Cahaba River Society

Restoring and protecting the Cahaba River watershed and its rich diversity of life

November 1st, 2017

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Re: Project Number ACAA59534-ATRIP(015), the Cahaba Beach Road Extension, including a Bridge over the Little Cahaba River

Dear ALDOT and FHWA staff:

The Cahaba River Society is a 501c3 nonprofit organization with a mission to restore and protect the Cahaba River watershed and its rich diversity of life. CRS is an educator, expert resource, and collaborative partner for science-based and practical solutions. We work with development professionals and with state, county and city officials to ensure that development is done in a way that sustains the River and our drinking water source for future generations as communities in the watershed grow. We have a track record as an advisor for development best practices that protect the River and our drinking water, and we have collaboratively contributed to ALDOT's planning and design for major highway and road improvement projects.

We appreciate the opportunity to comment on the extension of Cahaba Beach Road. CRS values our relationship with ALDOT and Shelby County, and we encourage you to continue to lead an open stakeholder process with meaningful public engagement in such an important set of decisions for the future of our river and drinking water for our communities.

For the reasons described in greater detail below, the Cahaba River Society must support the 'No-Build' alternative at this time. With the information now available, CRS believes the construction and long term impacts of any of the proposed alternative routes pose too great a risk of degrading our drinking water source and the vulnerable Little Cahaba River. Instead, we recommend that ALDOT develop and study a "build" alternative for spot improvements that does not require a road and bridge crossing the Little Cahaba River.

There are many places where well-built development can be positive for communities. However, lands purchased with public ratepayer money with the intention of permanently protecting the region's drinking water source are not the right place for development that risks our drinking water.

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The following summarizes our comments.

- The ***risks and impacts of the 'build alternatives' far outweigh the limited potential benefits that have been described.*** The project's transportation purpose is poorly defined, traffic benefits related to actual purposes have not been studied and demonstrated, and the full road improvement project costs are seriously underestimated. The risks and water resource costs, particularly those associated with protecting the integrity of one of the Birmingham areas' primary drinking water sources, are great.
- The project would **increase pollutant contamination risks to the primary drinking water source for Birmingham and potentially increase drinking water costs** via:
    - The increased potential for **construction runoff** mishaps,
    - Increased **post-construction urban stormwater impacts** from the project and spin-off development, causing sediment pollution, habitat destruction, and reduced water supply during drought,
    - **Forest loss,** which alters hydrology and reduces pollutant filtering and replenishment of the drinking water source, and
    - The enhanced **risk of a direct spill** into Birmingham's primary drinking water source.
- Building the road would require **removal of forested open spaces that were purchased with Birmingham Water Works Board (BWWB) ratepayer dollars** to protect our drinking water and would violate conservation easements intended to permanently protect the BWWB lands.
- The **actual purposes for the road proposal are so vaguely declared** that potential benefits, costs, impacts and alternatives cannot be adequately studied. The project purpose needs to be clearly identified and alternatives for achieving those purposes other than the proposed road, such as those suggested by O'C&L, Inc., should be evaluated.
    - If the project purpose is to relieve traffic congestion on Highway 280, the likelihood of success is unsupported by evidence. If the project purpose and likely indirect impact of the road is to open this sensitive area to development, a comprehensive risk assessment of indirect and cumulative impacts to our drinking water source is necessary.
- The **potential traffic impacts on surrounding areas have not been identified and the cost has been significantly underestimated**, because the project purpose is vague and there has not been a traffic study of indirect/cumulative impacts and necessary ancillary traffic improvements.
- These issues also raise **concerns about equity** – who benefits from the road and who bears the cost for the road, for the loss of drinking water protection lands, and for potential negative impacts to drinking water supply and price. Social equity issues should be considered.
- Environmental integrity concerns such as **wetland impacts and impacts to federally-listed threatened and endangered species** must be fully studied considering direct, indirect and cumulative impacts.
- A Finding of No Significant Impact based solely on an Environmental Assessment process would not be appropriate. **An Environmental Impact Statement process with full public involvement is necessary**.

The remainder of this letter provides supporting information for these points, poses questions we believe the environmental study should evaluate, and suggests resources for the environmental study.

As for all such road proposals, there are at least two overarching factors to consider:

> 1) What are the purposes and potential benefits of the proposed project, and
> 2) How do those benefits compare to the potential risks, mitigations and costs associated with the proposed project.

What are the potential benefits of the proposed project?

It appears that this project is about much more than reconnecting a 1-lane, part dirt road and replacing a historic bridge over the Little Cahaba that has been closed for 25 years. Throughout ALDOT's assessment process, the official response to queries about the purpose or benefit of this project has been "to improve connectivity." The phrase 'improve connectivity' is a vague term that cannot be adequately studied or quantified in an environmental process. Is the intent to relieve traffic on Highway 280, as has been stated by the project proponent at times? What level of traffic reduction on 280 would be sufficient to meet that goal, and would the project actually achieve that? Is the intent to reduce travel times, and for whom?

If such a vague justification for a road is deemed by this assessment process to be a sufficient justification, then perhaps *any road that connects* through any neighborhood or community resource can be justified. If 'improved connectivity' is accepted as justification for extending Cahaba Beach Road, then a future expansion to four lanes might be equally justifiable. An assessment process that accepts such a vague justification has failed as a means to weigh the competing needs and values of our community.

Shelby County needs to articulate *'to what end'* 'improved connectivity' is aimed. Without a more clearly defined purpose, it is impossible to evaluate the actual merits of the proposal and weigh those with impacts, costs and risks, or to propose and study alternatives that might address the same needs.

ALDOT and the public deserve to have in hand, before decisions are made, a clear articulation by Shelby County of the purpose of extending Cahaba Beach Road and an evaluation of a set of alternatives for achieving those purposes other than the proposed road. We ask that ALDOT consider the alternative traffic improvement proposals submitted by O'C&L, Inc.

What are the potential risks associated with the proposed project? How do those compare to the potential benefits?

We are particularly concerned that ALDOT must consider the full range and magnitude of negative impacts from road-building projects. In particular, we continue to recommend that ALDOT consider the full range of indirect and cumulative impacts. A previous and highly significant environmental study by ALDOT did not achieve this: the *Final Environmental Impact Statement Reevaluation, Project HPP-1602 (530)(529)(502)(531)(532) Birmingham Northern Beltline* evaluated the potential for increased sediment loading from the Northern Beltline project. Those results made the erroneous and unscientific assertion that sediment loading to streams would be *reduced* by construction of the Northern Beltline. This was based on a faulty understanding of watershed dynamics, including the assumption that less sediment results from urbanization because less sediment runs off from paving than from forest. This assumption ignored well-documented watershed science about the alterations to flow caused by impervious surfaces, which contribute to instream erosion and sedimentation.

The environmental assessment process for Cahaba Beach Road should be based on up to date, well-researched watershed science for direct, indirect and cumulative impacts, including post-construction changes to hydrology, instream erosion, and pollution. CRS attached a compendium of such research to our past comments about the Northern Beltline FEIS for the project's 404 permit, and we anticipate that the Cahaba Beach Road consultants would have current understanding of the science on this issue.

Environmental groups like ours are not the only voices expressing concerns that standard environmental assessments for road and highway projects often fail to consider the full range of the threats such projects promise for stream impacts. The following excerpt is a portion of the abstract from an article in *Reviews in Fisheries Science*, an academic journal, articulating the same concern [1].

> *New highways are pervasive, pernicious threats to stream ecosystems because of their short- and long-term physical, chemical, and biological impacts. Unfortunately, standard environmental impact statements (EISs) and environmental assessments (EAs) focus narrowly on the initial direct impacts of construction and ignore other long-term indirect impacts. More thorough consideration of highway impacts, and, ultimately, better land use decisions may be facilitated by conceptualizing highway development in three stages: initial highway construction, highway presence, and eventual landscape urbanization. Highway construction is characterized by localized physical disturbances, which generally subside through time. In contrast, highway presence and landscape urbanization are characterized by physical and chemical impacts that are temporally persistent. Although the impacts of highway presence and landscape urbanization are of similar natures, the impacts are of a greater magnitude and more widespread in the urbanization phase. Our review reveals that the landscape urbanization stage is clearly the greatest threat to stream habitat and biota, as stream ecosystems are sensitive to even low (<10%) of watershed urban development…(abstract continues).*

Being a review article, the body of the text cites a large number (193) of refereed academic articles (*i.e.*, published in scientific journals) that support the thesis of this review article.

Based on our current understanding of the potential benefits and risks, particularly those associated with protecting the integrity of one of the Birmingham areas' primary drinking water sources, we believe that the ***risks of the 'build alternatives' far outweigh the limited potential benefits that have been described.*** We further describe the potential risks of the project below:

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[1] A.P. Wheeler, P.L. Angermeier, and A.E. Rosenberger. 2005. *Impacts of New Highways and Subsequent Landscape Urbanization on Stream Habitat and Biota.* Reviews in Fisheries Science, 13:141-164. See attached Appendix A.

Increased risk to Birmingham's drinking water source

The BWWB provides service to about 600,000 customers. About 60% of those customers are directly served from the portion of their system that draws from the Cahaba River. All customers including the remaining 40% not served or only occasionally served by the Cahaba source would be impacted by increases in water bills that are very likely to occur as treatment costs rise from the cumulative impacts of converting water conservation lands into urbanized landscapes. Clearly, the health and cost of service for a large number of Birmingham's citizens relies on the health of the Cahaba River. Will estimates for those community expenses be included in ALDOT's assessment of this proposal?

The potential risks to the integrity of our community's drinking water supply demands that a high bar must be set for the traffic benefits of a proposed project and that a high standard for environmental review of such a project must be upheld. This environmental review process must not underestimate the full range of impacts to the cost, supply, treatability, and quality of Birmingham's drinking water source. As we noted in our October 18, 2016 comment letter, an ***Environmental Impact Statement process is essential*** to evaluate the full scope of negative impacts to a vitally important resource for our community.

Risks associated with new construction projects: We must be realistic and acknowledge that during the construction phase of a development project, spills and stormwater violations are far from uncommon. Our organization's 28 years of experience working with developers have shown us that even projects by careful and thoughtful developers can occasionally cause significant pollution problems. We have also seen projects by careless developers that cause severe pollution problems, particularly siltation problems. You may be aware that sediment pollution is especially damaging because a very wide variety of pollutants have the proclivity for attaching to sediment particles, thus facilitating their movement into a stream, which in this case is our drinking water source. Will ALDOT assess and quantify these risks?

Risk of increased siltation due to direct and indirect impacts of stormwater runoff: ALDOT has asserted that because each of the proposed bridge alternatives over the Little Cahaba River would span the active channel, they expect that sediment and erosion problems will be minimal. We agree that avoiding placing bridge abutments in an active stream channel is a valuable practice that does reduce direct sediment impacts. Keeping construction equipment out of the stream bed and off of the banks and minimizing alteration to the banks and the width of riparian forest clearing is also necessary to minimize sediment and channel impacts. Will these mitigations be required?

The study should also consider that both construction and post-construction stormwater pollutants from the entire roadway and disturbed zone have potential to degrade the waterway. The level of potential degradation is linked to the purposes of the road. A road that is intended as a reliever route for Highway 280 must have a design standard that will have minimal grades and curves. This will require a wide clearing, grading and construction zone, substantially more forest loss, and significantly greater potential for construction sediment runoff and post-construction hydrologic alterations. In contrast, a road designed for minimal forest loss and grading, such as Cherokee Road (east of Highway 280 in Mountain Brook), would have a lesser degree of impact but would have greater travel times and potentially would not meet project purposes.

The graphics for the 4 alternative roadways provided at the October 2017 meeting, for instance, show clearing/grading widths of 80 to 250 feet and cut/fill depths of up to 60 feet. Will the study evaluate alternatives for the purpose, scale and design criteria for the road and the different level of impacts and necessary mitigations?

In addition, the largest source of sediment loading to streams in the long-term is from cumulative direct and indirect post-construction sources. An adequate environmental assessment of sediment loading that would result from a proposed project must include a careful accounting of the largest source of that pollutant, which will be from hydrologic alterations caused by the road itself and by the indirect urban development generated or assisted by the road. This is why an adequate study of the indirect and cumulative impacts of a proposed project is essential. See more specifics below about the indirect development potential that should be studied.

Existing development and environmental regulations have not been successful in preventing impairment of the Cahaba River because environmental regulations have, so far, failed to address the largest source of sediment loading; the indirect and cumulative impacts of altered hydrology that results from urbanization [2]. Currently, ADEM lists the upper Cahaba River watershed as 'Impaired' due to excessive siltation. TMDLs for siltation and habitat alteration in the upper Cahaba Watershed call for a 48% reduction in average annual sediment loading [3]. Had existing development and environmental protection practices been adequate, the Cahaba River would not currently be impaired and the 48% reduction in sediment loading called for by the TMDL would not be necessary. Thus, any argument made by the project EA that relying on existing development and environmental protection regulations will be sufficiently protective of the River has already been proven wrong. Will the study identify additional mitigations?

The Cahaba River Society has asserted that post-construction stormwater impacts have come to be the dominant source of sediment loading in the Cahaba River. We have attached a report on hydrologic alteration of the Cahaba River in Appendix B. That study interprets evidence developed by ADEM and includes a statistical assessment of USGS gage data that together strongly indicate the Cahaba River's excessive siltation and habitat alteration problem is largely due to hydrologic alteration. That hydrologic alteration, in turn, is largely due to increased watershed imperviousness associated with typical urbanization.

We show that the rate, volume, and flashiness of flow from post-construction stormwater have increased significantly in the Cahaba River watershed over time, while base flow has decreased for upper river reaches (lower reaches have seen base flow increases related to treated sewage discharge). This highlights the need for ALDOT to conduct a thorough assessment of cumulative direct and indirect post-construction stormwater impacts. If ALDOT's environmental assessment of

[2] ADEM has been appropriately reluctant to regulate what some see as 'a land use' question. However, municipalities have not yet adequately addressed this significant environmental challenge through their MS4 permits.

[3] ADEM. 2013. *Total Maximum Daily Load (TMDL) for Siltation and Habitat Alteration in the Upper Cahaba River Watershed (HUC 03150202).* 91 pages. A pdf is available at http://adem.alabama.gov/programs/water/wquality/tmdls/FinalCahabaRiverSiltationTMDL.pdf

this proposed project concludes that sediment impacts will be abated over time, as was ALDOT's conclusion for the Northern Beltline, ALDOT would be on the wrong side of the scientific evidence readily available to them.

ALDOT has the capacity of assessing these types of impacts if they include use of the PLOAD subroutine for stormwater modeling. Will ALDOT assess these types of post-construction stormwater impacts? The study also needs to consider cumulative impacts on water supply, as increased impervious surfaces reduce groundwater recharge and base flow during dry weather and drought.

Risks associated with loss of forested areas: Forested areas are widely recognized as being vital for drinking water source protection. All of the proposed 'build' alternatives result in loss of forested landscape. We note that some of the best municipal drinking water available on earth is that for the City of New York [4]. In 1905 they had the foresight to set aside forested watersheds in the Catskill region that provides excellent drinking water to this day. Cities that fail to adequately protect the source of their drinking water are short-sighted and risk compromising the health of their citizens. Will ALDOT assess the potential water quality and supply impacts associated with the loss of forested areas required for this proposal? As noted above, will ALDOT evaluate the differing levels of impacts on forest loss depending upon the purpose of and design criteria for the road? Will the study assess projected acreage of forest loss and the loss of watershed benefits of that forest as among the costs of the project?

Enhanced risk of direct spills: Building a bridge over the Little Cahaba River that would encourage Highway 280 cut-through traffic increases the risk of a direct spill of hazardous materials into our drinking water supply. Has ALDOT consulted with ADEM in order to learn how frequently spills occur in the vicinity of Alabama bridges? Experience indicates that traffic will seek to use the cut-through and will overfill the capacity of the road and bridge, especially to avoid traffic snarls on 280, which will lead to risk of accidents on the cut-through bridge and road. Even if truck traffic is forbidden on the bridge, this is unenforceable.

A pollutant spill could be either catastrophic or an enormous inconvenience to BWWB customers, as well as degrading habitat and potentially taking federally-listed species. A spill would not only compromise water flowing from Lake Purdy, but would also settle and linger in the drinking water supply pool in the mainstem Cahaba. Clean up of those resources would be difficult and could further destroy listed species and instream habitat. Will ALDOT study these potential impacts and produce a plan for providing drinking water in the event of a spill that temporarily compromises the availability of drinking water from the Cahaba River system?

This proposal subverts the conservation values of land purchased to protect our drinking water

The new Cahaba Beach Road would cut a swath through forested open space lands around the Little Cahaba River, which help keep our drinking water clean as it comes from Lake Purdy to the intakes in the Cahaba River. The Little Cahaba River is one of the last healthy tributaries of the River. The

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[4] http://www.nyc.gov/html/dep/html/drinking_water/history.shtml

diverse, rare freshwater creatures that live there show how healthy and relatively unspoiled this creek is. Land protection by the Birmingham Water Works Board and by private property owners over generations have protected the forests of the Little Cahaba River and our drinking water supply.

The BWWB has expended rate-payer dollars to purchase important forested conservation lands surrounding the Little Cahaba River, Lake Purdy, and Cahaba River. BWWB has placed conservation easements on these lands intended to protect the lands from any development that could compromise drinking water supply and quality. This proposed road is development that would risk the drinking water source. We do not believe that this road is allowable under the criteria set out in the easements.

All of the proposed 'build' alternatives for this proposal cross a portion of those conservation lands to a greater or lesser degree. ALDOT should not try to find a legal way to get around those conservation easements. There is likely to be legal action to defend the Water Board conservation easements and lands. The potential for greater convenience for some drivers has not been demonstrated and, even if it were, that convenience is not more important to our region than the integrity of our drinking water supply.

What are the actual purposes for extending Cahaba Beach Road?

While Shelby County has not formally suggested during this process that relieving Highway 280 traffic and facilitating development are goals and benefits for this proposal, several media articles and statements by County officials make those assertions. By not declaring these project purposes as part of the EA process, Shelby County and ALDOT avoid having to demonstrate: whether those benefits could be achieved; what road design and ancillary improvements would be necessary to achieve them; what direct, indirect and cumulative impacts would ensue; and what alternatives to the road might achieve those purposes.

We have already expressed our dissatisfaction with the vague term 'improved connectivity' as a justification. Below, we focus on two of what we have heard as purposes for this proposal.

Relieving traffic on Highway 280 - If the purpose of the Cahaba Beach Road extension is to relieve traffic on Highway 280, then the scope of an appropriate traffic study would necessarily include a demonstration that such a reduction in Highway 280 traffic would actually occur, rather than simply assuming it, as has clearly occurred in the media [5]. While everyone likes the idea of relieving Highway 280 traffic, *there is no evidence* this proposal would achieve any such relief significant enough to improve safety and travel times on 280. That is because the current traffic study for this proposal does not address the question of potential impacts on Highway 280 traffic.

[5] For example,
https://patch.com/alabama/vestavia-hills/traffic-studies-grants-mill-cahaba-beach-road-proceed-late-2017
http://blog.al.com/spotnews/2013/03/cahaba_beach_road.html
http://vestaviavoice.com/news/aldot-to-host-public-meetings-for-cahaba-beach-road-bridge-p107/

The current traffic study also does not assess potential impacts on Sicard Hollow Road traffic, the intersection of Sicard Hollow and Blue Lake Road, the intersection of Sicard Hollow Road and Grants Mill Road, the traffic conditions on Grants Mill Road, nor the traffic conditions in Cahaba Heights. It does not examine the roadway integrity impacts of heavier traffic on Sicard Hollow Road, which already is unstable. Without a study of those ancillary impacts and the cost of upgrading them, it is not possible to assess the traffic impacts and benefits that intends to relieve Highway 280 traffic or provide a Highway 280 cut-through for traffic from the Liberty Park area. The limited scope of the current traffic study fails to assess either the potential benefits, potential problems, or full costs that extending Cahaba Beach Road might allow or cause.

Moreover, in the long-run, an effort to relieve Highway 280 traffic by building a 'cut-through' to I-459 is ultimately unlikely to help. Highway 280 traffic will ultimately increase to over-fill the freed-up capacity. Cahaba Beach Road is not a solution to this problem.

Facilitating Development in this area – The Cahaba Beach Road project would increase and facilitate development potential in the area, and therefore the scope of an appropriate water resource impacts assessment must include those indirect and cumulative impacts. The potential impact of increased construction and post-construction stormwater runoff on the cost, supply, treatability, and ultimate quality of Birmingham's drinking water, on the potential to meet Cahaba River TMDL targets, and on the habitat of federal T&E species should be extensive and carefully done. Underestimating the impacts on our drinking water could negatively affect 600,000 customers of the Birmingham Water Works Board (BWWB), either directly through drinking water quality degradation or through increased user fees to cover the increased treatment costs that inevitably accompany urbanization of the drinking water watershed.

An indirect and cumulative analysis of environmental impacts and of traffic impacts and improvement needs must consider the build-out of Liberty Park, of private properties along Cahaba Beach Road that are not protected by permanent conservation easements, of buildable properties along Sicard Hollow and Grants Mill Road, and of undeveloped areas slated for development in Vestavia Hill's plan for Cahaba Heights. In particular, the analysis should consider impacts under two conditions: the condition that Liberty Park has not yet completed the extension of Liberty Parkway to Sicard Hollow Road, in which case cut-through traffic must funnel to Blue Lake Drive/Cahaba Heights or to Grants Mill/Rex Lake Road, and the condition that the Liberty Parkway connection is made through to I-459, in which case Cahaba Beach Road will draw even more traffic from/to Highway 280.

The current cost estimates are incomplete

The current cost estimates for the four 'build' alternatives do not include essential improvements to the following:

- Cahaba Beach intersection with Highway 280
- Sicard Hollow Road itself would need improvements if it is to handle increased traffic volume
- Sicard Hollow Road intersections with Blue Lake Road and Grants Mill Road
- Other intersections and roadways in Cahaba Heights

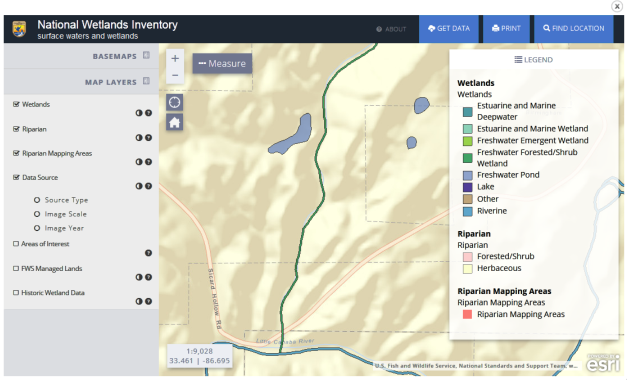
If Cahaba Beach Road is to serve as a Highway 280 reliever route or to reduce travel times from these areas to Highway 280, the proposal would not be functional without these essential improvements to existing infrastructure, which should be included in cost estimates for this project.

Equity considerations should be studied

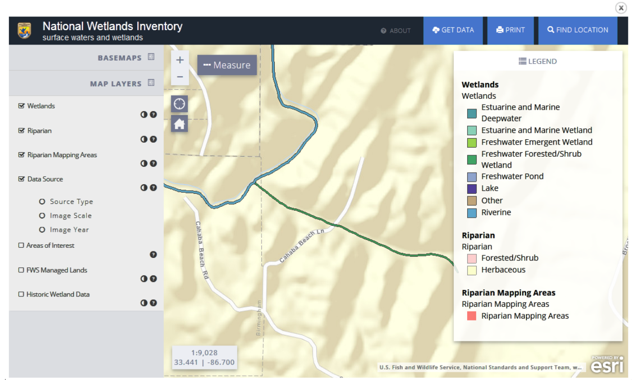
There are often equity issues about who benefits from and who pays for projects that impact water supply, quality and costs. Who would benefit from the road, depending upon the true purposes and how well those can be achieved? What is the larger base of people who would pay, through tax dollars used to build the road, and especially through drinking water impacts? In essence this project would take land purchased by and for the benefit of the BWWB customers to protect their drinking water, using their tax dollars spent in ways that endanger their water, and, together with all the other impacts to the River, increasing the cost of their drinking water. Will the EA study the equity implications of who benefits and who pays?

Biologically defined Wetlands in the Area

We wanted to be certain ALDOT is aware that wetlands are present in the general vicinity of the 'build' alternatives. Using the U.S. Fish & Wildlife Service 'National Wetlands Inventory' [6], which displays the type and extent of wetlands based on a biological definition, we note that Coal Branch is a 'Freshwater Forested/Shrub Wetland'. Also, an unnamed tributary that would be crossed by Alternative 4 is also shown as a 'Freshwater Forested/Shrub Wetland'. The two areas are shown below and may be located online using the URL cited below for a closer inspection.



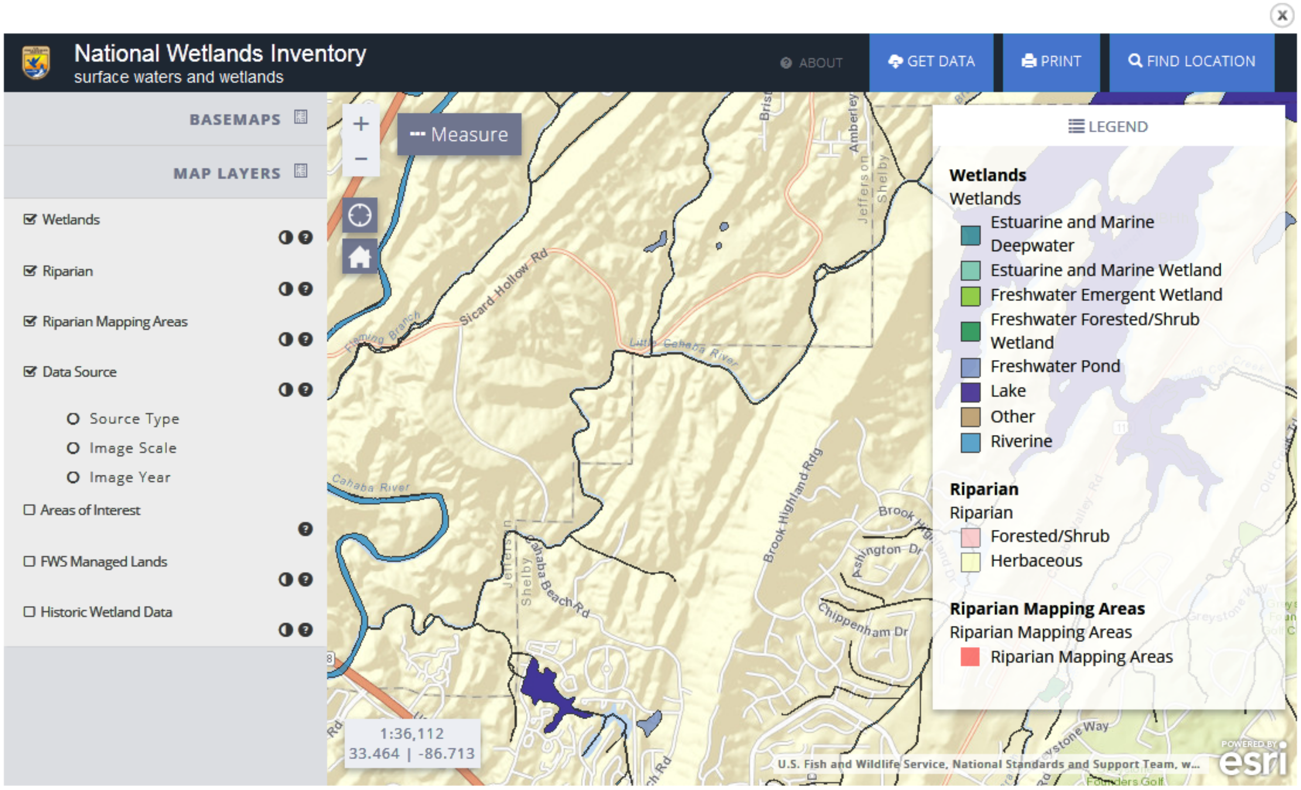
Wetlands along Coal Branch



Wetlands along an unnamed tributary

Also, ALDOT is probably aware that the Little Cahaba River itself and its banks are also defined by USF&W as 'Riverine Wetland', and we include that below for the sake of completeness.

[6] Available at https://www.fws.gov/wetlands/data/mapper.html . This website notes a number of caveats and disclaimers, but



Concerns about Federally-listed Threatened or Endangered Species

The degree to which the project may adversely affect a federally threatened or endangered species (T&E species) or its habitat is a key NEPA consideration. As noted in our October 18, 2016 comment letter, this project's direct, indirect and cumulative impacts are highly likely to negatively impact federally listed mussel species that have been documented to exist in the Little Cahaba River in the vicinity of and downstream of the project. The assertion that there will be no impacts on T&E species because all proposed bridge crossings would span the active channel fails to consider the indirect siltation and habitat alteration impacts that accompany watershed urbanization, as detailed above. Please also see specifics concerning T&E impact studies in our October 18, 2016 letter on record for this project.

A Finding of No Significant Impact would be inappropriate

In that October 18th, 2016 comment, we noted that based on criteria in 40 C.F.R. § 1508.27, an EA alone would not provide sufficient information to support agency decisions, and must lead to an EIS. A "Finding of No Significant Impact" would not be supportable. There would be significant potential direct, indirect, and cumulative impacts of the project and the development it will induce, and of probable future associated projects that would be necessary to achieve the purpose of the project to improve connectivity to the surrounding road network including Highway 280.

The impacts of this project meet the threshold test of 'significance,' thereby triggering the need for an EIS. Potential significant impacts to public health and unique or ecologically critical areas are key NEPA considerations. This project would impact the water quality of a major drinking water source for the Birmingham region and a river system that is nationally and globally-significant for freshwater biodiversity. We did not see these potential impacts listed in the "Preliminary Alternatives Comparison Matrix" provided at the October 11th 2016 meeting.

Under NEPA, significance exists if it is reasonable to expect that the project and its indirect and cumulative effects, both short-term and long-term, have potential for significant environmental impact. Such effects of this project would include loss of natural forested lands, risks to a drinking water source, the construction and post-construction stormwater impacts on the Little Cahaba River and Cahaba River that would be caused by the road and the development it will induce, and the resulting potential impacts to an impaired river with a TMDL for sediment and to federally-listed T&E species, and negative impacts to a unique regional educational resource.

An EIS should also consider the project within the context of trends in the drinking water supply. The Cahaba River is vulnerable and facing increasing damage. Because of urban runoff, there is more pollution during rains and less water in the river during droughts. Parts of the Cahaba River have had unsafe levels of human disease pathogen indicators, including the 280 pool downstream from the project. More treated sewage is being diverted into Lake Purdy and the River than in the past, and that increases potential nutrient pollution sources, carcinogens, drugs, and hormones in our water source.

Summary

Combining the vague and unquantifiable benefits of the proposed extension with an inadequate assessment of the full range of potential direct, indirect and cumulative negative impacts would lead to a decision that harms BWWB customers and our community. Substantial additional environmental studies need to be conducted as part of an Environmental Impact Statement process. Based on the information available to us now, the 'No-Build' alternative is the responsible decision.

Thank you for your thoughtful consideration of these comments.

Sincerely,

Beth K. Stewart

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Cc: Edward Austin, ALDOT, Assistant Chief Engineer, Policy & Planning
Steven Walker, ALDOT, Bureau Chief, State Design Engineer
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Shelby County Commission
Alex Dudchock, County Manager, Shelby County
Rosemary Hall, EPA Region IV

Appendix A

A.P. Wheeler, P.L. Angermeier, and A.E. Rosenberger. 2005. *Impacts of New Highways and Subsequent Landscape Urbanization on Stream Habitat and Biota.* Reviews in Fisheries Science, 13:141-164.

Reviews in Fisheries Science, 13:141–164, 2005

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Impacts of New Highways and Subsequent Landscape Urbanization on Stream Habitat and Biota

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New highways are pervasive, pernicious threats to stream ecosystems because of their short- and long-term physical, chemical, and biological impacts. Unfortunately, standard environmental impact statements (EISs) and environmental assessments (EAs) focus narrowly on the initial direct impacts of construction and ignore other long-term indirect impacts. More thorough consideration of highway impacts, and, ultimately, better land use decisions may be facilitated by conceptualizing highway development in three stages: initial highway construction, highway presence, and eventual landscape urbanization. Highway construction is characterized by localized physical disturbances, which generally subside through time. In contrast, highway presence and landscape urbanization are characterized by physical and chemical impacts that are temporally persistent. Although the impacts of highway presence and landscape urbanization are of similar natures, the impacts are of a greater magnitude and more widespread in the urbanization phase. Our review reveals that the landscape urbanization stage is clearly the greatest threat to stream habitat and biota, as stream ecosystems are sensitive to even low levels (<10%) of watershed urban development. Although highway construction is ongoing, pervasive, and has severe biological consequences, we found few published investigations of its impacts on streams. Researchers know little about the occurrence, loading rates, and biotic responses to specific contaminants in highway runoff. Also needed is a detailed understanding of how highway crossings, especially culverts, affect fish populations via constraints on movement and how highway networks alter natural regimes (e.g., streamflow, temperature). Urbanization research topics that may yield especially useful results include a) the relative importance and biological effects of specific components of urban development—e.g., commercial or residential; b) the scenarios under which impacts are reversible; and c) the efficacy of mitigation measures—e.g., stormwater retention or treatment and forested buffers.

Keywords road, urbanization, motorway, macroinvertebrate, fish, urban

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Introduction

Due to their large surface area, high traffic volume, and potential to induce urban development, the construction of large (≥ four-lane) paved roads (herein defined as highways), are often detrimental to local ecosystems. Stream ecosystems are particularly sensitive to the construction of new highways due to characteristics of the fluvial environment and biota. Downstream transport of water and sediment spreads chemical and fine sediment pollution, causing the ecological impacts of highways to extend farther in aquatic than in terrestrial environments (Forman and Alexander, 1998). Aquatic fauna often have a more difficult time avoiding spreading impacts than terrestrial fauna because their movements are generally confined to the narrow linear geometry of the stream channel. In addition, highways and urban development alter the hydraulic connection of streams to their watersheds, fundamentally altering processes, which control channel geomorphology, form habitat, and ultimately contribute to biotic integrity (Wang et al., 2001; 2003).

Angermeier et al. (2004) conceptualized the extent and nature of highway impacts on streams in three consecutive stages: initial highway construction, highway presence, and eventual landscape urbanization (Table 1). Because this framework reflects the spatial and temporal dimensions of impacts, it is useful for organizing, describing, and evaluating the environmental concerns of new highways. The initial phase, highway construction, includes all the short-term impacts from the construction process. These impacts are generally physical, temporary (i.e., subside through time), and local. The second phase, highway presence, encompasses secondary impacts that are chronically generated from the physical presence of the highway including chemical pollutants from automobile traffic and stream channel alterations. These chemical and physical impacts are regional and occur as long as the highway exists. Finally, landscape urbanization includes the impacts from general economic development and results in a variety of chemical and physical impacts that are widespread and chronic. Previous reviews have focused on single phases of highway impacts (Atkinson and Cairns, 1992; Little and Mayer, 1993; Forman and Alexander, 1998; Trombulak and Frissell, 2000; Forman and Deblinger, 2000; Paul and Meyer, 2001) but not clearly described or considered the inherent connectivity of the nature and scales of the impacts.

Table 1

Conceptual framework for primary physico-chemical impacts of highway construction. The scale and nature of primary environmental impacts change from the direct effects of highway construction to the secondary and indirect effects associated with the presence of a highway and urban development. These may be viewed as a gradient of changing concerns and impacts through time. All physico-chemical impacts have important consequences for stream biota but the degree of peer-reviewed investigation differs among stages

	Developmental stage		
Impact characteristics	Highway construction	Highway presence	Urbanization
Temporal extent	Temporary	Chronic	Chronic
Spatial extent	Local	Regional	Regional
Primary nature	Physical	Physical and chemical	Physical and chemical
Degree of investigation	Low	Moderate	High

The predictable effects of the three consecutive stages of new highway construction are seldom considered simultaneously in environmental assessments. The National Environmental Policy Act (NEPA), the Council on Environmental Quality (CEQ), and various state environmental laws (CEQ, 1997) require state and federal transportation agencies to consider the significance of anticipated impacts in environmental assessments (EAs) or prepare environmental impact statements (EISs) when significant impacts are anticipated. However, these assessments generally focus almost exclusively on short-term, localized impacts and ignore the long-term secondary and cumulative impacts (Spaling and Smit, 1993; McCold and Holman, 1995; Burris and Canter, 1997; Cooper and Canter, 1997; Angermeier et al., 2004) that are often primary concerns of the government agencies and civilian stakeholders reviewing these documents (e.g., NCWRC and NCDPR, 2002). Although European countries more rigorously apply ecological principles to transportation projects than the United States (Forman and Alexander, 1998), inadequate assessment of cumulative effects is a global problem (Cooper and Sheate, 2002).

Evaluations of the thoroughness of EISs and EAs are often limited due to a lack of published summaries of the impacts that may be expected from proposed projects. For example, evaluations of EISs and EAs have searched for the assessments for key words or concepts rather than assessing how meaningful and thoroughly probable impacts were considered (e.g., Burris and Canter, 1997; Cooper and Canter, 1997). A new review of the extent and nature of impacts from new highways that considers the stages and changing impacts identified by Angermeier et al. (2004) will assist reviewers of EISs and EAs in explicitly linking the successive stages, a step often ignored in assessment-proposed highway projects. Our review summarizes investigations that will help environmental and fisheries scientists consider potential impacts of proposed highway projects over multiple dimensions, but are often unavailable in field offices, and spread widely across academic disciplines. In addition EISs, EAs, and previous reviews often make assertions based on unpublished government reports which suffer the general inadequacies of "grey" literature (Collette, 1990). In contrast, we rely almost exclusively on published, peer-reviewed studies.

The purpose of this article is to review the impacts of new highways through undeveloped land. Although not the focus of this review, much of the information presented may be relevant to more common highway improvements, such as lane additions and surface upgrades. We focus on studies conducted in the United States, but some relevant international research is included to supplement sparsely researched topics. Following our conceptual framework (Table 1), we synthesize the scientific knowledge on physical, chemical, and biological responses of streams during 1) highway construction, 2) highway presence, and 3) watershed urbanization. The ultimate goals of this review are to provide information that will: 1) improve the ability of transportation planners to prepare more through, meaningful, and science-based EISs and EAs, and 2) spur research in subject areas where rigorous studies are lacking but information is needed for comprehensive impact assessment of new highways.

Highway Construction

Highway construction can be highly destructive to stream habitat and biota. Impacts on streams are primarily acute, local, and physical in nature (Table 1). Highway construction primarily degrades stream habitat locally but some of these impacts may transport downstream. In contrast to impacts of highway presence and landscape urbanization, many construction impacts may be temporary and streams can recover if not recurrently disturbed. In this section, we review literature assessing these acute impacts (e.g., sedimentation). Other impacts initiated during construction but posing long-term threats, such as channelization and culverts, are considered in the Highway Presence section.

Highway Construction and Physical Habitat

As with any earth-moving activity, the greatest threat of highway construction to streams is fine sediment pollution, which can cause a variety of problems for resident biota, including direct mortality, reduced reproductive success, and a reduction in the food base (reviewed in Waters, 1995). Fine sediment pollution originates as bare soil erodes into streams, usually after exposure to precipitation or flowing water. Streams impacted by highway construction accumulate (Clarke and Scruton, 1997) and transport (Weber and Reed, 1976) many times more sediment than undisturbed streams. Although a variety of erosion control procedures are available and often legally required, they are seldom evaluated for their effectiveness (but see Grace (1999), Benik et al. (2003a, 2003b)) and have a risk of failure seldom considered in published investigations or environmental impact statements. A Pennsylvania study found that, even in the presence of sediment control techniques, streams impacted by highway construction carried 5 to 12 times more fine sediment than a control stream (Weber and Reed, 1976). The suspended solids load of a Ontario stream increased from an average of 2.8 mg/l to 352.0 mg/l during the initial "clearing phase" and peaked at 1,390 mg/l during highway construction (Barton, 1977). In addition, Barton (1977) observed a 10-fold increase in fine sediment deposition following a highway construction channelization project but stream sediment loads approached preconstruction levels near the completion of the construction. Increases in suspended sediment are detectable for long distances (kms) downstream of construction sites (Wellman et al., 2000). These sediments deposit in downstream pools, riffles, and impoundments (Duck, 1985; Brookes, 1986).

Highway construction can result in a variety of other seldom studied physical habitat degradations by encroaching onto floodplains and damaging riparian areas. Heavy equipment accessing the stream may incidentally damage (Hubbard et al., 1993) or purposely remove (Stout and Coburn, 1989) riparian vegetation during highway construction. Riparian vegetation is a critical component of stream watersheds and performs many important functions for streams (see Urbanization section). Streams near highways are often channelized and the initial effect of heavy equipment modifying the stream channel may alter the dynamic equilibrium of streams and result in rapid channel reorganization, all of which can lead to additional sedimentation and erosion downstream.

Highway Construction and Stream Chemistry

We found no studies documenting chemical impacts of highway construction on streams. However, the use of heavy machinery in and around streams likely causes some chemical pollution. In addition, many highway construction materials are highly toxic to aquatic biota. For example, industrial waste materials and byproducts such as shredded tires, ashes, mining wastes, municipal sludge, and wood wastes may be used in highway construction (Eldin, 2002). These materials release heavy metals and hydrocarbons which are toxic to water fleas *Daphnia magna* and algae *Selenastrum capricornutum* (Eldin, 2002). The toxicity of these materials may be reduced when in contact with soil, and during typical construction these toxins are unlikely to reach detrimental levels in streams. Nevertheless, the proximity of toxic materials to streams increases the chances of accidental spills and releases.

Biological Effects of Highway Construction

The impact of highway construction on stream fishes and macroinvertebrates is rarely studied. Similar to other anthropogenic landscape changes, highway construction is difficult to research for several reasons. Highway construction consists of many individual impacts that occur concurrently; thus, specific causal mechanisms are difficult to establish. An additional obstacle to research is that construction timeframes are often unpredictable, and construction often takes longer than the tenure of a typical graduate student. In addition, highway construction presents statistical and study design difficulties; for example, treatments are difficult to replicate and meaningful controls difficult to establish.

We found only a few studies investigating the effects of highway construction on stream fishes and macroinvertebrates. However, fine sediment pollution occurs from a variety of anthropogenic sources and is widely studied outside the context of highway construction. The effect of fine sediments on stream biota has been recognized for decades (Ellis, 1936) and is the subject of many previous reviews (Chutter, 1969; Bruton, 1985; Ryan, 1991; Waters 1995; Wood and Armitage, 1997; Henley et al., 2000). Therefore, in addition to studies that directly focus on highway construction, this section includes more general investigations of the effect of fine sediment on stream biota.

Fine sediment pollution from highway construction can immediately alter macroinvertebrate and fish communities (Barton, 1977). Reductions in the abundance and diversity of macroinvertebrates may depend on the timing and duration of construction impacts (Cline et al., 1982). Stout and Coburn (1989) found an absence of macroinvertebrate shredders in pools below highway construction. Fine sediment from highway construction may result in reduced macroinvertebrate diversity and density (Lenat et al., 1981). Highway construction can immediately reduce the overall abundance of stream fishes by over 50% (Whitney and Bailey, 1959; Barton, 1977). Taylor and Roff (1986) reported that the abundance of bottom-feeding fishes is initially reduced, but recovers after fine sediment deposition rates decline. Fish and invertebrate communities begin recovering after the fine sediment loads are reduced and deposits wash downstream, but full recovery may require years (Taylor and Roff, 1986).

Fine sediment pollution degrades stream biotic communities through a variety of mechanisms. Stream periphyton and macrophytes are abraded, suffocated, and shaded by fine sediment (Waters, 1995). Fine sediment loads impact macroinvertebrates by inducing catastrophic drift (Culp et al., 1986), damaging individual's respiratory structures (Lemly, 1982), and reducing habitat by clogging interstitial spaces in streambeds (Lenat et al., 1981). Fine sediment can also clog the gills of fishes and reduce the quality of their habitats for feeding by impairing visibility and reducing prey abundance (Bruton, 1985). It is possible that construction interferes with a variety of feeding strategies; Berkman and Rabeni (1987) found that fine sediment deposition reduced populations of both insectivorous and herbivorous fishes. In addition, fine sediment suspended in the water can lower reproductive success of fishes (Burkhead and Jelks, 2001). For example, egg survival of some species depends on substrate that is permeable to water flow (Kondou et al., 2001).

Highway Presence

Although highway construction can be highly detrimental to stream habitat and biota, construction sites are sparse compared to the land covered and increasingly affected by existing highways. Currently in the United States, there are 6.3 million km of public roads, 60% of which are paved with a surface area of about 50,000 km^2 (Eldin, 2002). At present, 20% of the United States' land area is directly affected by road presence (Forman, 2000), and 50% is within 382 m of a road (Ritters and Wickham, 2003). In contrast to the localized, temporary effects of highway construction, the extensive effects of highway presence are persistently generated by highways with direct hydraulic connections to streams (Table 1).

Highways and Physical Habitat

Although pulses of highway runoff can substantially affect stream channels, we found no studies of its impact on physical stream habitat. However, many investigators have examined the impacts of logging roads (see Gucinski et al., 2001). Although unpaved forest roads are not the subject of this review and differ from paved highways in many aspects, they are similar in that their impervious surfaces collect stormwater and route runoff into streams. Collecting and routing runoff to streams causes logging roads to increase the magnitude and frequency of stream flooding (King and Tennyson, 1984; Jones and Grant, 1996). These runoff changes are also characteristic of urban areas and cause a variety of physical changes to stream channels, such as channel widening and downcutting (see Urbanization section). However, because paved roads are only minor components of the total impervious surfaces of an urban watershed, the presence of a single highway in a watershed likely results in less changes to flow regimes and, ultimately, less severe changes to physical stream habitat than urban development.

Streams near highways are often channelized during construction. However, unlike many construction impacts such as fine sediment pollution, this modification has continual long-term consequences for physical stream habitat. Channelization increases channel slope, reduces base flows, increases peak flows, alters substrate composition, and severs floodplain links (Hubbard et al., 1993). Overall, channelization reduces the habitat diversity characteristic of natural streams by replacing coarse substrates with finer substrates, reducing depth and velocity heterogeneity, creating more laminar flows, removing cover, and eliminating natural pool-riffle sequences (Peters and Alvord, 1964; Narf, 1985).

If engineered properly, bridges may cause minimal impacts on the physical stream channel; however, through channelization or poor construction practices, bridges can destabilize stream channels. Although culverts are generally more detrimental to stream habitat and biota, they are often installed as a cheaper alternative to spanning structures. The presence of cluverts destabilizes stream channels by interrupting the downstream transport of woody debris, sediment, substrate, and water. Although few quantitative studies of the impact of culverts on physical stream habitat are available, Gubernick et al. (2003) provided a qualitative overview. Unlike dynamic natural stream channels, culverts are rigid and unaccommodating to changes in channel morphology. In addition, the stream channel is often widened above the culvert, reducing current velocities and forming a sediment trap. Although downstream sediment flow is reduced above the culvert, it continues or accelerates below the culvert causing channel downcutting and resulting in an elevation drop, even if initial construction put the pipe at stream level. Typically, culverts are sized to accommodate rare flood flows but are too small to allow passage of woody debris. Accumulations of woody debris near the inlet can starve downstream areas of this important component of stream habitat (see Urbanization section) and may plug the culvert, causing failure of road fill during floods and increasing the risk of catastrophic debris torrents.

Highways and Stream Chemistry

Highway surfaces collect a variety of chemical pollutants from automobile traffic and are disproportionate contributors to overall pollutant loads. For example, public highways

cover 8% of Rhode Island, but produce 16% of the state's oil and grease pollution, and 77% of the state's zinc pollution (Hoffman *et al.*, 1985). These pollutants are mobilized by runoff water and transported to streams where they accumulate in sediments and biota and spread downstream, resulting in chronic and widespread effects. This runoff represents an important, but relatively unstudied, component of stream pollution (Wu et al., 1998).

Traffic residue adds a variety of metals to highway runoff, including iron, zinc, lead, cadmium, nickel, copper, and chromium. Tires contain up to 1% zinc by weight (Hedley and Lockley, 1975) and are a significant source of zinc in the environment (Davis et al., 2001). Brake pad dust contributes copper (Davis et al., 2001). These metals accumulate in roadside dust (Leharne et al., 1992), soil (Goldsmith et al., 1976; Garcia-Miragaya et al., 1981), and stream sediments (Van Hassel et al., 1979; Maltby et al., 1995b). The concentrations of metals in stream sediments are positively related to the volume of traffic (Van Hassel et al., 1980; Callender and Rice, 2000) and accumulate in proportion to the length of highway drained (Maltby et al., 1995b), suggesting that pollution will be most severe when large highways are drained by small streams.

Highway surfaces also accumulate petroleum from automobile traffic. Motor oil accumulates from crankcase drippings, washes off the highway surface, and accumulates in stream sediments (Hoffman et al., 1985). Until the Clean Air Act of 1970 phased out leaded gasoline, lead was the most widespread metal pollutant from automobile traffic. Unleaded gasoline permits the use of catalytic converters, which convert gaseous exhaust pollutants such as carbon monoxide, nitrous oxides, and hydrocarbons to less toxic chemicals such as carbon dioxide, nitrogen, and water. The chemical reactions are catalyzed in automobile exhaust systems by platinum group elements (PGEs), including platinum, palladium, and rhodium, which are emitted on highway surfaces during operation. Since the introduction of catalytic converters, PGEs have become a new and relatively unstudied metal pollutant of stream sediments (Rauch and Morrison, 1999). In addition, iridium, rubidium, and osmium are common impurities in PGE catalysts and may also be deposited on highways (Rauch et al., 2004). Concentrations of PGEs in roadside soils are related to traffic volume and are increasing to such a degree that their recovery (i.e., mining roadside soil) may become economically viable (Ely et al., 2001).

In areas that undergo winter weather, deicing salt is another widespread, but little studied, chemical pollutant of streams. Deicing salt is spread on highways in anticipation of and during snow and ice accumulation, from where it washes directly into streams or is stored in the soil. A study in Pennsylvania found 20- to 30-fold increases in a stream's conductivity during winter thaws (Koryak et al., 2001). Although concentrations harmful to fish are considered rare (Transportation Research Board, 1991), few studies have addressed the effects of these "shock loads" of salt on stream biota. Koryak et al. (2001) observed only pollution-tolerant macroinvertebrates and stressed fish communities in areas receiving shock loads of deicing salt. Furthermore, deicing salt may be contaminated by metals and nutrients. Phosphorous, lead, and zinc were found in highway deicing salt and anti-skid sand in Minnesota (Oberts, 1986) and iron, nickel, lead, zinc, chromium, and cyanide in deicing salt in England (Hedley and Lockley, 1975). Road salt that does not run off directly into streams may still cause chronic problems through slow release into adjacent soils; chlorine ions from road salt have a soil residence time of at least 2 years (Mason et al., 1999).

Another concern associated with the presence of a highway is the inevitability of toxic chemical spills. In 1982, hazardous materials made up more than 25% of all domestic freight shipments (List and Abkowitz, 1986). Almost all types of hazardous wastes and 62% of all hazardous materials (by weight) are moved by truck (Abkowitz et al., 1989; Atkinson and Cairns, 1992). Unfortunately, accidental releases during shipping are not infrequent.

Between 1990 and 1994 an average of 10,000 accidents per year were reported, releasing 2,445 kl of hazardous materials annually on U.S. highways (USEPA, 1996).

Biological Effects of Highways

Highways have many detrimental effects on stream biota. Toxic chemical spills often occur from truck accidents, and can cause fish kills extending downstream for great distances (kms). Stream crossings may be especially vulnerable to spills because bridge surfaces encourage automobile accidents because during winter weather conditions by icing more frequently than terrestrial paved surfaces. Furthermore, the inherent vicinity of bridge accidents to streams increases that risk that spilled chemicals may enter streams before containment. Accidental spills are particularly devastating for isolated populations of rare species with limited potential for movement and recolonization, such as freshwater mussels. Although there are many documented cases of such acute effects (USEPA, 1996), we found no studies describing chronic changes in macroinvertebrate or fish communities resulting from repeated toxic spills. Studies examining streams after catastrophic toxic spills have documented eventual recovery and recolonization from adjacent areas (Ensign et al.,1997; Meade, 2004), emphasizing the importance of well-connected habitats to increase resilience of stream biota to the effects of highway presence. Thus, stream reaches that are isolated by culverts, dams, or natural barriers may be particularly vulnerable to spills.

Macroinvertebrates and fishes near highways may have elevated metal concentrations in body tissues. Levels of lead and zinc in fishes and aquatic macroinvertebrates may be locally related to the amount of traffic at upstream highway crossings (Van Hassel et al., 1980) and regionally related to highway densities across large areas (Stemberger and Chen, 1998). Fish species accumulate metals from highway runoff at differential rates (Ney and Van Hassel, 1983). Aquatic macroinvertebrates may absorb platinum from stream sediments (Rauch and Morrison, 1999). The accumulation of toxic chemicals in animal tissue likely results in widespread impacts that spread to terrestrial communities, particularly animals that feed exclusively on aquatic species (e.g., many members of the avian order Ciconiiformes).

Many components of highway runoff such as metals and petroleum are suspected toxicants to aquatic organisms. Although few studies have addressed the toxicity of highway runoff, the sediment from contaminated streams is considered more toxic than the water. Although a variety of potential toxicants, including hydrocarbons, copper, and zinc are found in highway runoff, polycyclic aromatic hydrocarbons (PAHs) in stream sediments may be responsible for the majority of macroinvertebrate toxicity (Maltby et al., 1995a). Boxall and Maltby (1997) confirmed that three specific PAHs, pyrene, fluoranthene, and phenanthrene, were major sediment toxicants for *Gammarus pulex* and accounted for >30% of the toxicity of runoff-contaminated sediments.

Comparisons of macroinvertebrate communities above and below highway crossings are rare but indicate that reductions in diversity and pollution-sensitive species below highway crossing are most pronounced where small streams receive runoff from large sections of highways (Maltby et al., 1995b). These patterns may reflect greater hydrocarbon pollution in sediments below road crossings. Reductions in pollution-sensitive shredders may result in slower leaf litter breakdown (Maltby et al., 1995b), altering stream productivity, nutrient cycling, and food webs.

In addition to chemical effects, highways also impact biota through physical changes to the stream channel. Channelization can have numerous effects on the physical structure and natural environmental regimes of stream systems; these dynamics provide a mosaic of habitats to support resident organisms (Stanford et al., 1996; Poff et al., 1997; Poole, 2002).

Moyle (1976) compared channelized and unchannelized sections of a California stream and found the biomass of fish and invertebrates in channelized locations was less than one-third of that in unchannelized locations. He also found differences in fish and macroinvertebrate species composition between channelized and unchannelized areas. Channelization may reduce the recruitment and production of fishes by eliminating nursery habitat. For example, removal of gradually sloping streambanks increases the area of unsuitable habitat with velocities greater than the swimming speeds of age–0 fishes (Copp, 1991, 1997; Scheidegger and Bain, 1995; Mann and Bass, 1997; Mérigoux and Ponton, 1999; Meng and Matern, 2001).

Culverts are a feature of highway presence that can have a variety of negative impacts on stream biota. Culverts provide poor internal habitat due to low-bottom complexity and uniformly high-flow velocities inside culverts provide poor habitat (Slawski and Ehlinger, 1998), but most importantly, they are notorious fish movement barriers. The effects of highway crossings on stream fish movement depend on the swimming speed and behavior of individual species (Toepfer et al., 1999). Fish passage is obstructed by high current velocities and shallow depths inside culverts, as well as vertical drops at the culvert outflow (Baker and Votapka, 1990). In addition, concrete box culverts may develop internal gravel bars (Wellman et al., 2000) that impede fish movement. Warren and Pardew (1998) found that overall fish movement was an order of magnitude lower through culverts than through other crossing types or natural channels in small, warmwater Arkansas streams. Culverts throughout a tributary network can reduce production of species that require spawning migrations, such as coho salmon *Oncorhynchus kisutch*, by preventing adults from reaching spawning habitat (Beechie et al., 1994). Barriers can isolate populations, resulting in reduced genetic diversity and increased probability of extinction due to demographic instability and impeded recolonization. Most investigations of fish movement barriers have focused on economically important fishes with known migration patterns; for example, Belford and Gould (1989) determined combinations of water velocity and culvert length that prevented passage by brook trout *Salvelinus fontinalis*, rainbow trout *Oncorhynchus mykiss*, and brown trout *Salmo trutta*. However, entire fish communities are vulnerable to highway crossing movement barriers (Jackson, 2003) and the importance of movement and movement barriers to nongame fishes and fish communities is poorly understood. In one of the few published studies for a nongame species, Schaefer et al. (2003) found that a variety of culvert types significantly decreased the probability of movement of the federally threatened leopard darter *Percina pantherina* between habitat patches. Although culverts present a variety of obstacles to fish movement, engineers designing passable culverts may narrowly focus on the effects of singular parameters such as vertical outflow drop distance or current velocity (e.g., Rowland et al., 2003) and not consider the cumulative effects of multiple passage inhibiting features.

Urbanization

Urbanization is difficult to define, as the meaning of "urban" varies across disciplines (Paul and Meyer, 2001). We modify the definition by Kemp and Spotila (1997) and define urbanization as development in a watershed, such as building construction, that changes land use typical of rural areas (e.g., farming, grazing) to uses more typical of residential and industrial areas (e.g., retail, suburban residential areas, plants and factories). This definition describes the general process of watershed-altering development that is characteristic of the urban landscape and the focus of this review.

The construction of new highways is the "quintessential public sector investment" by which government attempts to encourage economic growth in rural areas (Chandra and Thompson, 2000). At the state level, new highways are ineffective at increasing economic activity (Evans and Karras, 1994; Holtz-Eakin, 1994; Dalenberg and Partridge, 1997), but they effectively redistribute economic activities among locales. New highways reduce traditional rural economic activities of nearby counties such as agriculture, but enhance and concentrate urban economic activities such as manufacturing and retail in the county the highway intersects (Rephann and Isserman, 1994; Chandra and Thompson, 2000). The construction of new highways also increases the price of agricultural land (Shi et al., 1997), thereby encouraging development. Shifting the economic productivity from rural to urban activities promotes urbanization, at least in the county the highway passes through, as reduced travel time to cities encourages establishment of commerce in previously undeveloped areas. Although final decisions for urban development are made by local governments, new highways clearly and purposely provide impetus for urban development.

Much of our understanding of the relation between new highways and urban development is based on patterns observed at interstate highway exits. Key characteristics of interstate exits related to the rate and nature of urban development in North Carolina include traffic volume of the interstate and crossroad, location, and population of nearby communities, distances to urban centers, degree of preexisting development, and distance to the next interchange (Hartgen et al., 1992). A later study concluded that these relationships were consistent for interstate exits nationally (Hartgen and Kim, 1998). Hartgen et al. (1992) described the general requirements, stages, and potential paths of interchange development, and all potential paths predict that interstate construction leads to the conversion of forested and agricultural areas to commercial or residential development. Improvements to existing highways, such as lane additions, also increase development activity along the highway corridor (Cervero, 2003).

Other studies have documented land use change induced by the presence of nearby highways. Although these studies do not address the construction of new highways, they provide insight into the relationship between a new highway and landscape urbanization at points other than exits. Bradshaw and Muller (1998) forecasted the conversion of farmland to urban areas in California, describing highways between cities as "magnets for decentralized growth." In the southern Appalachian Mountains, areas close to highways were more likely to experience development (Wear and Bolstad, 1998).

Although the relation between the construction of a new highway and urban development is intuitive, predictable, and often a declared political goal, few investigators have examined this connection. Indeed, this connection is a contentious issue for transportation planners. The position that new highways do not result in urban development, although apparently ubiquitous among transportation planners, is not well-supported by published studies and our literature review failed to produce any peer-reviewed examples refuting a positive relation between highway construction and urban development (but see Hartgen (2003a, 2003b)).

A stream's physical habitat and chemical environment are largely products of its watershed. Thus, as a watershed urbanizes, changes occur in stream habitat, water chemistry, and ultimately biota. Similar to the presence of a hydraulically connected highway, urban development continually affects streams and causes extensive and chronic impacts (Table 1), but at greater magnitudes. Runoff from urban areas contains all the chemical pollutants from automobile traffic as well as those from urban sources. In addition, urbanization drastically alters how a watershed produces stream flow, resulting in many changes in physical habitat.

Urbanization and Physical Habitat

Undeveloped watersheds are characterized by land surfaces that are pervious to precipitation. Rain falling in undeveloped watersheds infiltrates the soil and reaches streams slowly as subsurface flow. The urban landscape, however, is characterized by rooftops, asphalt, compacted soils, and other highly impervious surfaces (Schueler, 1994, 1995). These impervious surfaces with direct hydraulic connections to streams (Schueler, 1994; Wang et al., 2001, 2003), capture precipitation and route it quickly into storm sewers and gutters and, ultimately, into streams (Hollis, 1975). Similarly, precipitation falling on impervious surfaces without direct hydraulic connections to streams may reach streams quickly as overland flow (Horton, 1945; Leopold, 1973). Thus, urbanization fundamentally alters the delivery of water to streams (Booth, 1991).

These changes in precipitation delivery alter stream flow regimes. As a watershed urbanizes, peak flow volume from precipitation events increase (Hollis, 1975; Beard and Chang, 1979; Neller, 1988; Booth, 1990; Clark and Wilcock, 2000; Rose and Peters, 2001), thereby increasing the frequency of bankfull flows (Leopold, 1973; Hollis, 1975; Arnold et al., 1982; Moscrip and Montgomery, 1997). Even low levels of paving increase the magnitude of frequent floods (recurrence interval $\leq$ 1 year); for example, paving 20% of the watershed can increase the peak discharge of the mean annual flood by an order of magnitude (Hollis, 1975). Thus, discharge rates that previously occurred once every 2 years may double in frequency following watershed development (Booth, 1991). Ten-year floods may occur 2.5 to 10 times more frequently following watershed urbanization (Moscrip and Montgomery, 1997). In addition, precipitation events that produced no increase in stream flow prior to urbanization may generate substantial flooding following watershed urbanization (Booth, 1991).

These changes in flood frequency and magnitude result in a variety of changes to physical features of streams. Bankfull and greater flows cut and form stream channels and adjust channel capacity such that bankfull conditions occur on an average of once every 1 to 2 years (Wolman and Miller, 1960; Leopold, 1973). The increased frequency of bankfull flows following urbanization causes a stream to increase its channel capacity by eroding its banks, downcutting its channel, or both (Hammer, 1972; Leopold, 1973; Arnold et al., 1982; Allen and Narramore, 1985; Booth, 1990, 1991; Gregory et al., 1992; Pizzuto et al., 2000). Thus, urban streams are wider and deeper than unaffected channels.

Impervious surfaces increase peak flow at the expense of base flow. Base flows result from subsurface flow and groundwater that steadily contributes to streams between precipitation events. Because impervious surfaces prevent precipitation from infiltrating below the surface, urban streams are characterized by low base flows (Simmons and Reynolds, 1982; Wang et al., 2001, 2003). Low flows combined with the effects of channel enlargement, results in urban streams that feature oversized stream channels with little water between runoff events.

Streams in urbanized watersheds enlarge their channels by eroding their banks. Bank erosion as well as runoff from urban construction activities adds fine sediment to the receiving stream (Waters, 1995; Trimble, 1997). Typically, fine sediment is a minor component of pristine streams. For example, a stream flowing through a completely forested watershed receives about 11.3–33.8 metric tons per ha of sediment annually; in contrast, an urbanizing watershed may receive more than 226,000 metric tons per ha annually (Wolman, 1967; Wolman and Schick, 1967). This dramatic increase in fine sediment can devastate, and ultimately, extirpate stream biota (see Highway Construction section). Channel enlargement may be balanced by rapid loading of fine sediment during the initial phases of urbanization. For example, Wolman (1967) hypothesized that high sediment loads from the construction phases of urbanization could temporarily clog and constrict stream channels, a phenomenon later observed by Leopold (1973).

When the extent of urbanization in a watershed stabilizes, stream channel enlargement may cease, and the channel banks may restablize. In addition, as the rate of urban development declines, fine-sediment loading may be greatly reduced as construction site soils are stabilized via revegetation or pavement, and prior deposits may be removed by scouring during subsequent flooding (Wolman, 1967; Clark and Wilcock, 2000; Finkenbine et al., 2000). However, the process of bank erosion, downcutting, and channel adjustment may continue for several decades, and some streams never stabilize (Henshaw and Booth, 2000).

Urbanization typically results in loss of streamside (riparian) vegetation as areas near streams are cleared. The degree of riparian disturbance varies with type of urban land use. For example, Thibault (1997) found the land used for transportation, schools, and industry had more intact riparian areas than residential, commercial, and recreational land. Riparian vegetation is a critical component of the watershed (reviewed by Karr and Schlosser, 1978; Gregory et al., 1991; Naiman and Décamps, 1997; Pusey and Arthington, 2003) and, although they cover a small percentage of the watershed, riparian areas are disproportionately important for stream health. Intact riparian areas absorb and filter out metals, fine sediment, and nutrients from overland runoff (Castelle et al., 1994) and generally mitigate the physical and chemical effects of urbanization (May et al., 1997). Riparian vegetation stabilizes streambanks and reduces bank erosion (Whipple et al., 1981; Beeson and Doyle, 1995; Finkenbine et al., 2000), and helps moderate urban stream temperatures (LeBlanc et al., 1997).

Riparian vegetation contributes leaves, wood, and other organic debris to streams. The biota of small ($\leq$ fourth-order) streams, such as those generally associated with urban areas (Heaney and Huber, 1984), depend on leaves and organic inputs as their energy base (Vannote et al., 1980; Hawkins and Sedell, 1981). Large woody debris is an important component of stream channels because it stabilizes stream banks (Keller and Swanson, 1979; Booth, 1991; Gregory et al., 1991; Finkenbine et al., 2000), creates pools (Keller and Swanson, 1979; Larson et al., 2001), and provides habitat for macroinvertebrates (Benke et al., 1985) and fishes (Angermeier and Karr, 1984; Flebbe and Dolloff, 1995). In urban areas, recruitment of woody debris declines as development removes floodplain trees and instream abundance is typically reduced by intentional debris removal (Larson et al., 2001).

Stream water temperature is a major determinant of the distribution and abundance of aquatic biota and is primarily regulated at two spatial scales, the riparian and the watershed. Riparian vegetation shelters streams from warming by absorbing or reflecting sunlight before it reaches the water. Thus, loss of riparian vegetation contributes to the warming of urban streams (Barton et al., 1985; LeBlanc et al., 1997). At the watershed scale, impervious surfaces, especially parking lots, collect and heat runoff water before it reaches streams. For example, Van Buren et al. (2000) developed a computer model to predict runoff temperature and observed that a parking lot produced runoff 5.9°C warmer than summer rainfall. The maximum daily water temperature in Wisconsin and Minnesota streams increase by 0.25°C with every 1% increase in the impervious area of the watershed (Wang et al., 2003). In addition to increases in average water temperature, urban streams exhibit increased temporal variability (Moglen et al., 2004).

Urbanization and Water Chemistry

Urban runoff contains a variety of chemical pollutants including petroleum, metals, and nutrients. Rivers and streams receive the majority of urban runoff (84%) (Heaney and Huber, 1984) and chemical pollutants are often stored in stream sediments. House et al. (1993) reviewed the constituents and impacts of urban runoff on receiving waters.

Oil and grease enter urban runoff from a variety of sources including deliberate dumping, automobile engine emissions, and chemical spills; however, the majority originates from automobile crankcase drippings (Hoffman et al., 1982). Parking lots accumulate oil and grease deposited by parked vehicles and become the primary land use source of oil and grease in urban runoff. Stenstrom et al. (1984) observed concentrations of oil and grease up to 15 mg/l in parking lot runoff. Automotive sources of metals in urban runoff include zinc from tire wear (Hedley and Lockley, 1975) and motor oil (Davis et al., 2001), platinum from catalytic converter emissions (Rauch and Morrison, 1999), and lead from motor oil (Davis et al., 2001).

In addition to automotive sources, urban runoff accumulates metals from a variety of other sources. For example, iron originates from the corrosion of steel (Characklis and Wiesner, 1997), zinc from the corrosion of galvanized metals (Hedley and Lockley, 1975), roofing, and painted wood (Davis et al., 2001), and lead from brick and painted surfaces (Davis et al., 2001). Other metals in urban runoff include chromium and nickel (Klein et al., 1974; Helsel et al., 1979; Rhoads and Cahill, 1999). Metals from urban runoff accumulate in stream sediments (Garie and McIntosh, 1986; Rauch and Morrison, 1999), where concentrations are related to both population and traffic densities (Callender and Rice, 2000).

Urban runoff is high in nutrients such as nitrogen and phosphorous that can result in detrimental algal blooms and decreased dissolved oxygen levels. Nutrient levels in streams are typically predictable from land use (e.g., Herlihy et al., 1998). For example, the risk of nutrient pollution increases as nonforest land cover reaches 10% of the watershed (Wickham et al., 2000). Historically, nutrient pollution has been associated with agricultural land use, but urban land often produces greater nutrient loading. For example, concentrations of total phosphorous and total nitrogen in urban streams were 2 to 10 times higher than agricultural and forested streams in Missouri (Smart et al., 1985). Other studies have reported higher concentrations of nitrogen and phosphorous in urban streams than in agricultural and forested streams (Osborne and Wiley, 1988; Wahl et al., 1997).

Biological Impacts of Urbanization

Altered and impaired biotic communities are characteristic of urban streams. Urban macroinvertebrate communities have reduced taxa richness (Garie and McIntosh, 1986; Jones and Clark, 1987; Kemp and Spotila, 1997), reduced density (Garie and McIntosh, 1986), lower index of biotic integrity (IBI) scores (Steedman, 1988; Kennen, 1999), lower functional diversity (Pedersen and Perkins, 1986), and lower taxonomic diversity (Pratt et al., 1981; Shutes, 1984; Pedersen and Perkins, 1986). In an extensive survey of New Jersey streams, Kennen (1999) found that locations with severe macroinvertebrate community impairment were most commonly downstream from urban areas. Urbanization reduced taxa-diversity and richness by reducing the density of pollution intolerant taxonomic orders (Ephemeroptera, Coleoptera, Megaloptera, and Plecoptera) and increasing the density of pollution tolerant Diptera in Virginia streams (Jones and Clark, 1987). Macroinvertebrate diversity may decline progressively as streams flow through urban areas (Pratt et al., 1981).

Macroinvertebrate diversity was reduced to taxa-tolerant of physical disturbances in an urban Washington stream (Pedersen and Perkins, 1986).

Fish communities are similarly impaired by urbanization. Urban stream fish communities have lower overall abundance (Weaver and Garman, 1994; Albaneese and Matlack, 1998; Wang et al., 2000, 2003), diversity (Tramer and Rogers, 1973; Klein, 1979; Scott et al., 1986; Weaver and Garman, 1994; Onorato et al., 2000; Wang et al., 2000), IBI scores (Schleiger, 2000; Wang et al., 2003), taxa richness (Weaver and Garman, 1994; Albanese and Matlack, 1998; Schleiger, 2000; Wang et al., 2000), darter species richness (Weaver and Garman, 1994; Albanese and Matlack, 1998; Schleiger, 2000), and darter abundance (Kemp and Spotila, 1997; Onorato et al., 2000), and are dominated by pollution tolerant species (Wichert, 1994, 1995; Kemp and Spotila, 1997; Albanese and Matlack, 1998; Wang et al., 2003). Lead content in fish tissue is higher in urban areas (Stemberger and Chen, 1998). Furthermore, the proximity of urban streams to humans increases the risk of nonnative species introduction and establishment.

Although many studies describe the alteration of stream macroinvertebrate and fish communities by urbanization, the mechanisms linking specific urban impacts to specific community responses are largely unknown. Since multiple chemical and physical impacts of urbanization occur simultaneously, it is difficult to determine how specific environmental stresses affect biotic communities. However, changes in physical habitat likely impacts biotic communities more than changes in water chemistry. For example, fish and macroinvertebrate communities become impaired at the onset of urbanization (Klein, 1979), when physical changes are more prevalent than water chemistry changes. Most water chemistry changes are not detectable until urban land cover exceeds 40% of a watershed (May et al., 1997).

Threshold Effect of Urbanization

In the last 100 years, the field of stream ecology has expanded its spatial focus from small habitat patches to entire watersheds (Miranda and Raborn, 2000). Consistent with this paradigm shift and advances in geographic information systems and remote sensing, recent studies have addressed how different spatial configurations of urbanization affect stream communities. For example, investigators have documented relations between percent urban land cover (ULC) (Steedman, 1988), percent impervious area (Klein, 1979; Booth and Jackson, 1997; Wang et al., 2000), percent impervious area with direct connections to streams (Booth and Jackson, 1997; Wang *et al.*, 2001, 2003), and biotic parameters. These studies overwhelmingly conclude that very low levels (8–10%) of ULC (or surrogate measures) result in highly altered fish and macroinvertebrate communities. Even after this low level of development, successful restoration of these communities back into preurban conditions may be near impossible, as this small change could result in a shift into a new, less desirable, stable state that is difficult to reverse (Mayer and Rietkerk, 2004).

Initial watershed urbanization following the construction of a new highway is more damaging to stream ecosystems than later, more extensive, development. In macroinvertebrate and fish communities, pollution- and stress-tolerant species rapidly replace intolerant species as ULC approaches 10%. After ULC exceeds 10%, further increases result in little or no fish community changes (Schueler, 1994; Booth and Jackson, 1997; Wang et al., 1997, 2000, 2001). For perspective, 10% ULC is characteristic of areas typically considered "suburban" rather than "urban" (Wang et al., 2000). Although agriculture can have similar effects, streams may support relatively healthy fish communities until agricultural land cover exceeds 80% of the watershed (Wang et al., 1997). Because fish communities in currently undeveloped or agricultural watersheds are likely to be severely degraded by the onset of urbanization (Wang et al., 2000), protection against urbanization impacts should focus on watersheds where urbanization has not yet begun (May et al., 1997). In the context of highway impacts, this means that the greatest damage to stream health is inflicted by building new highways through undeveloped watersheds, which, ultimately, become subject to urban sprawl.

Conclusions

The short-term environmental consideration of transportation projects in EISs and EAs focuses on the initial construction impacts. However, the most serious threats to stream ecosystems are the long-term secondary effects of a highway's presence in the watershed and the cumulative effects of urban development. For example, the biotic integrity of streams in undeveloped (primarily forested or agricultural watersheds) is substantially degraded by the onset of urbanization, thus, streams in undeveloped watersheds are more sensitive to the construction of new highways than streams in urban watersheds. Because many aquatic impacts from the existence of the highway and urban development are long-term considerations, the narrow, short term focus of EISs and EAs provides inadequate protection for stream ecosystems. As new highways continue to diminish the percentage of the landscape that is unaffected by roads, expanding the spectrum of environmental impacts considered for highway projects is increasingly important.

Highway construction and highway presence impose a variety of impacts on stream habitat and biota. Urban development results from the construction of new highways and is clearly the most pernicious threat, as stream habitat and biota are sensitive to even low levels (<10%) of development in a watershed. Watershed urbanization is a predictable indirect or secondary effect of the construction of new highways and NEPA, the CEQ, and various state environmental laws require consideration of indirect and cumulative effects in EISs and similar documents (CEQ, 1997). Although secondary and cumulative impacts are often important considerations of environmental agencies that comment on such assessments (e.g., NCWRC and NCDPR, 2002), landscape urban development resulting from the construction of new highways is generally ignored by the transportation agencies preparing the assessments. The importance of considering the impacts of landscape urban development during initial planning is amplified because this is the final opportunity to consider all effects cumulatively. Landscape urbanization ultimately results from the "tyranny of small decisions" (Odum, 1982) on many individual projects, the cumulative impacts of which are overlooked by the Clean Water Act section 404 permitting process (Stein and Ambrose, 2001), as well as other regulatory mechanisms.

Given the severity and extent of highway impacts on stream biota, we were impressed by the paucity of peer-reviewed literature on many aspects of those impacts. We believe the lack of published studies demonstrates a failure of both management agencies and academic researchers to address a severe and politically thorny environmental issue. Well-designed descriptive studies, in addition to conceptual or theoretical investigations, could contribute substantially to how society views and manages highway impacts. We urge scientists, managers, and policymakers to cooperate more closely to generate comprehensive knowledge about how highways affect ecosystem operation, make that knowledge available to the public (e.g., in EISs and EAs), and apply that knowledge to policy decisions regarding development of sustainable transportation systems.

Although highway construction is ongoing, pervasive, and has severe biological consequences, we found few published investigations of its impacts on streams. We encourage environmental and fisheries scientists to pay closer attention to the effects of new highway construction or highway improvements on streams. Carefully designed, comparative investigations could contribute substantially to our understanding of the differential impacts of various construction techniques, as well as the efficacy and risk of failure of various mitigation practices.

There are many unexploited opportunities to investigate the impacts of highway presence on stream biota. Researchers know little about the occurrence, loading rates, and biotic responses to specific contaminants in highway runoff. Understanding the dynamics and roles of specific pollutants could facilitate more effective mitigation. Future investigation should address the relative importance of chronic pollution, such as metals accumulated in stream sediments, versus acute impacts such as pulses of petroleum and deicing salt. Additional research is also needed to understand how highway crossings, especially culverts, affect fish populations via constraints on movement and how highway networks alter flow regimes of watersheds.

Impairment of stream biotic communities due to urbanization is severe and widely studied. However, opportunities still exist for relatively simple descriptive investigations. For example, we are impressed but the paucity of studies addressing stream thermal pollution from urban runoff and reduced riparian areas. In addition, techniques for minimizing impact or restoring biotic integrity are poorly developed. Research topics that may yield especially useful results include a) the relative importance and biological effects of specific components of urban development: e.g., highway, commercial, or residential, b) the scenarios under which impacts are reversible, and c) the efficacy of mitigation measures: e.g., stormwater retention or treatment and forested buffers. Finally, comprehensive risk analyses that incorporate both social and biotic components are badly needed to examine potential for catastrophic events during all phases of new highway impacts. Risks include mitigation failures and catastrophic spills during the highway construction, presence, and urbanization phases. Depending on the nature of the biotic community (e.g., is it isolated, is the stream small, does it contain sessile species), it may be more or less vulnerable to these kinds of events. Without a spatially explicit, rigorous risk analysis framework, managers cannot properly weigh the risks and benefits of road projects proposed in their areas and have no scientific basis for proposing alternatives that may be less damaging to stream ecosystems.

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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

[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

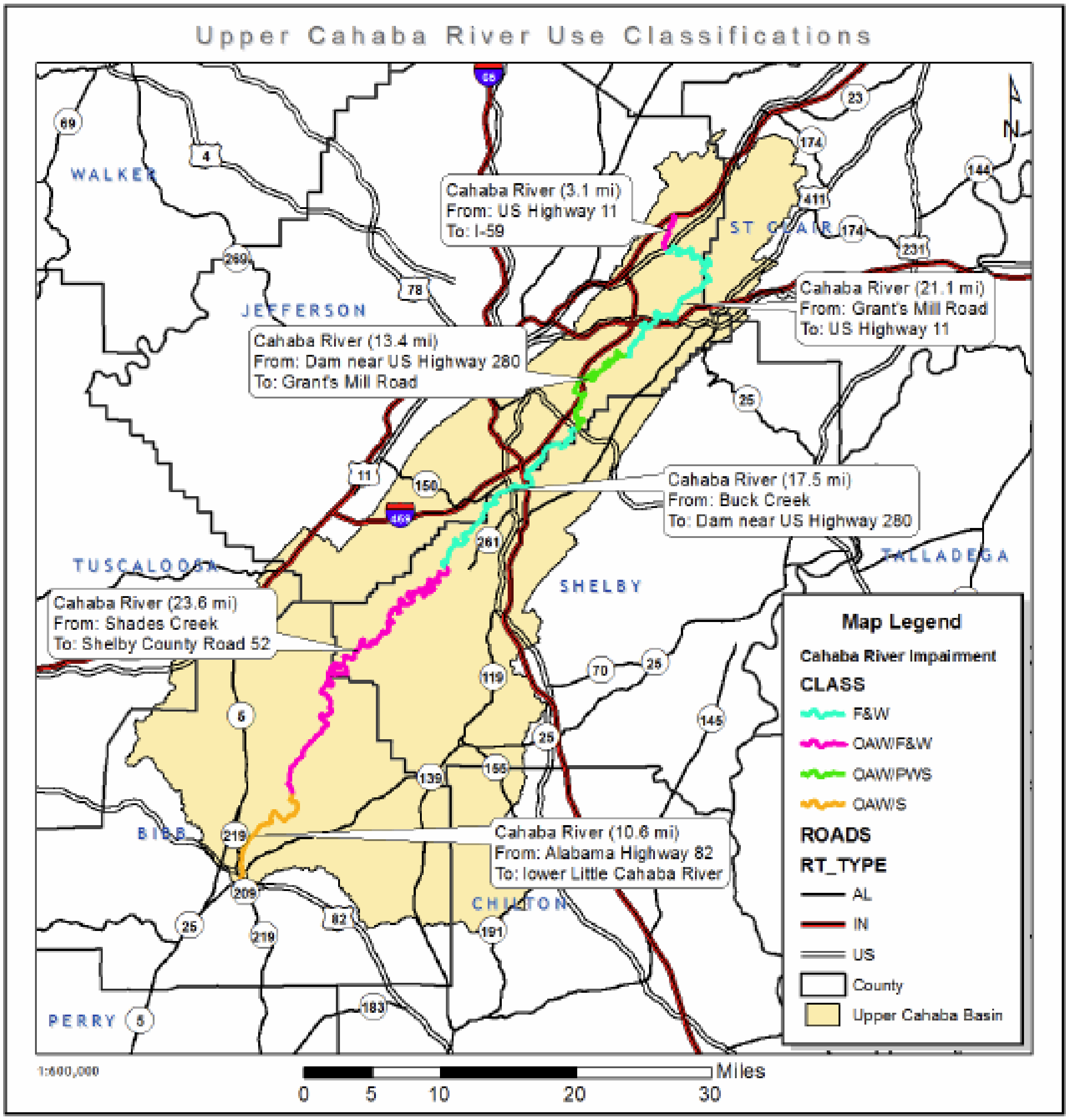

Figure from page 10 of Final Total Maximum Daily Load (TMDL) for Siltation and Habitat Alteration in the Upper Cahaba River Watershed (HUC 03150202), Bibb, Chilton, Jefferson, Shelby, St. Clair and Tuscaloosa Counties, Alabama.

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

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[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.

[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:

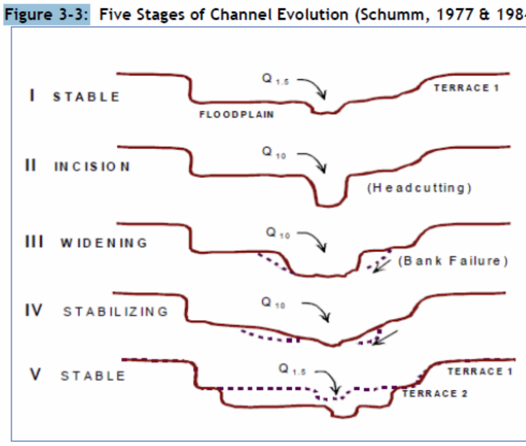
- Variables that reflect increasingly 'flashy' flows
- Variables that reflect diminished groundwater contributions to flow
- Increased average low-flow downstream from wastewater discharges

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.

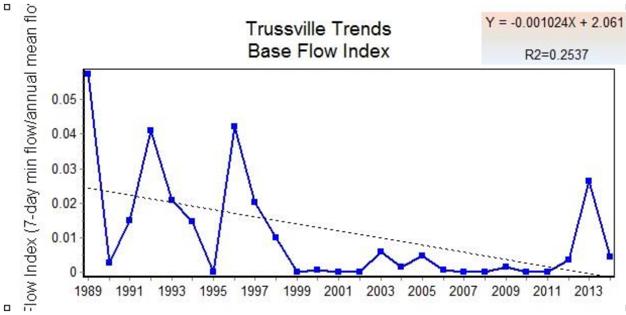
Table 1. Statistically significant trends in Cahaba River Hydrologic Variables as assessed by the TNC's IHA approach.

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.	

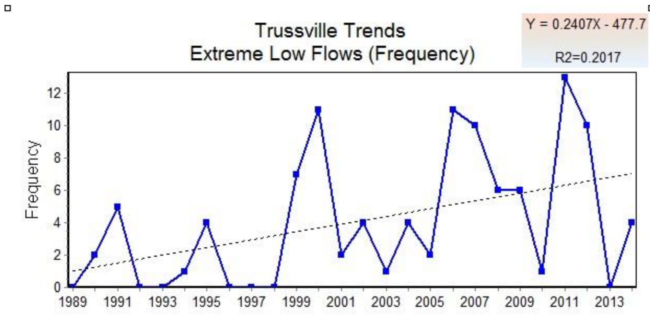
Variable trends with smaller p-values should be considered as potentially important, particularly if those variables measure various aspects of a common cause for hydrologic alteration and particularly if the p-values are 0.01 or less. Here, where urbanization has been widely recognized to contribute 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

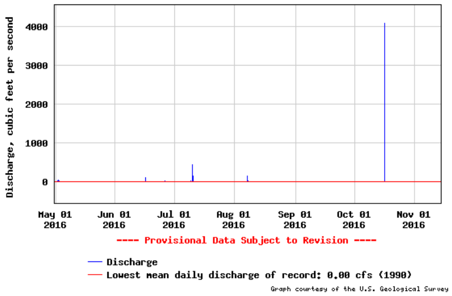


A 'base-flow index' for Trussville is the 7-day minimum flow normalized for a given year by dividing the magnitude of that flow by the mean annual flow for that year. As the proportion of flow that is groundwater diminishes, this index falls. Over the past decades, Trussville has increasingly relied 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.



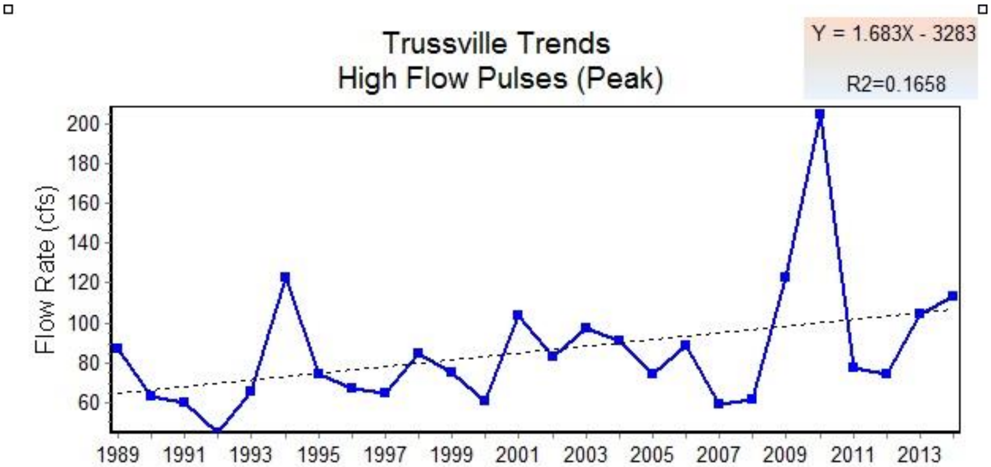
Reduced base-flow will result in an increase in 'Low-pulse Count', a measure of how often the river experiences a significant drop in flow. It also results in the frequency of distinct 'low-flow' events. The graph at right shows the number of 'low-flow' events has increased from an average of one per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

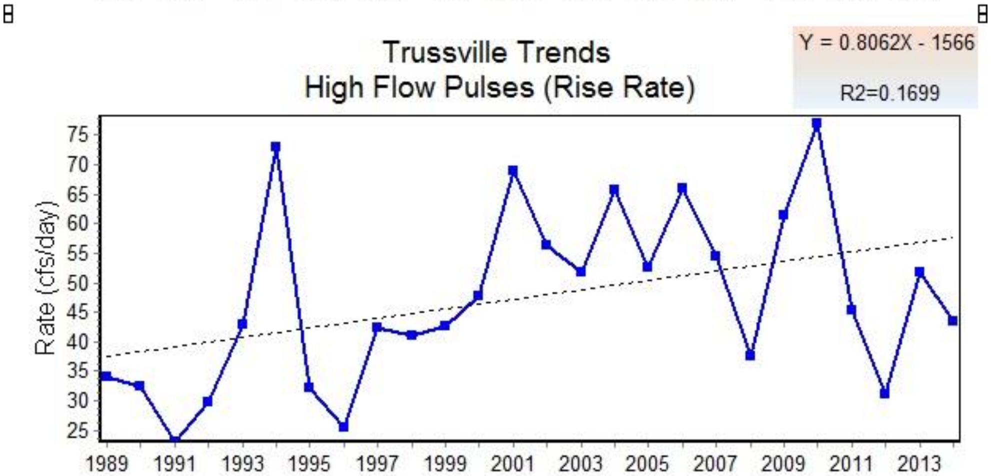
The Trussville gage has a 20 square mile watershed. The following photos are from that same section of the Cahaba River. The left photo from the year 2000 and the right photo from 2016 are examples of no flow events for this segment of the Cahaba River.

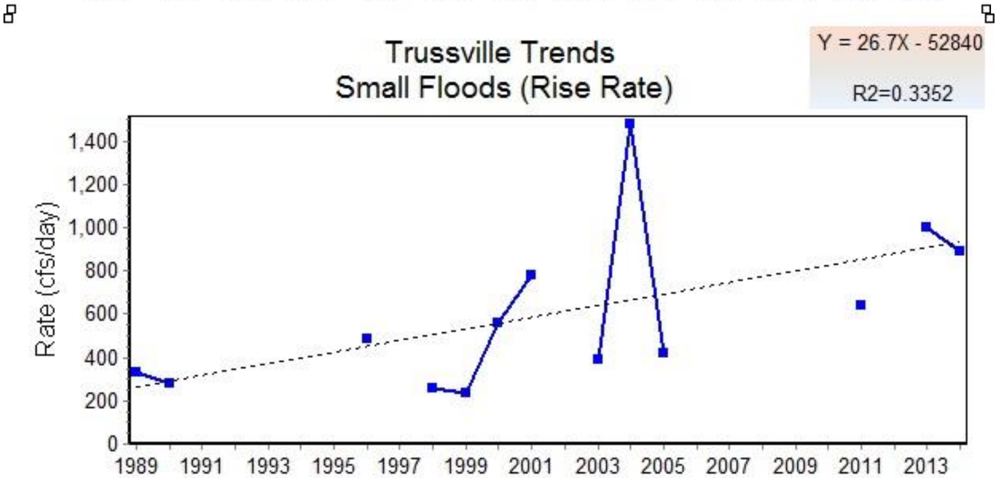


The low-flow stress on the Cahaba River in Trussville is not limited to short duration events. The hydrograph at left from the USGS Trussville gage for 2016 (a drought year) shows there was essentially no flow in the river from early May through early November, except for a half-dozen very brief rain 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.

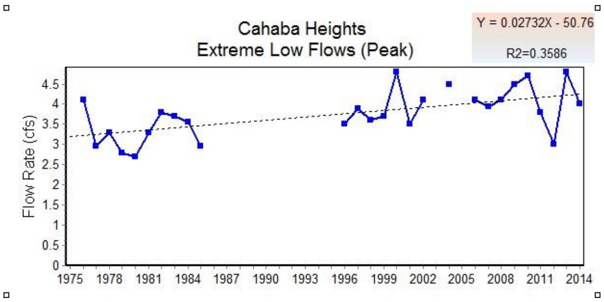


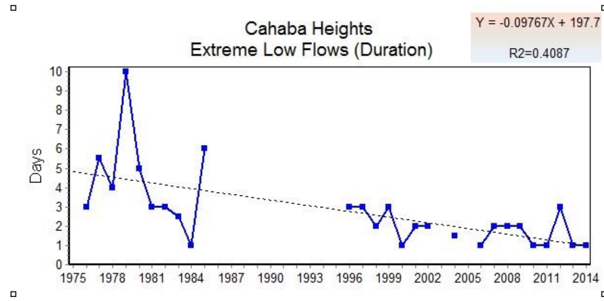




Cahaba Heights USGS Gage Trends

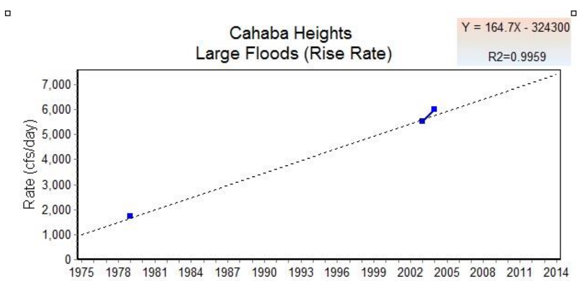
The USGS gage at Cahaba Heights is downstream from several major wastewater facilities [22]. The relatively constant discharge from these facilities results in a relatively increased flow during low-flow conditions. Thus, the most extreme low-flow conditions are now less extreme than in the past. The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

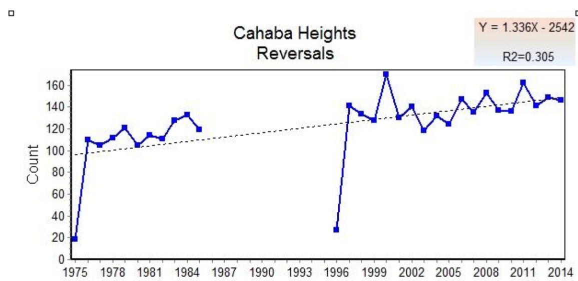


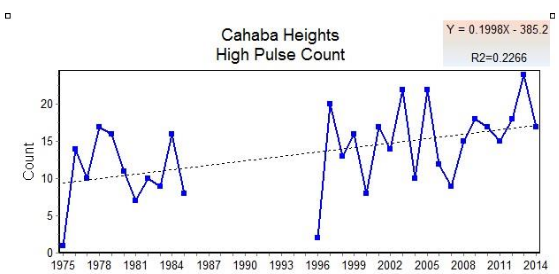


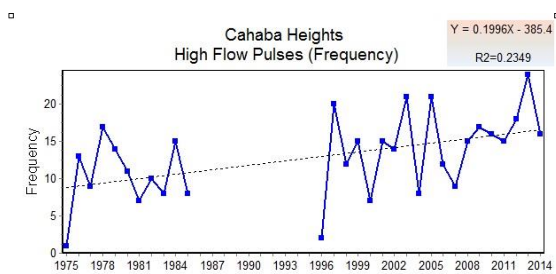
Some readers might count this hydrologic change as an 'improvement' over the natural flow regime. This change in the hydrological regime may improve dissolved oxygen levels during low flow, at least temporarily. In the larger picture, this hydrologic alteration is not one of our gravest concerns. However,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





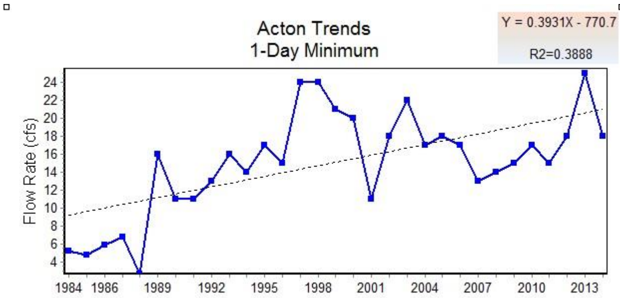


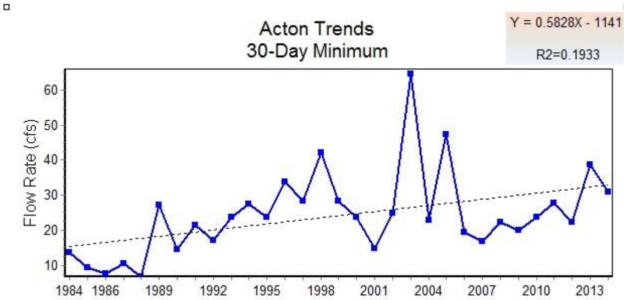


[22] Trussville WWTP, SWWC Riverview WWTP, and Hoover's Inverness WWTP.

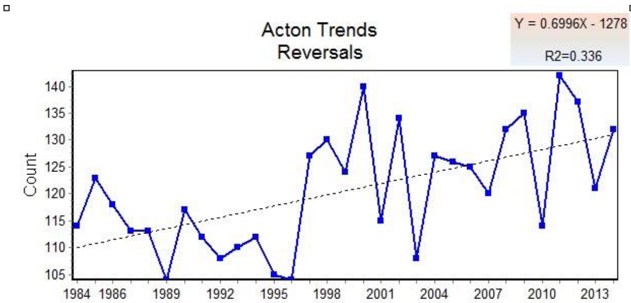
Acton USGS Gage Trends

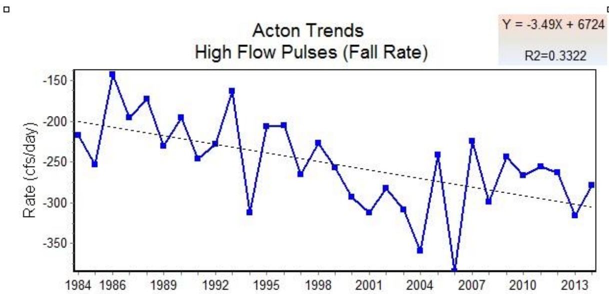
The USGS gage at Acton is influenced by additional wastewater discharges [23]. Once again, hydrologic alterations associated with those wastewater discharges are recognized by the IHA software assessment. ‘1-Day Minimum Flows’, ‘3-Day Minimum Flows’, ‘7-Day Minimum Flows’, ‘Extreme Low Peaks’, ‘Extreme 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.



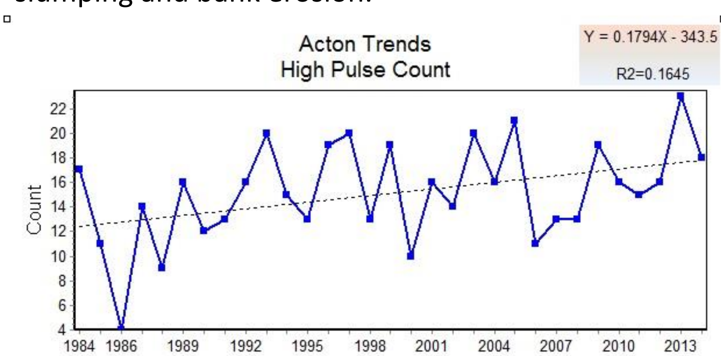


The Acton gage also shows increasingly flashy flows. The ‘Number of Reversals’, the ‘High Flow Rise Rate’, the ‘High Pulse Count’, the ‘High Flow Frequency’, and the magnitude of the ‘High Flow Pulse Peaks’ have increased over time. Here again, we show a couple of these variable with especially low p-values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





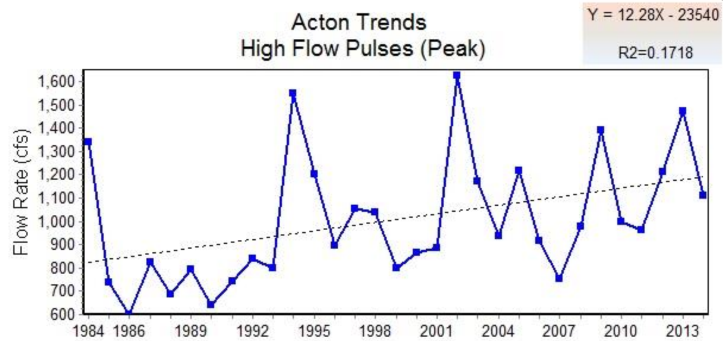
Here, the ‘High Pulse Flow Fall Rate’ becomes increasingly severe. In 1994, that fall rate value was about -200 cfs/day. That is, following a ‘High Pulse’ event, the river would drop at that rate. In 2013, that rate of fall was about -300 cfs/day. This increasingly rapid fall rate will contribute to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

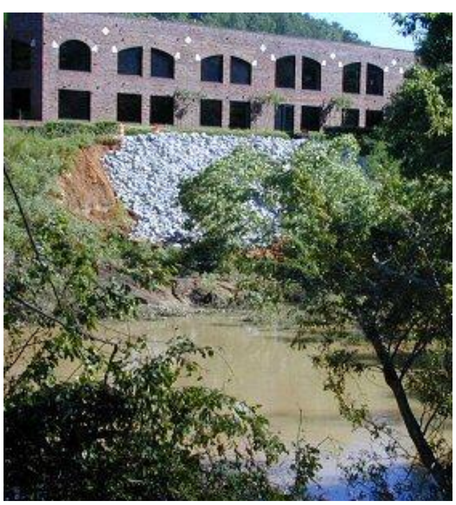
The Acton gage also shows the magnitude of the 'High Flow Peaks' has increased from about 800 cfs in 1984 to about 1200 cfs in 2014, a 50% increase. Just as for the 'High Pulse Count', increases in the magnitude of the discharge result in more erosive flows that cause streambanks and the bed to erode. 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.

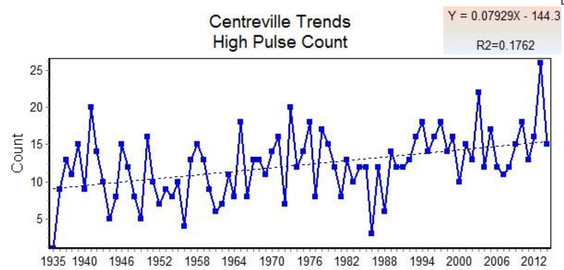


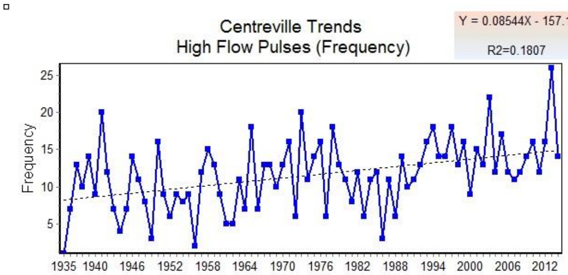
This bank collapse, shown at left, on the Cahaba River at the River Run Shopping Center, came within about twelve feet from the foundation of this building. This highlights the potential for bank collapses to imperil human habitats as well as aquatic wildlife habitats.

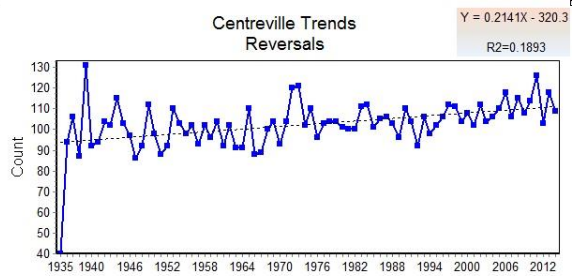
These photos are examples of the very large number of stream bank slumps/collapses on the Cahaba River mainstem and tributaries.

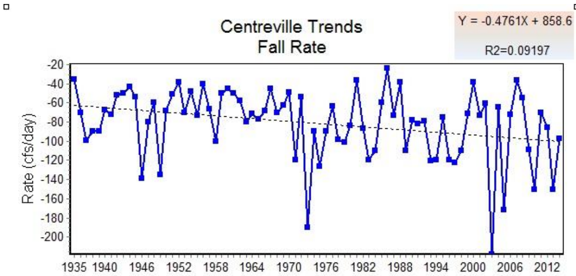
Centreville USGS Gage Trends

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.









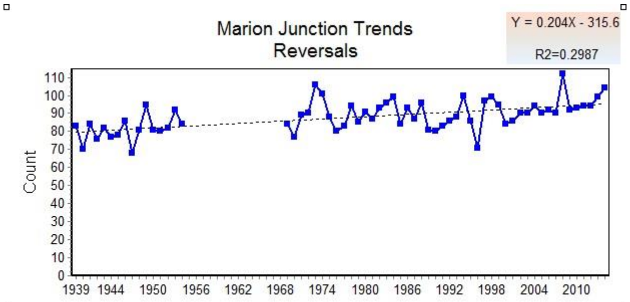
The number of ‘Reversals’ has climbed from about 94 times per year to 110 times per year. The ‘Fall Rate’ has become more extreme over time. In 1935, the fall rate was about -60 cfs/day and by 2013 it has become about -100 cfs/day. This means that the stream banks are less well supported following a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

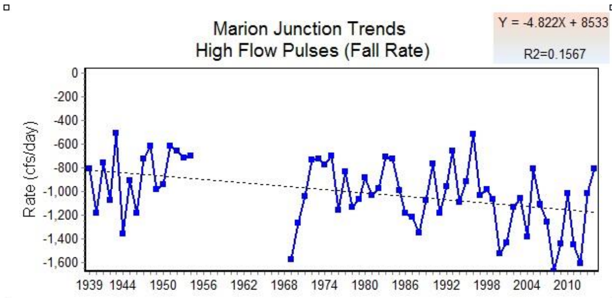
The reader might be a bit surprised that these hydrologic alteration impacts have not been ameliorated by a diminished magnitude of landscape impacts further from the urbanized portion of the watershed. But it appears some hydrologic alterations are still observable well downstream from the more urbanized 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.

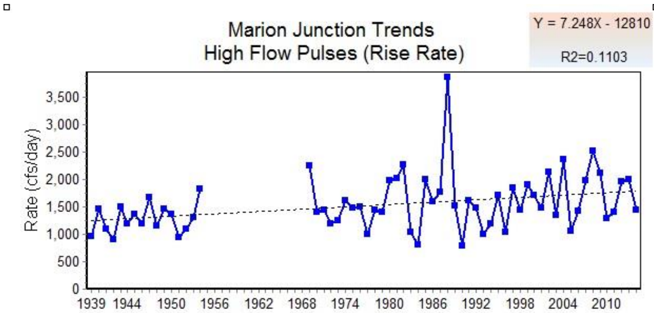
As we will see for the Marion Junction USGS Gage Trends, observable impacts continue still further downstream, to a part of the watershed that extends well into the Fall-line Hills of the coastal plain.

Marion Junction USGS Gage Trends

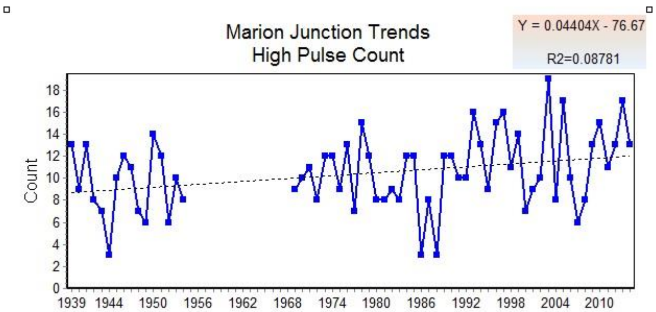
Marion Junction is the fifth and most downstream USGS gage with sufficient data to allow IHA analysis. Here, the 'Number of Reversals' has grown from about 80 to 95 times per year, about a 19% increase. The 'High Flow Fall Rate' increased from 800 cfs/day to over 1200 cfs/day, a 50% increase. The 'High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

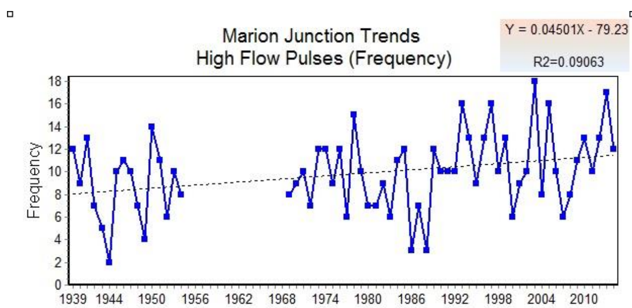


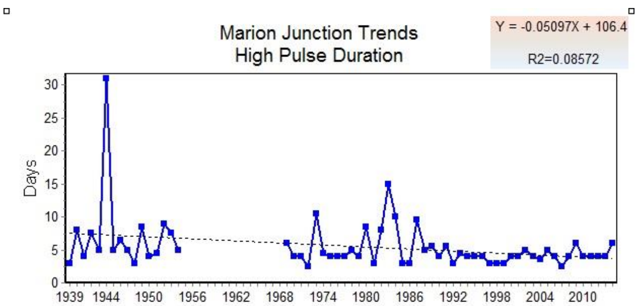


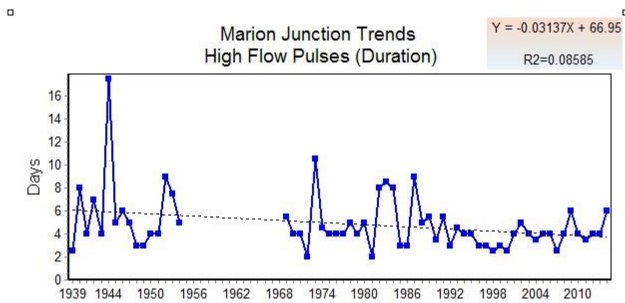


Other variables that reflect increasingly flashy flow include 'High Pulse Count', 'High Flow Frequency' (as noted previously, these two are related), 'High Pulse Duration', and 'High Flow Pulse Duration' (again, related but calculated in a slightly different manner).









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.