Appendix B

Evidence of Significant Hydrological Alteration in the Cahaba River Watershed

Evidence for Hydrologic Alteration in the Upper Cahaba River Watershed

In a letter to EPA Regional Water Division Directors, EPA's Director of the Office of Wetlands, Oceans, and Watersheds provided clarification concerning 2016 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions [1]. That letter encourages state programs to identify streams that have been impaired by hydrologic alteration and list those streams in the state's 305(B) Report. That letter included the following section:

> ***5. Clarification on the assessment and assignment of waters to Category 4C***
>
> *As the nation's waters face an increasing degree of stress from anthropogenic influences, and the effects of climate change and extreme weather events, it will become important to more fully understand the impacts and causes of all types of pollution on our nation's waters. While the focus of previous IR Guidance has predominantly been on the assessment and listing of impairments caused by pollutants and waters assigned to Category 5 (i.e., a State's CWA 303(d) list of impaired and threatened waters needing a TMDL), the assessment and categorization of impairments caused pollution [2] not caused by a pollutant have not been covered as extensively. However, the effects of such pollution can be significant, including the effects of hydrologic alteration [3] or habitat alteration. A 2010 study by the U.S. Geological Survey [4] found that anthropogenic hydrologic alteration is extensive in the U.S. and may be a primary cause of ecological impairment in river and stream ecosystems. Examples of such alteration include: water withdrawals, impoundments, or extreme high flows that scour out stream beds, destabilize stream banks and cause a loss of habitat. Climate change is expected to exacerbate these effects. Recognizing the interplay between pollutants and pollution, EPA encourages States to more fully monitor, assess, and report the impacts of all types of pollution, thereby improving the opportunities for increasing resilience and restoration of these waters. To assist States with this effort, EPA is clarifying previous guidance about the assessment and categorization of waters into Category 4C when a State demonstrates that the failure to meet an applicable water quality standard is not caused by a pollutant, but instead is caused by other types of pollution.*[5]

The EPA guidance can result in an improved understanding and willingness to recognize and address the significant impacts of hydrologic alteration on Alabama's streams in general and in the Cahaba River watershed in particular. The following information provides justification for ADEM to include

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[1] Available at: http://www.epa.gov/sites/production/files/2015-10/documents/2016-ir-memo-and-cover-memo-8_13_2015.pdf

[2] Defined under the CWA as "the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water" (Section 502(19))

[3] In discussing causes that contribute to the actual or threatened impairment of a designated use in a waterbody, EPA defines "flow alteration" as "frequent changes in flow or chronic reductions in flow that impact aquatic life". U.S. EPA *Guidelines for Preparation of the Comprehensive State Water Quality Assessments (305(b) Reports) and Electronic Updates*, EPA Doc No. 841-B-97-002A, 4-14 (1997). 'Hydrologic alteration' is the currently used term for flow alteration, which includes impacts to aquatic life as well as recreation, drinking water, etc.

[4] Carlisle, Wolock and Meador, "Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment," *Front Ecol Environ* 2010; doi: 10.1890/100053.

[5] See U.S. EPA, *Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act, available at* http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/2006IRG_index.cfm

the portions of the Cahaba River that are included in the Siltation and Habitat Alteration TMDL for the Cahaba River in the 2018 305(b) Report as a 4c stream due to hydrologic alteration, as shown below.

Map 2-2: §303(d) Listed Segments of the Cahaba River

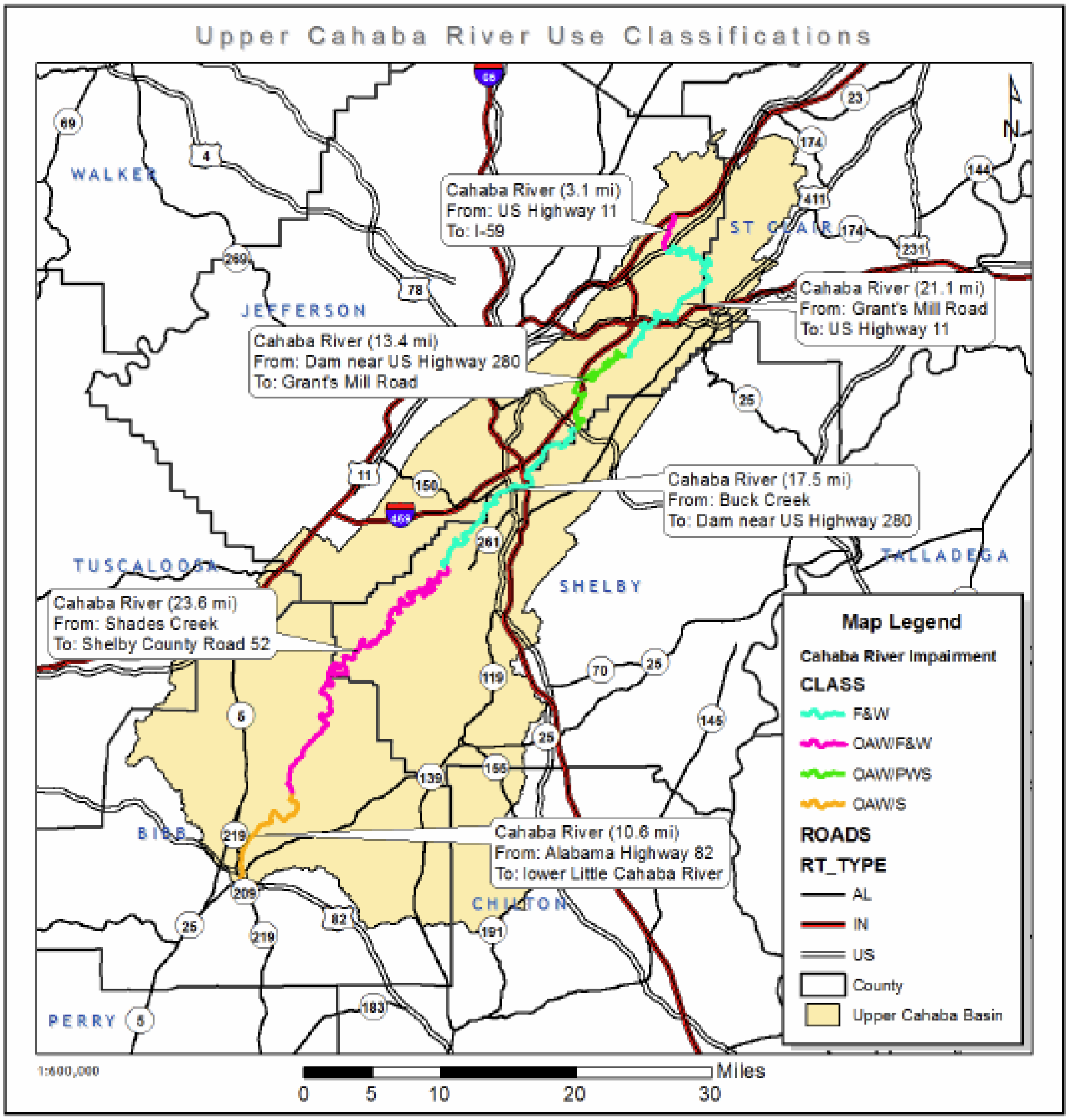

Figure from page 10 of Final Total Maximum Daily Load (TMDL) for Siltation and Habitat Alteration in the Upper Cahaba River Watershed (HUC 03150202), Bibb, Chilton, Jefferson, Shelby, St. Clair and Tuscaloosa Counties, Alabama.

In this proposal, we document that hydrologic alteration of the Cahaba River has occurred and plays a significant role in generating excessive sedimentation in the Cahaba River basin. In general, the supportive information includes:

- Information developed for EPA's Siltation, Turbidity, and Habitat Alteration TMDL for Shades Creek (the Shades Creek Siltation TMDL)
- Information developed for ADEM's Siltation and Habitat Alteration TMDL for the Cahaba River (the Cahaba Siltation TMDL)
- A statistical analysis of changes in hydrologic variables for five Cahaba River U.S. Geological Survey (USGS) gages over time

Relevant Information from the *Total Maximum Daily Load (TMDL) for Siltation, Turbidity, and Habitat Alteration in Shades Creek, Jefferson County, Alabama* [6]

Extensive field monitoring and modeling studies directed by Andrew Simon with the Channel and Watershed Processes Research Unit of the U.S. Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory developed for the Shades Creek Siltation TMDL for U.S. EPA Region 4 were used to assess the relative contributions to sediment loading from 'upland processes' (e.g., from land disturbance erosion) versus 'in-stream processes' (e.g., from channel and bank erosion). Because Alabama has no maximum numerical target for siltation [7], suspended sediment loads, or for the makeup of bed-material, the characteristics at various locations in Shades Creek were compared to sediment conditions in stable "reference" streams in the Ridge and Valley ecoregion.

This Shades Creek Siltation TMDL study served, in many respects, as a model for the development of the Cahaba Siltation TMDL. These two TMDLs for sediment load-reductions called for very similar load reductions, despite using differing protocols and approaches; the Shades Creek Siltation TMDL called for a 53% sediment load reduction and the Cahaba Siltation TMDL called for a 48% sediment load reduction.

An important feature of the Shades Creek Siltation TMDL is that the modeling approach used allowed the authors to estimate the relative sediment contributions of 'upland processes' versus 'in-stream processes'. The authors of the Shades Creek Siltation TMDL found that for 2001 Land Use Conditions in the Shades Creek watershed, 37.6% of the total suspended sediment came from 'Uplands', while 62.4% of the total suspended sediment was from 'Streambanks' [8]. Thus, almost twice as much of the total sediment loading was due to "adjustment of channel width by mass-wasting and related processes…" Streambed and bank erosion processes were "…an important mechanism of channel response to increased streamflow."[9] Estimating the relative magnitude of sediment loading from the predominant sources of sediment loading is fundamentally important

[6] Available at http://adem.alabama.gov/programs/water/wquality/tmdls/FinalShadesCreekSiltationTMDL.pdf

[7] ADEM does not allow an individual permittee to increase turbidity in a receiving stream by more than 50 NTU. However, since every permittee is allowed to increase turbidity by this much, there is no 'ceiling'. In this sense, Alabama does not have an ultimate upper limit on allowed instream turbidity levels.

[8] See Shades Creek Siltation, Turbidity, and Habitat Alteration TMDL, *Table 11. Comparison of relative source contributions between 1991 and 2001 landuse scenarios*; found on page 23. Available at http://adem.alabama.gov/programs/water/wquality/tmdls/FinalShadesCreekSiltationTMDL.pdf

[9] Based on 2001 Land Use validation scenarios, the Shades Creek TMDL authors found that average annual sediment loads for Little Shades Creek increased from 23 T/yr/km^2 to 36 T/yr/km^2. The authors wrote "This indicates that increased urbanization within Little Shades Creek watershed between 1991 and 2001 resulted in about a 56% increase in sediment loads entering Shades Creek." Thus, they attribute the increased sediment loading to changes in urbanization.

because it facilitates identification of the most effective ways to ***address*** siltation and sedimentation problems.

Unfortunately, due to ADEM's resource constraints at the time of the study, the Cahaba Siltation TMDL does not identify the *relative* significance of the various sources of sedimentation in a similar manner as described for the Shades Creek Siltation TMDL. Although specific information about the relative magnitude of sediment loading sources is not included in the Cahaba Siltation TMDL, it is reasonable to assume that the relative significance of upland processes versus in-stream processes is similar to what has been determined for the Shades Creek Siltation TMDL. The geophysical, climatological, and urbanization conditions for Shades Creek and the Cahaba River are very similar. Also, the Cahaba Siltation TMDL states clearly that peak flows and velocities are "due to the abundance of impervious surfaces within the upper part of the watershed" (see description of ***Section 2.6 Hydrology*** below).

Supportive Information from the *Final Total Maximum Daily Load for Siltation and Habitat Alteration in the Upper Cahaba River Watershed (HUC 03150202)* [10]

The Cahaba Siltation TMDL describes the basis for §303(d) listing of the Cahaba River that prompted that study. That discussion references the eight extant fish and mollusk species and three extirpated mollusk species listed by the U.S. Fish & Wildlife Service as federally imperiled species and notes there is an abundance of data and studies that confirm that water quality degradation has contributed to the decline of these federally listed species and of aquatic wildlife in general in the Cahaba River. Implicit, but unstated in the TMDL, is that the U.S. Fish & Wildlife Service specifically states that excessive sedimentation resulting in habitat alteration as an important cause for declines of these listed Cahaba River species and of the Cahaba's aquatic wildlife in general [11]. Excessive sedimentation buries essential habitats for many aquatic species, severely diminishing their opportunities for survival. So, the question of 'what is causing sedimentation?' is an important one.

As mentioned above, the Cahaba Siltation TMDL does not attempt to parse the relative contributions of upland erosion versus channel and bank erosion as was possible through extensive modelling done for the Shades Creek TMDL. However, the Cahaba Siltation TMDL authors frequently mention the role of hydrologic alteration and its contribution to sediment loading. The TMDL authors' repeated reference to the significance of hydrologic alteration as a source of excessive sedimentation in this TMDL is an acknowledgement by ADEM that this source of siltation is environmentally important on the Cahaba River. The following sections from the Cahaba Siltation TMDL support the hypothesis that urbanization in the Upper Cahaba watershed has resulted in significant hydrologic alteration of streamflow that has contributed to streambed and bank erosion and sedimentation that, in turn, has caused water quality and habitat degradation of the Cahaba River and required the development of the Cahaba Siltation TMDL.

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[10] Available at http://adem.alabama.gov/programs/water/wquality/tmdls/FinalCahabaRiverSiltationTMDL.pdf

[11] https://ecos.fws.gov/docs/federal_register/fr3335.pdf for Cylindrical Lioplax, Flat Pebblesnail, and Round Rocksnail; https://ecos.fws.gov/docs/federal_register/fr2245.pdf for Upland Combshell, Coosa Moccasinshell, Triangular Kidneyshell, Fine-line Pocketbook, Orange-nacre Mucket, and Southern Clubshell; https://ecos.fws.gov/docs/federal_register/fr2036.pdf for the Goldline Darter and the Blue Shiner; https://ecos.fws.gov/docs/federal_register/fr1780.pdf for the Cahaba Shiner.

Section 1.1 TMDL at a Glance (page 6) includes bullet points about the TMDL, noting that "Major Source(s):" were found to be "Urban runoff, storm sewers, land development."

While this brief reference does not specify that the increased *rate and volume* of stormwater runoff from urbanized areas is the major source of sediment loading for the Cahaba River, the scientific literature and numerous USGS and EPA publications widely recognize and document a common and important pattern of stream degradation that has been called 'urban stream syndrome' [12] that is the result of the increased rate and volume of stormwater runoff from urbanized areas [13].

The Cahaba Siltation TMDL also cites several previous Cahaba basin studies that refer to siltation resulting from disturbances in surrounding land uses and urban hydrology [14].

Section 2.6 Hydrology (page 15) notes the following in the second paragraph.

> *…The Cahaba River also exhibits increased peak flows and velocities due to the abundance of impervious surfaces within the upper part of the watershed, relatively low groundwater infiltration and retention rates, and large swings in streamflow due to the effluent-dominated nature of the watershed. All of these factors have the potential to exacerbate the siltation and habitat alteration issues present.*

This is ADEM's own clear description of the occurrence of hydrological alteration in the upper Cahaba River watershed, due, in large part, to increased imperviousness associated with urban development.

Section 3.2.2 Morphology (page 23) describes the rapid geomorphic assessments (RGAs) that were conducted to evaluate stream stability characteristics. The authors note that stream channels "act as conduits for energy, flow and materials as they move through the watershed and will reflect a balance or imbalance in the delivery of flow and sediment." The authors describe the use of "Rapid Geomorphic Assessments (RGAs) as a tool to evaluate streambed and bank stability:

> *As such, unstable channels with failing streambanks are inherently a chronic source of sediment loading. When developing siltation TMDLs, it is necessary to determine if the majority of sediment in the stream is from land-based sources or evolving stream channels themselves. The RGA is a semi-quantitative tool that is useful for determining where in the Cahaba River watershed the dynamics of perturbed stream channel equilibrium and channel evolution dominate the total sediment loading to the Cahaba River.*

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[12] Walsh CJ, Fletcher TD, Ladson AR (2005) Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. Journal of the North American Benthological Society 24(3):690-705.

[13] Also see https://www3.epa.gov/caddis/ssr_urb_urb2.html .

[14] Examples include:
Shepard, Thomas E., Patrick E. O'Neil, Stuart W. McGregor, Maurice Mettee, and Steven C. Harris. 1994. Biomonitoring and Water Quality Studies in the Upper Cahaba River Drainage of Alabama, 1989-1994. Geological Survey of Alabama Bulletin 165. Montgomery, Alabama.
USEPA Region 4. 2003. Cahaba River: Biological and Water Quality Studies, Birmingham, Alabama, March/April, July and September, 2002. Science and Ecological Support Division, Athens, GA. https://www.epa.gov/quality/cahaba-river-biological-and-water-quality-studies-birmingham-al-marchapril-july-and

Even though the authors assert "When developing siltation TMDLs, it is necessary to determine if the majority of sediment in the stream is from land-based sources or evolving stream channels themselves.", this TMDL does not make this important determination. These RGAs did reveal a number of locations where stream channel disequilibrium 'dominated' the total sediment loading to the Cahaba River. Sixteen of twenty-nine sites (55%) in the upper Cahaba assessed for bank stability were found to be 'marginal' (11 sites) or 'unstable' (5 sites). At the top of page 27, the authors continue, referring to a previous Geological Survey of Alabama study [15]:

> *The (GSA) study goes on to state that about 50% of the sample reaches displayed intense bank scouring and that the effluent-dominated urban hydrology and sedimentation were adversely impacting these sites.*

In ***Section 3.2.4 Urbanization and Land Use Change*** (page 30), the authors again articulate the importance of urbanization and its impacts on the Cahaba River. In referring to Map 3-4, which shows the increase in impervious surfaces over a relatively short 5-year period between 2001 and 2006, the authors state the following:

> *This figure is an indication that urbanization of the Cahaba River Watershed is certainly increasing over time and thus is considered* ***one of the primary causes of habitat loss due to excess sediment and instream erosion****.* (**emphasis** added)

While not explicitly pointing to hydrologic alteration, it is widely understood that urbanization causes hydrologic alteration of urban streams and is a primary cause of stream habitat degradation. Hydrologic alteration is the linkage between urbanization and habitat degradation.

Section 4.2 Source Assessment reviews a variety of both NPDES-Regulated Point Sources and Nonpoint Sources. Wastewater treatment facilities were not considered to be significantly impacting the Cahaba River with respect to sediment impairment and so were not included in the Waste Load Allocation for this TMDL. Regulated Industrial Facilities were judged to be relatively uncommon in this watershed, particularly when compared to the potential for municipal and residential sources to contribute to the siltation problem. Regulated Mining Facilities, having, at the time this TMDL was written, 40 active mining permits with 465 permitted outfall locations, were recognized as having the potential for significant sediment loading if permit requirements were not strictly followed. The TMDL authors do not venture an opinion as to whether the current compliance levels for Construction Stormwater General Permits results in significant sediment loading.

The TMDL authors discuss Municipal Separate Storm Sewer Systems (MS4s) in the Cahaba River watershed on page 43. Here, ADEM very clearly describes the hydrologic alteration that we are requesting ADEM to acknowledge in the 2018 305(b) Report:

> *…Increased urbanization of the Upper Cahaba River watershed is widely considered one of the primary causes for habitat loss and sedimentation within portions of the Cahaba River. As development increases in a watershed, so does impervious surfaces such as paved roads,*

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[15] O'Neil, Patrick E., Shepard, Thomas E. 2005. Hatchet Creek Reference Watershed Study. Geological Survey of Alabama. Open file Report 0509. Tuscaloosa, Alabama. This report includes additional references to hydrologic alteration in the Cahaba River watershed.

parking lots, roofs, concrete storm drains, curb and gutter, and drive ways. With the increase of impervious surface, the total volume and stream power increases exponentially. This process can dramatically alter the stream morphology, bed characteristics, and habitat by blowing out stream sinuosity, degrading stream banks, depositing excess sediment, and scouring sensitive habitat.

A more succinct description of the Cahaba River's challenges with hydrologic alteration would be difficult to imagine. While the TMDL authors did not have the resources needed to generate an estimate of the relative proportion or significance of this potential sediment source when compared to other sources, we will note that most of the other potential sediment loading sources were specifically declared by the authors to be unlikely sources of significant sediment loading.

Section **4.2.3.2 Chronic Sediment Loading** on page 46 of the Cahaba Sediment TMDL includes the following:

> *The natural process of channel evolution (Simon, 1992) [16] may result in a re-stabilized channel over geologic time, but due to the* ***extreme alteration of hydrologic conditions experienced in the middle Cahaba watershed****, such a re-stabilization seems highly unlikely, unless the hydrologic conditions can be remediated to near pre-development conditions. (****emphasis*** *added).*

Here, the TMDL authors are explicitly stating that the middle Cahaba River has been subjected to extreme hydrologic alteration. What is clear from this is that ***ADEM has already determined that some portions of the Cahaba River have undergone hydrologic alteration***.

The paragraph on page 47 with the heading ***4.2.3.3 Instream versus External Sediment Contributions*** held out some hope that the authors would resolve this important question**.** However, the authors do not actually address the topic directly. The TMDL authors only say "…there is room for debate on the sources and allocation of suspended-sediment with the Cahaba River".

We note that ADEM's Source Assessment discussion lists a variety of potential siltation and sedimentation sources, most of which are described as unlikely to be significant sources. The discussion does not identify any particular source as likely being an important sediment-loading source. Although the Cahaba Siltation TMDL does not quantify the proportion of sediment loading derived from in-stream erosion processes, ADEM's Cahaba Siltation TMDL document leaves readers with no doubt that streambed and bank erosion is a significant source of sediment loading for the Cahaba River. Thus, it is possible to rely entirely on ADEM's own existing information and interpretations to support the assertion that the Cahaba River has been hydrologically altered, and that the understanding and acknowledgement of this process is essential to developing effective strategies for restoring water quality and habitat.

The Cahaba Siltation TMDL authors note that using a sediment target based on stable eco-regional reference sites "ensures that regulated entities are treating effluent and managing stormwater to a

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[16] Simon, A., 1992. Energy, time, and channel evolution in catastrophically-disturbed fluvial systems. In: Phillips, J.D., Renwick, W.H. (eds.), *Geomorphic Systems: Geomorphology* vol. 5, pp. 345-372.

level that is known to be protective of water quality and aquatic life." However, the TMDL authors do not address the very large, very important question of ***"what if the largest source of suspended-sediment loading is <u>not</u> from regulated entities?"***

Given that the tools and approaches needed to address different sources of sediment loading are themselves very different, it is unfortunate that ADEM did not have the resources available that might have allowed making this very important distinction. In the absence of that important distinction for the Cahaba River, we assert that the best available information on this important point is from the Shades Creek Siltation TMDL, which did make an informed determination through an extensive modelling approach. The Shades Creek Siltation TMDL found that *two-thirds* to *nearly three-fourths* of the total sediment loading was due hydrologic alteration[17].

Since in-stream erosion is noted as a primary source contributing to the total sediment-loading for the Cahaba River by the Cahaba Siltation TMDL, not addressing management alternatives for controlling this source of sedimentation is an important shortcoming of ADEM's approach to reducing siltation and sediment-loading to the Cahaba River.

ADEM asserts they do not have the authority to regulate flow; they may only regulate the discharge of 'pollutants' and that clean water is not a 'pollutant'. We agree that clean water is not a pollutant, but it does indirectly ***cause discharge of pollutants***. While the connection is indirect, it is nevertheless ***an inevitable result of hydrologic alteration***.

Another way to express this is that hydrologic alteration impacts the **physical integrity** of Alabama's streams. The Clean Water Act preamble expresses the intent that the physical integrity of waters of the U.S. are to be protected.

So far, our proposal has relied on an EPA's Shades Creek Siltation TMDL and ADEM's own Cahaba Siltation TMDL. From the information ADEM has provided, it should be sufficiently clear that the Cahaba River is currently impaired to a significant degree by hydrologic alteration. However, if additional confirmation is desirable, we invite the reader to consider the following statistical analysis of changes in Cahaba River hydrologic variables over time.

[17] Table 11. Comparison of relative source contributions between 1991 and 2001 landuse scenarios. Page 23. Available at http://adem.alabama.gov/programs/water/wquality/tmdls/FinalShadesCreekSiltationTMDL.pdf

A Statistical Analysis of Hydrologic Variables for Five Cahaba River USGS Gages over Time

The Nature Conservancy (TNC) is a non-profit conservation organization dedicated to protection and restoration of important natural resources around the world. Their science-based approach has helped TNC focus their financial resources on high priority natural resources. In recent years, TNC has devoted considerable attention to protection of aquatic ecosystems, particularly rivers and streams where aquatic faunas are particularly imperiled compared to terrestrial ecosystems. To facilitate that work, TNC has developed a software program [18] that statistically assesses 67 ecologically-relevant variables derived from daily hydrograph data available on-line from USGS gage stations. Below, we describe results from an analysis of the Cahaba River using "Indicators of Hydrologic Alteration, Version 7.1" (IHA) software.

IHA software utilizes 'Average Daily Flow' data readily available from websites for USGS gages as input for the IHA program. These hydrologic data may be evaluated in either of two ways. If a stream has experienced a hydrologic alteration event that occurred at a discrete point in time, it may be evaluated 'before' and 'after' the discrete event. This approach is most appropriate when a stream impoundment, major new withdrawal, or other discrete flow alteration has occurred.

However, for watershed alterations that occur gradually over time, it is difficult to assign discrete points in time that are 'before' and 'after' a gradual change. For this situation, the IHA software evaluates the statistical significance of changes in hydrologic variables using standard linear regression analysis on individual variables over time. For the Cahaba River, where urbanization has increased over time, we used the latter assessment approach and assumed that when the slope of a regression line is statistically different from zero ($p \leq 0.05$), the variable value is changing over time.

There are five USGS gages on the Cahaba River with records of adequate length for evaluation of hydrologic trends; Trussville (25 years of record), Cahaba Heights (39 years), Acton (30 years), Centreville (79 years [19]), and Marion Junction (83 years, with an intervening 13 year gap). If we consider only those hydrologic variables whose slopes are different from zero (i.e., there is an 'up' or 'down' trend over time) with a statistical significance of $p \leq 0.025$, we identified 44 variables that have changed over time for those five Cahaba River gages (see ***Table 1. Statistically significant trends in Cahaba River Hydrologic Variables***). For many of these variables, the probability that the trend at least that great could have occurred by chance alone is much lower than 2.5% ($p = 0.025$).

A reader with some background in statistics would note that, when using a p-value of ≤ 0.025, about 1 in 40 results that *appear* to be significant may actually be due only to chance. For 67 variables times 5 locations (335 tests), one might expect that, if there were no time trends, about 8 or 9 apparently "significant" trends could be expected to occur due to chance alone [20]. But here, we identified 44 statistically significant trends, a number much greater than 8 or 9.

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[18] Information about the program, including downloads, publications using IHA, frequently asked questions, and training in its use are available at: https://www.conservationgateway.org/ConservationPractices/Freshwater/EnvironmentalFlows/MethodsandTools/IndicatorsofHydrologicAlteration/Pages/indicators-hydrologic-alt.aspx . Also, see Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A Method for Assessing Hydrologic Alteration within Ecosystems. Conservation Biology 10 (4): 1163-1174.

[19] Centreville has a flow record that begins in 1901, but that record has a 30 year gap. We elected to base the assessment on the continuous record from 1935 to 2014.

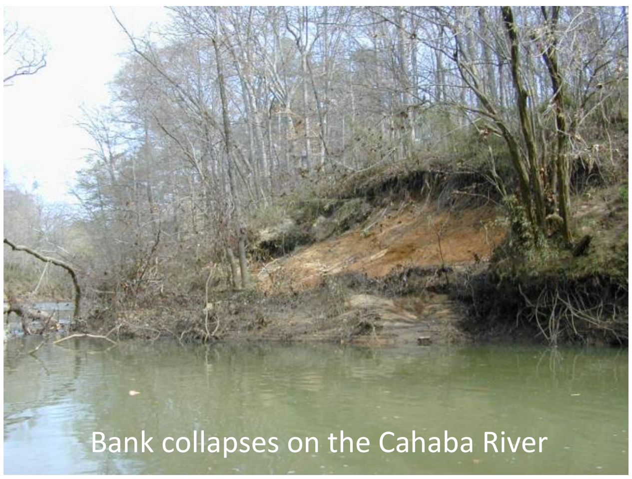
[20] That is, 67 variables times 5 locations is 335 statistical tests. 2.5% of 335 is 8.37 (about 8 or 9).

Not all of these variables are independent. Nevertheless, the high number of hydrologic variables that do appear to be changing over time, and are changing in the direction expected with urban development, strongly supports the hypothesis that hydrologic changes are occurring in the Cahaba River basin.

The trends described below that are consistent with the hypothesis that the Cahaba River's hydrology has changed in response to urbanization of the upper watershed fall into three categories:

- Variables that reflect increasingly 'flashy' flows
- Variables that reflect diminished groundwater contributions to flow
- Increased average low-flow downstream from wastewater discharges

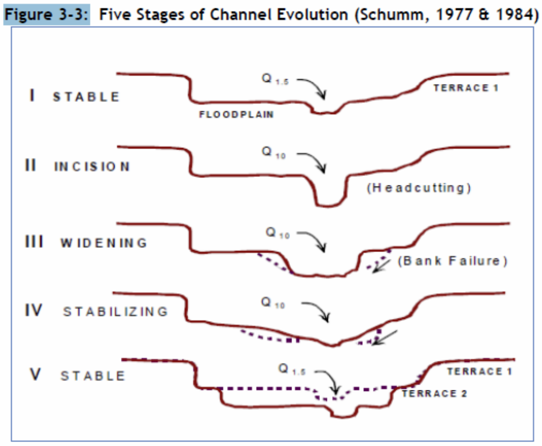
When we assert that some hydrologic variables reflect increased 'flashiness', we are referring to a statistically significant *increase* in variables that measure the magnitude, frequency, or the rate of change in flow over time. These variables include the 'Low Pulse Count', 'High Pulse Count', 'High Flow Frequency', 'Extreme Low Flow Frequency', 'High Flow Peak', 'High Flow Rise Rate', 'Number of Annual Reversals', 'Fall Rate', 'Small Flood Rise Rate', 'Large Flood Rise Rate', and 'High Flow Duration'.




Bank collapses on the Cahaba River

Streambed and bank erosion rates physically adapt to flow magnitude, the frequency of high flow events, and the rate of change of flow. Understanding how increased magnitude and frequency of flows can lead to increased erosion is intuitive. However, understanding how increases in the *rate of change* in flow may be less intuitive. The following paragraph is an example of the hydrologic importance of rate of change in flow.

Figure 3-3: Five Stages of Channel Evolution (Schumm, 1977 & 1984)



When water levels drop exceptionally quickly, waterlogged soils on streambanks do not have as much time to slowly drain. The result is that streambanks subjected to unusually rapid 'fall rates' experience more frequent 'bank slumps' (as shown in the two photos on the previous page) because of the extra weight of the water in the saturated soils on the streambanks. These saturated streambanks 'slump' or collapse more readily than streambanks that are allowed to drain slowly as water levels slowly recede. Thus, 'flashy flows' contribute to increased bank slumping. Also, as the frequency of high water level events increases or the magnitude of such events increases, streambanks are more often subjected to shearing power of moving water.

The Cahaba Siltation TMDL illustrated the importance of this process by including **Figure 3-3: Five Stages of Channel Evolution (Schumm, 1977 & 1984)** [21]. That diagram, shown above, illustrates the process of stream bank erosion that is exacerbated by a regime of increasingly flashy flows. The area shown for 'Stage V' below the dotted line and above the solid red line is an indication of the volume of earth that has been removed from the bed and banks of the stream at that cross-section to allow re-stabilization of the stream channel. The Cahaba Siltation TMDL includes the following photograph to further illustrate the impact of eroding streambanks that result from hydrologic alteration.

Picture 3-3: Example of an Unstable Bank on the Cahaba River

From: Cahaba Siltation TMDL, page 23.

Our goal with the IHA analysis is to assess whether the changes in the upper Cahaba River watershed have actually resulted in statistically significant hydrologic changes. In the text below,

[21] We could not readily find ADEM's references to the 1977 and 1984 publications. However, Stanley Schumm has published many refereed articles on this topic. For example: Schumm, S. 1981. Evolution and Response of the Fluvial System, Sedimentologic Implications. Society of Economic Paleontologists and Minerologists Special Publication No. 31: 19-29.

we describe many of those significant hydrological trends in the context of where those trends have occurred within the Cahaba River watershed.

The output from the IHA program includes tables enumerating the variables, their values, and the statistical significance of trends for linear regressions on the data (See Appendix 1) as well as graphs of the data, including the linear regression fit to that data. We will present many of those graphs below.

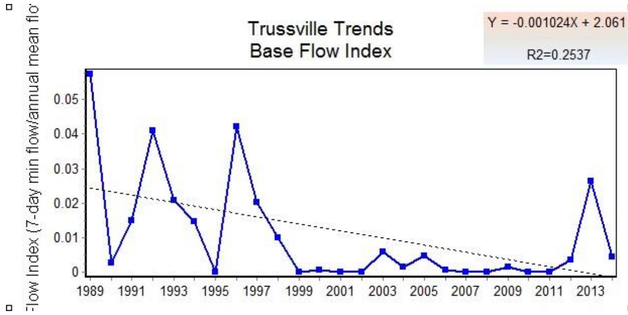
Table 1. Statistically significant trends in Cahaba River Hydrologic Variables as assessed by the TNC's IHA approach.

p Values:	0.0005	0.001	0.0025	0.005	0.0125	0.025
	Hydrologic Variable					
Trussville				Base Flow Index	Low Pulse Count	High Flow Peak
					Extreme Low Freq.	High Flow Rise Rate
						Small Flood Rise Rate
Cahaba Heights		Extreme Low Peak	No. Reversals	High Pulse Count		
		Extreme Low Duration		High Flow Freq.		
	Large Flood Rise Rate					
Acton		1-Day Minimum		Extreme Low Peaks		Sept Flows
		3-Day Minimum		Low Pulse Duration	Extreme Low Freq.	30-Day Minimum
		7-Day Minimum			High Pulse Count	
	No. of Reversals				High Flow Peak	
	High Flow Fall Rate				High Flow Freq.	
Centreville	High Pulse Count		Fall Rate		Date of Min. Flow	Nov Low Flow
	No. of Reversals					1-Day Max. Flow
	High Flow Freq.					3-Day Max. Flow
Marion Junction	No. of Reversals			Extreme Low Timing	Large Flood Fall Rate	High Pulse Count
	High Flow Fall Rate			High Flow Rise Rate	High Pulse Duration	
	Large Flood Duration				High Flow Duration	
		Large Flood Rise Rate			High Flow Freq.	

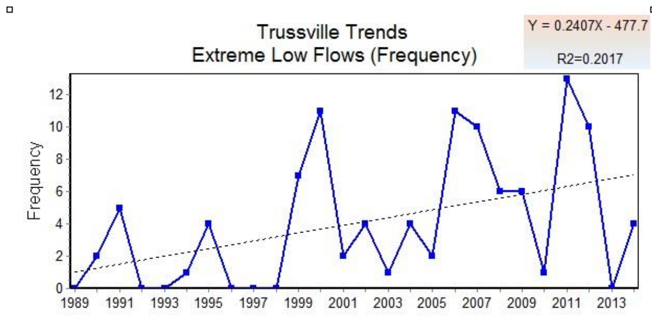
Variable trends with smaller p-values should be considered as potentially important, particularly if those variables measure various aspects of a common cause for hydrologic alteration and particularly if the p-values are 0.01 or less. Here, where urbanization has been widely recognized to contribute to increasingly 'flashy' flows, we see statistical confirmation of increasingly flashy flows occurring over time. Variables in the brown font are for variables that reflect increasingly more flashy flows.

The results for five USGS gages on the Cahaba River are examined individually below.

Trussville USGS Gage Trends

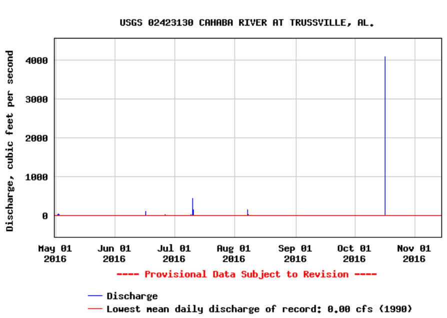


A 'base-flow index' for Trussville is the 7-day minimum flow normalized for a given year by dividing the magnitude of that flow by the mean annual flow for that year. As the proportion of flow that is groundwater diminishes, this index falls. Over the past decades, Trussville has increasingly relied on pumping groundwater for its drinking water supply, a practice that will likely diminish the flow of groundwater to the Cahaba River. Also, as development, and the proportion of land covered by impervious surfaces, has increased over time, the amount of surface area capable of infiltrating rainwater to groundwater has diminished. So, the City of Trussville is both withdrawing more groundwater over time and simultaneously reducing infiltration to groundwater.



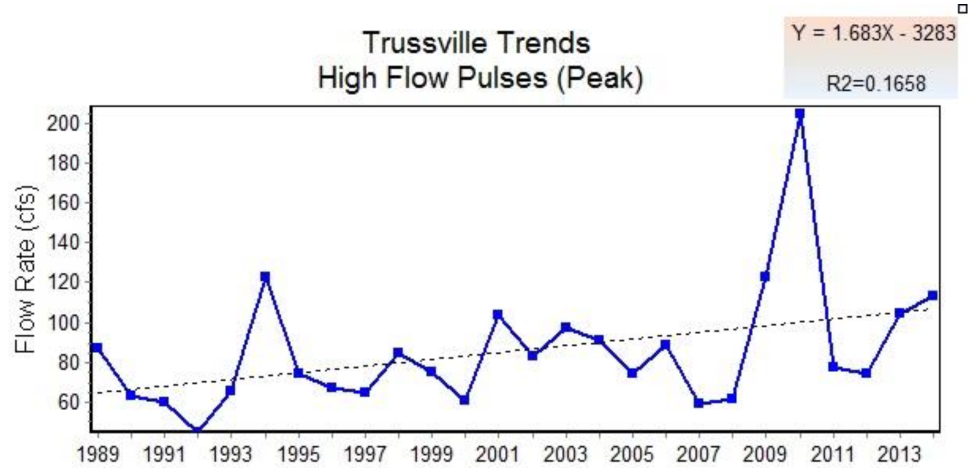
Reduced base-flow will result in an increase in 'Low-pulse Count', a measure of how often the river experiences a significant drop in flow. It also results in the frequency of distinct 'low-flow' events. The graph at right shows the number of 'low-flow' events has increased from an average of one per year to an average of six per year.

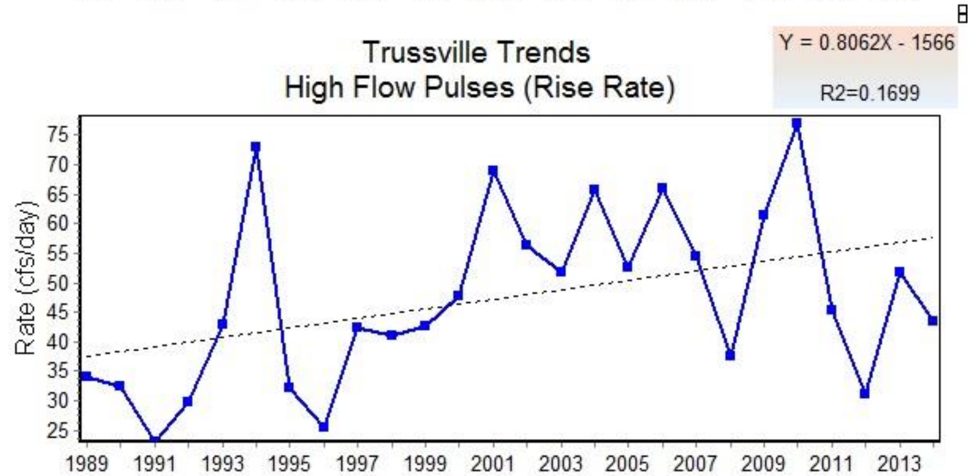
The Trussville gage has a 20 square mile watershed. The following photos are from that same section of the Cahaba River. The left photo from the year 2000 and the right photo from 2016 are examples of no flow events for this segment of the Cahaba River.

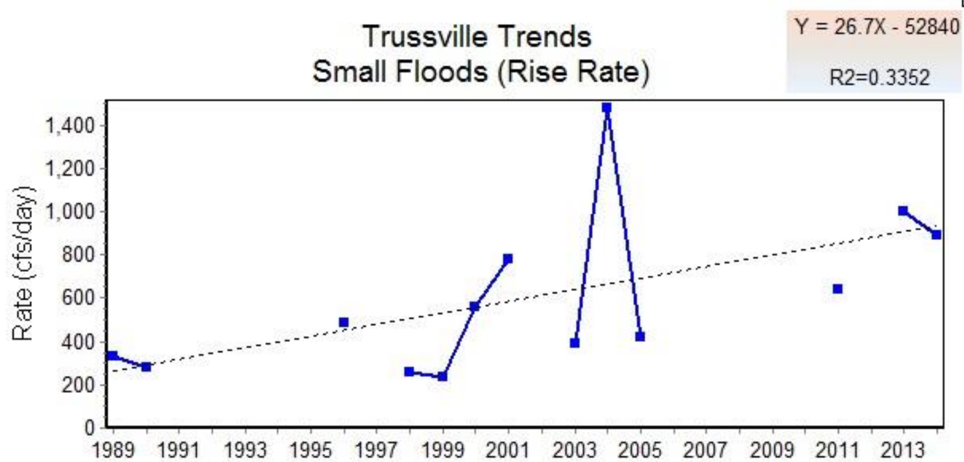


The low-flow stress on the Cahaba River in Trussville is not limited to short duration events. The hydrograph at left from the USGS Trussville gage for 2016 (a drought year) shows there was essentially no flow in the river from early May through early November, except for a half-dozen very brief rain events. These long-duration de-watering events are increasingly common for the section of the Cahaba River below Happy Hollow Road to Highway 11.

Changes in base-flow and the frequency of low flow events illustrate our concerns about low-flow stresses for this portion of the Cahaba River. However, the Cahaba River in Trussville also experiences increasingly flashy flows resulting from high-flow events. Measures of the number of 'High-flow Pulse Peaks', 'High-flow Rise Rates', and 'Small Flood Rise Rates' all show significant positive trends over time.







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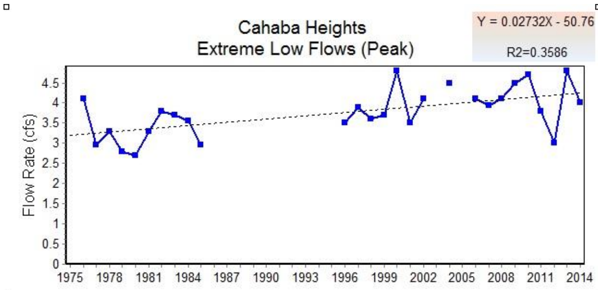
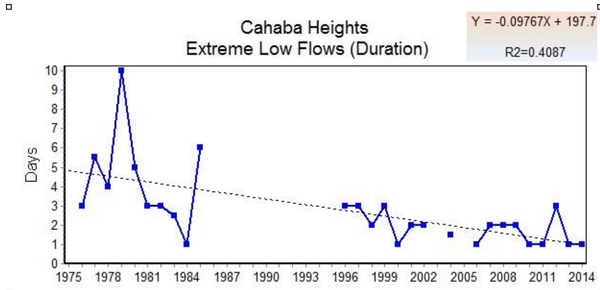
Cahaba Heights USGS Gage Trends

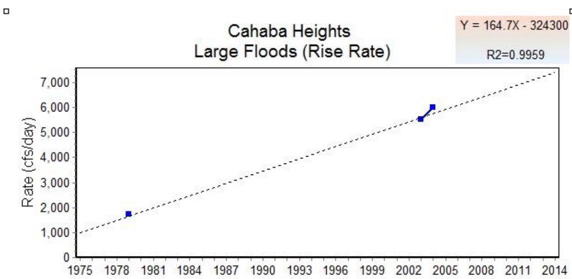
The USGS gage at Cahaba Heights is downstream from several major wastewater facilities [22]. The relatively constant discharge from these facilities results in a relatively increased flow during low-flow conditions. Thus, the most extreme low-flow conditions are now less extreme than in the past. The duration of extreme low-flow events has been shortened by WWTP discharges as well.

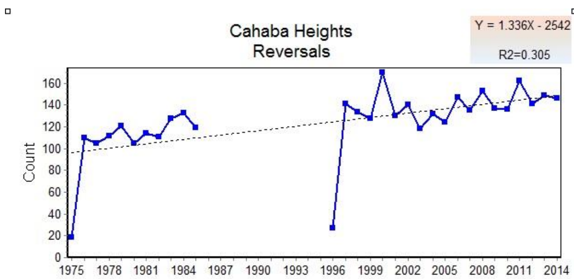


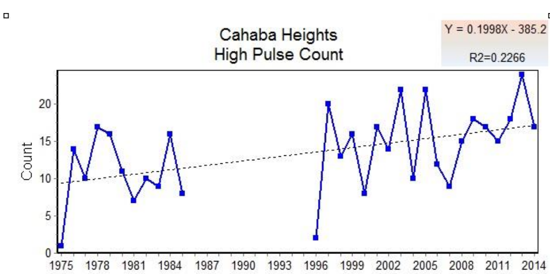


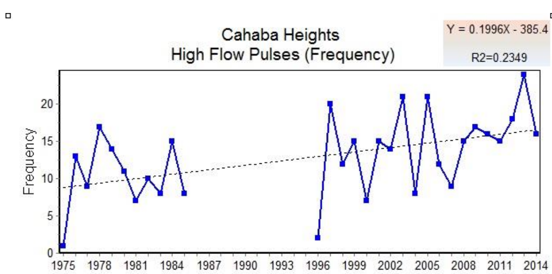
Some readers might count this hydrologic change as an 'improvement' over the natural flow regime. This change in the hydrological regime may improve dissolved oxygen levels during low flow, at least temporarily. In the larger picture, this hydrologic alteration is not one of our gravest concerns. However, it is an observed, statistically significant hydrologic alteration, so we note that here.

As noted for the USGS gage at Trussville, we also see indicators of increasingly flashy flows at the Cahaba Heights gage. 'Large Flood Rise Rates', 'Number of Reversals', 'High Pulse Counts', and 'High Flow Frequency' (the latter two being only slightly different measures) are all observed to increase over time at the Cahaba Height USGS gage. The 'Large Flood Rise Rate' change is based on only three events. While statistically significant at the p = 0.001 level, we should be very cautious about over-interpreting the actual significance of this variable. On the other hand, we see the change in number of 'Reversals' as being especially important because that phenomenon is a significant cause of bank slumping associated with bank soil saturation followed by a falling water level.





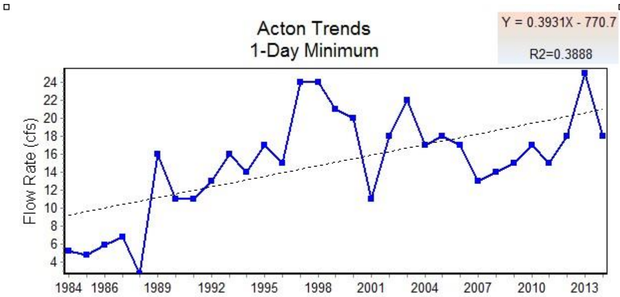


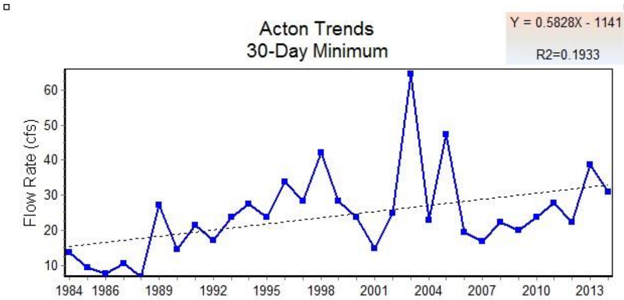


[22] Trussville WWTP, SWWC Riverview WWTP, and Hoover's Inverness WWTP.

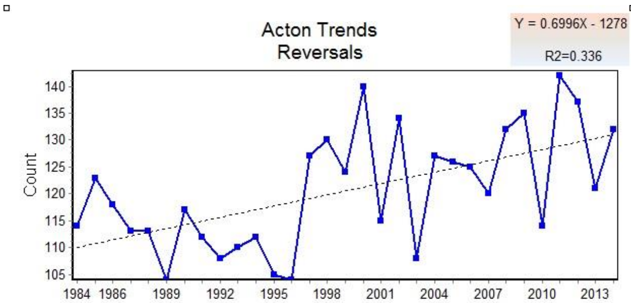
Acton USGS Gage Trends

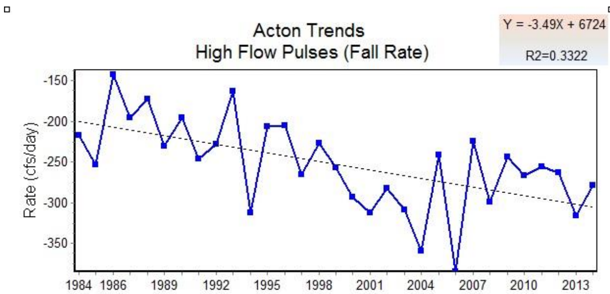
The USGS gage at Acton is influenced by additional wastewater discharges [23]. Once again, hydrologic alterations associated with those wastewater discharges are recognized by the IHA software assessment. '1-Day Minimum Flows', '3-Day Minimum Flows', '7-Day Minimum Flows', 'Extreme Low Peaks', 'Extreme Low-Flow Frequency', 'September Flow', 'Low Pulse Duration, and the '30-Day Minimum Flows' are all now less extreme than in the past. Here we present only a few graphs that serve to illustrate the results for all eight significantly altered variables.



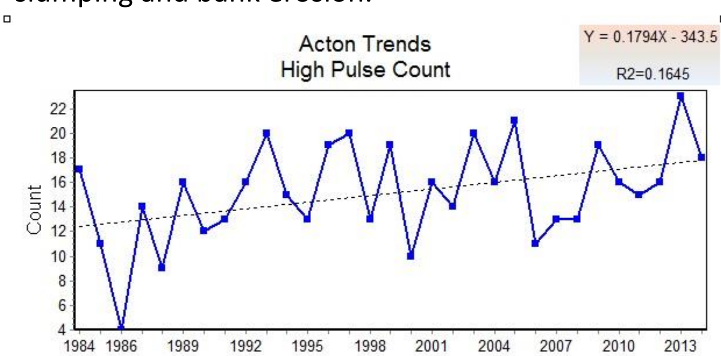


The Acton gage also shows increasingly flashy flows. The 'Number of Reversals', the 'High Flow Rise Rate', the 'High Pulse Count', the 'High Flow Frequency', and the magnitude of the 'High Flow Pulse Peaks' have increased over time. Here again, we show a couple of these variable with especially low p-values (i.e., unlikely to be due to chance alone) rather that all five of these variables.





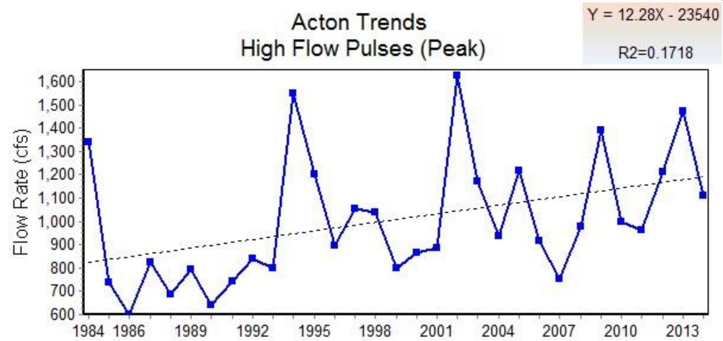
Here, the 'High Pulse Flow Fall Rate' becomes increasingly severe. In 1994, that fall rate value was about -200 cfs/day. That is, following a 'High Pulse' event, the river would drop at that rate. In 2013, that rate of fall was about -300 cfs/day. This increasingly rapid fall rate will contribute to bank slumping and bank erosion.



Similarly, increases in the number of 'High Pulse Count' from an average of about 12 per year in 1984 to 17 per year in 2014, a 42% increase, reflects the increasing number of erosive events occurring each year. The more frequently these Pulse Flows occur, the more streambank and bed erosion will occur.

[23] Trussville WWTP, SWWC Riverview WWTP, Hoover's Inverness WWTP, Jefferson County's Cahaba WWTP, and Hoover's Riverchase WWTP.

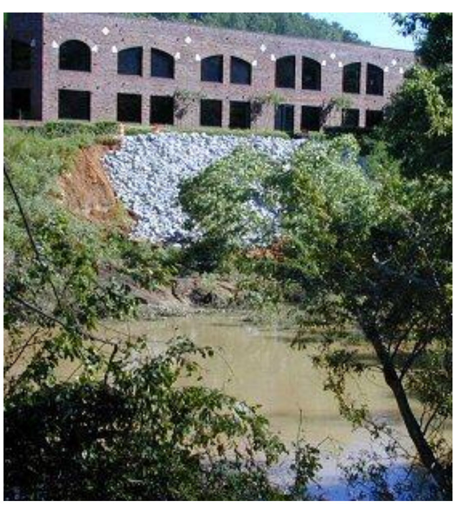
The Acton gage also shows the magnitude of the 'High Flow Peaks' has increased from about 800 cfs in 1984 to about 1200 cfs in 2014, a 50% increase. Just as for the 'High Pulse Count', increases in the magnitude of the discharge result in more erosive flows that cause streambanks and the bed to erode. It should be clear that more frequent and higher magnitude 'high flow' events per year will contribute to more extensive bank erosion.



The impact of greater peak magnitudes is that these peak flows are both more erosive and they contribute to stream bank collapses. Enhanced stream bank collapse is an important characteristic of 'urban stream syndrome'. Examples of stream bank collapse are shown below.

July 29, 2017. A new bank collapse adjacent to an old collapse. Note that leaves are still on the tree, indicating this is a recent event.

March 13, 2003. A large bank slump deposits tons of sediment Into the Cahaba mainstem.

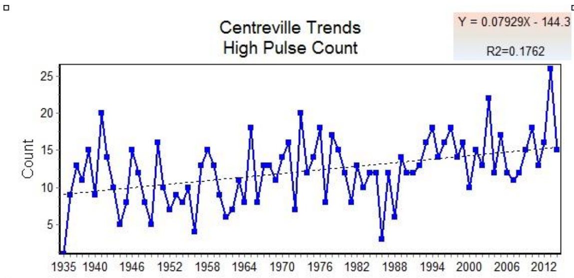


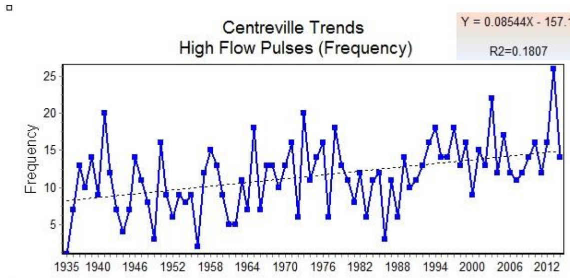
This bank collapse, shown at left, on the Cahaba River at the River Run Shopping Center, came within about twelve feet from the foundation of this building. This highlights the potential for bank collapses to imperil human habitats as well as aquatic wildlife habitats.

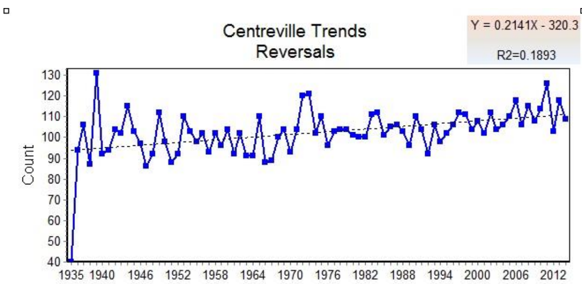
These photos are examples of the very large number of stream bank slumps/collapses on the Cahaba River mainstem and tributaries.

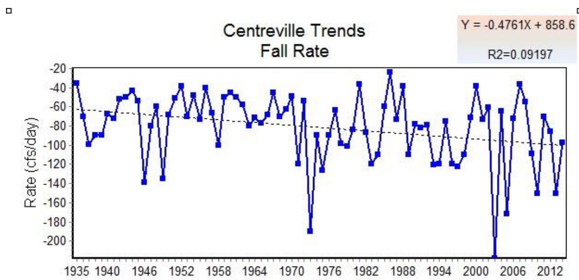
Centreville USGS Gage Trends

The hydrologic record for the Cahaba River at Centreville begins in 1901 and runs discontinuously to the present. Given there is a 30 year gap in this record, we chose to evaluate the 79 years of continuous record. The trends observed for Centreville are similar to those noted upstream. Here again, variables that reflect ‘flashy flows’ show significant statistical trends; ‘High Pulse Counts’, ‘High Flow Frequency’ (these two being only slightly different measures), ‘Number of Reversals’, and ‘Fall Rate’ have increased over time.









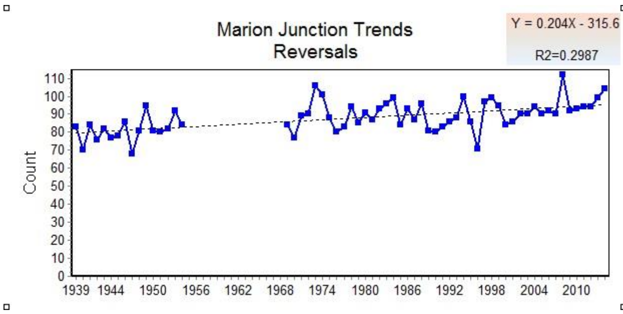
The number of ‘Reversals’ has climbed from about 94 times per year to 110 times per year. The ‘Fall Rate’ has become more extreme over time. In 1935, the fall rate was about -60 cfs/day and by 2013 it has become about -100 cfs/day. This means that the stream banks are less well supported following a high flow event, contributing to the type of bank slumping illustrated in Figure 3-3 on page 24 of ADEM’s Cahaba Siltation TMDL.

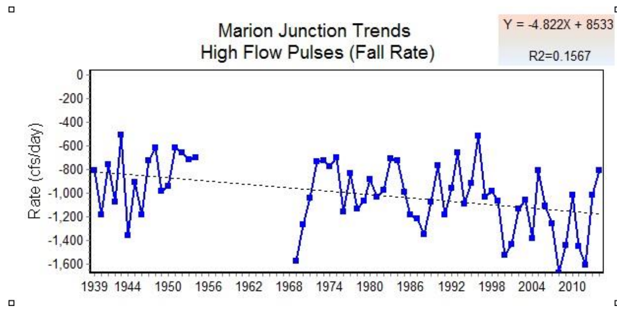
The reader might be a bit surprised that these hydrologic alteration impacts have not been ameliorated by a diminished magnitude of landscape impacts further from the urbanized portion of the watershed. But it appears some hydrologic alterations are still observable well downstream from the more urbanized portions of this watershed. Perhaps being located in the Ridge and Valley physiographic province has confined the Cahaba’s flows within relatively narrow valleys which has propagated these impacts downstream.

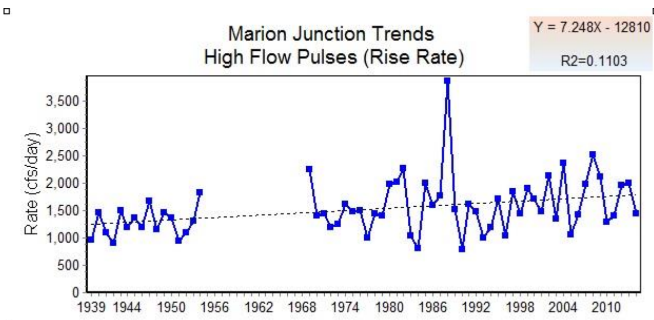
As we will see for the Marion Junction USGS Gage Trends, observable impacts continue still further downstream, to a part of the watershed that extends well into the Fall-line Hills of the coastal plain.

Marion Junction USGS Gage Trends

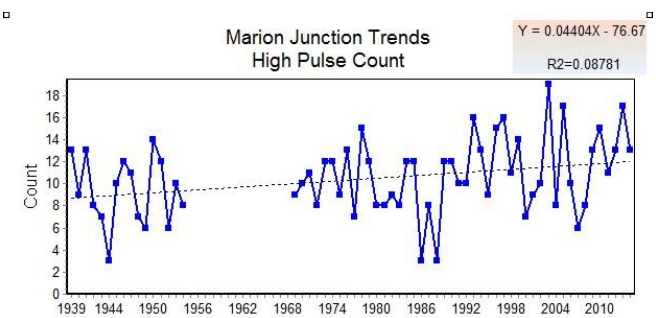
Marion Junction is the fifth and most downstream USGS gage with sufficient data to allow IHA analysis. Here, the 'Number of Reversals' has grown from about 80 to 95 times per year, about a 19% increase. The 'High Flow Fall Rate' increased from 800 cfs/day to over 1200 cfs/day, a 50% increase. The 'High Flow Rise Rate' increased from about 1250 cfs/day to about 1750 cfs/day.

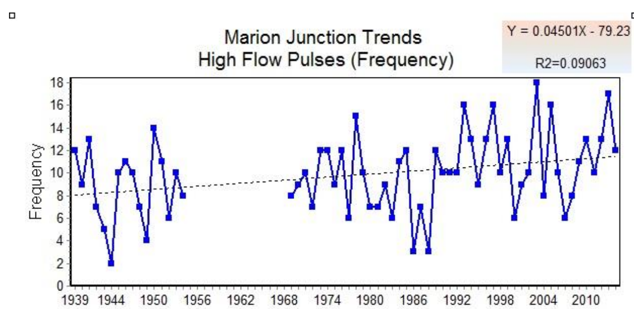


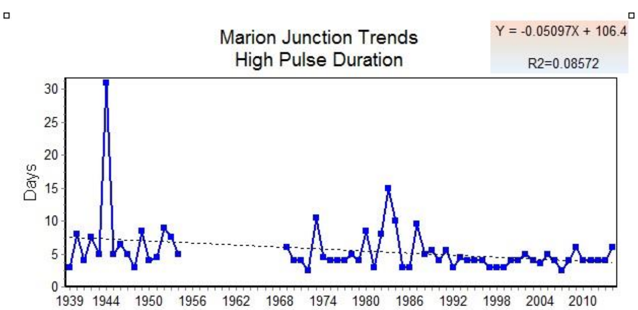


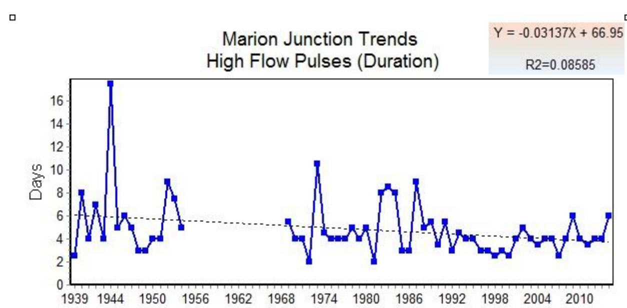


Other variables that reflect increasingly flashy flow include 'High Pulse Count', 'High Flow Frequency' (as noted previously, these two are related), 'High Pulse Duration', and 'High Flow Pulse Duration' (again, related but calculated in a slightly different manner).









If the reader accepts that this analysis reveals a variety of hydrologic changes, we are still left with the question of whether these changes are the cause of or are correlated with the observed degradation of aquatic wildlife uses. To address this question we note that the ecological consequences of excessive sediment impacts has been confirmed by US Fish & Wildlife Service Threatened and Endangered Species Listing documents noted above. The available information on the sources of excessive sedimentation in the Cahaba River system strongly indicates that in-stream erosion is a major source if not the predominant source of that excessive sedimentation.

Potential Advantages of a 4c Designation for the Cahaba River

For many years, the Cahaba River Society staff have discussed with municipal decision-makers the issue of how increased imperviousness in urbanizing watersheds leads to increased streambed and bank erosion and increased sediment deposition. While a few decision-makers have assimilated this information and been responsive to it, unfortunately most have not addressed the significance of this concern as they have developed management strategies for meeting the targets of the Cahaba and Shades Creek Sedimentation TMDLs.

These decision-makers tell us that they rely on ADEM to be the arbiters of whether or not a significant environmental problem actually exists. They essentially tell us that if an environmental concern was really a problem, then ADEM would deal with it. These decision-makers assume that ADEM has the authority to directly deal with any significant environmental issue. But regarding hydrologic alteration, ADEM does not accept that it has authority to directly address it. So, without a 4c Categorization for the Cahaba River from ADEM, it is less likely that municipal decision-makers will accept that a significant problem actually exists and should be addressed. While it is ADEM's policy that addressing hydrologic alteration is not an ADEM regulatory requirement, it is a significant cause of siltation and sedimentation in the Cahaba River basin that ADEM could speak to in a way that facilitates adoption of better land use and development management requirements by municipalities.

There is a similar potential to educate civil engineers in our area about the importance of properly managing the volume of stormwater discharge. We recently learned about a comment by a local engineering firm in response to a question from a city council person regarding a stormwater management issue. The engineer indicated that, in his opinion, ADEM does not focus on reducing stormwater volume; they only require reduction of pollutant loading. By categorizing the Cahaba River as a 4c stream, ADEM would show that it considers hydrologic alteration and volume of stormwater discharge to be important factors in effective environmental management for water quality and habitat restoration.

ADEM staff tell us that they cannot regulate flow or exercise a specific, direct, regulatory role that addresses hydrologic alteration. Nevertheless, ADEM's expertise and acknowledgement that hydrologic alteration of the Cahaba River *has occurred* would be extremely valuable and would have a significant weight in raising awareness regarding the environmental importance of this source of environmental degradation. We seek an acknowledgement that Cahaba River's hydrologic alteration is a real concern to Alabama's environmental regulatory agency and others who seek to protect this resource. A 4c Categorization would help municipal decision-makers, the local civil engineering community, and others involved in stormwater management in the Cahaba River watershed more clearly understand the significant causes of impairment and the strategies they need to undertake to meet TMDL targets and restore the River.

Some development professionals and public officials recognize that hydrologic alteration is a significant problem for the Cahaba River. However, most of the efforts that have been made to address this problem have been for individual projects, rather than as improvements to codes and standards, which is necessary to systemically address the problem.

A 4c Categorization applied to much of the Cahaba River above Centreville would provide needed justification that would give municipal decision-makers a firmer foundation for adopting more focused development standards to address the increased stormwater runoff volume from projects under their jurisdiction. ADEM's acknowledgement that hydrologic alteration is an important factor that deserves attention would be extremely helpful to advocates of good stormwater management.

Summary

As for the question of whether or not hydrologic alteration of the Cahaba River has actually occurred, there are three lines of evidence that strongly support the assertion that hydrologic alteration has occurred; 1) Information developed for EPA's Sediment TMDL for Shades Creek, 2) Information developed for ADEM's Sediment TMDL for the Cahaba River, and 3) A statistical analysis of hydrologic variables from five Cahaba River USGS gages over time. These data and their interpretation by EPA and ADEM and our own interpretation of flow data from USGS gages provide overwhelming evidence of hydrologic alteration in the Cahaba River watershed.

Given the documented declines noted for federally listed imperiled aquatic species and of aquatic species in general in the upper Cahaba River watershed, the fact that hydrologic alteration is widely known to be the most frequent source of sedimentation in urbanized streams, that sedimentation has contributed to declines of imperiled species and other aquatic wildlife in general, and that urbanization exacerbates in-stream bed and bank erosion, the assertion that hydrologic alteration has contributed to the Cahaba's aquatic wildlife losses is inescapable. ADEM's Cahaba Siltation TMDL clearly implicates hydrologic alteration as an important source of siltation and sediment loading in the Cahaba River.

In light of the evidence above and the overwhelming body of literature that supports the hypothesis that urbanization contributes to hydrologic alteration of streams, it follows that hydrologic alterations have contributed to a decline of federally listed imperiled aquatic species, a decline of aquatic species in general, increased treatment costs for drinking water, and diminished recreational value of the Cahaba River.

The potential benefits of a 4c Category designation are not regulatory, but there are important educational benefits that could result in improved local decision-making for water resource restoration. Acknowledging the real causes of a problem is always a step in the right direction towards more effective solutions.