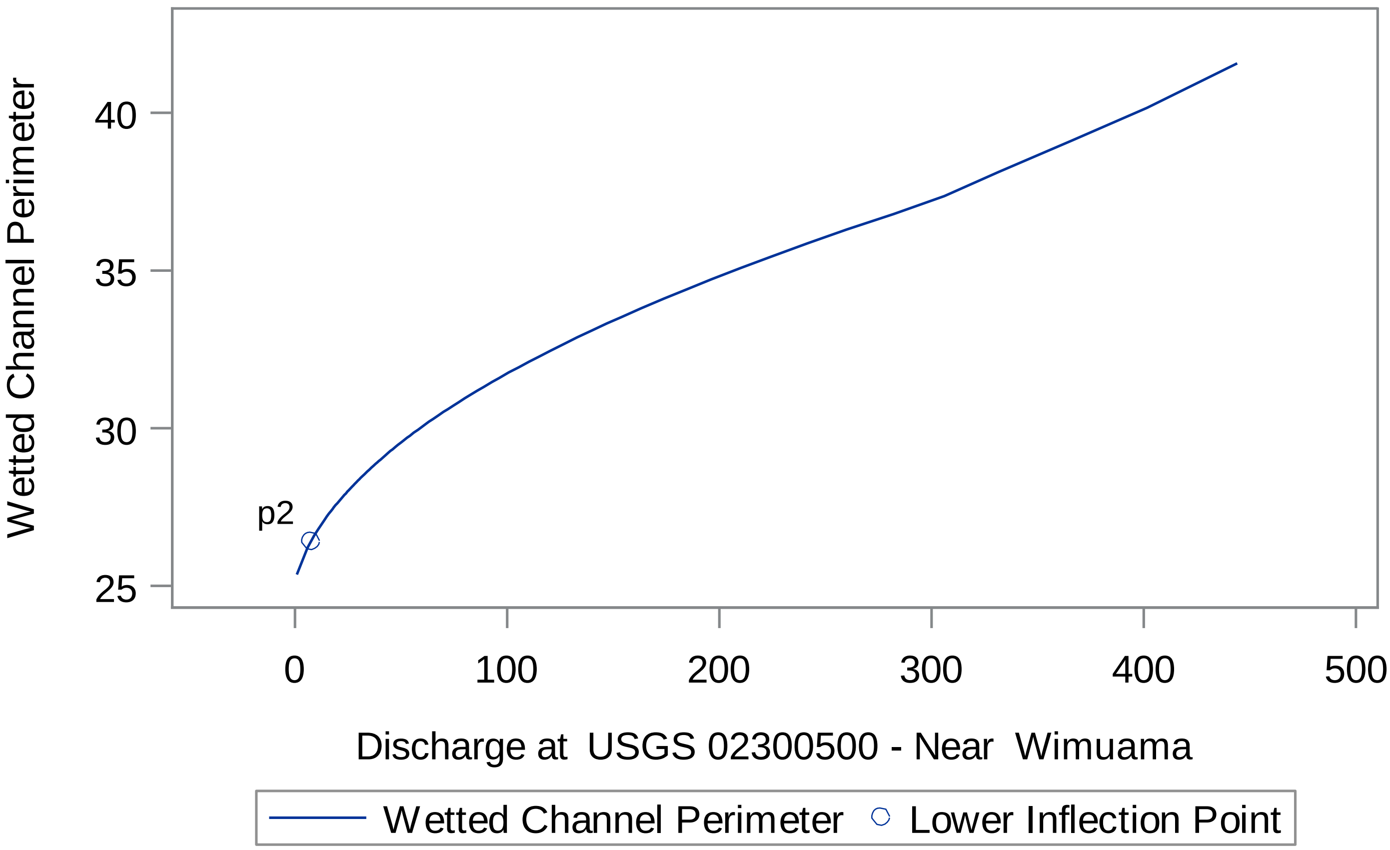



inflection points between the 2nd and 93rd percentile




inflection points between the 2nd and 93rd percentile

Flow Range 0 - 500 cfs
Reach=4 Cross Section #=57596.7

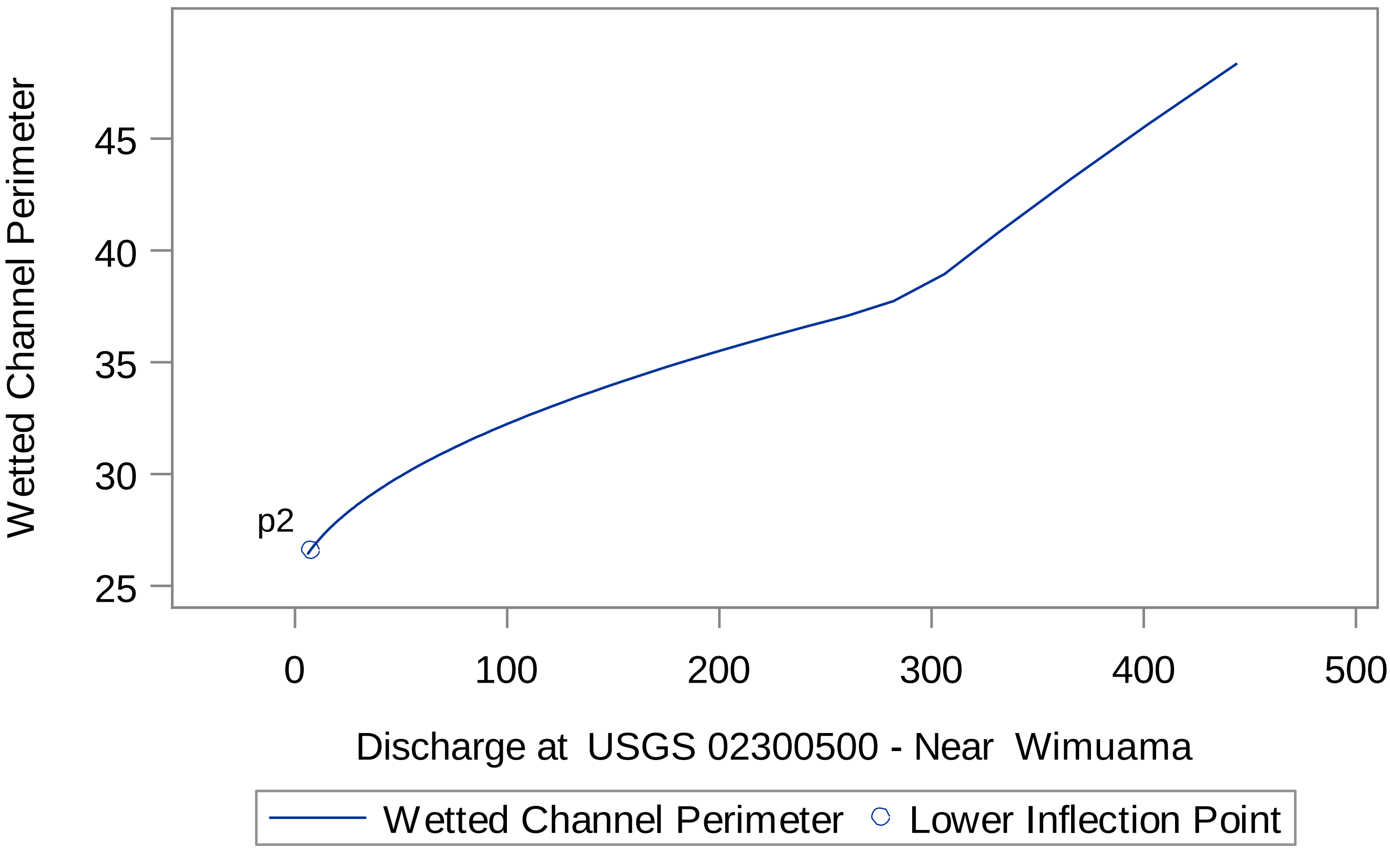



inflection points between the 2nd and 93rd percentile

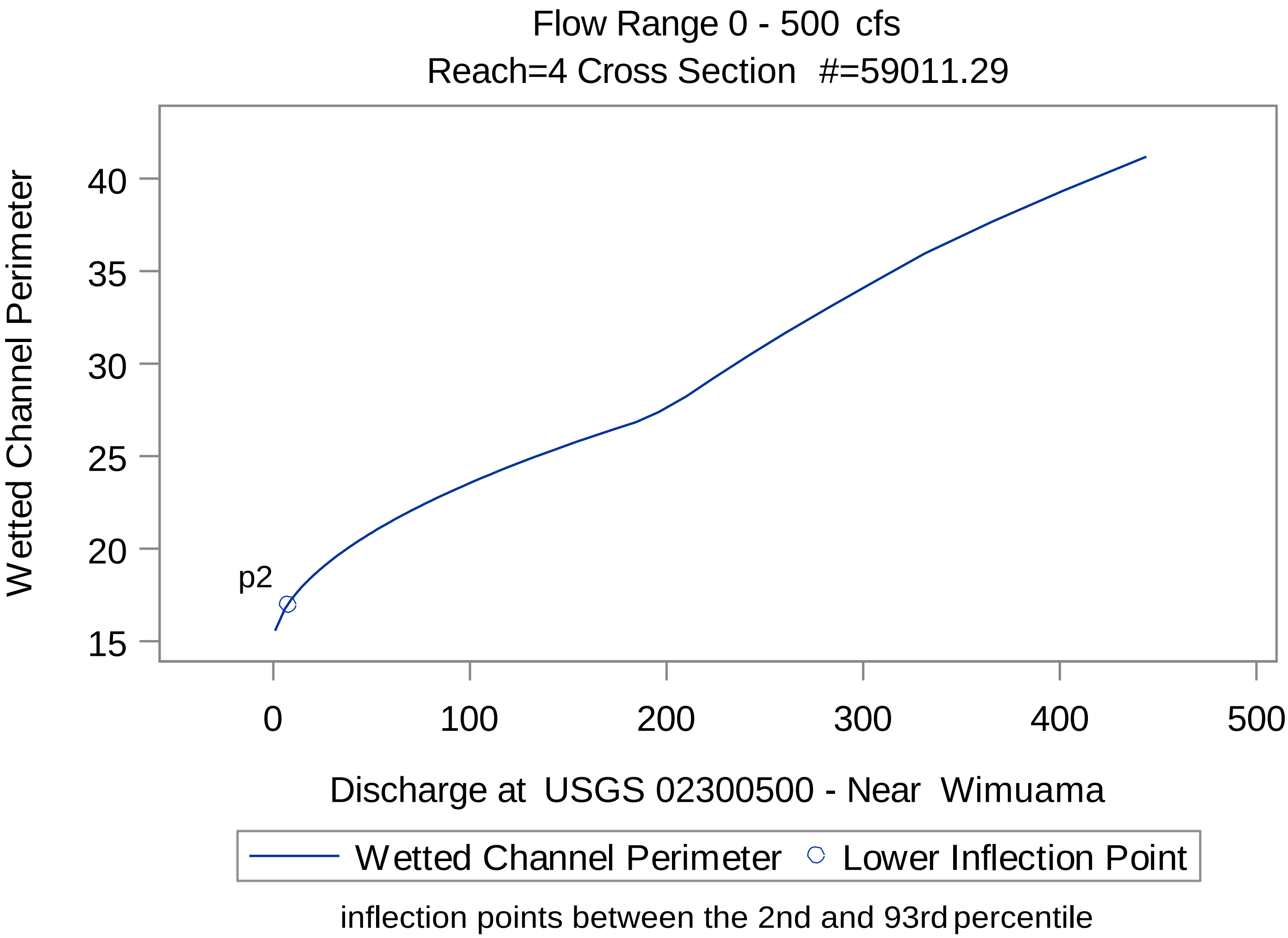
Flow Range 0 - 500 cfs
Reach=4 Cross Section #=57667.23

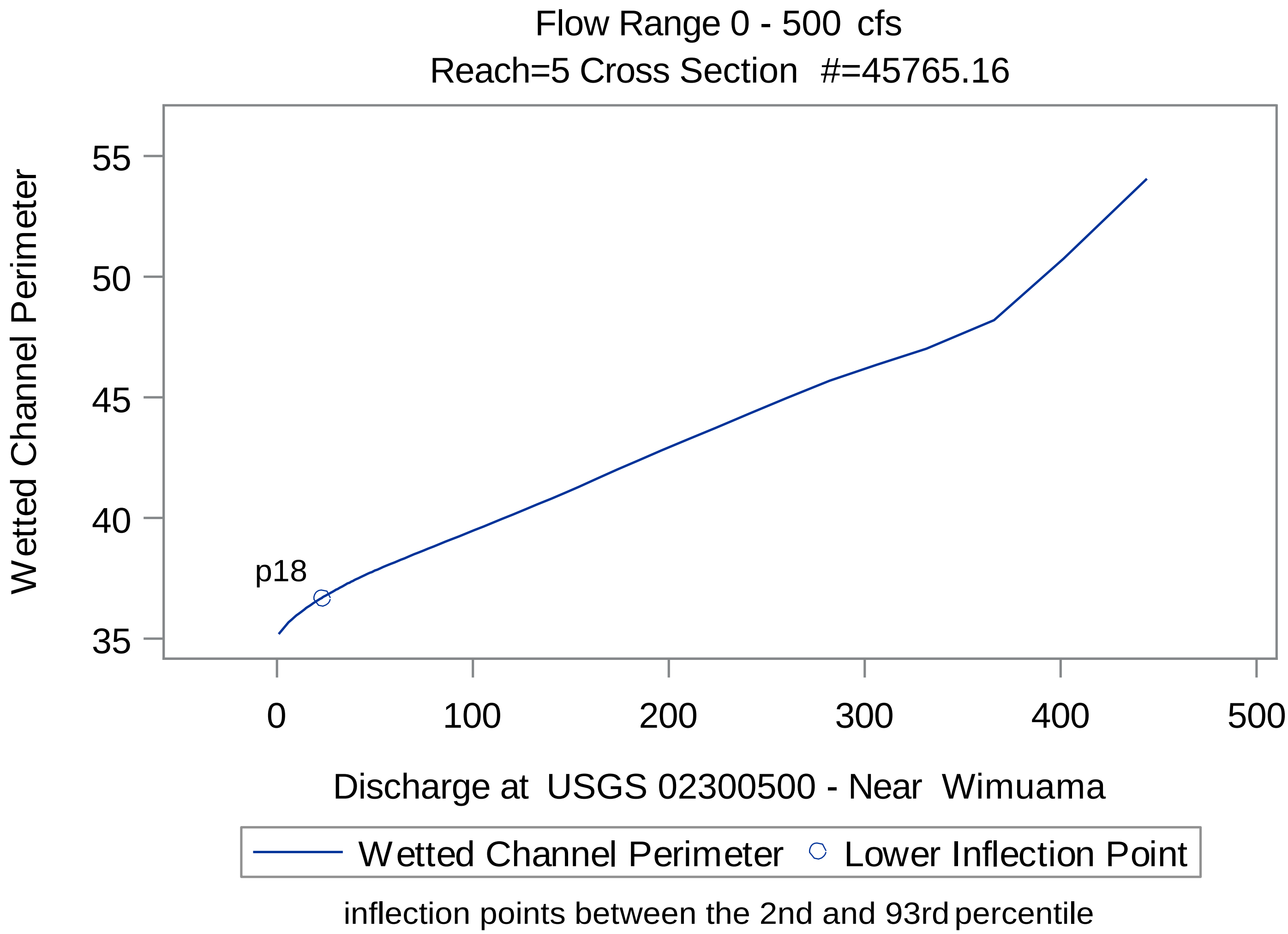
inflection points between the 2nd and 93rd percentile

Flow Range 0 - 500 cfs
Reach=4 Cross Section #=57729.21

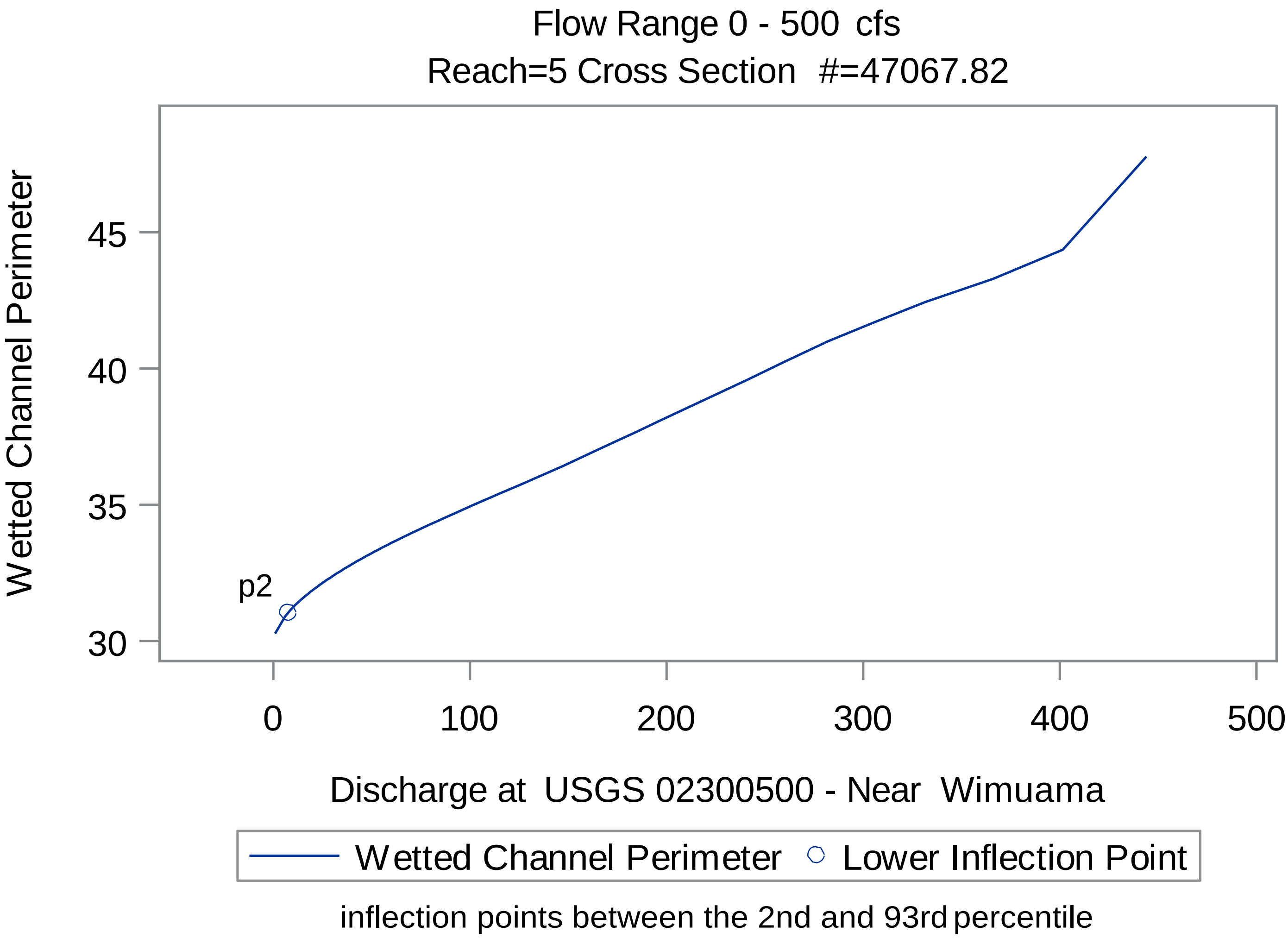


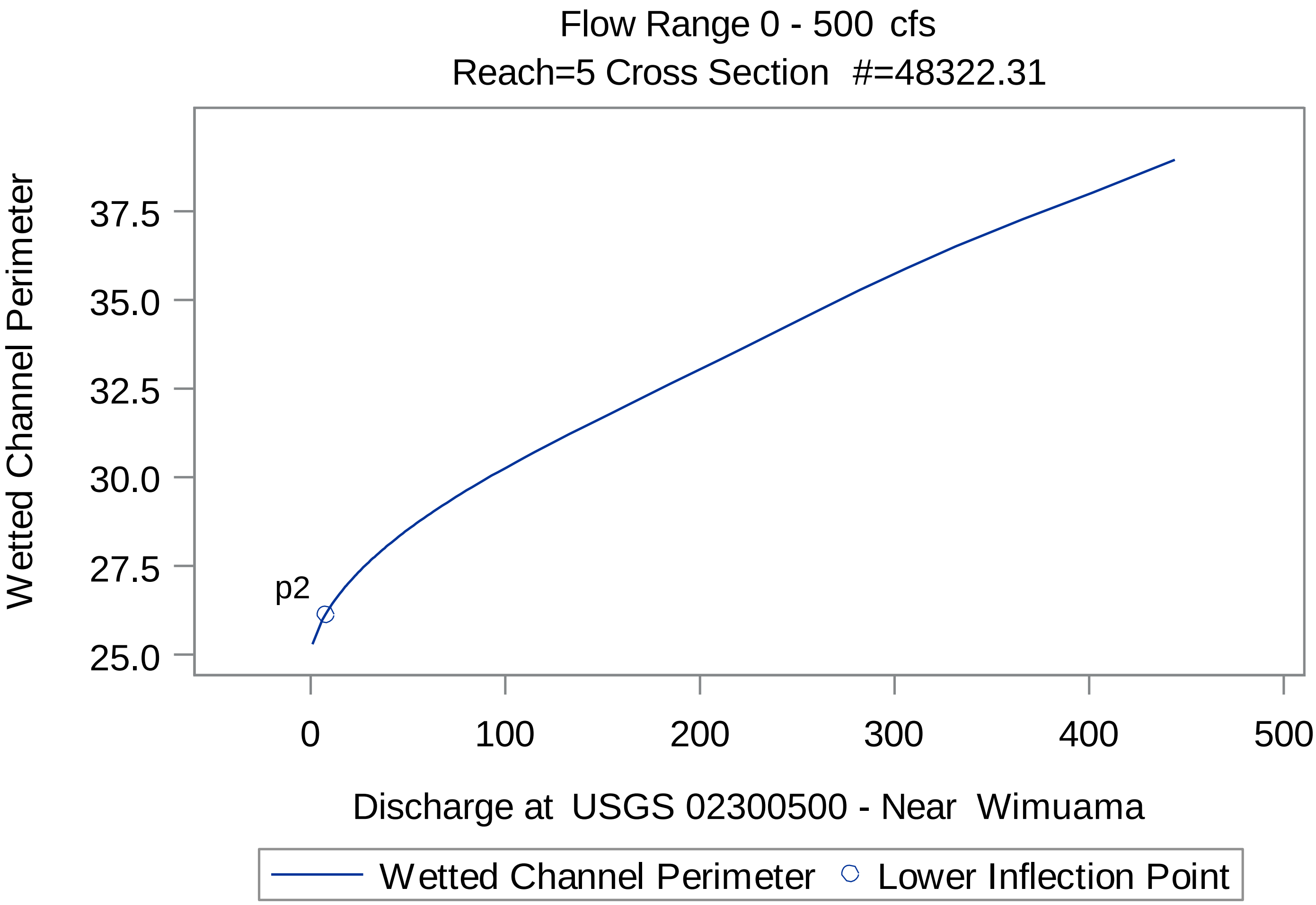

inflection points between the 2nd and 93rd percentile


Flow Range 0 - 500 cfs
Reach=4 Cross Section #=59011.29
Wetted Channel Perimeter
40
35
30
25
20
15
p2
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

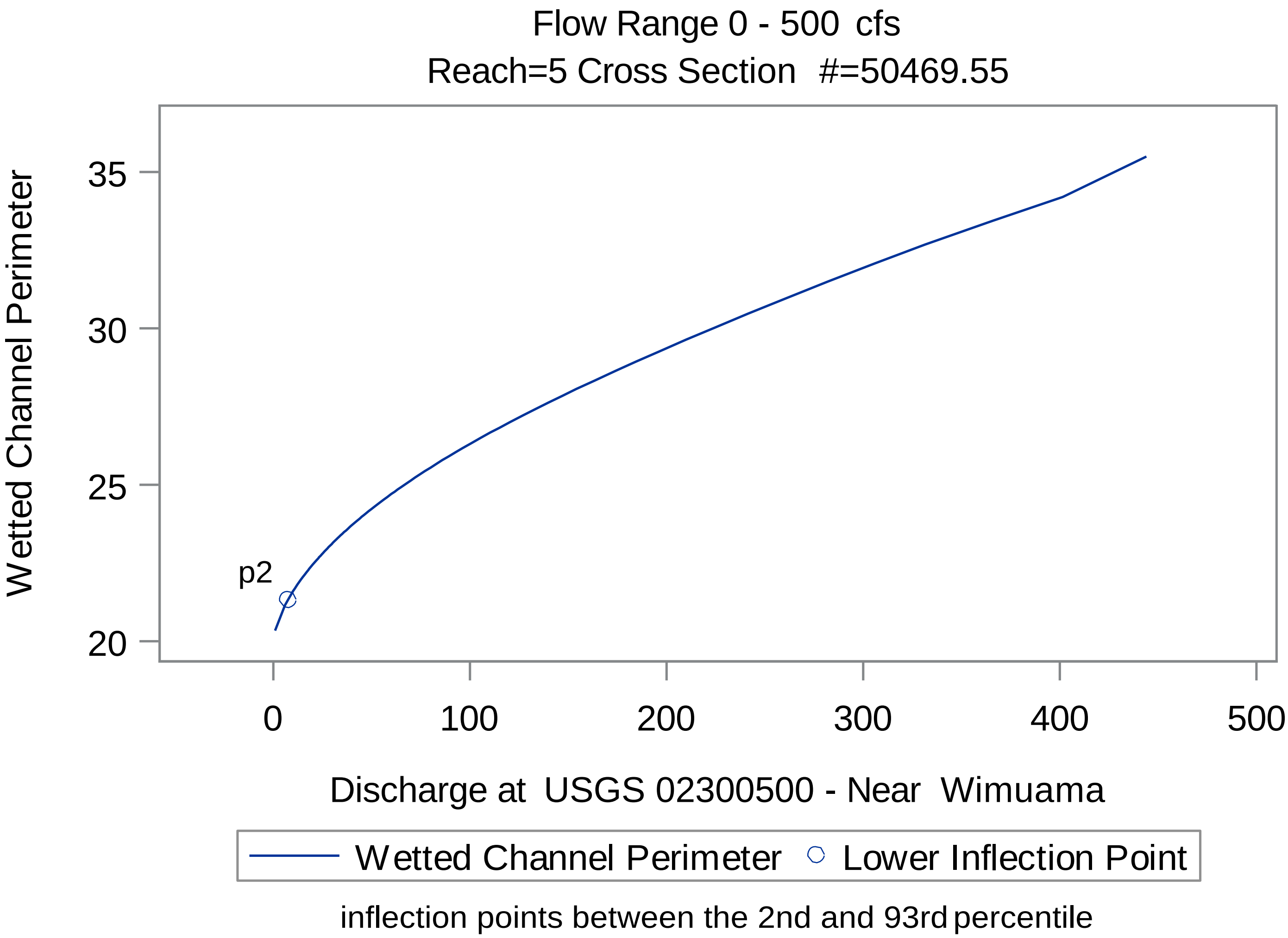


Flow Range 0 - 500 cfs
Reach=5 Cross Section #=45765.16
Wetted Channel Perimeter
55
50
45
40
35
p18
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

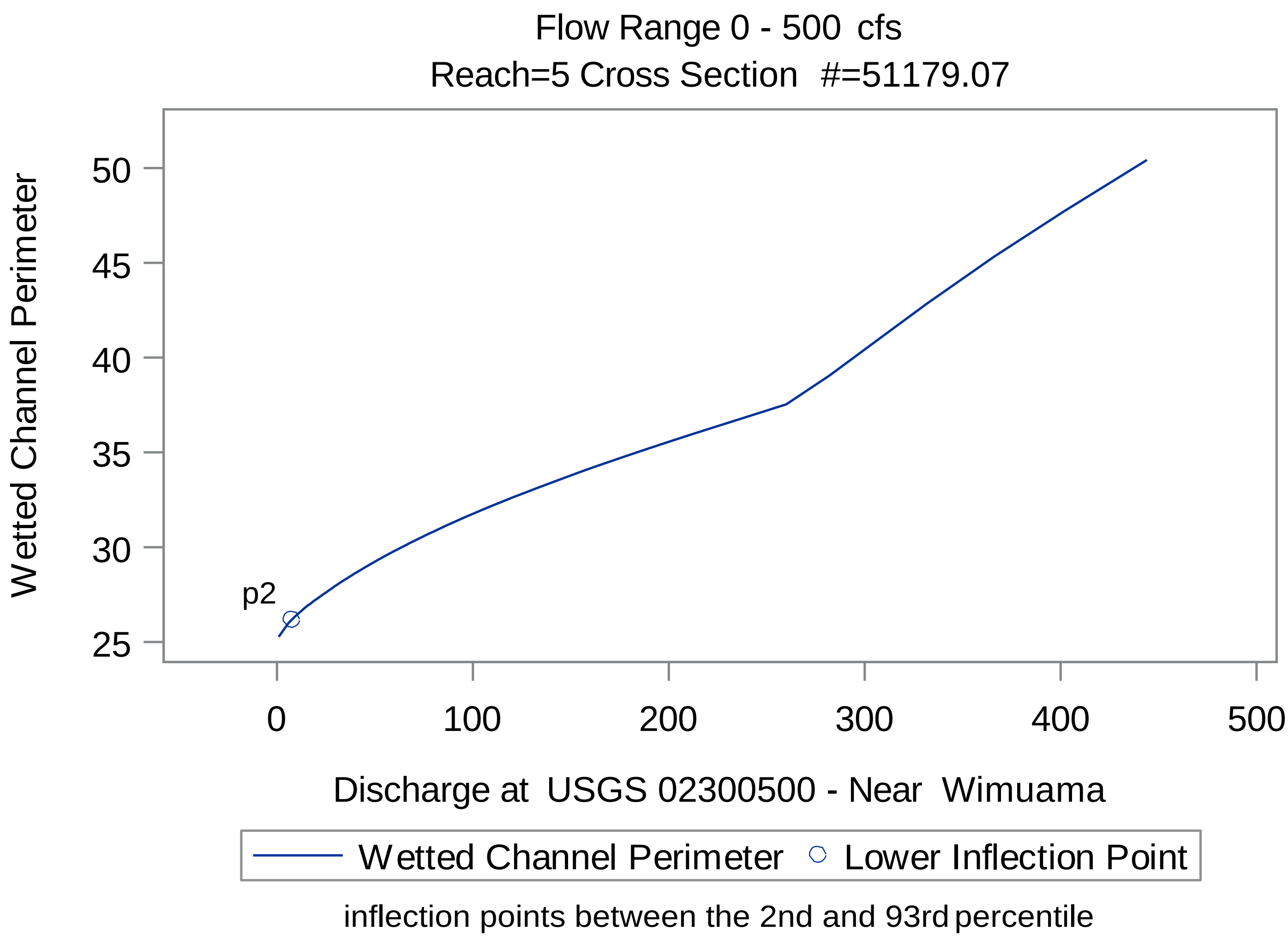

Flow Range 0 - 500 cfs
Reach=5 Cross Section #=47067.82
Wetted Channel Perimeter
45
40
35
30
p2
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile



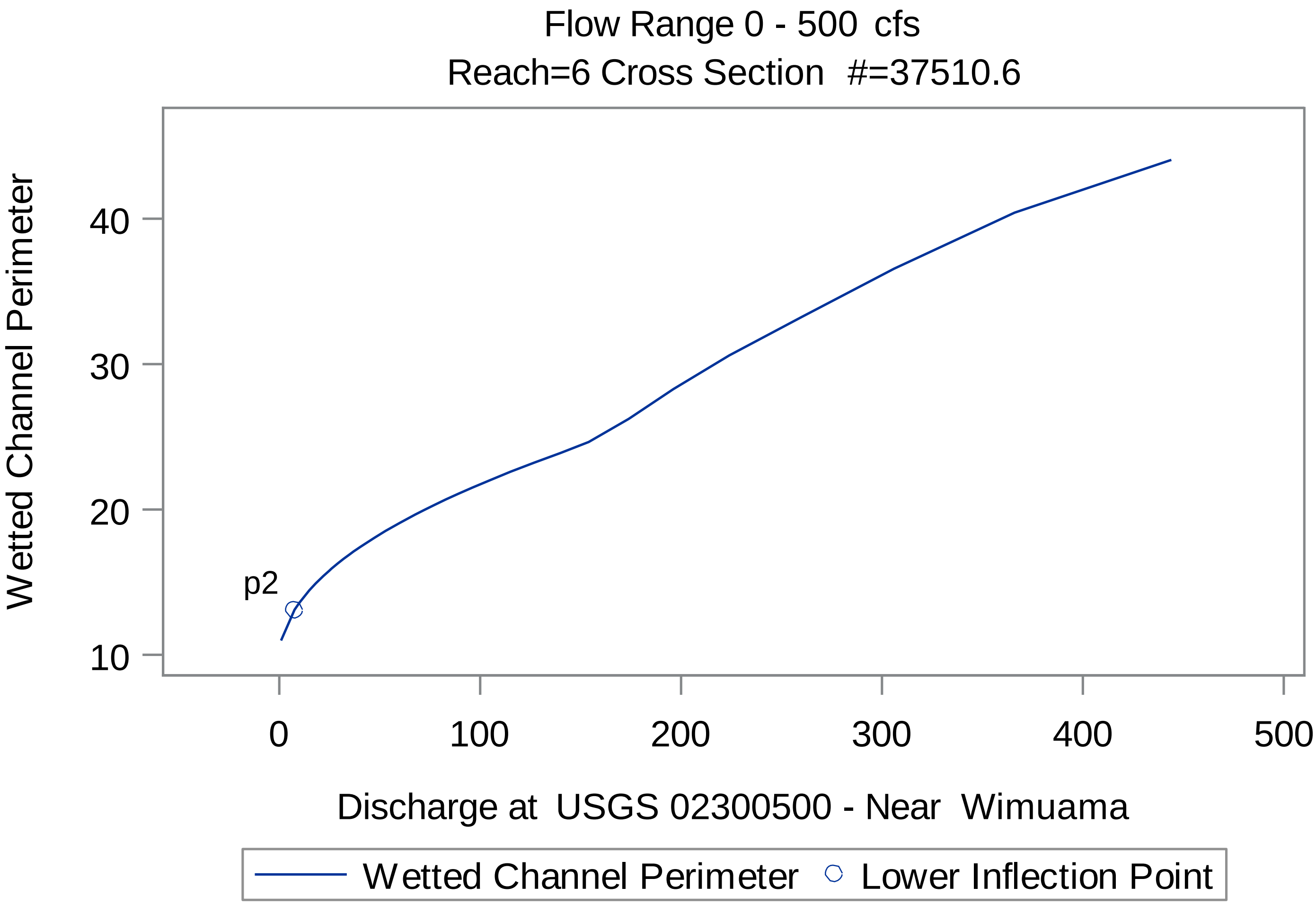

inflection points between the 2nd and 93rd percentile



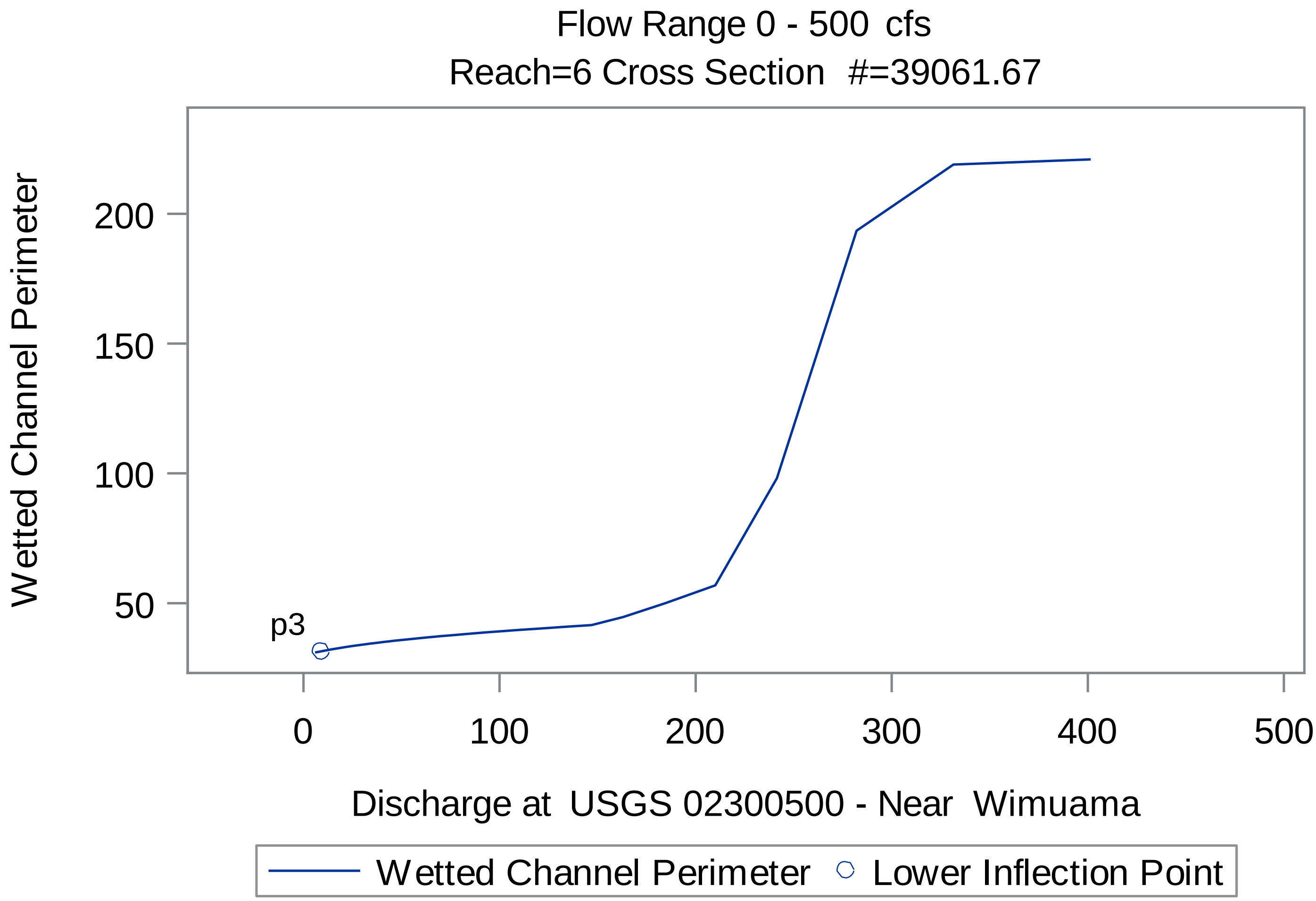
Flow Range 0 - 500 cfs
Reach=5 Cross Section #=50469.55
Wetted Channel Perimeter
35
30
25
20
p2
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile



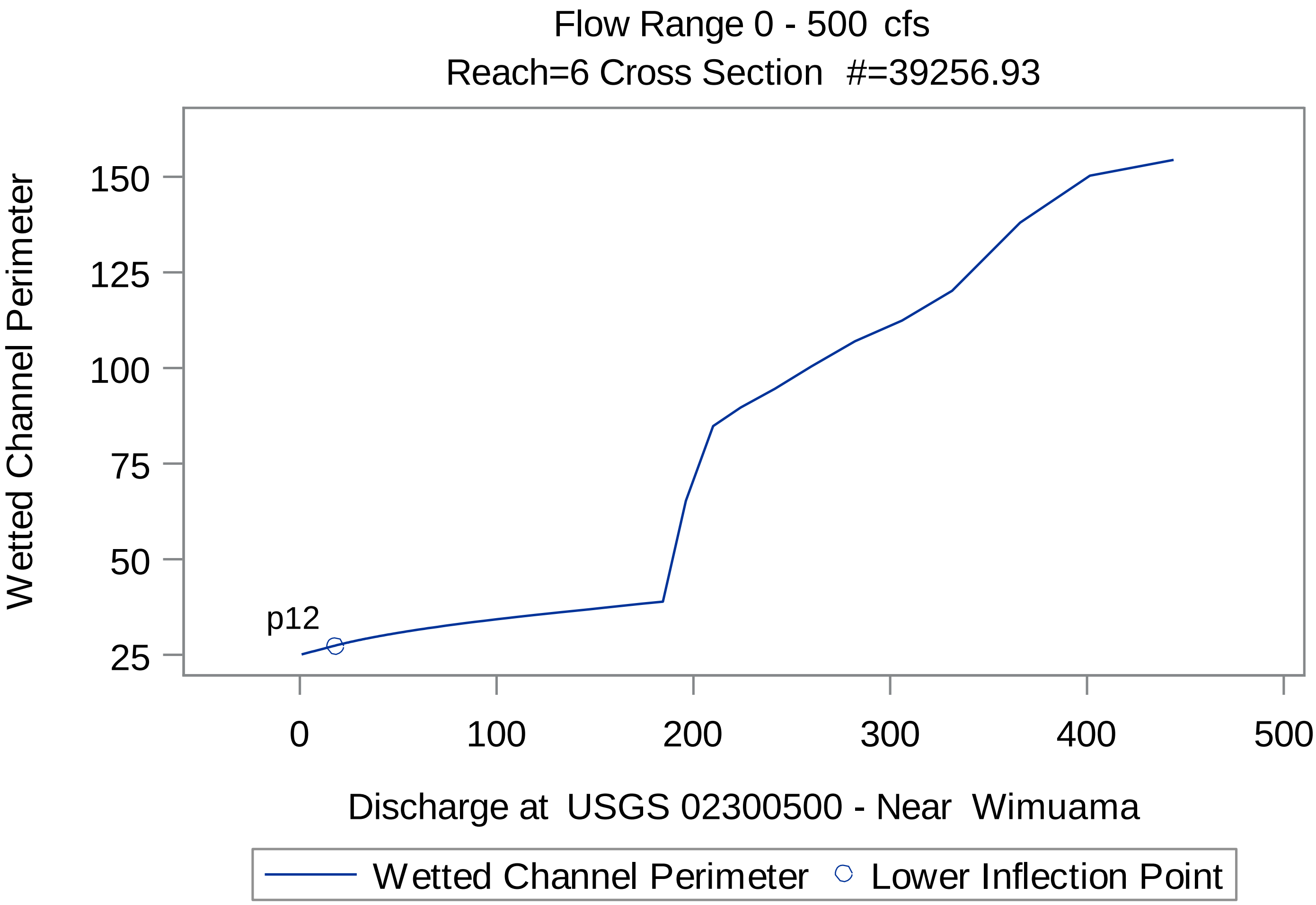
Flow Range 0 - 500 cfs
Reach=5 Cross Section #=51179.07
Wetted Channel Perimeter
50
45
40
35
30
25
p2
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile



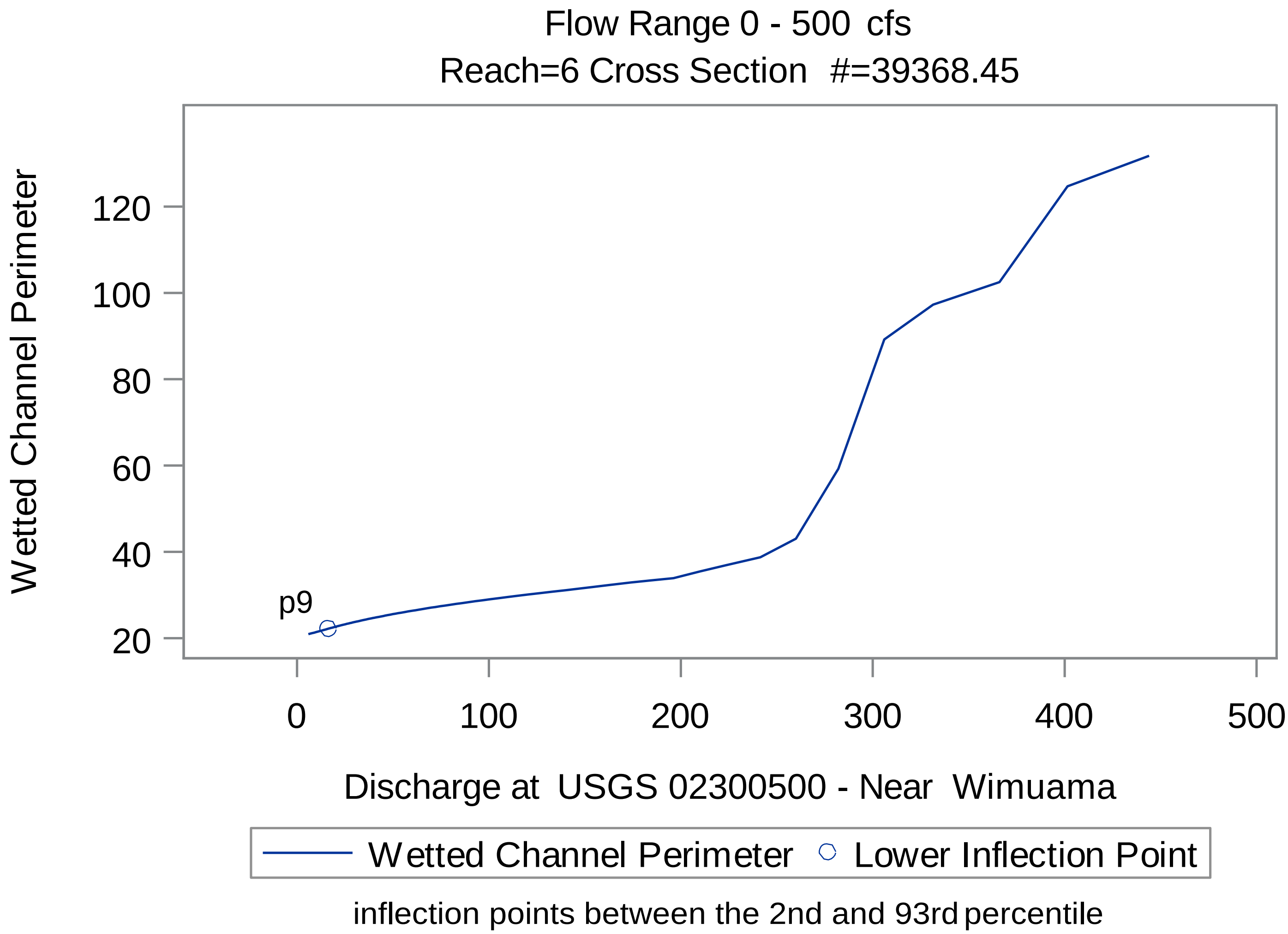

inflection points between the 2nd and 93rd percentile

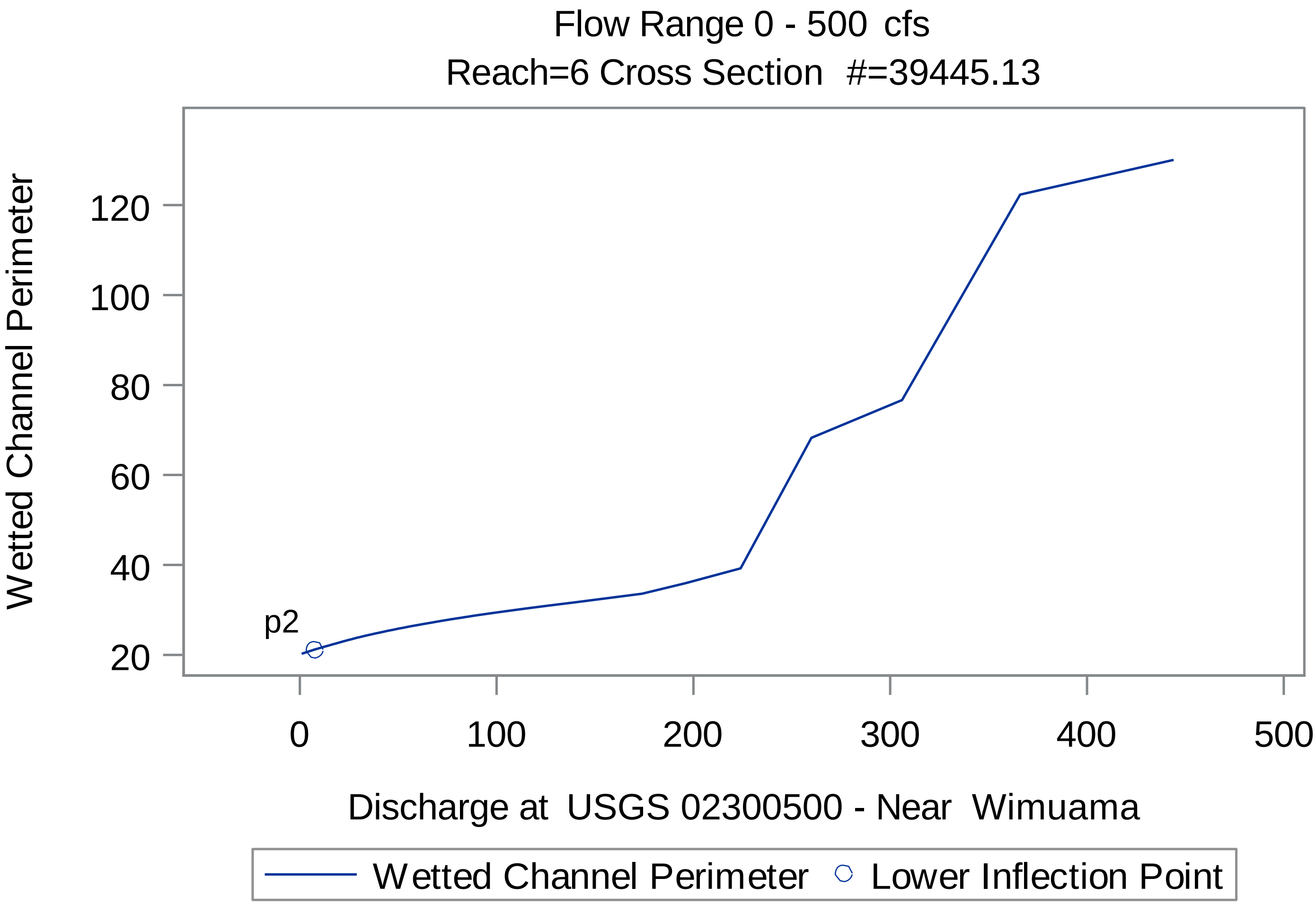



inflection points between the 2nd and 93rd percentile

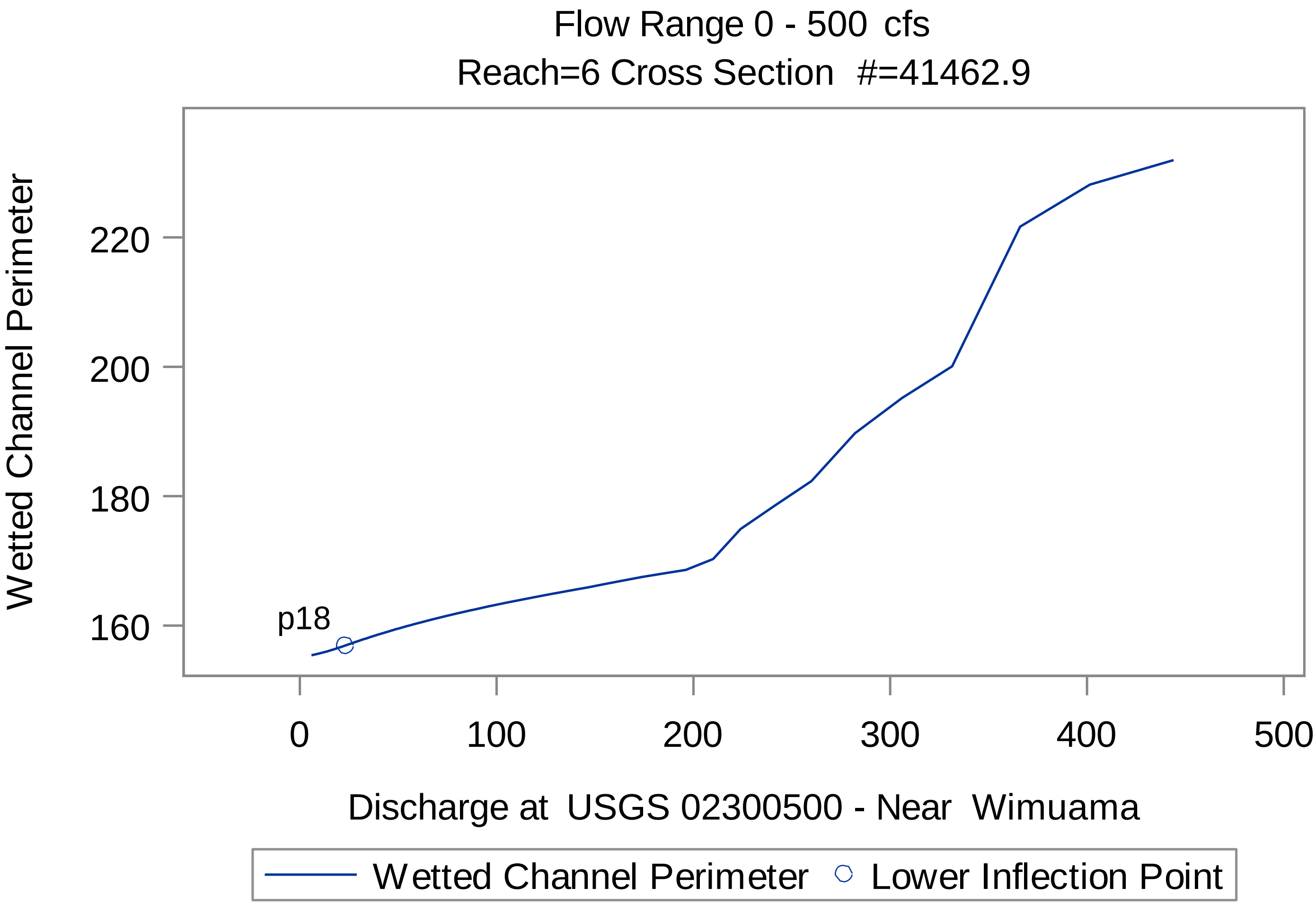



inflection points between the 2nd and 93rd percentile

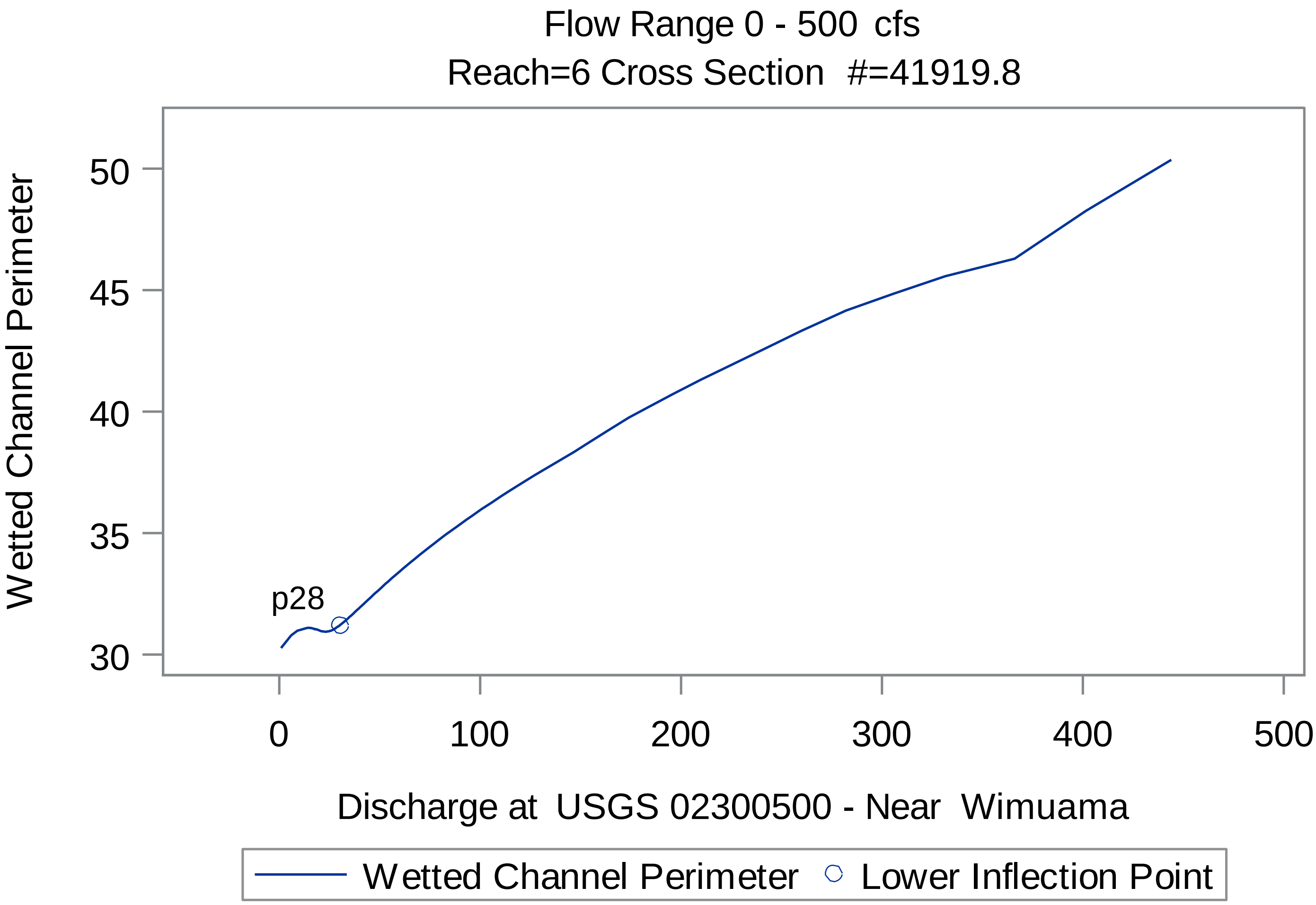

Flow Range 0 - 500 cfs
Reach=6 Cross Section #=39368.45
Wetted Channel Perimeter
120
100
80
60
40
20
p9
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile



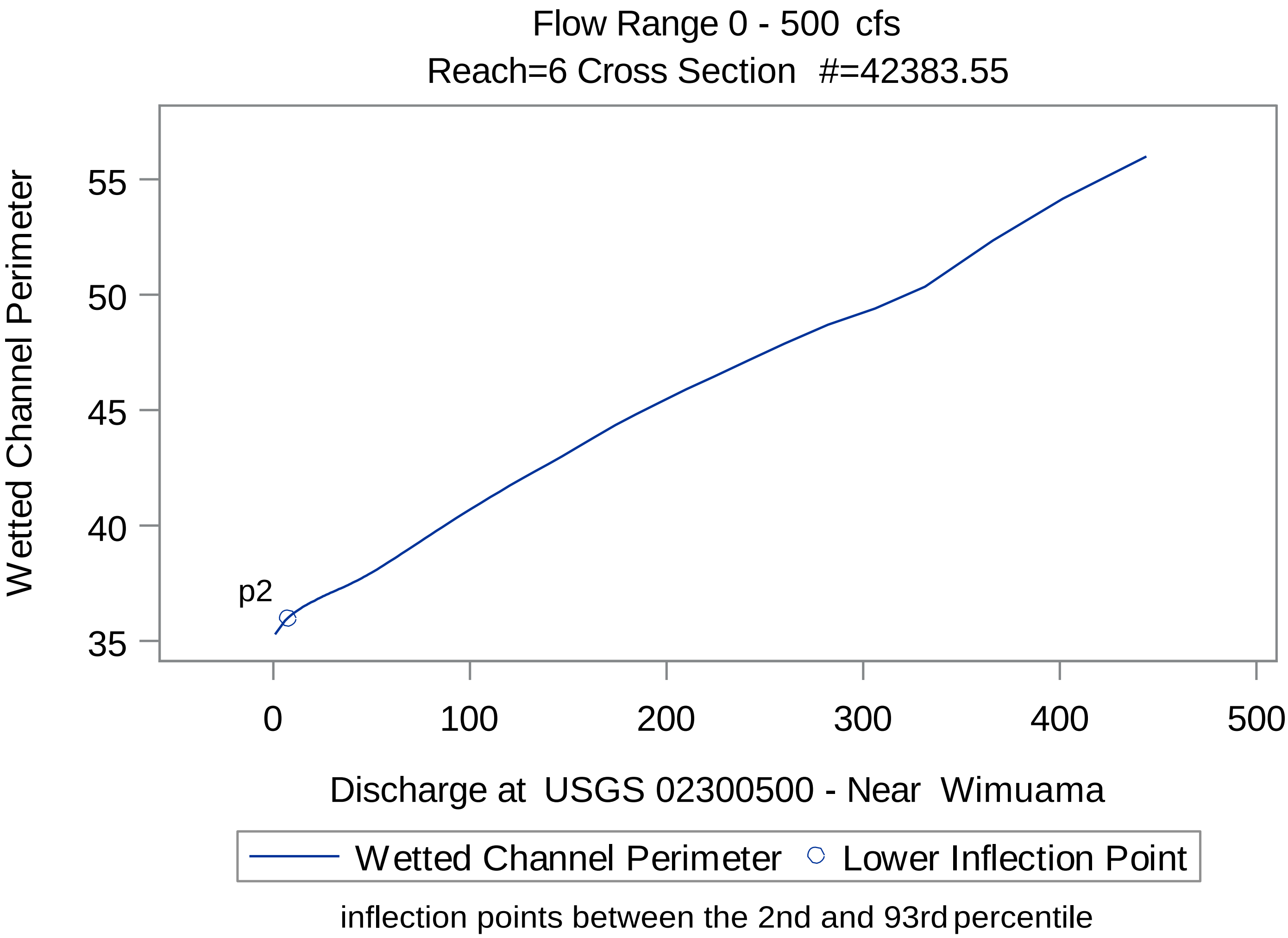
inflection points between the 2nd and 93rd percentile



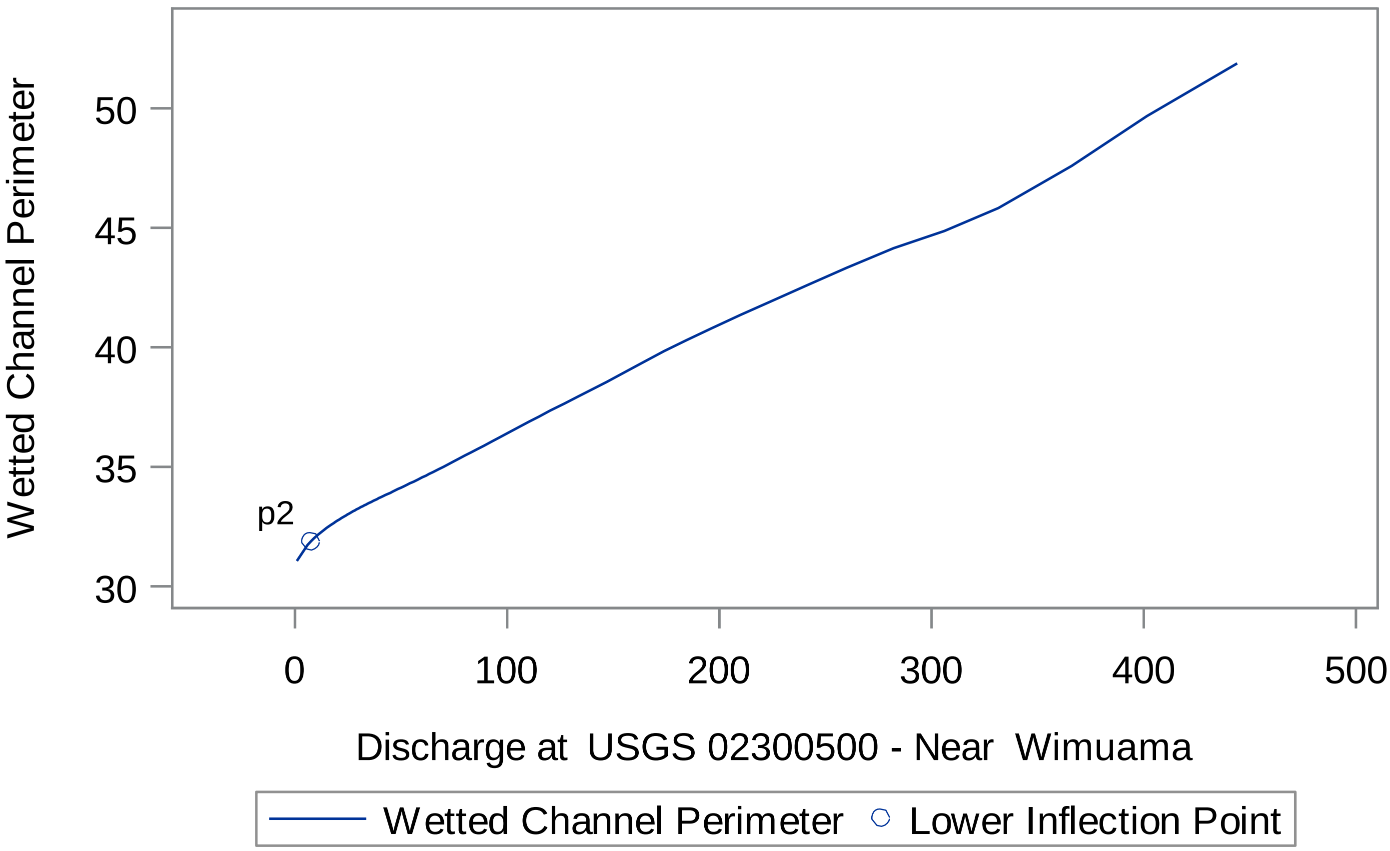

inflection points between the 2nd and 93rd percentile



inflection points between the 2nd and 93rd percentile

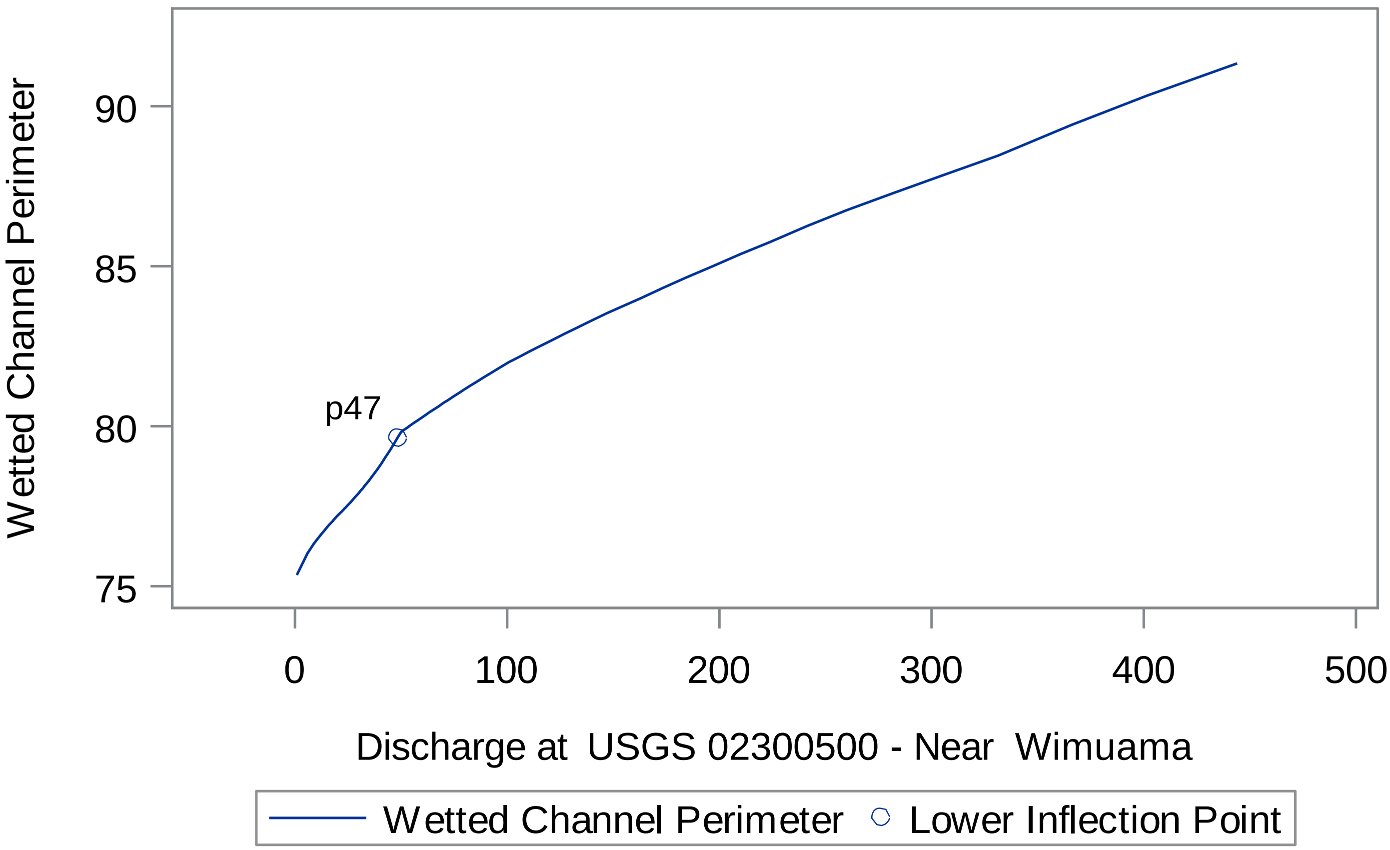

Flow Range 0 - 500 cfs
Reach=6 Cross Section #=42383.55
Wetted Channel Perimeter
55
50
45
40
35
p2
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

Flow Range 0 - 500 cfs
Reach=6 Cross Section #=43187.77

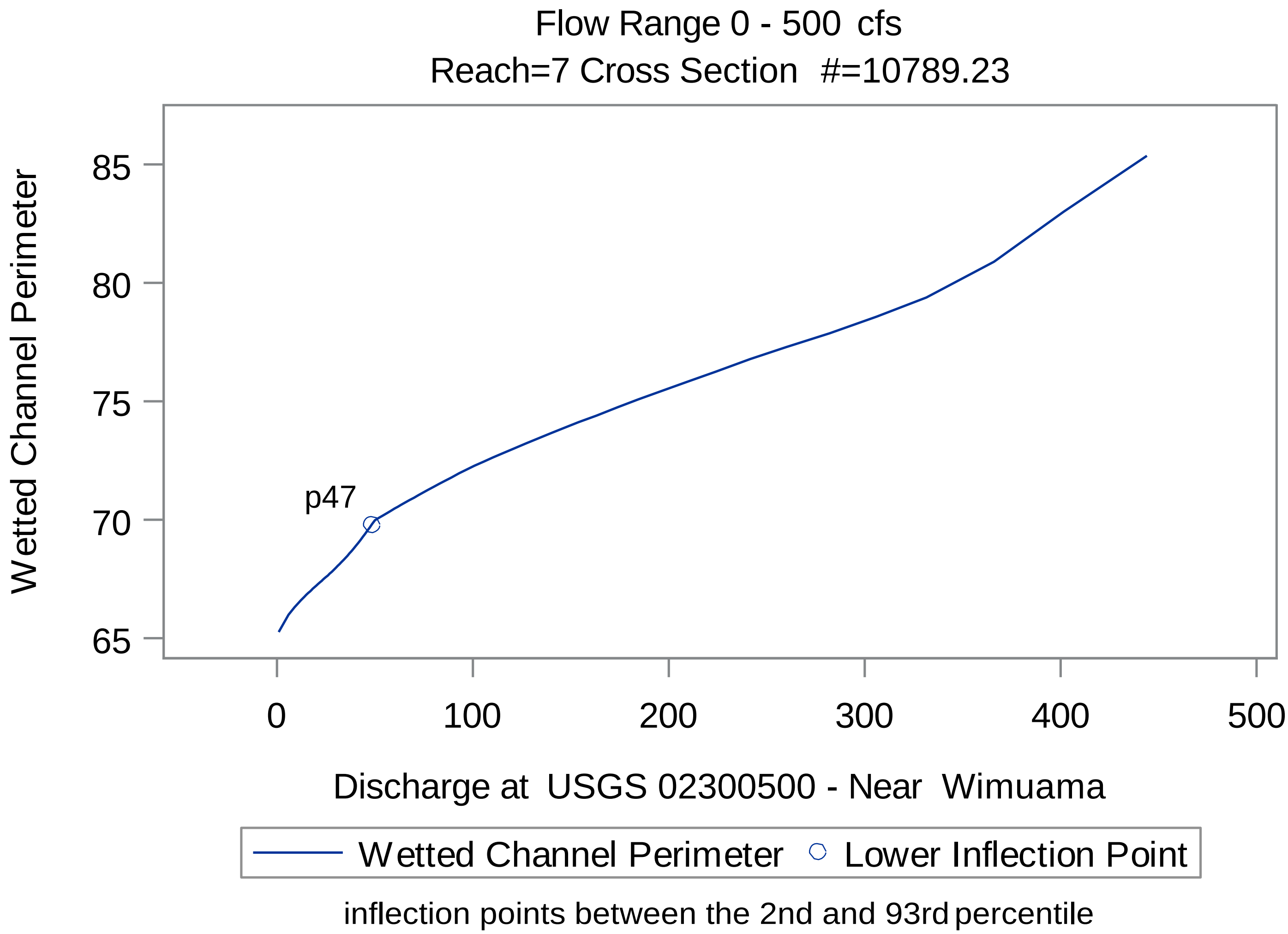


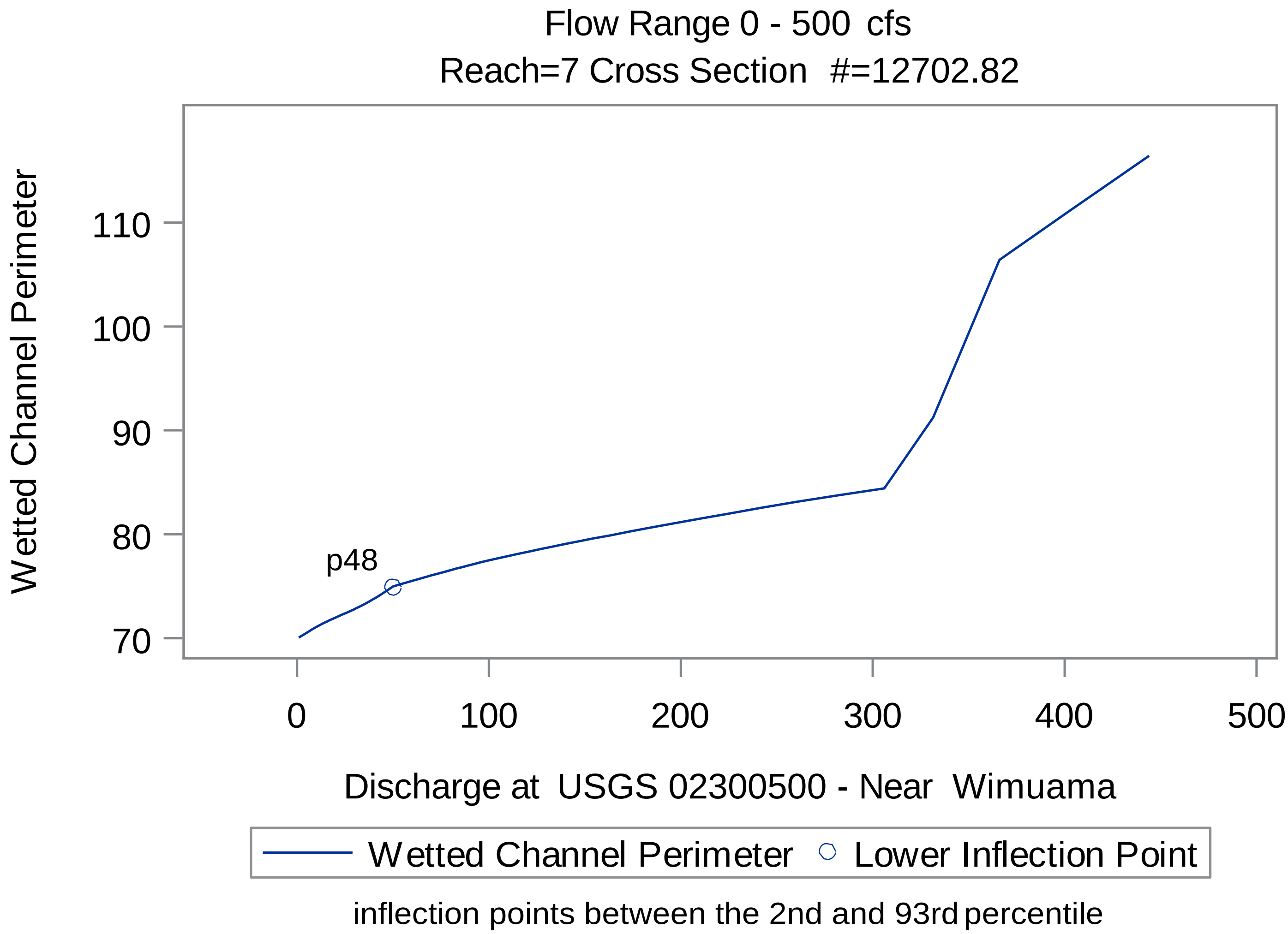

inflection points between the 2nd and 93rd percentile

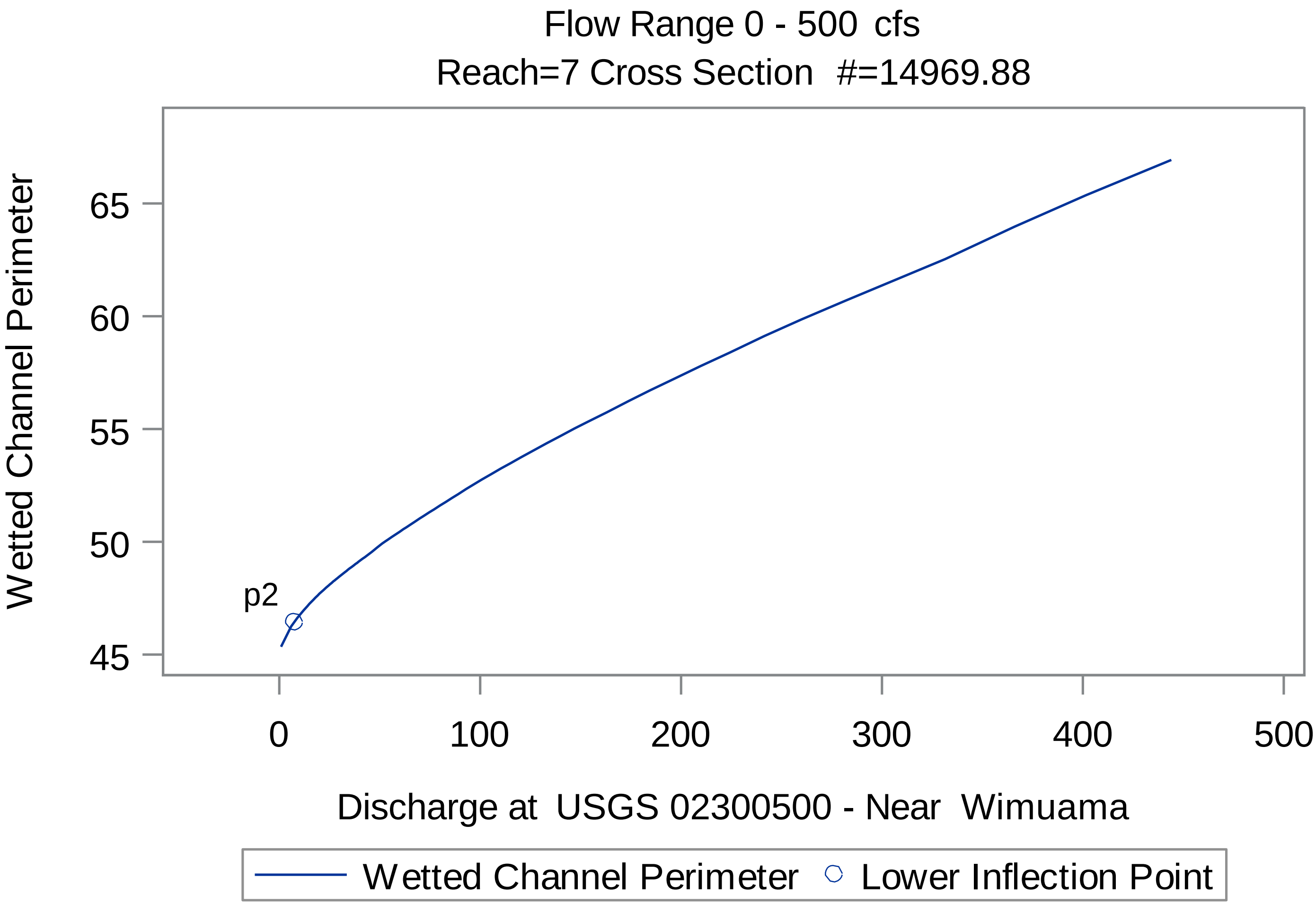
Flow Range 0 - 500 cfs
Reach=7 Cross Section #=10034.6



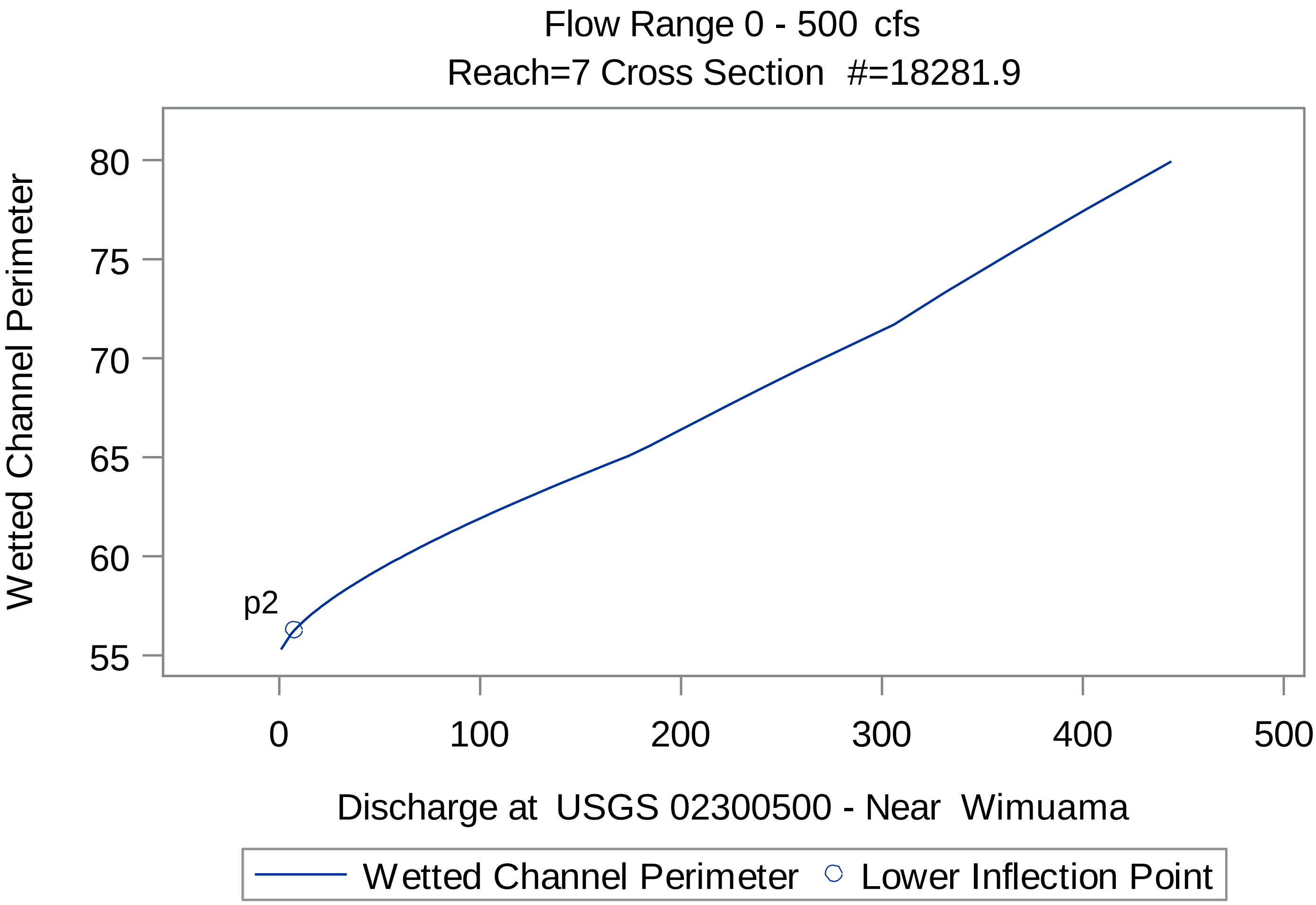

inflection points between the 2nd and 93rd percentile


Flow Range 0 - 500 cfs
Reach=7 Cross Section #=10789.23
Wetted Channel Perimeter
85
80
75
70
65
p47
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile


Flow Range 0 - 500 cfs
Reach=7 Cross Section #=12702.82
Wetted Channel Perimeter
110
100
90
80
70
p48
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

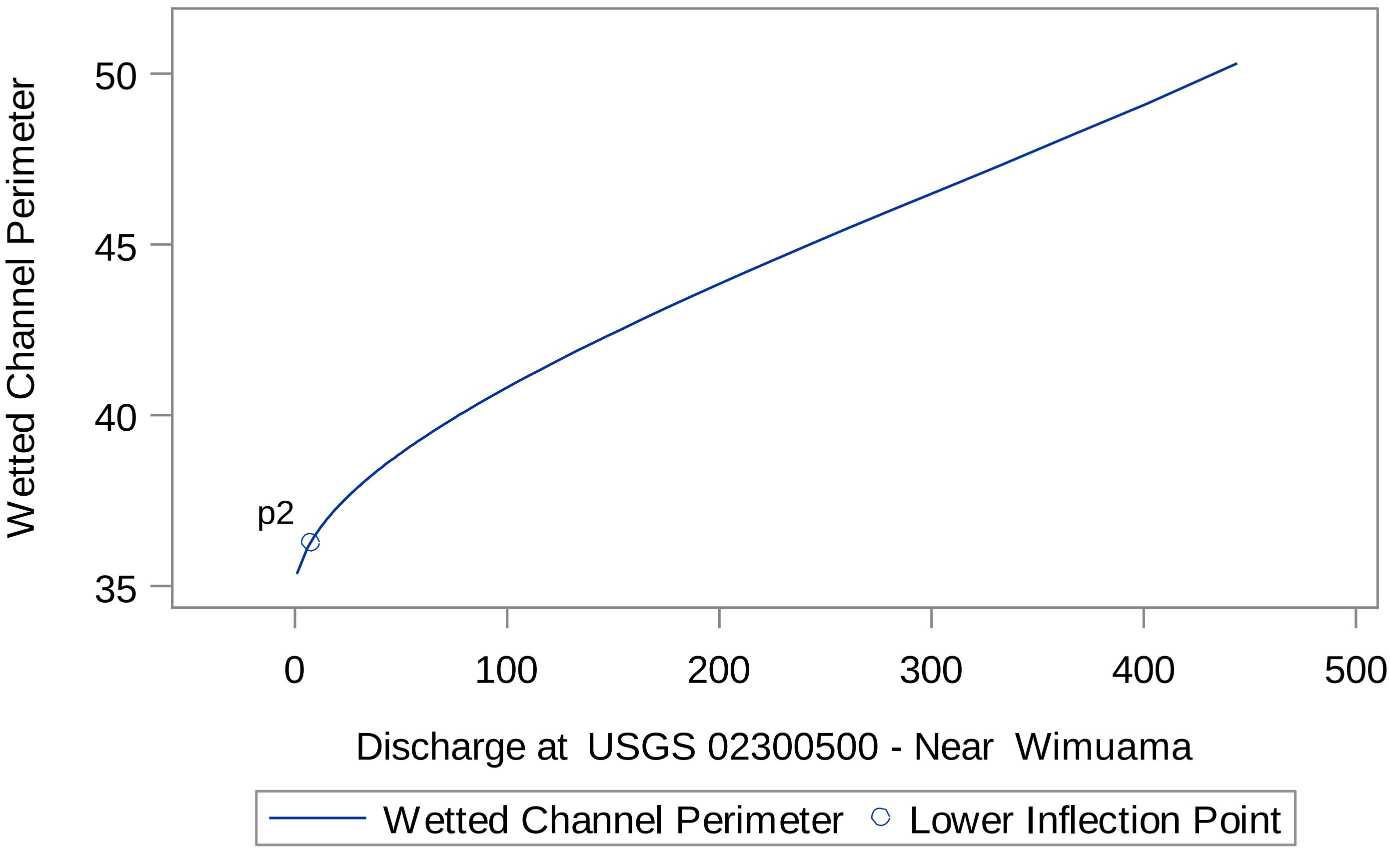



inflection points between the 2nd and 93rd percentile

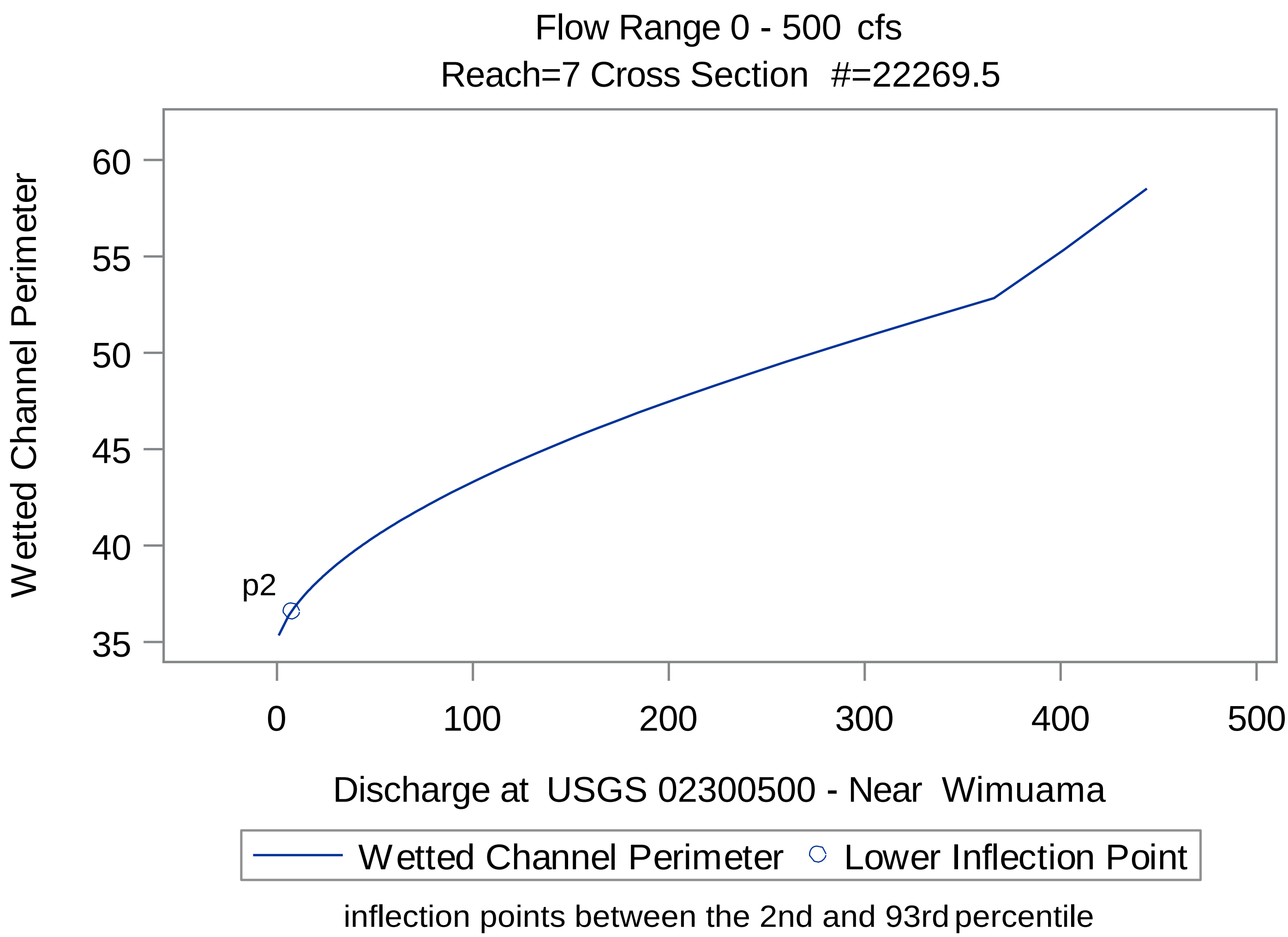


inflection points between the 2nd and 93rd percentile

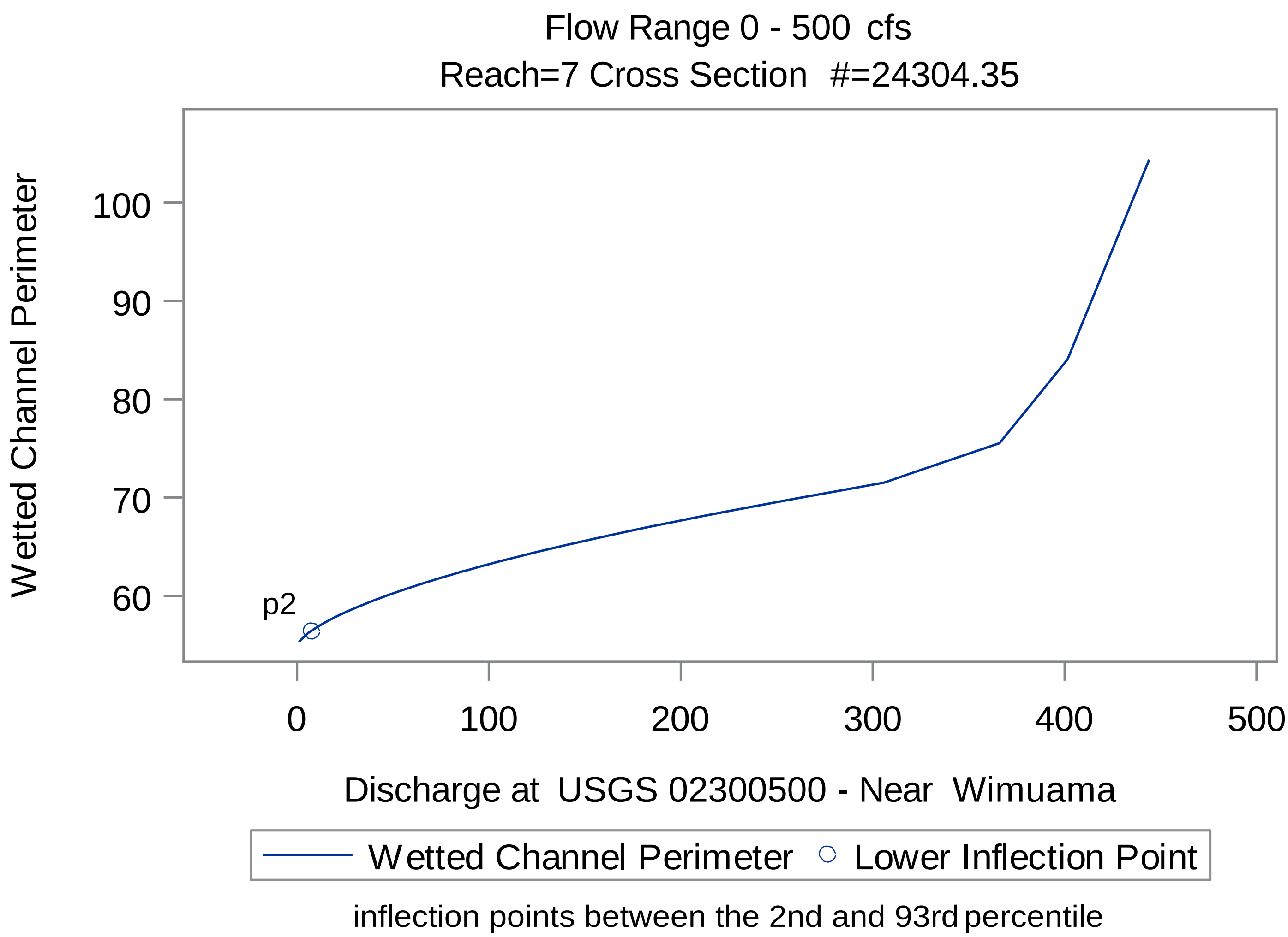
Flow Range 0 - 500 cfs
Reach=7 Cross Section #=20115.56

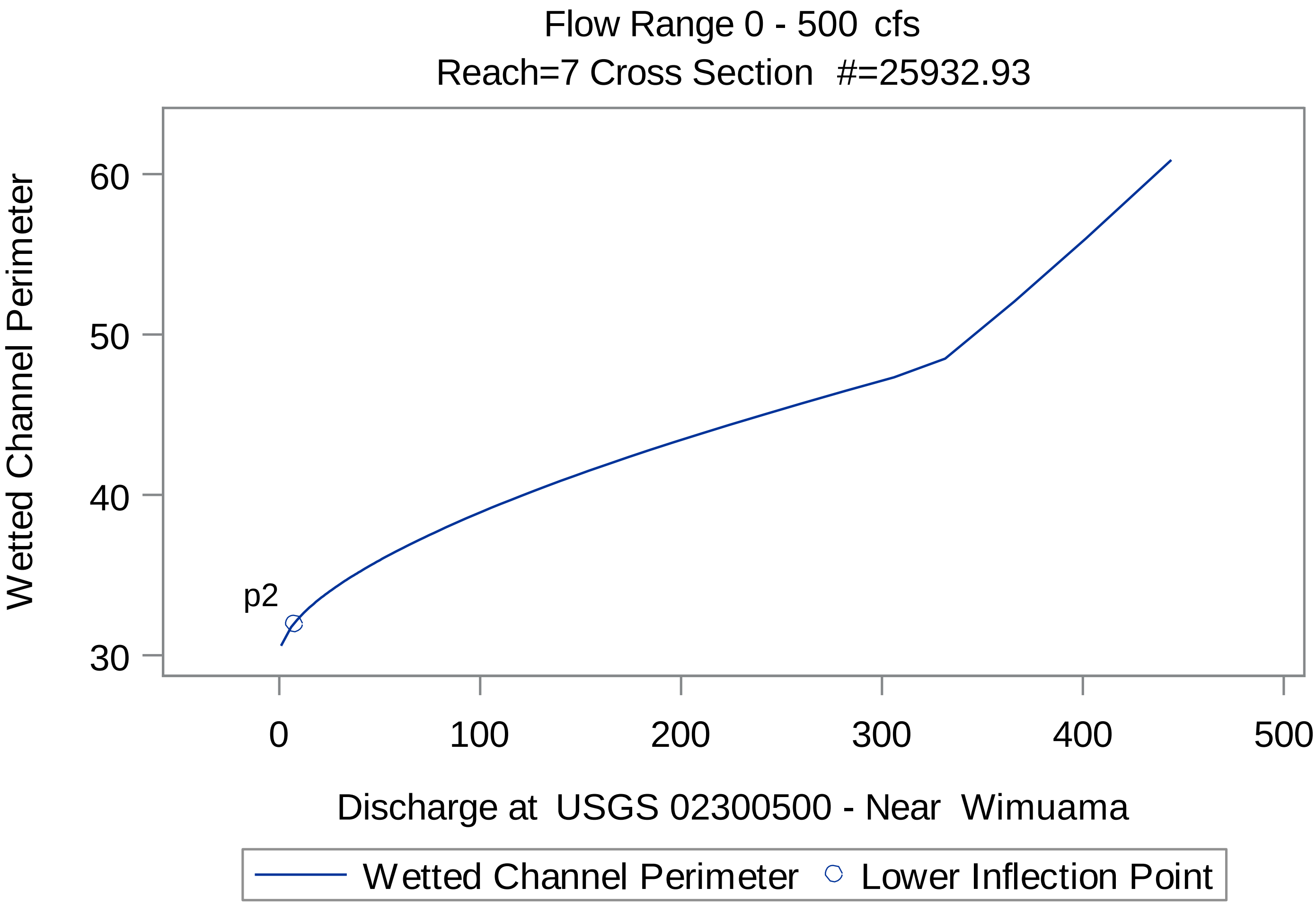



inflection points between the 2nd and 93rd percentile

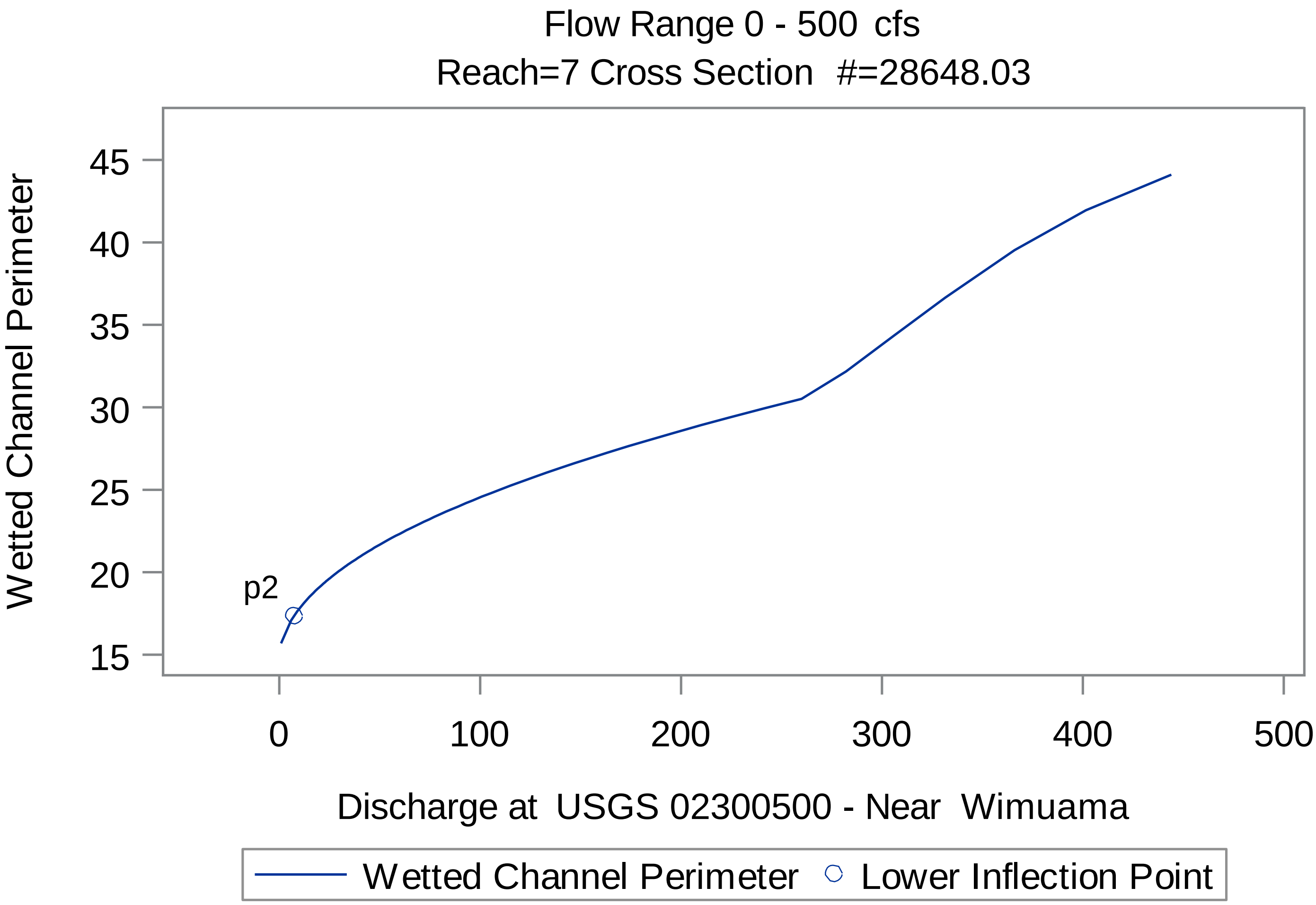


Flow Range 0 - 500 cfs
Reach=7 Cross Section #=22269.5
Wetted Channel Perimeter
60
55
50
45
40
35
p2
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

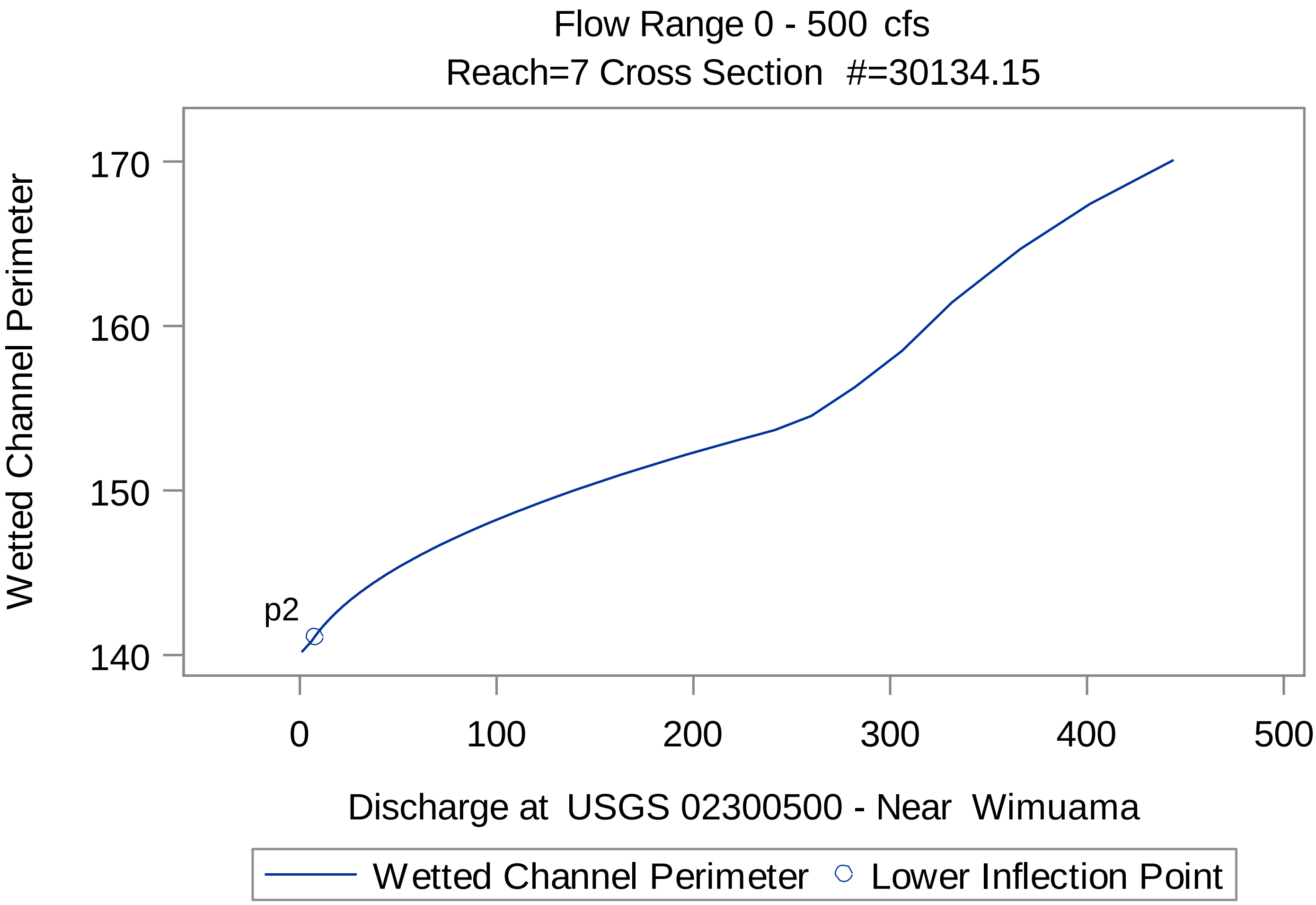

Flow Range 0 - 500 cfs
Reach=7 Cross Section #=24304.35
Wetted Channel Perimeter
100
90
80
70
60
p2
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile



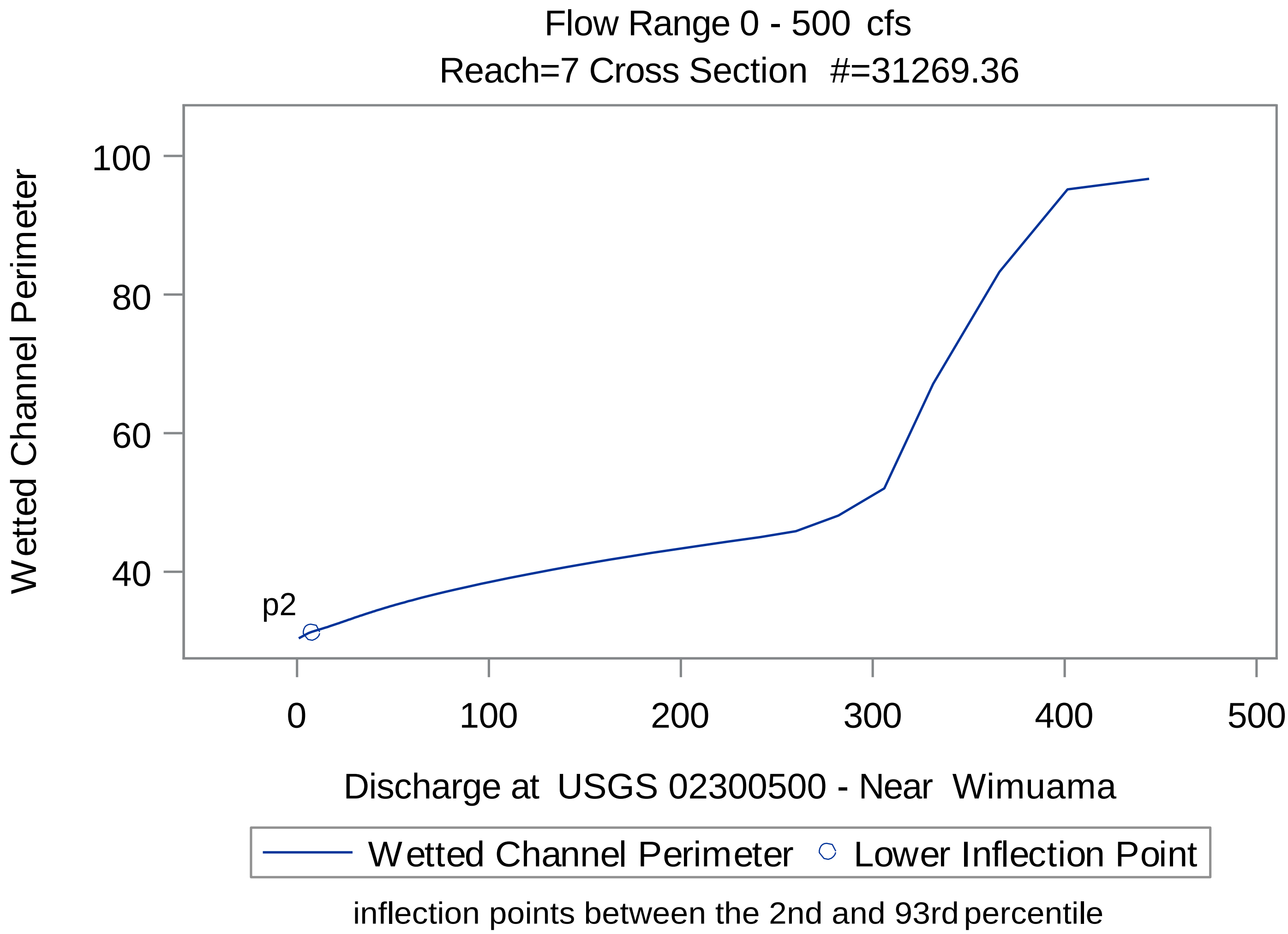

inflection points between the 2nd and 93rd percentile




inflection points between the 2nd and 93rd percentile

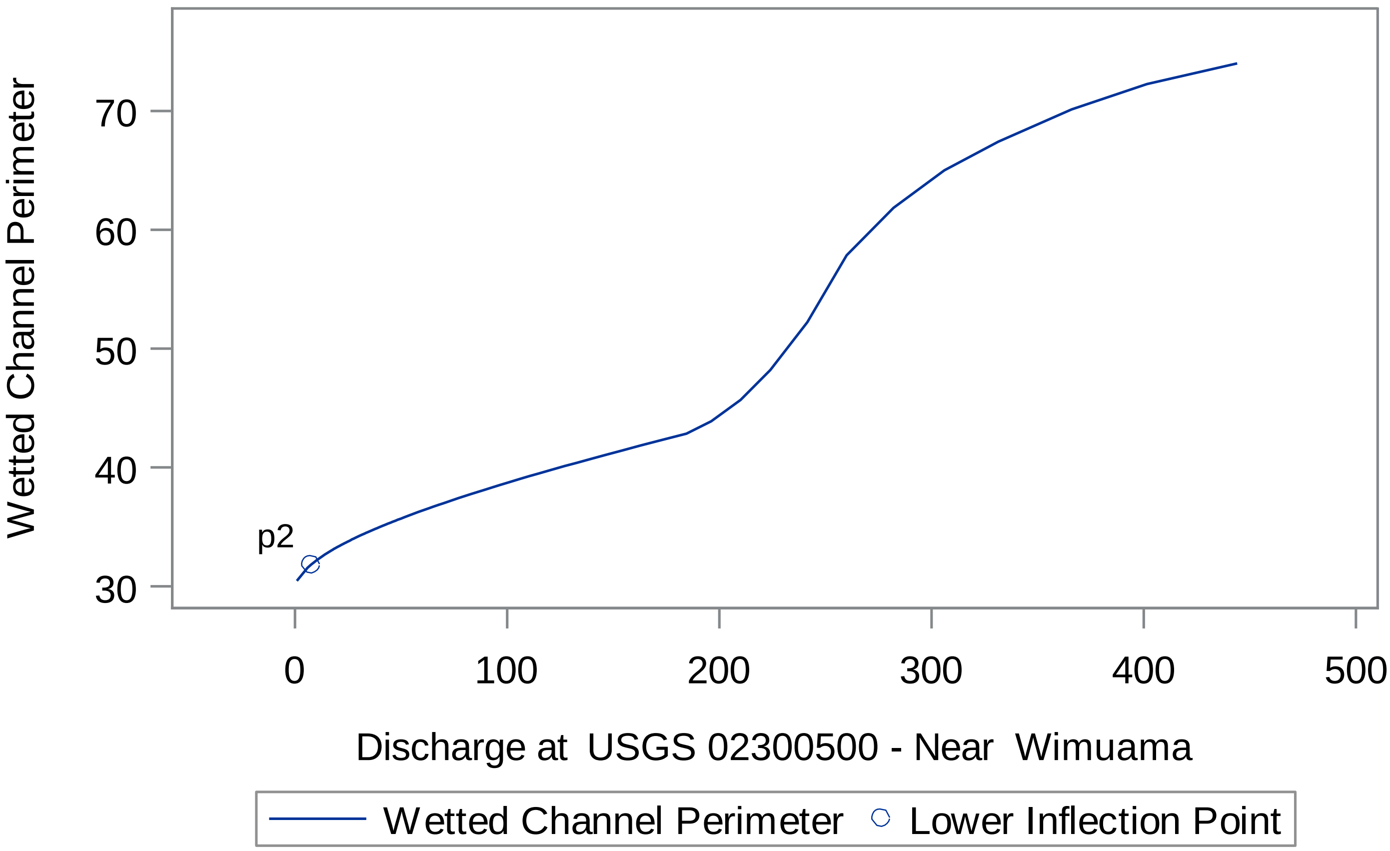



inflection points between the 2nd and 93rd percentile



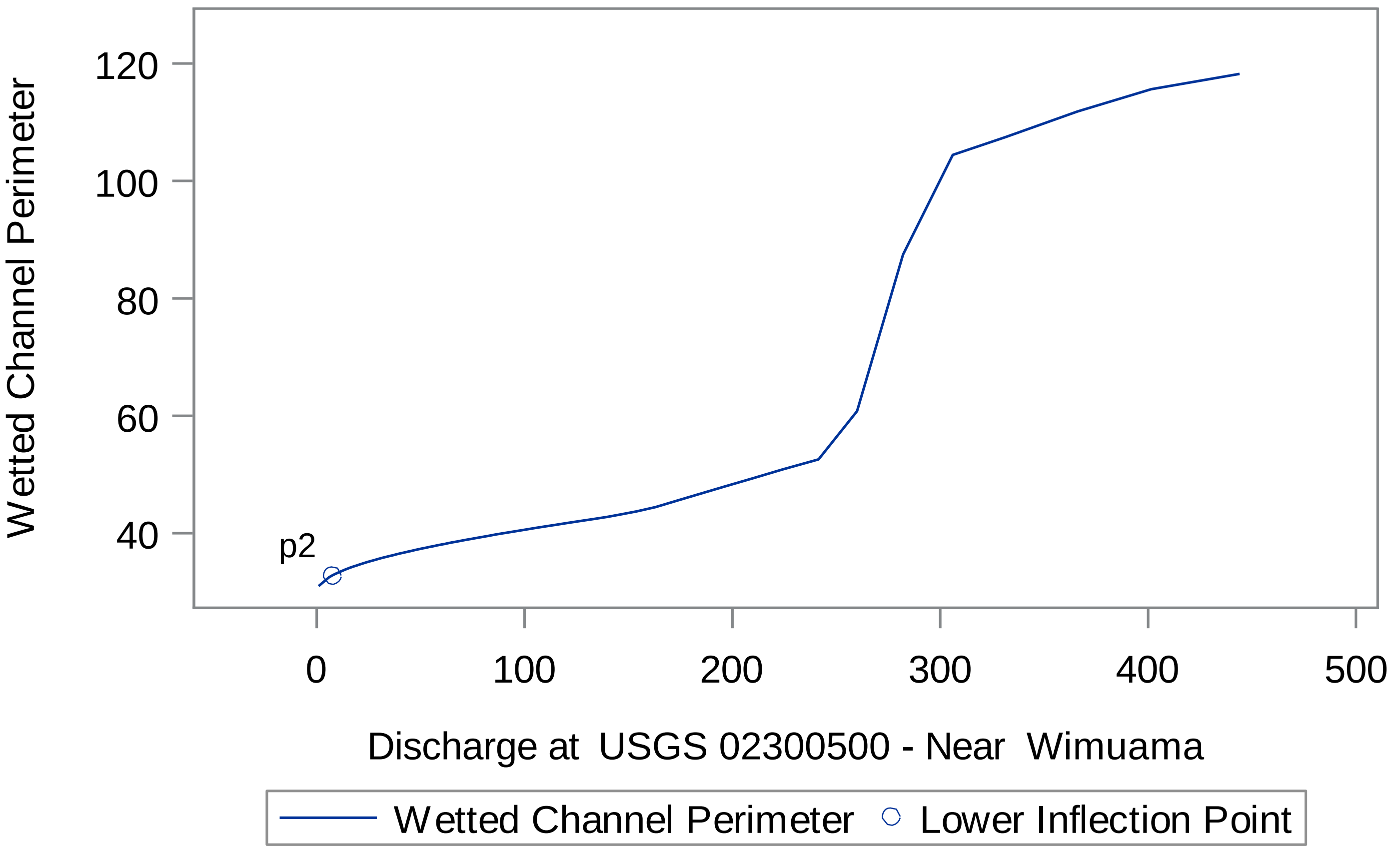
Flow Range 0 - 500 cfs
Reach=7 Cross Section #=31269.36
Wetted Channel Perimeter
100
80
60
40
p2
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

Flow Range 0 - 500 cfs
Reach=7 Cross Section #=32976.95

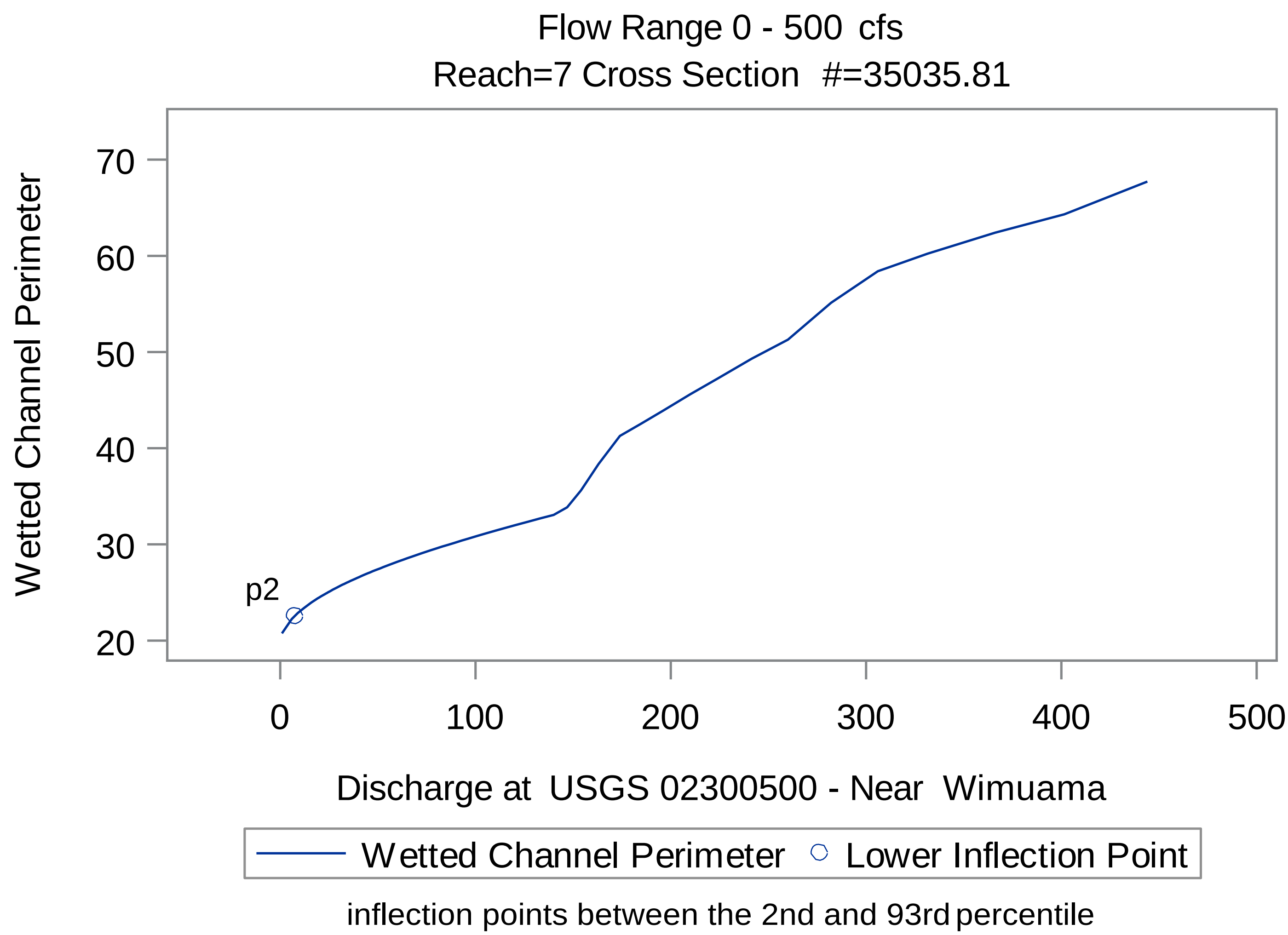


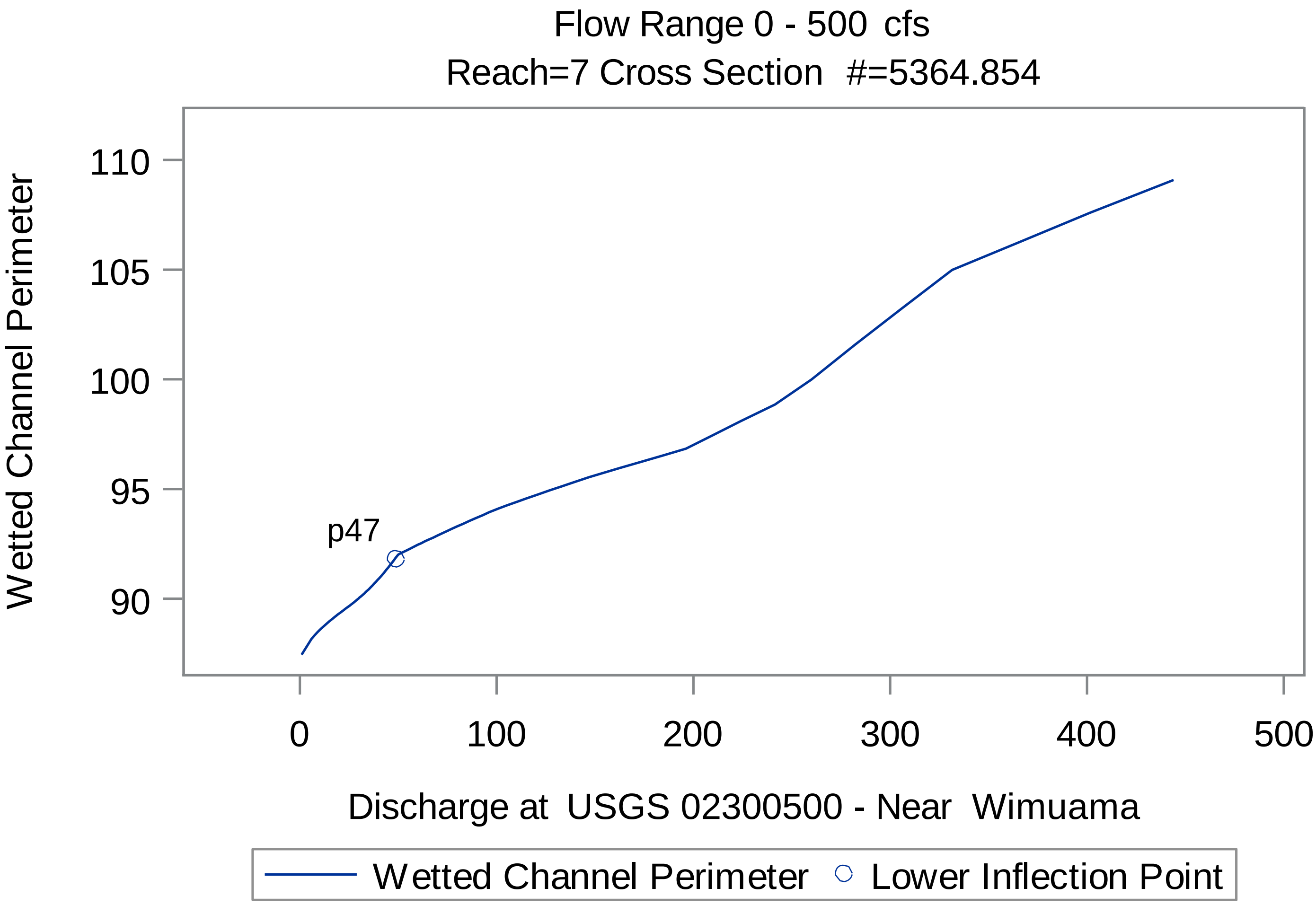

inflection points between the 2nd and 93rd percentile

Flow Range 0 - 500 cfs
Reach=7 Cross Section #=34123.74

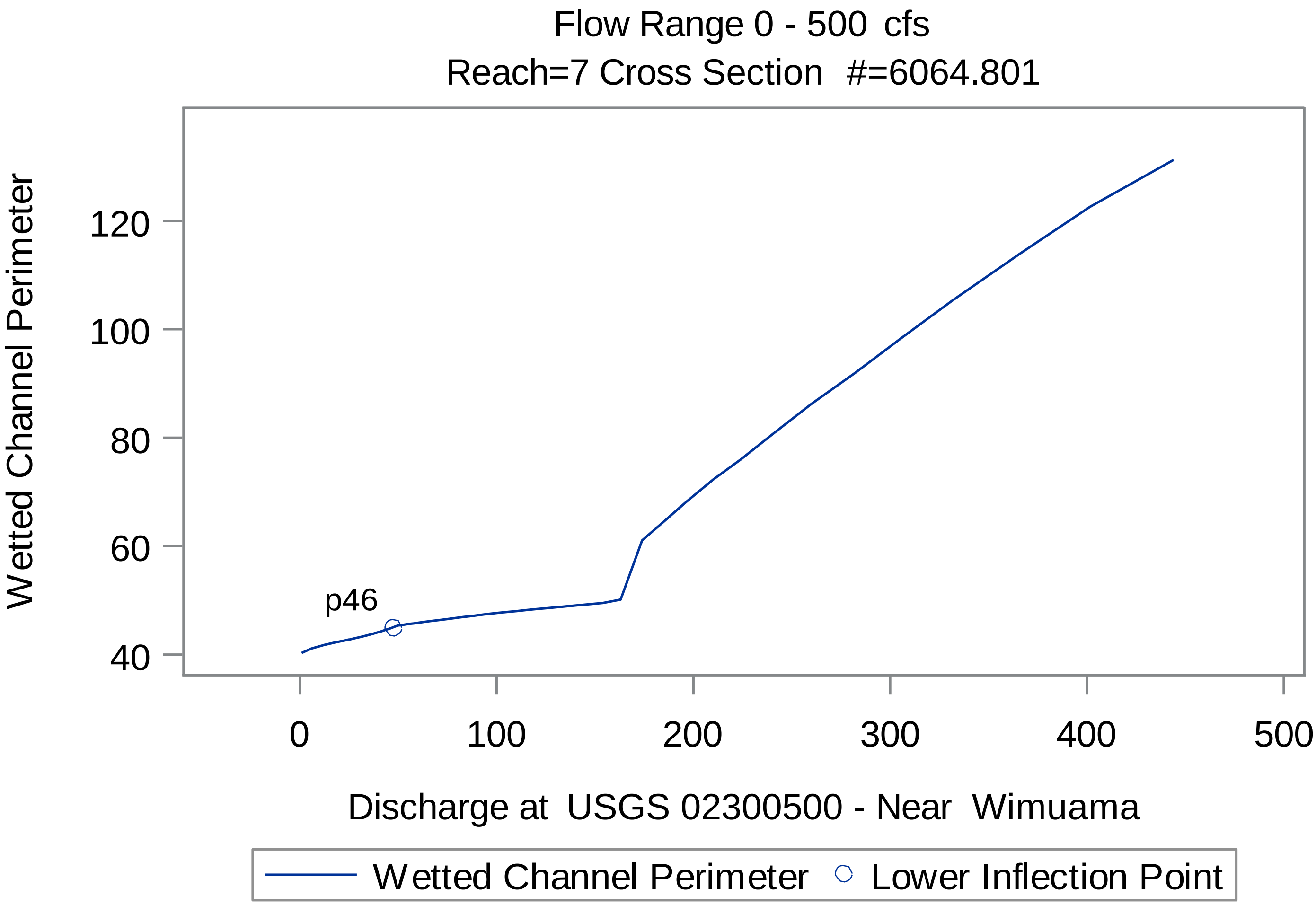



inflection points between the 2nd and 93rd percentile

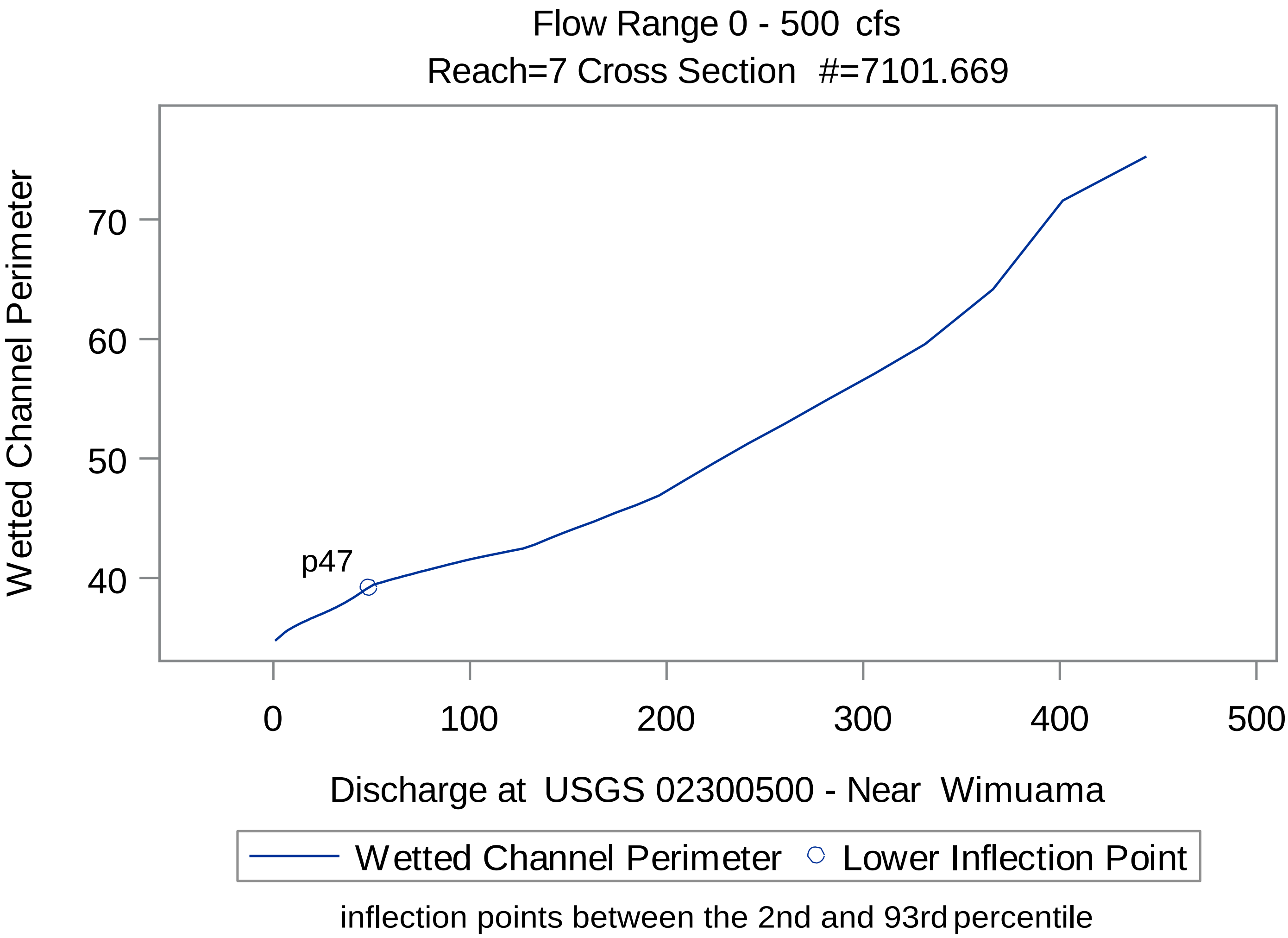

Flow Range 0 - 500 cfs
Reach=7 Cross Section #=35035.81
Wetted Channel Perimeter
70
60
50
40
30
20
p2
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile



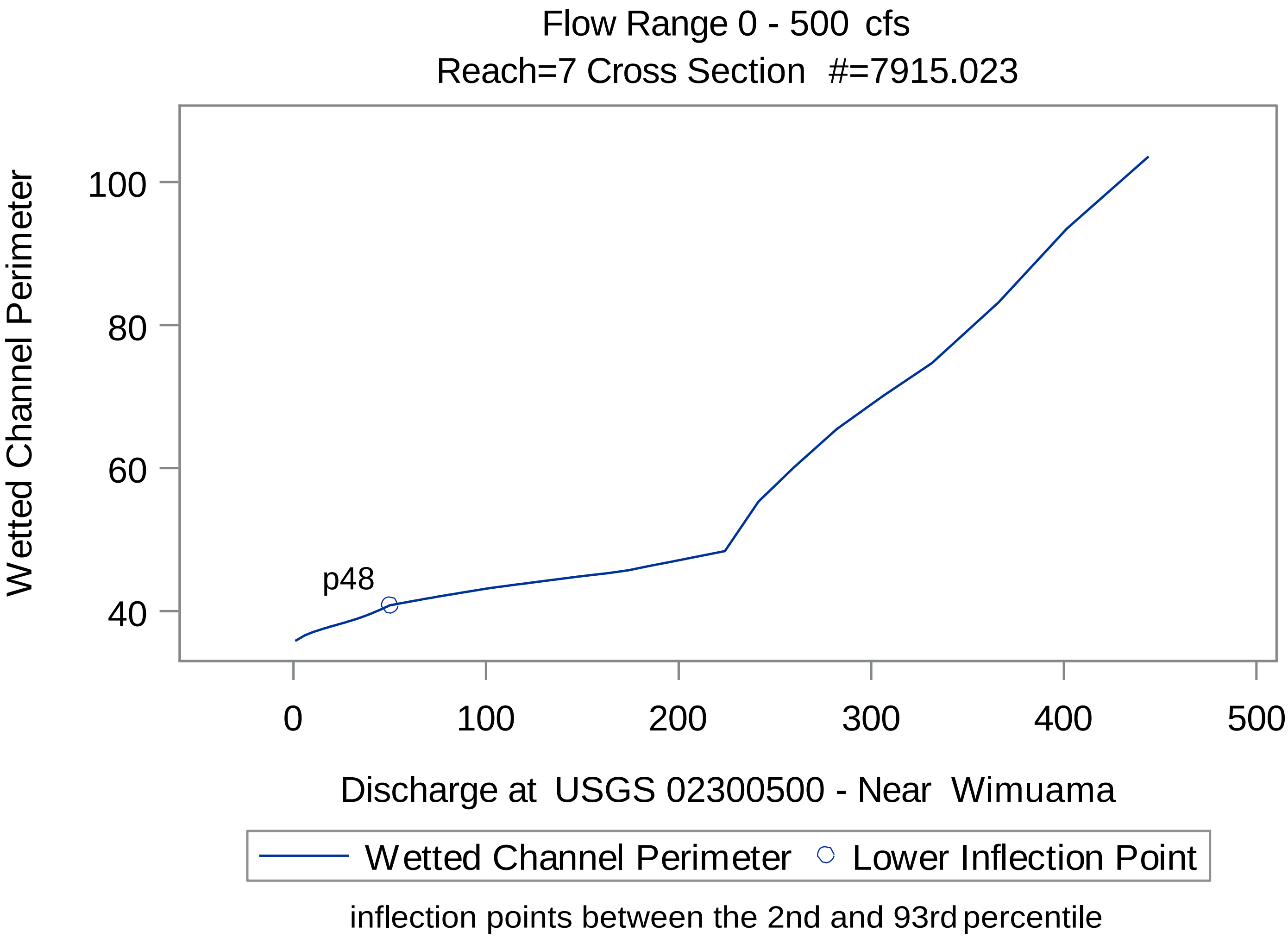

inflection points between the 2nd and 93rd percentile



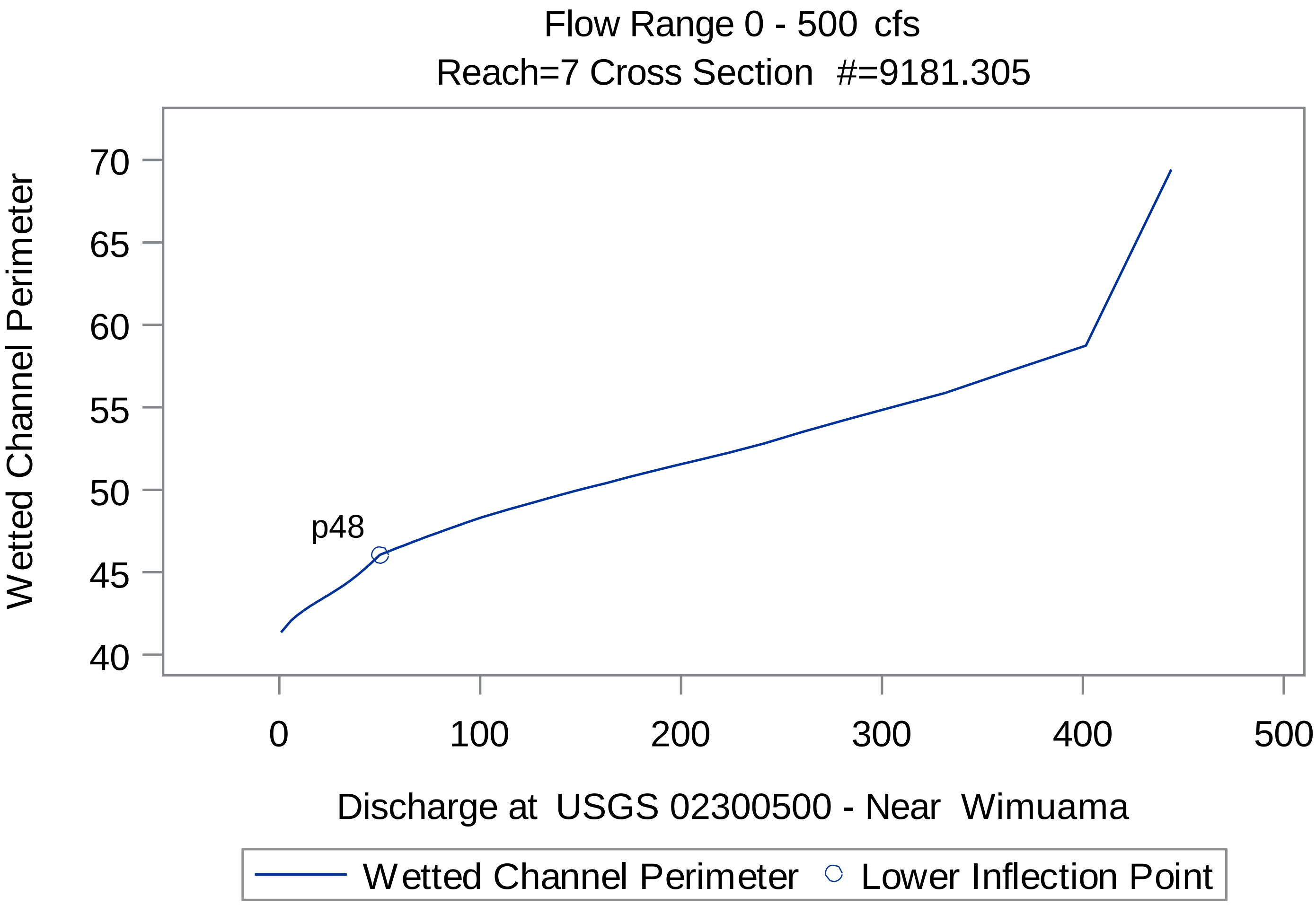

inflection points between the 2nd and 93rd percentile



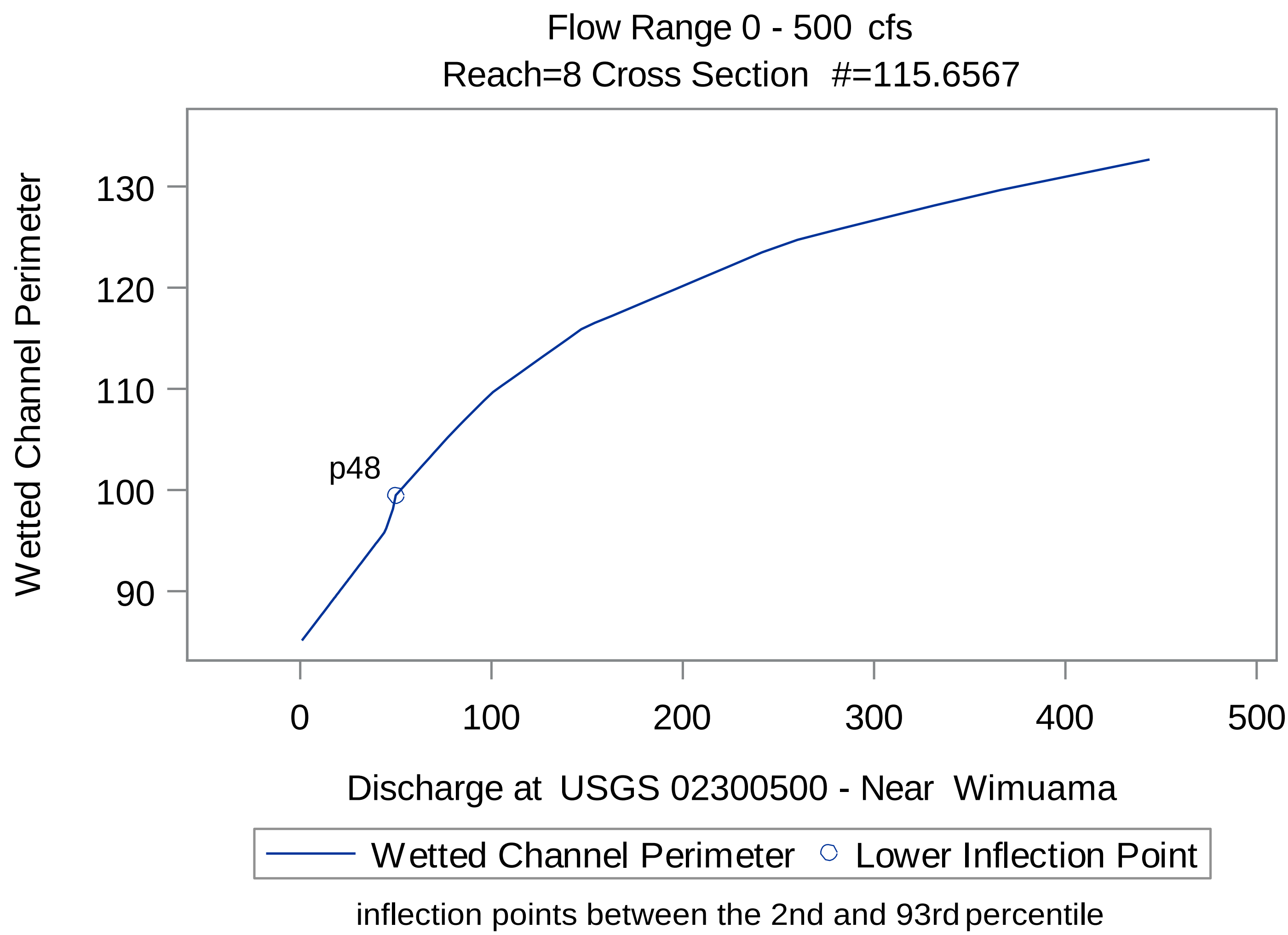
Flow Range 0 - 500 cfs
Reach=7 Cross Section #=7101.669
Wetted Channel Perimeter
70
60
50
40
p47
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

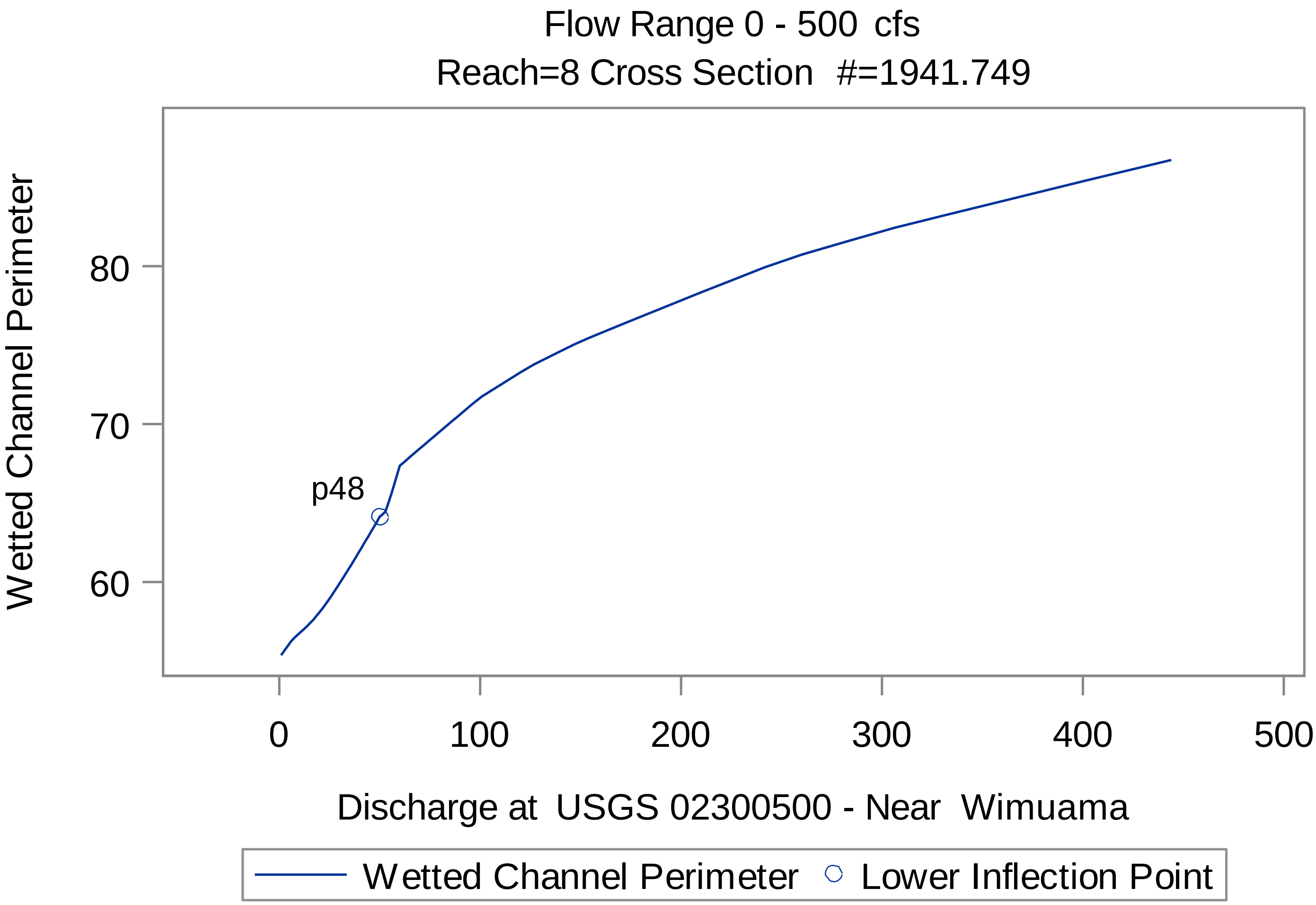


Flow Range 0 - 500 cfs
Reach=7 Cross Section #=7915.023
Wetted Channel Perimeter
100
80
60
40
p48
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile



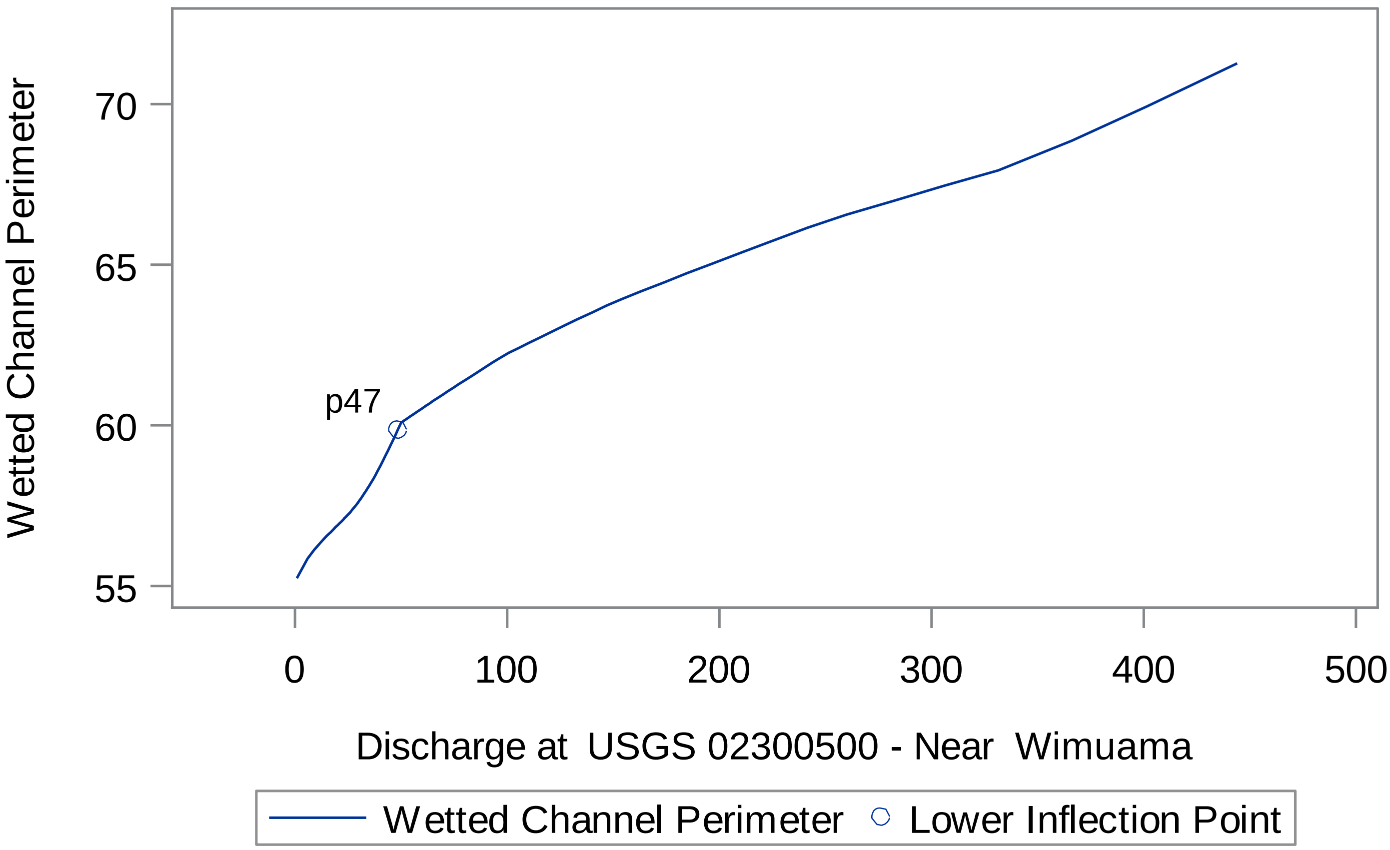

inflection points between the 2nd and 93rd percentile


Flow Range 0 - 500 cfs
Reach=8 Cross Section #=115.6567
Wetted Channel Perimeter
130
120
110
100
90
p48
0
100
200
300
400
500
Discharge at USGS 02300500 - Near Wimuama
Wetted Channel Perimeter
Lower Inflection Point
inflection points between the 2nd and 93rd percentile

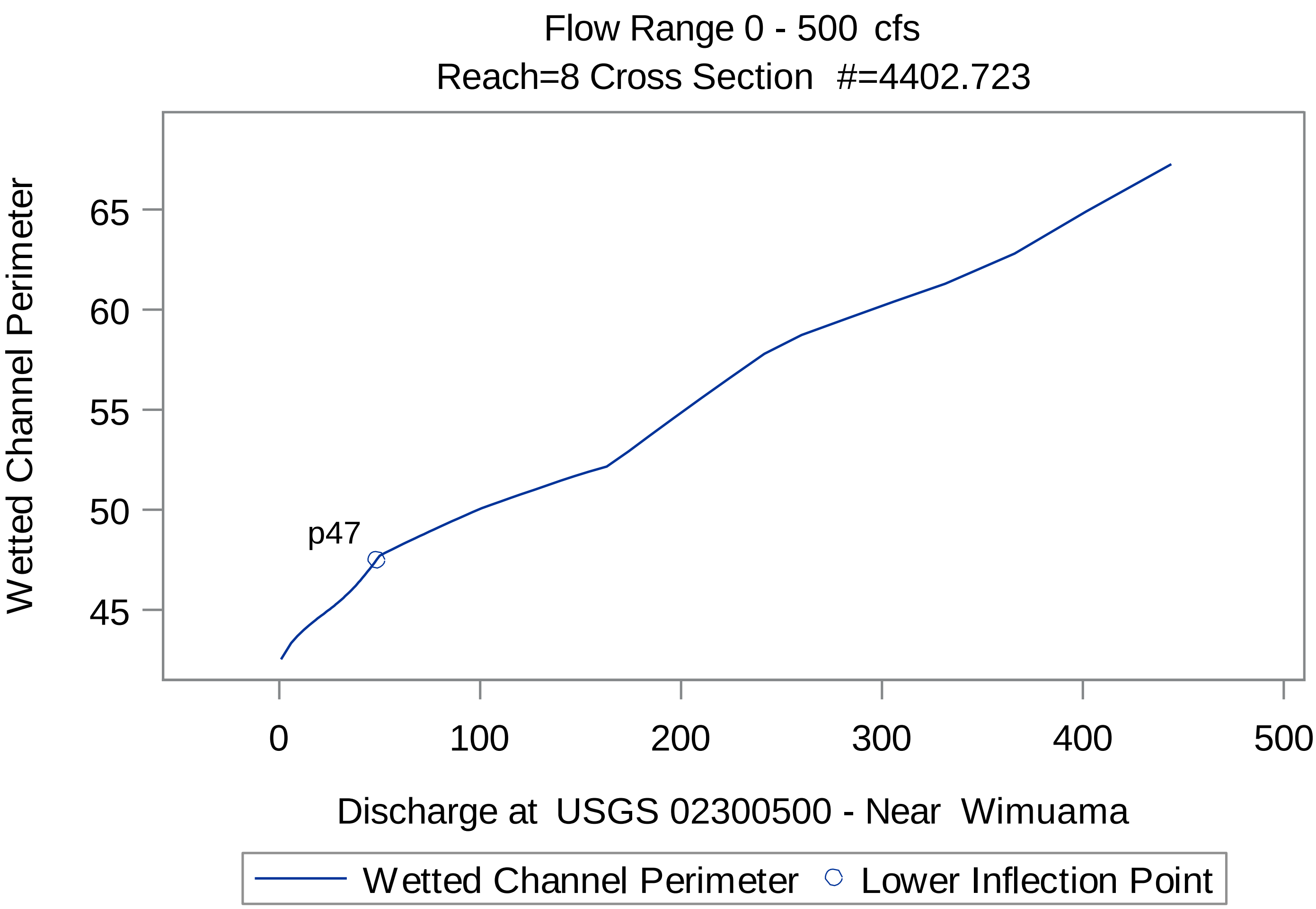



inflection points between the 2nd and 93rd percentile

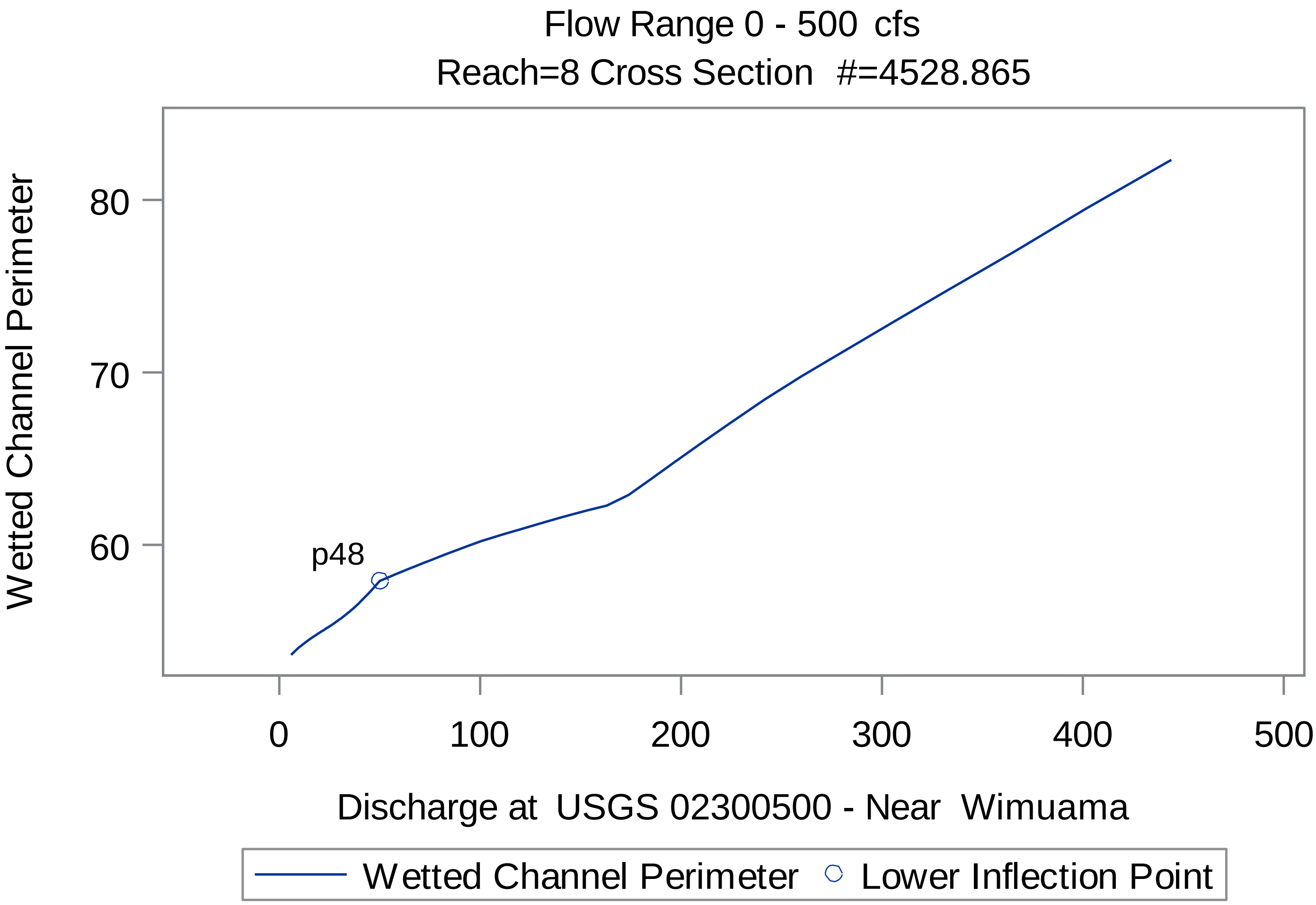
Flow Range 0 - 500 cfs
Reach=8 Cross Section #=3562.291



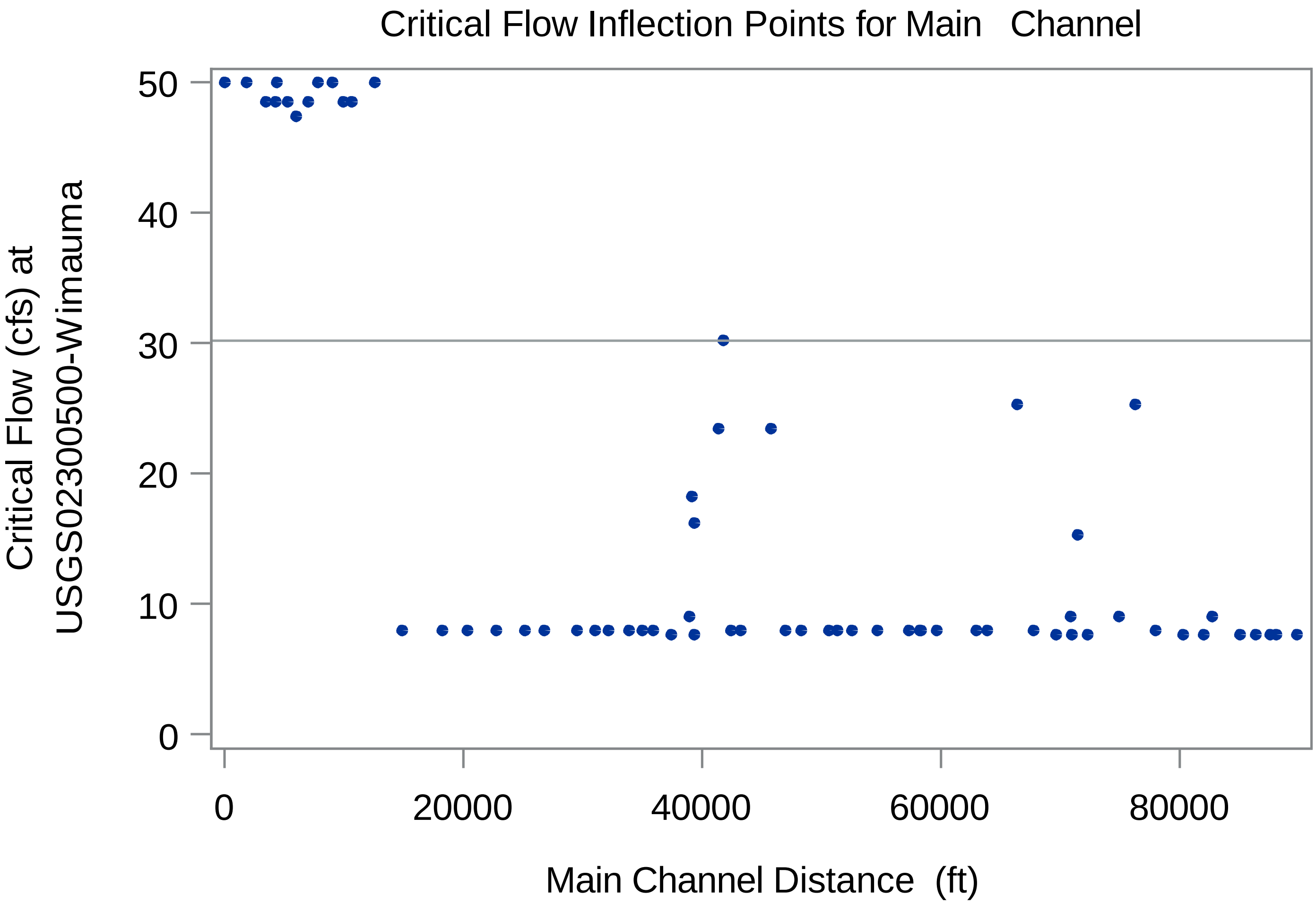

inflection points between the 2nd and 93rd percentile




inflection points between the 2nd and 93rd percentile



inflection points between the 2nd and 93rd percentile



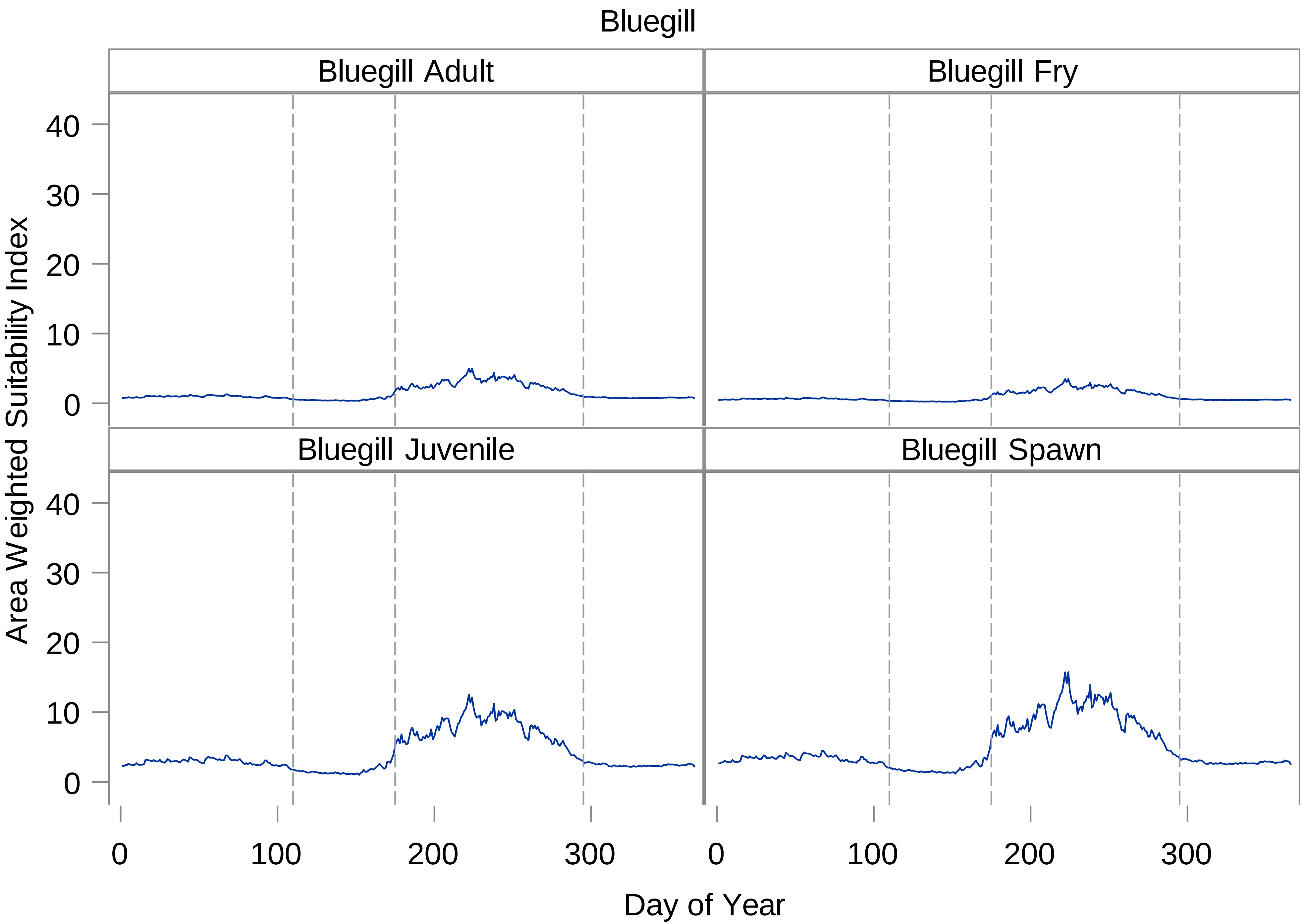
inflection points between the 2nd and 93rd percentile

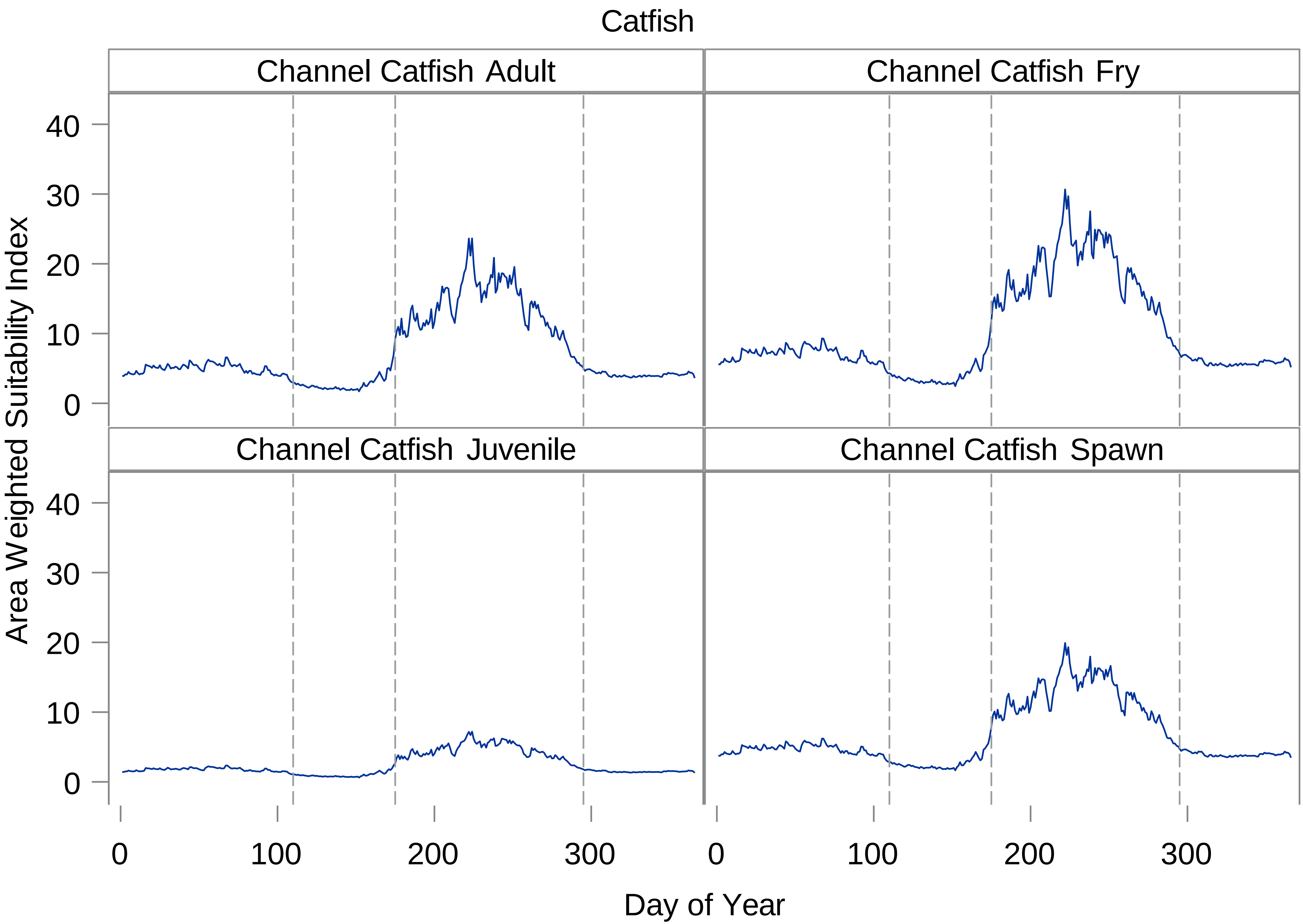
# APPENDIX C

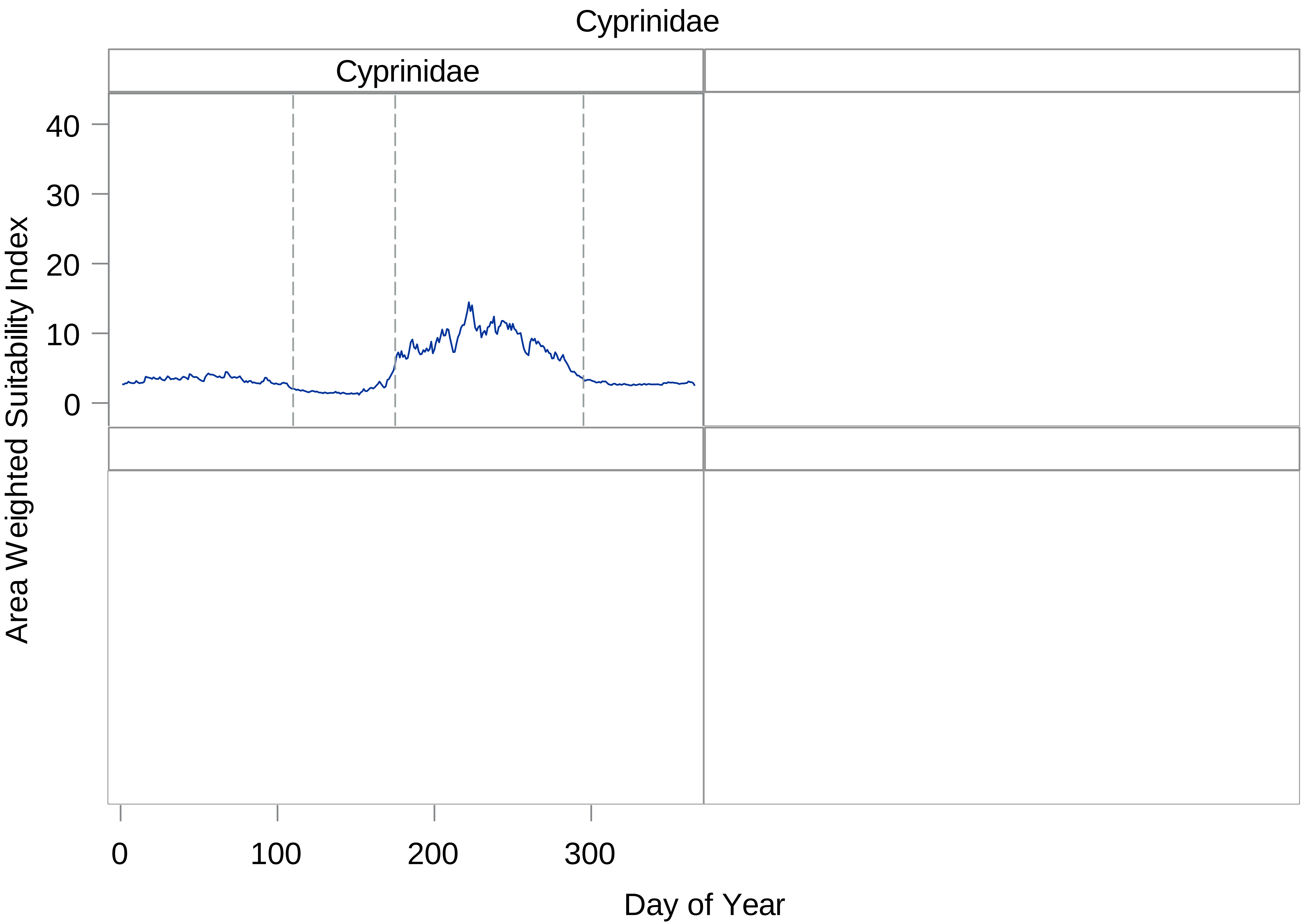
System for Environmental Flows Analysis

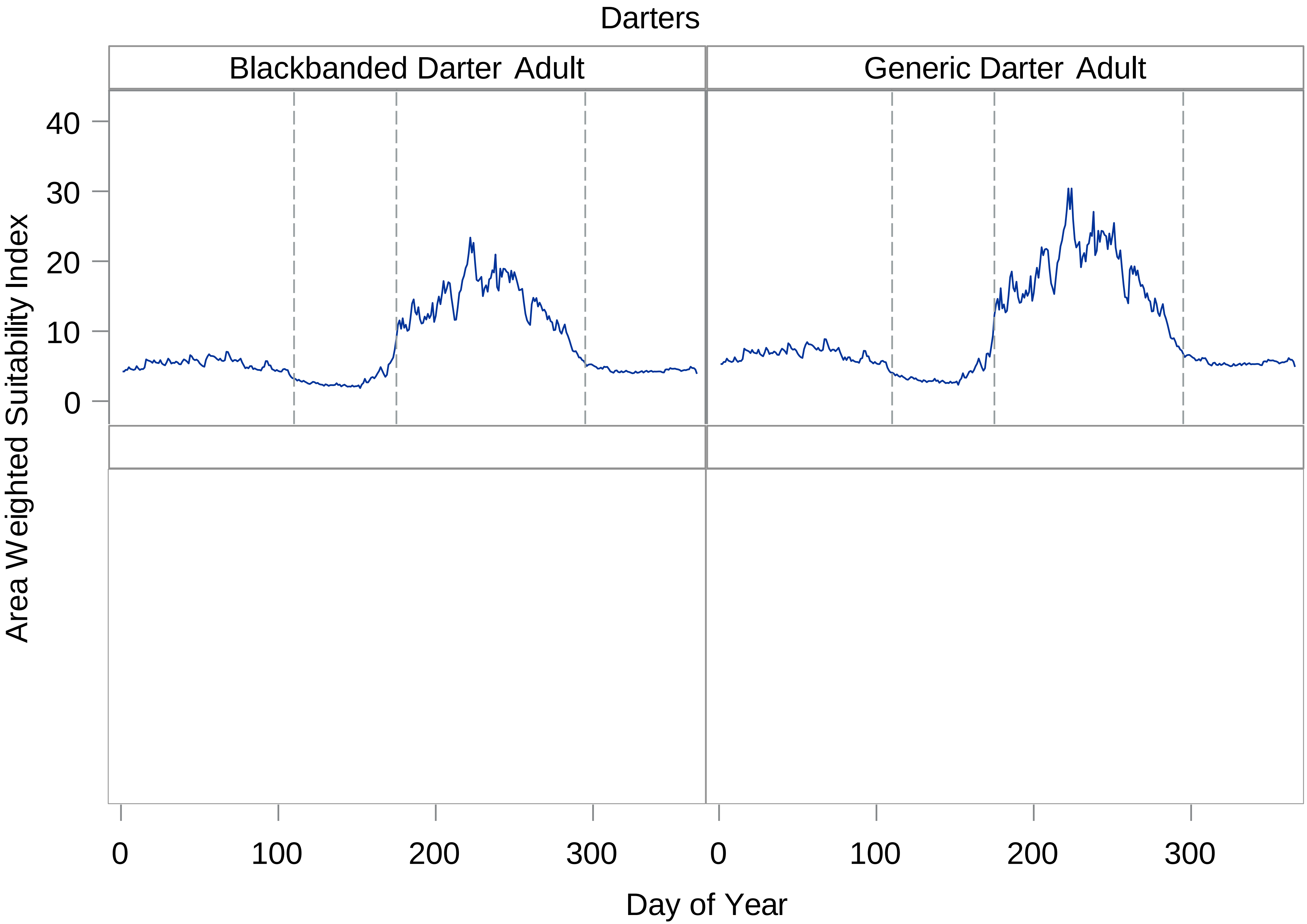
Results are sorted by benchmark period and descending percent change from baseline condition

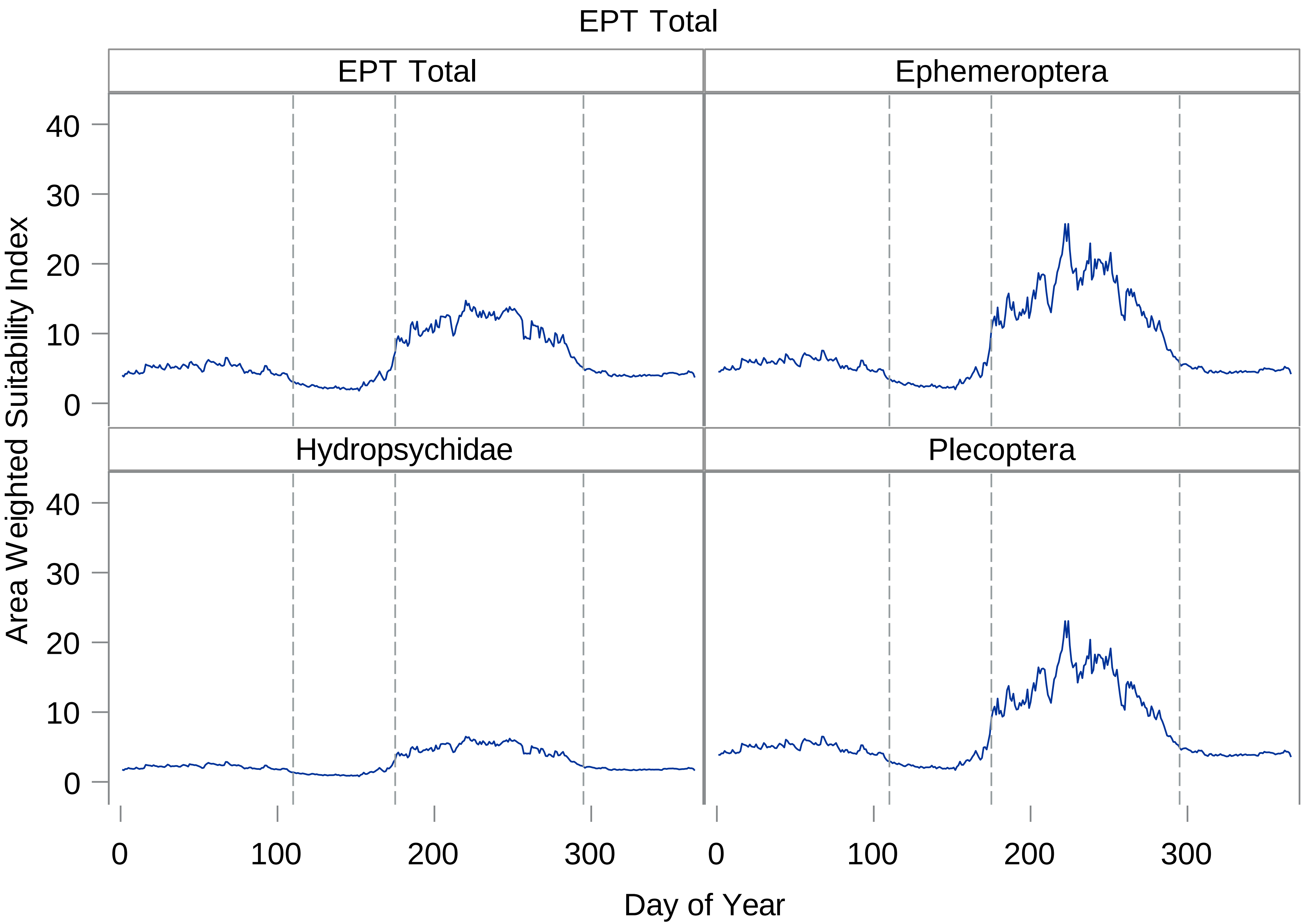
# Modeled Intra-Annual Variability in Habitat Suitability for Taxa Groups Used in SEFA Analysis

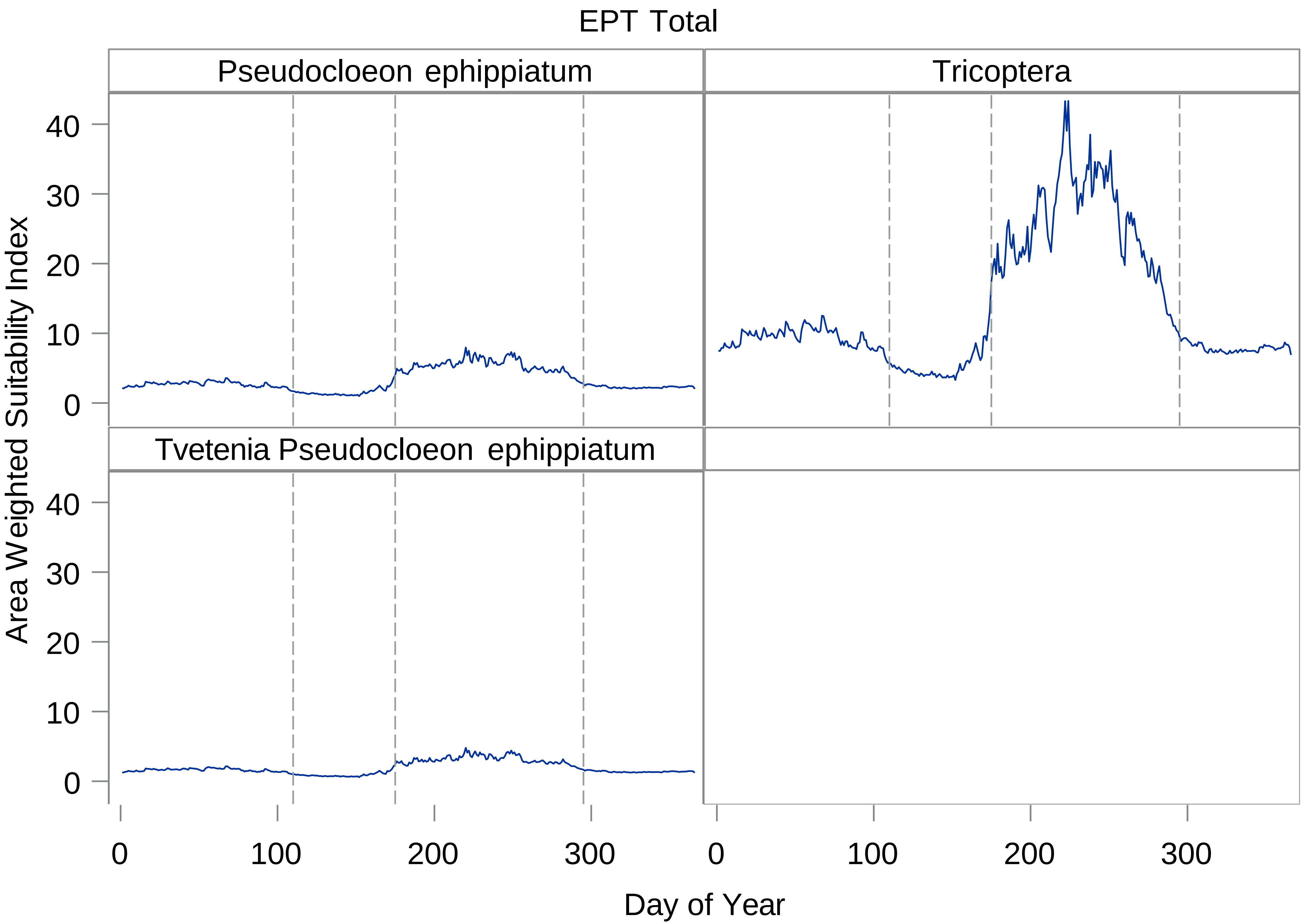

Bluegill
Bluegill Adult
Bluegill Fry
Bluegill Juvenile
Bluegill Spawn
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
Day of Year


Catfish
Channel Catfish Adult
Channel Catfish Fry
Channel Catfish Juvenile
Channel Catfish Spawn
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
Day of Year

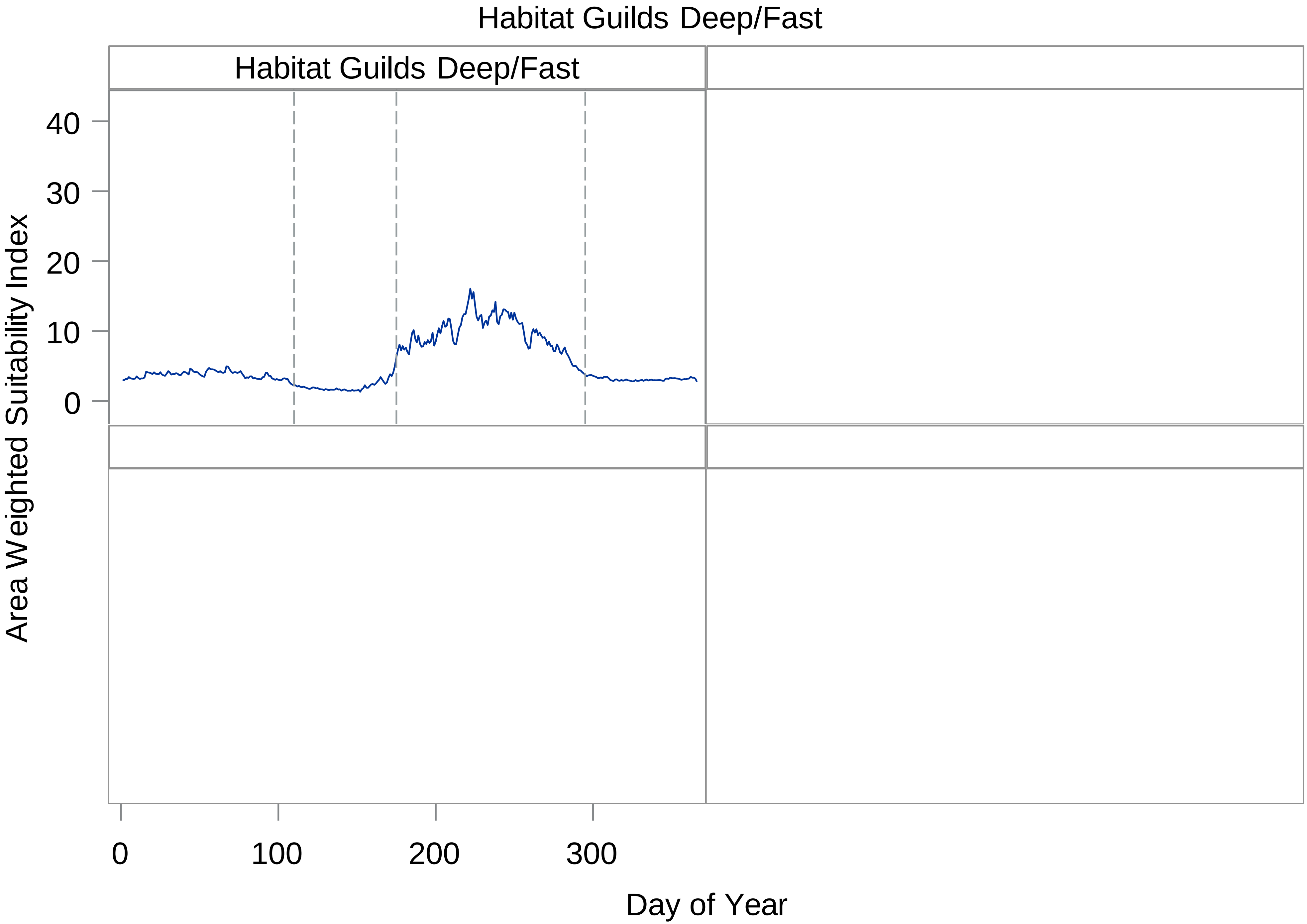

Cyprinidae
Cyprinidae
Area Weighted Suitability Index
40
30
20
10
0
0
100
200
300
Day of Year


Darters
Blackbanded Darter Adult
Generic Darter Adult
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
0
100
200
300
Day of Year

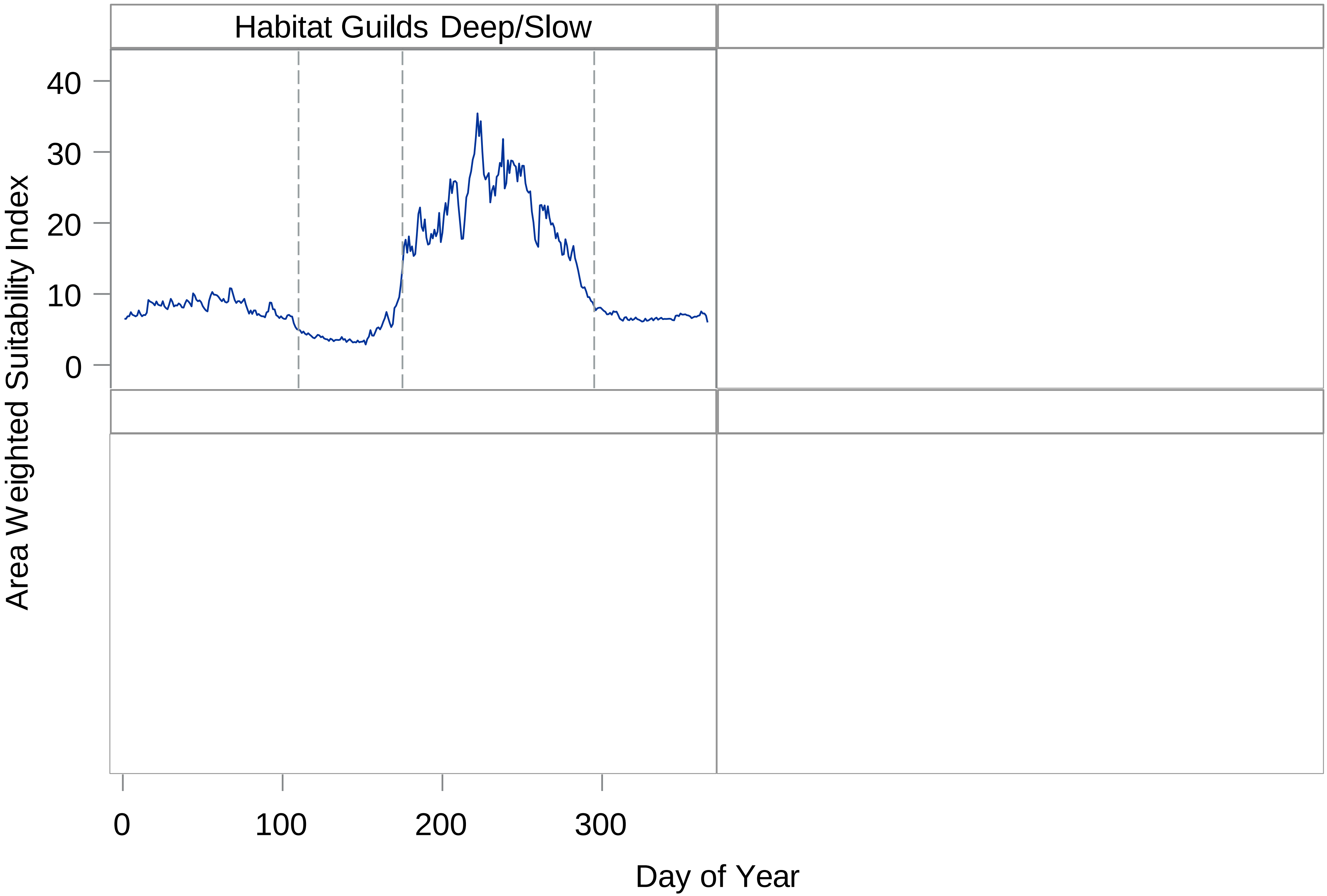

EPT Total
EPT Total
Ephemeroptera
Hydropsychidae
Plecoptera
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
Day of Year

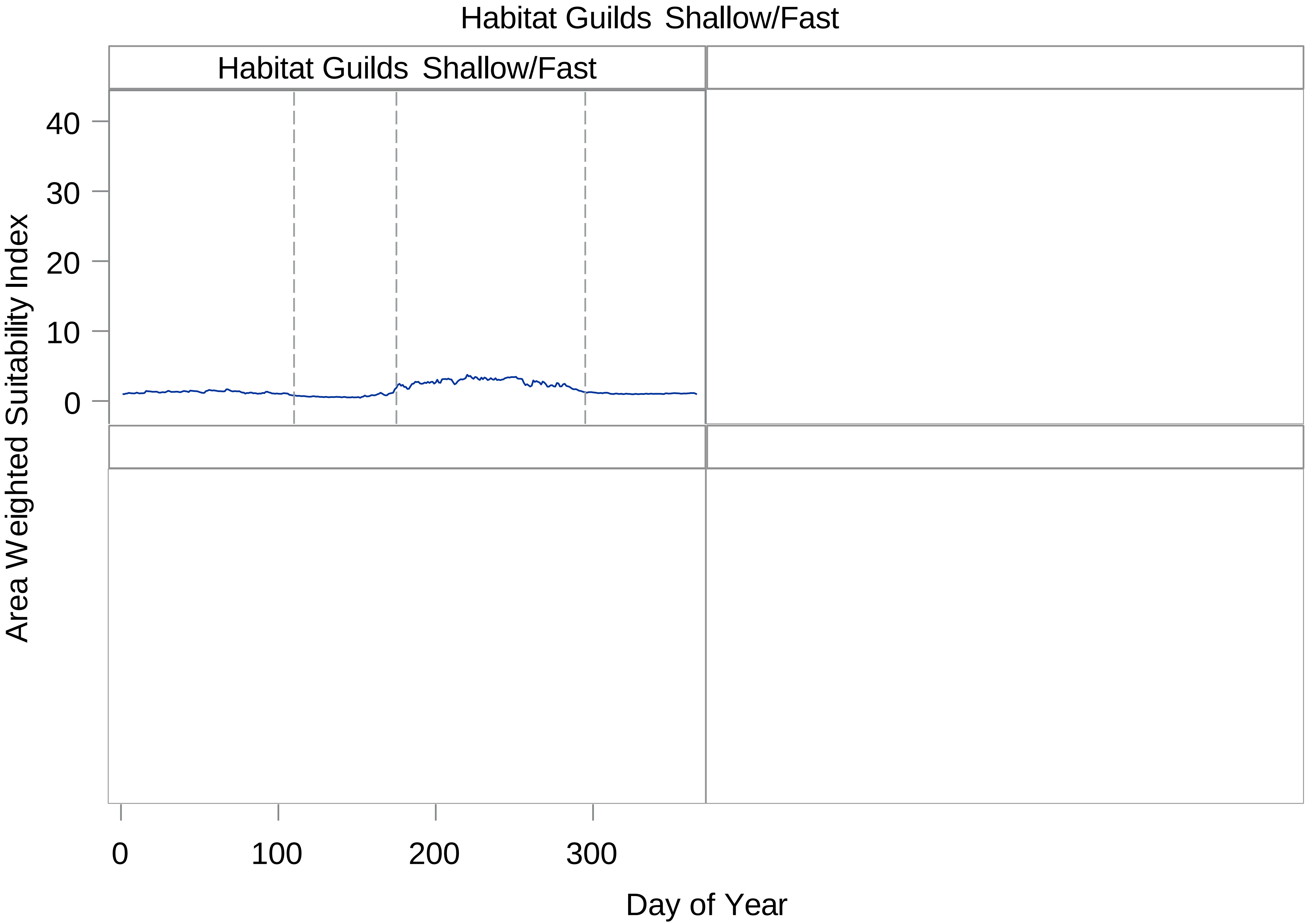


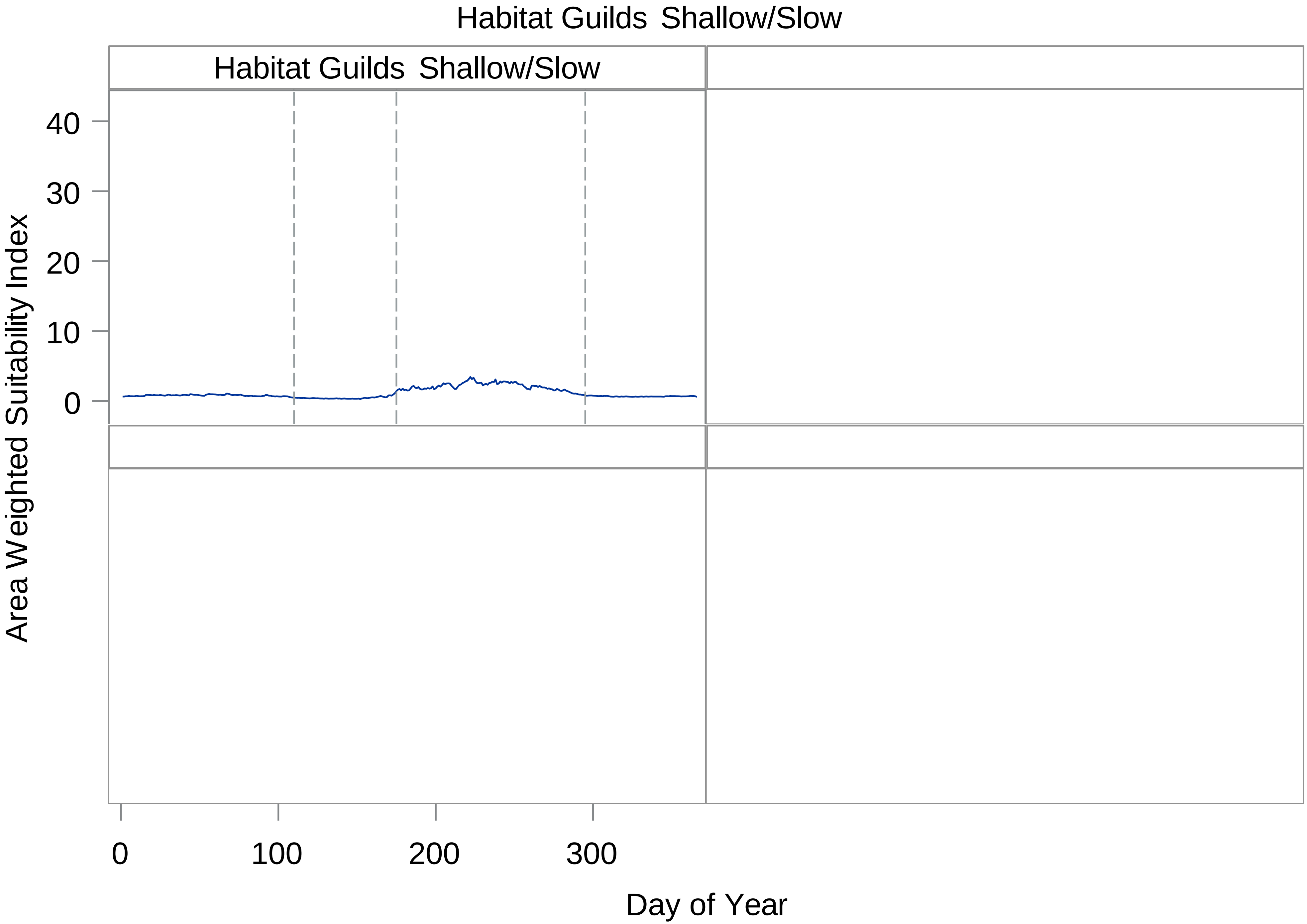
EPT Total
Pseudocloeon ephippiatum
Tricoptera
Tvetenia Pseudocloeon ephippiatum
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
Day of Year

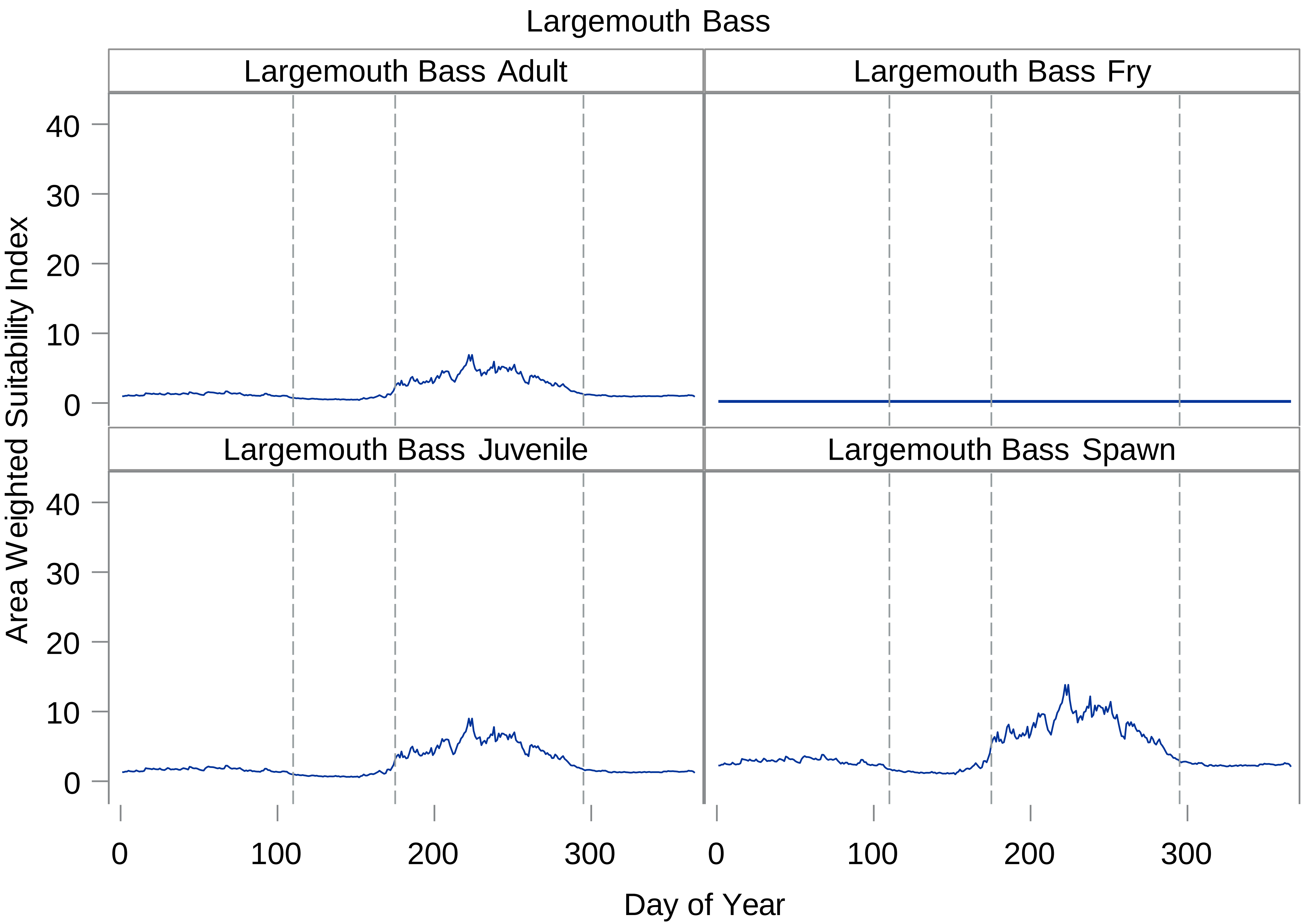

Habitat Guilds Deep/Fast
Habitat Guilds Deep/Fast
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
Day of Year

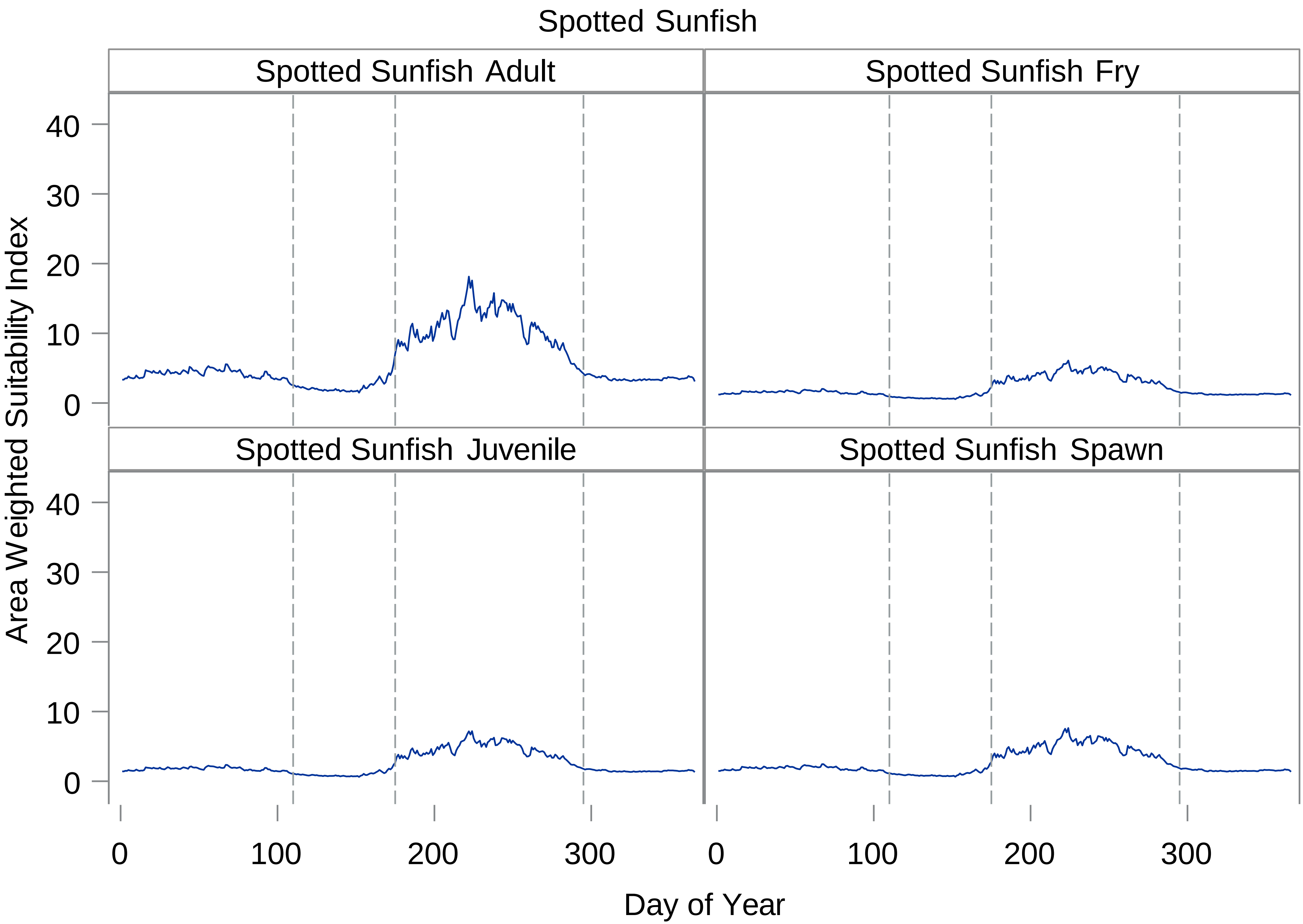
## Habitat Guilds Deep/Slow



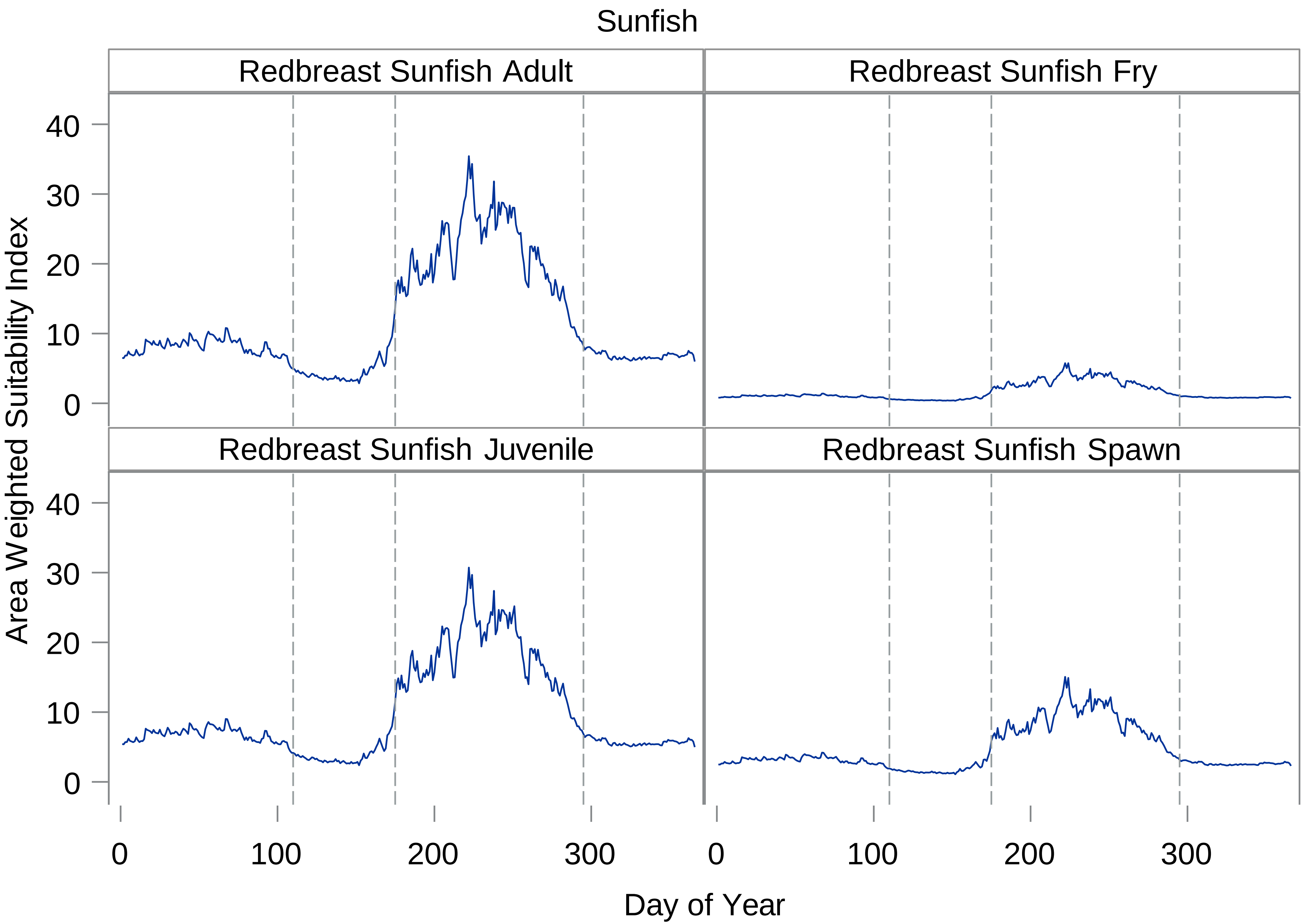

Habitat Guilds Shallow/Fast
Habitat Guilds Shallow/Fast
Area Weighted Suitability Index
40
30
20
10
0
0
100
200
300
Day of Year

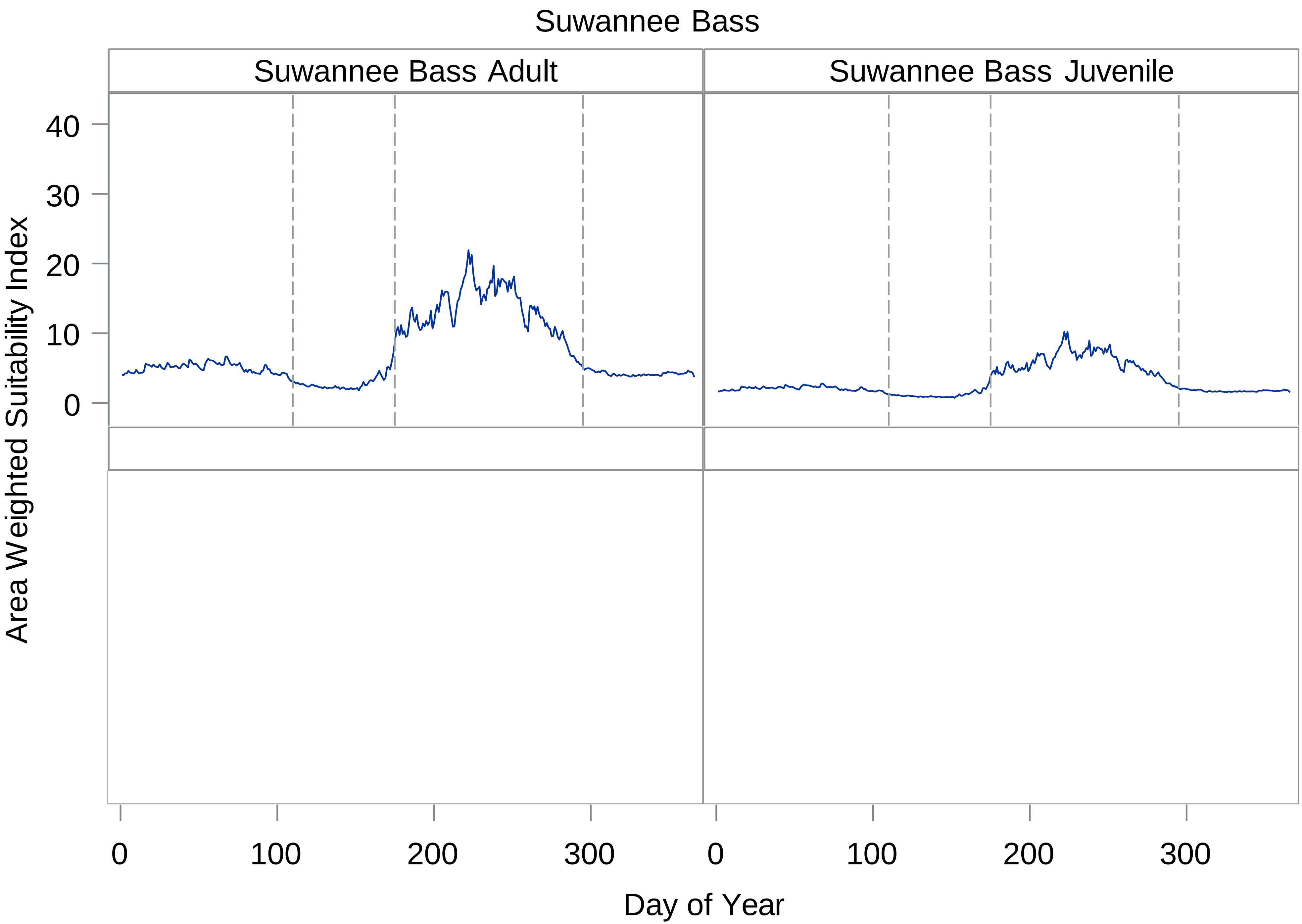

Habitat Guilds Shallow/Slow
Habitat Guilds Shallow/Slow
Area Weighted Suitability Index
40
30
20
10
0
0
100
200
300
Day of Year


Largemouth Bass
Largemouth Bass Adult
Largemouth Bass Fry
Largemouth Bass Juvenile
Largemouth Bass Spawn
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
Day of Year



Spotted Sunfish
Spotted Sunfish Adult
Spotted Sunfish Fry
Spotted Sunfish Juvenile
Spotted Sunfish Spawn
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
Day of Year


Sunfish
Redbreast Sunfish Adult
Redbreast Sunfish Fry
Redbreast Sunfish Juvenile
Redbreast Sunfish Spawn
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
Day of Year


Suwannee Bass
Suwannee Bass Adult
Suwannee Bass Juvenile
Area Weighted Suitability Index
0
10
20
30
40
0
100
200
300
0
100
200
300
Day of Year

# SEFA Results By Calendar Block

| Benchmark Period | Species Life History stage | Block | 10% Reduction | 20% Reduction | 30% Reduction | 40% Reduction |
|---|---|---|---|---|---|---|
| 1940 - 1976 | Largemouth Bass Fry | 1 | -11.32 | -22.55 | -33.54 | -44.03 |
| 1940 - 1976 | Bluegill Fry | 1 | -10.34 | -20.29 | -30.51 | -40.84 |
| 1940 - 1976 | Largemouth Bass Adult | 1 | -10.22 | -20.37 | -30.58 | -40.82 |
| 1940 - 1976 | Redbreast Sunfish Fry | 1 | -9.42 | -18.80 | -28.60 | -38.86 |
| 1940 - 1976 | Bluegill Adult | 1 | -9.26 | -18.44 | -27.71 | -37.48 |
| 1940 - 1976 | Largemouth Bass Juvenile | 1 | -9.02 | -18.11 | -27.60 | -37.27 |
| 1940 - 1976 | Channel Catfish Adult | 1 | -8.81 | -17.84 | -27.04 | -36.46 |
| 1940 - 1976 | Largemouth Bass Spawn | 1 | -8.70 | -17.59 | -26.72 | -36.11 |
| 1940 - 1976 | Suwannee Bass Juvenile | 1 | -8.47 | -17.03 | -25.95 | -35.23 |
| 1940 - 1976 | Plecoptera | 1 | -8.42 | -17.04 | -25.96 | -35.18 |
| 1940 - 1976 | Redbreast Sunfish Spawn | 1 | -8.28 | -16.66 | -25.40 | -34.58 |
| 1940 - 1976 | Tricoptera | 1 | -8.25 | -16.76 | -25.56 | -34.69 |
| 1940 - 1976 | Generic Darter Adult | 1 | -8.18 | -16.60 | -25.32 | -34.37 |
| 1940 - 1976 | Bluegill Spawn | 1 | -8.18 | -16.46 | -25.09 | -34.15 |
| 1940 - 1976 | Ephemeroptera | 1 | -8.03 | -16.28 | -24.87 | -33.82 |
| 1940 - 1976 | Redbreast Sunfish Juvenile | 1 | -7.86 | -15.92 | -24.39 | -33.38 |
| 1940 - 1976 | Bluegill Juvenile | 1 | -7.72 | -15.55 | -23.77 | -32.44 |
| 1940 - 1976 | Blackbanded Darter Adult | 1 | -7.62 | -15.47 | -23.72 | -32.46 |
| 1940 - 1976 | Channel Catfish Fry | 1 | -7.62 | -15.48 | -23.75 | -32.51 |
| 1940 - 1976 | Suwannee Bass Adult | 1 | -7.57 | -15.47 | -23.80 | -32.56 |
| 1940 - 1976 | Habitat Guilds Deep/Slow | 1 | -7.56 | -15.40 | -23.65 | -32.39 |
| 1940 - 1976 | Redbreast Sunfish Adult | 1 | -7.56 | -15.40 | -23.65 | -32.39 |
| 1940 - 1976 | Habitat Guilds Shallow/Slow | 1 | -7.54 | -15.37 | -23.64 | -32.38 |
| 1940 - 1976 | Cyprinidae | 1 | -7.49 | -15.17 | -23.27 | -31.85 |
| 1940 - 1976 | Spotted Sunfish Spawn | 1 | -7.46 | -15.07 | -23.04 | -31.51 |
| 1940 - 1976 | Channel Catfish Juvenile | 1 | -7.42 | -15.03 | -23.01 | -31.48 |
| 1940 - 1976 | Spotted Sunfish Juvenile | 1 | -7.42 | -15.03 | -23.01 | -31.48 |
| 1940 - 1976 | Spotted Sunfish Adult | 1 | -7.41 | -15.13 | -23.32 | -31.94 |
| 1940 - 1976 | Channel Catfish Spawn | 1 | -7.39 | -15.11 | -23.24 | -31.90 |
| 1940 - 1976 | Spotted Sunfish Fry | 1 | -7.33 | -14.78 | -22.59 | -30.94 |
| 1940 - 1976 | Habitat Guilds Deep/Fast | 1 | -7.26 | -14.94 | -23.11 | -31.72 |
| 1940 - 1976 | EPT Total | 1 | -6.53 | -13.49 | -20.88 | -28.87 |
| 1940 - 1976 | Habitat Guilds Shallow/Fast | 1 | -6.51 | -13.37 | -20.61 | -28.50 |
| 1940 - 1976 | Hydropsychidae | 1 | -6.47 | -13.42 | -20.84 | -28.86 |
| 1940 - 1976 | Pseudocloeon ephippiatum | 1 | -6.29 | -13.11 | -20.36 | -28.25 |
| 1940 - 1976 | Tvetenia Pseudocloeon ephippiatum | 1 | -6.23 | -12.99 | -20.19 | -28.04 |
| 1977 - 2014 | Largemouth Bass Fry | 1 | -11.40 | -22.49 | -33.20 | -44.13 |
| 1977 - 2014 | Largemouth Bass Adult | 1 | -10.24 | -20.57 | -30.99 | -41.40 |
| 1977 - 2014 | Bluegill Fry | 1 | -10.03 | -20.27 | -30.62 | -41.20 |
| 1977 - 2014 | Redbreast Sunfish Fry | 1 | -9.49 | -19.38 | -29.53 | -39.60 |
| 1977 - 2014 | Bluegill Adult | 1 | -9.32 | -18.74 | -28.36 | -38.24 |
| 1977 - 2014 | Channel Catfish Adult | 1 | -8.91 | -17.95 | -27.21 | -36.75 |
| 1977 - 2014 | Largemouth Bass Juvenile | 1 | -8.82 | -18.10 | -27.77 | -37.73 |

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|---|---|---|---|---|---|---|
| 1977 - 2014 | Largemouth Bass Spawn | 1 | -8.69 | -17.62 | -26.80 | -36.34 |
| 1977 - 2014 | Plecoptera | 1 | -8.38 | -17.05 | -26.07 | -35.45 |
| 1977 - 2014 | Tricoptera | 1 | -8.26 | -16.81 | -25.67 | -34.90 |
| 1977 - 2014 | Suwannee Bass Juvenile | 1 | -8.26 | -16.92 | -25.93 | -35.45 |
| 1977 - 2014 | Generic Darter Adult | 1 | -8.16 | -16.60 | -25.38 | -34.55 |
| 1977 - 2014 | Redbreast Sunfish Spawn | 1 | -8.09 | -16.58 | -25.49 | -34.88 |
| 1977 - 2014 | Bluegill Spawn | 1 | -7.96 | -16.31 | -25.10 | -34.40 |
| 1977 - 2014 | Ephemeroptera | 1 | -7.94 | -16.21 | -24.87 | -33.97 |
| 1977 - 2014 | Redbreast Sunfish Juvenile | 1 | -7.79 | -15.98 | -24.55 | -33.61 |
| 1977 - 2014 | Suwannee Bass Adult | 1 | -7.56 | -15.51 | -23.86 | -32.70 |
| 1977 - 2014 | Channel Catfish Fry | 1 | -7.51 | -15.43 | -23.77 | -32.63 |
| 1977 - 2014 | Habitat Guilds Deep/Slow | 1 | -7.50 | -15.39 | -23.71 | -32.54 |
| 1977 - 2014 | Redbreast Sunfish Adult | 1 | -7.50 | -15.39 | -23.71 | -32.54 |
| 1977 - 2014 | Blackbanded Darter Adult | 1 | -7.46 | -15.35 | -23.71 | -32.59 |
| 1977 - 2014 | Habitat Guilds Shallow/Slow | 1 | -7.45 | -15.31 | -23.52 | -32.34 |
| 1977 - 2014 | Bluegill Juvenile | 1 | -7.42 | -15.24 | -23.43 | -32.36 |
| 1977 - 2014 | Channel Catfish Spawn | 1 | -7.41 | -15.19 | -23.37 | -32.04 |
| 1977 - 2014 | Spotted Sunfish Adult | 1 | -7.28 | -15.02 | -23.27 | -32.02 |
| 1977 - 2014 | Cyprinidae | 1 | -7.26 | -14.95 | -23.07 | -31.85 |
| 1977 - 2014 | Habitat Guilds Deep/Fast | 1 | -7.21 | -14.93 | -23.15 | -31.81 |
| 1977 - 2014 | Spotted Sunfish Spawn | 1 | -7.12 | -14.70 | -22.80 | -31.56 |
| 1977 - 2014 | Channel Catfish Juvenile | 1 | -7.11 | -14.69 | -22.78 | -31.53 |
| 1977 - 2014 | Spotted Sunfish Juvenile | 1 | -7.11 | -14.69 | -22.78 | -31.53 |
| 1977 - 2014 | Spotted Sunfish Fry | 1 | -6.96 | -14.36 | -22.27 | -30.92 |
| 1977 - 2014 | EPT Total | 1 | -6.41 | -13.24 | -20.59 | -28.55 |
| 1977 - 2014 | Hydropsychidae | 1 | -6.41 | -13.26 | -20.66 | -28.61 |
| 1977 - 2014 | Habitat Guilds Shallow/Fast | 1 | -6.28 | -13.00 | -20.34 | -28.33 |
| 1977 - 2014 | Pseudocloeon ephippiatum | 1 | -6.25 | -12.92 | -20.13 | -27.98 |
| 1977 - 2014 | Tvetenia Pseudocloeon ephippiatum | 1 | -6.19 | -12.80 | -19.96 | -27.78 |
| 1940 - 1976 | Largemouth Bass Fry | 2 | -12.28 | -13.39 | -14.51 | -15.63 |
| 1940 - 1976 | Largemouth Bass Adult | 2 | -10.62 | -11.60 | -12.57 | -13.54 |
| 1940 - 1976 | Bluegill Fry | 2 | -10.45 | -11.41 | -12.36 | -13.32 |
| 1940 - 1976 | Redbreast Sunfish Fry | 2 | -9.85 | -10.76 | -11.66 | -12.57 |
| 1940 - 1976 | Channel Catfish Adult | 2 | -9.77 | -10.67 | -11.58 | -12.49 |
| 1940 - 1976 | Bluegill Adult | 2 | -9.60 | -10.51 | -11.41 | -12.31 |
| 1940 - 1976 | Largemouth Bass Spawn | 2 | -9.48 | -10.37 | -11.25 | -12.14 |
| 1940 - 1976 | Largemouth Bass Juvenile | 2 | -9.46 | -10.33 | -11.21 | -12.08 |
| 1940 - 1976 | Plecoptera | 2 | -9.22 | -10.08 | -10.94 | -11.80 |
| 1940 - 1976 | Tricoptera | 2 | -9.10 | -9.95 | -10.80 | -11.65 |
| 1940 - 1976 | Generic Darter Adult | 2 | -8.98 | -9.82 | -10.67 | -11.51 |
| 1940 - 1976 | Suwannee Bass Juvenile | 2 | -8.94 | -9.78 | -10.62 | -11.46 |
| 1940 - 1976 | Ephemeroptera | 2 | -8.78 | -9.61 | -10.43 | -11.26 |
| 1940 - 1976 | Redbreast Sunfish Spawn | 2 | -8.78 | -9.61 | -10.44 | -11.26 |
| 1940 - 1976 | Bluegill Spawn | 2 | -8.69 | -9.50 | -10.32 | -11.14 |
| 1940 - 1976 | Redbreast Sunfish Juvenile | 2 | -8.51 | -9.32 | -10.12 | -10.93 |
| 1940 - 1976 | Suwannee Bass Adult | 2 | -8.36 | -9.16 | -9.95 | -10.74 |

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|---|---|---|---|---|---|---|
| 1940 - 1976 | Habitat Guilds Deep/Slow | 2 | -8.29 | -9.07 | -9.86 | -10.65 |
| 1940 - 1976 | Redbreast Sunfish Adult | 2 | -8.29 | -9.07 | -9.86 | -10.65 |
| 1940 - 1976 | Channel Catfish Fry | 2 | -8.27 | -9.06 | -9.85 | -10.63 |
| 1940 - 1976 | Blackbanded Darter Adult | 2 | -8.25 | -9.03 | -9.82 | -10.60 |
| 1940 - 1976 | Habitat Guilds Shallow/Slow | 2 | -8.20 | -8.98 | -9.76 | -10.55 |
| 1940 - 1976 | Channel Catfish Spawn | 2 | -8.19 | -8.97 | -9.75 | -10.53 |
| 1940 - 1976 | Bluegill Juvenile | 2 | -8.18 | -8.97 | -9.75 | -10.54 |
| 1940 - 1976 | Spotted Sunfish Adult | 2 | -8.11 | -8.88 | -9.65 | -10.42 |
| 1940 - 1976 | Habitat Guilds Deep/Fast | 2 | -8.08 | -8.84 | -9.61 | -10.37 |
| 1940 - 1976 | Cyprinidae | 2 | -8.06 | -8.83 | -9.60 | -10.38 |
| 1940 - 1976 | Spotted Sunfish Spawn | 2 | -7.95 | -8.71 | -9.48 | -10.24 |
| 1940 - 1976 | Channel Catfish Juvenile | 2 | -7.95 | -8.71 | -9.47 | -10.24 |
| 1940 - 1976 | Spotted Sunfish Juvenile | 2 | -7.95 | -8.71 | -9.47 | -10.24 |
| 1940 - 1976 | Spotted Sunfish Fry | 2 | -7.81 | -8.56 | -9.32 | -10.07 |
| 1940 - 1976 | EPT Total | 2 | -7.32 | -8.03 | -8.73 | -9.44 |
| 1940 - 1976 | Hydropsychidae | 2 | -7.31 | -8.02 | -8.72 | -9.42 |
| 1940 - 1976 | Habitat Guilds Shallow/Fast | 2 | -7.24 | -7.94 | -8.63 | -9.33 |
| 1940 - 1976 | Pseudocloeon ephippiatum | 2 | -7.21 | -7.90 | -8.60 | -9.30 |
| 1940 - 1976 | Tvetenia Pseudocloeon ephippiatum | 2 | -7.18 | -7.87 | -8.57 | -9.26 |
| 1977 - 2014 | Largemouth Bass Fry | 2 | -12.16 | -13.25 | -14.34 | -15.42 |
| 1977 - 2014 | Largemouth Bass Adult | 2 | -10.79 | -11.78 | -12.76 | -13.75 |
| 1977 - 2014 | Bluegill Fry | 2 | -10.59 | -11.55 | -12.51 | -13.48 |
| 1977 - 2014 | Redbreast Sunfish Fry | 2 | -10.20 | -11.13 | -12.06 | -12.99 |
| 1977 - 2014 | Bluegill Adult | 2 | -10.05 | -10.98 | -11.90 | -12.83 |
| 1977 - 2014 | Channel Catfish Adult | 2 | -9.97 | -10.90 | -11.82 | -12.74 |
| 1977 - 2014 | Largemouth Bass Spawn | 2 | -9.75 | -10.65 | -11.55 | -12.45 |
| 1977 - 2014 | Largemouth Bass Juvenile | 2 | -9.73 | -10.64 | -11.54 | -12.44 |
| 1977 - 2014 | Plecoptera | 2 | -9.50 | -10.39 | -11.27 | -12.15 |
| 1977 - 2014 | Tricoptera | 2 | -9.40 | -10.28 | -11.15 | -12.03 |
| 1977 - 2014 | Generic Darter Adult | 2 | -9.31 | -10.18 | -11.04 | -11.91 |
| 1977 - 2014 | Suwannee Bass Juvenile | 2 | -9.31 | -10.17 | -11.04 | -11.90 |
| 1977 - 2014 | Redbreast Sunfish Spawn | 2 | -9.18 | -10.04 | -10.90 | -11.75 |
| 1977 - 2014 | Ephemeroptera | 2 | -9.14 | -9.99 | -10.85 | -11.70 |
| 1977 - 2014 | Bluegill Spawn | 2 | -9.09 | -9.94 | -10.78 | -11.63 |
| 1977 - 2014 | Redbreast Sunfish Juvenile | 2 | -8.96 | -9.80 | -10.64 | -11.48 |
| 1977 - 2014 | Suwannee Bass Adult | 2 | -8.81 | -9.64 | -10.46 | -11.29 |
| 1977 - 2014 | Habitat Guilds Deep/Slow | 2 | -8.75 | -9.58 | -10.40 | -11.22 |
| 1977 - 2014 | Redbreast Sunfish Adult | 2 | -8.75 | -9.58 | -10.40 | -11.22 |
| 1977 - 2014 | Channel Catfish Fry | 2 | -8.75 | -9.58 | -10.40 | -11.22 |
| 1977 - 2014 | Blackbanded Darter Adult | 2 | -8.73 | -9.55 | -10.37 | -11.19 |
| 1977 - 2014 | Channel Catfish Spawn | 2 | -8.70 | -9.52 | -10.33 | -11.15 |
| 1977 - 2014 | Habitat Guilds Shallow/Slow | 2 | -8.69 | -9.51 | -10.32 | -11.14 |
| 1977 - 2014 | Bluegill Juvenile | 2 | -8.66 | -9.47 | -10.29 | -11.10 |
| 1977 - 2014 | Spotted Sunfish Adult | 2 | -8.60 | -9.42 | -10.23 | -11.04 |
| 1977 - 2014 | Habitat Guilds Deep/Fast | 2 | -8.57 | -9.38 | -10.19 | -11.00 |
| 1977 - 2014 | Cyprinidae | 2 | -8.56 | -9.37 | -10.18 | -10.98 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1977 - 2014 | Spotted Sunfish Spawn | 2 | -8.47 | -9.28 | -10.08 | -10.88 |
| 1977 - 2014 | Channel Catfish Juvenile | 2 | -8.47 | -9.27 | -10.07 | -10.87 |
| 1977 - 2014 | Spotted Sunfish Juvenile | 2 | -8.47 | -9.27 | -10.07 | -10.87 |
| 1977 - 2014 | Spotted Sunfish Fry | 2 | -8.35 | -9.14 | -9.93 | -10.73 |
| 1977 - 2014 | EPT Total | 2 | -7.83 | -8.58 | -9.33 | -10.08 |
| 1977 - 2014 | Hydropsychidae | 2 | -7.82 | -8.57 | -9.32 | -10.07 |
| 1977 - 2014 | Habitat Guilds Shallow/Fast | 2 | -7.76 | -8.50 | -9.25 | -9.99 |
| 1977 - 2014 | Pseudocloeon ephippiatum | 2 | -7.75 | -8.50 | -9.24 | -9.99 |
| 1977 - 2014 | Tvetenia Pseudocloeon ephippiatum | 2 | -7.72 | -8.47 | -9.21 | -9.96 |