The Etowah Habitat Conservation Plan

Overview of the Runoff Limits Program

Seth Wenger, Tim Carter, Laurie Fowler
and the Etowah HCP Runoff Limits Technical Committee

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Bioretention area in The Estates at Brooke Park, Canton.
Photo courtesy of Diane Minick.

ETOWAH
habitat conservation plan

Executive Summary
Stormwater runoff from impervious surfaces is considered the greatest threat to imperiled fishes in the Etowah basin. As part of a Habitat Conservation Plan designed to protect these fish while allowing development, a program of stormwater "runoff limits" has been developed. This program requires that in the most sensitive watersheds, the volume of runoff from new development must match that of the site in an undeveloped, forested condition. For moderately sensitive watersheds and designated development nodes, the runoff limits are higher. The limits are based on studies of sensitive fish tolerances and the distributions of imperiled fish species in the Etowah, and are intended to provide assurance that development impacts will not exceed the thresholds that these species can tolerate. Although the program will compel significant changes in stormwater management practices in the basin—including widespread use of infiltration—its performance standards are straightforward and only simple engineering calculations are required. It will be supported by a design manual and training program.

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Mark Anderson, *Greater Atlanta Homebuilders' Association*
Rob Bocarro, *MACTEC Engineering*
David Edwards, *Sivica*
Jim Garrigus, *Falling Waters*
Evert Grobbelaar, City of Canton
Joe Guido, *Sivica*
Marjorie Hicks, *Biohabitats*
Steve Holder, *City of Dawsonville*
James Irvin, *Rochester and Associates*
Shane Keebaugh, *Acer Environmental*
Jim King, Dawson County
Kevin Middlebrooks, *Acer Environmental*
Diane Minick, *Upper Etowah River Alliance*
Mark Mink, *Rindt-McDuff Associates*
Geoff Morton, *Cherokee County*
Gary Mullinax, *City of Canton*
Tiras Petrea, *Forsyth County*
Jahnee Prince, *Council for Quality Growth*
Kim Shorter, *City of Roswell*
Margaret Tanner, *MACTEC Engineering*
Roy Taylor, *Cherokee County*
Ken Trevor, *Trevor Consulting*
Mike Tuller, *Cobb County*
Steve Turner, *City of Kennesaw*
Dean Wilder, *Ecological Solutions*
Ron Wikle, *Wikle Land Surveying*

Introduction: The Etowah Habitat Conservation Plan

The Etowah River is a major headwater tributary of the Coosa River system located in North Georgia. The basin is exceptional for its aquatic biodiversity, with 76 native species of fish, including three that are listed under the federal Endangered Species Act and six others that are considered imperiled but are not currently listed (Table 1). Five federally listed mussel species are also previously known from the Etowah, although all but one are now considered extirpated (locally extinct).

Table 1. Imperiled fish species of the Etowah basin. All species without federal status are considered likely candidates for listing under the Endangered Species Act.

Scientific Name	Common Name	Federal Status
Macrhybopsis sp. cf. *aestivalis*	Coosa chub	
Noturus sp. cf. *munitus*	Coosa madtom	
Etheostoma sp. cf. *brevirostrum* A	holiday darter	
Etheostoma sp. cf. *brevirostrum* B	holiday darter	
Etheostoma etowahae	Etowah darter	US Endangered
Etheostoma scotti	Cherokee darter	US Threatened
Percina antesella	amber darter	US Endangered
Percina lenticula	freckled darter	
Percina sp. cf. *macrocephala*	bridled darter	

Due largely to its proximity to Atlanta, the Etowah River basin is undergoing rapid development. Over the course of the 1990s the Atlanta metropolitan area added more people than any other region in the U.S. except Los Angeles (McCosh 2000), and in the last decade the counties in the southern portion of the basin have consistently ranked among the most rapidly developing in the nation. Accordingly, the urban land cover of the Etowah Basin has increased rapidly (Kramer 2004). This growth has prompted concerns about sedimentation, toxins and other impacts that may threaten the survival of imperiled aquatic species, as well as the future utility of Lake Allatoona.

In response to these concerns, the local governments of the Etowah watershed are developing a Habitat Conservation Plan (HCP) for the federally listed and other imperiled fish species. The purpose of the plan is to implement a set of growth management policies and ordinances that minimize the impact of future development on the aquatic species, thus permitting additional growth without risking the survival of federally protected fish. Once approved, local governments participating in the plan will receive incidental take permits, which provide assurance that as long as they abide by the terms of the HCP, local governments won't be prosecuted for the accidental loss of protected species. This assurance also extends to developers and other building professionals within those jurisdictions, as long as they obey all the regulations required by the HCP. The most critical of those regulations are the ones managing stormwater runoff.

Development of the Etowah HCP is governed by a Steering Committee, whose voting members are representatives of the counties and municipalities of the Etowah region. The Steering Committee is supported by the Advisory Committee, composed of faculty, staff and students of the University of Georgia and Kennesaw State University, as well as employees of the Georgia Conservancy, the Nature Conservancy, and representatives of the FWS and Georgia Department of Natural Resources. Other participating stakeholders include the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, several regional water and sewer authorities, local development interests and local conservation and citizens' organizations.

In 2003, the Steering Committee approved a model stormwater ordinance as part of the package of growth management regulations to be included in the Etowah HCP. In October 2006, the Steering Committee added an additional set of stormwater performance standards for areas critical to imperiled species' survival (these areas are called priority areas, although in the original version of the stormwater ordinance they were termed sensitive areas). These performance standards are referred to as runoff limits.

The Problem with Stormwater Runoff

Urbanization of streams tends to lead to degradation of fish assemblages and the extirpation of some fish species (Klein 1979, Walters et al. 2003, Wang et al. 2001). The impacts of urbanization involve a range of effects, including changes to hydrology, geomorphology, water temperature and stream chemistry, as well as inputs of various toxins (for recent reviews, see Allan 2004, Paul and Meyer 2001, Walsh et al. 2005). The primary mechanism for many of these effects is stormwater runoff from impervious surfaces (Walsh et al. 2005).

An increase in impervious cover (roads, parking lots, rooftops, etc.) leads to increased stormwater runoff and reduced infiltration of rainfall. As a result, the storm discharges of urban streams can be twice those of rural streams draining watersheds of similar size (Rose and Peters 2000) and the frequency of highly erosional "channel-forming" events can be ten times that of the pre-development conditions (Booth and Jackson 1997). Low flows may be reduced in magnitude due to reduced groundwater recharge (Ferguson and Suckling 1990), although these may be offset by inputs from lawn watering and septic systems (Walsh et al. 2005). The hydrologic alteration associated with increased impervious cover may affect fishes via:

- Excessive instability of habitat
- Sedimentation from channel erosion
- Mortality and stress on eggs and larvae
- Reduction in food base
- Reduction in recruitment due to alteration of the natural flow regime
- Facilitation of invasion by exotic species
- Reduction in lotic habitat during baseflow

In addition to hydrologic impacts, stormwater runoff is a major source of pollutants. Streets and parking lots can contribute large quantities of heavy metals and nutrients (Bannerman et al. 1993) as well as hydrocarbons (reviewed in Paul and Meyer 2001). These can affect fishes via direct mortality, various sublethal effects, and reduction in food base. Finally, impervious runoff is often much warmer than the receiving waters, and the temperature alteration may lead to further impacts on sensitive fish species.

Stormwater Management and Runoff Limits

Performance standards for stormwater management
Traditionally, stormwater management was focused on the rapid conveyance of runoff offsite and downstream. The goal was to prevent flooding, but there was little or no consideration given to the effects on aquatic systems. This was reflected in ordinances of cities and counties in the Etowah—for those jurisdictions that had stormwater ordinances at all. More recently, however, a new generation of stormwater regulations has appeared in the region. These set additional performance standards designed to protect both water quality and stream channels. The model stormwater ordinance of the Metropolitan North Georgia Water Planning District (the "Metro District") (Metropolitan North Georgia Water Planning District 2004), which is required by state law to be adopted by many of the counties and cities in the Etowah, is a good example of this more progressive ordinance. Its performance standards include:

- Water quality protection: capture and treat runoff from all storm events 1.2" or less, as well as the first 1.2" of runoff for all larger storm events.
- Channel protection volume: provide 24 hours of extended detention for runoff generated by the one-year, 24-hour storm event.
- Overbank flood protection: reduce the post-development 25-year, 24-hour storm event peak discharge rate to no more than the pre-development discharge rate.
- Extreme flood protection: design all stormwater management facilities to safely convey the runoff from the 100-year, 24-hour storm event.

Implementation of this ordinance will provide substantial benefits to the imperiled fish species of the Etowah basin. In fact, this ordinance has been adapted to form the basis of the stormwater ordinance of the Etowah HCP. But despite its strengths, the Metro District ordinance does not provide a complete solution to stormwater management for purposes of the Etowah HCP. This is because the performance standards of the Metro District ordinance do not provide any guarantees that the impacts of stormwater runoff will be within the limits that the imperiled fish of the Etowah can tolerate. First, the effectiveness of 24-hour extended detention in minimizing hydrologic alteration has not been quantified. Second, the water quality protection requirement mandates a reduction in pollutant loads, but not an absolute limit. If impervious cover is very high, the concentrations of pollutants—although reduced—may still be excessive for sensitive fish species. Furthermore, depending on the design of the system, runoff from small events can flow through with only minimal treatement.

These problems can largely be solved, however, if excess runoff (beyond what would occur in a forested setting) from small storms is infiltrated back into the soil as close as possible to where it is generated. This will provide near-natural hydrologic function and highly effective pollutant removal (Walsh et al. 2004a). This is the essence of the runoff limits performance standard.

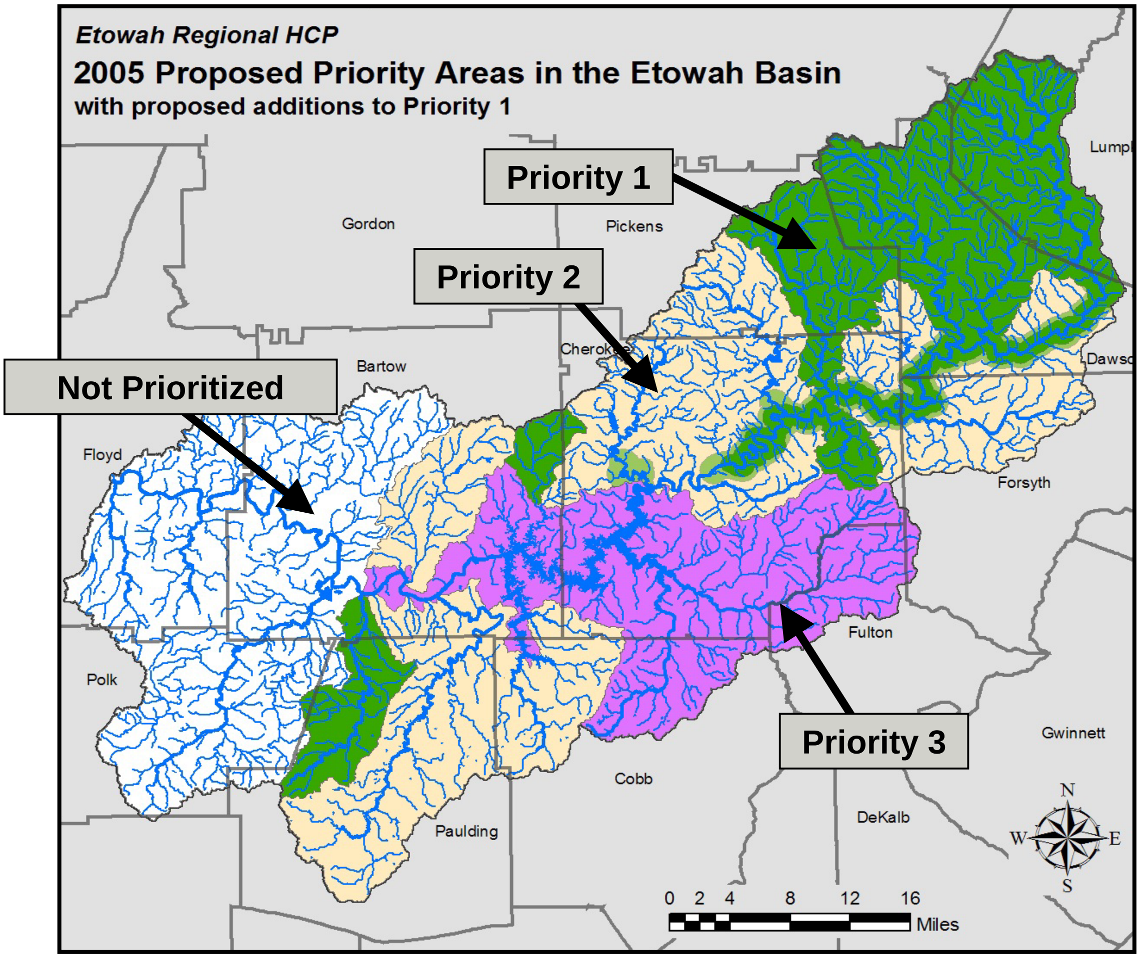
The Runoff Limits Program
The proposed runoff limits program is a new performance standard that states that in the most sensitive watersheds (designated *Priority One*), the volume of surface runoff from a site must be the same as the volume that would come from the site under a forested condition. This standard applies to small storms (less than the two-year recurrence interval), and calculations are made using actual soil conditions, which means that sites with less permeable soils are allowed to produce more runoff. For moderately sensitive watersheds (*Priority Two*) and designated development nodes, the runoff limits are higher; i.e., an allowance is provided for an additional volume of runoff from impervious surfaces.

Developers have great flexibility in meeting the runoff limits. Various best management practices (BMPs) can be used to provide infiltration, including bioretention (also called rain gardens), dry wells, infiltration trenches and swales. In addition, they can be supplemented by evapotranspiration BMPs (those that allow water to evaporate or transpire; transpiration is evaporation of water from plant leaves), such as green roofs. One of the best strategies for meeting the runoff limits, however, is to design the site in a way that minimizes impervious cover and maximizes retention of natural forest. It is cheaper and easier to *prevent* runoff by minimizing the site footprint than to manage the runoff with BMPs.

The same stormwater management practices that are used to meet the runoff limits can also be used to meet the other performance standards of the Etowah HCP Stormwater Ordinance. Infiltration and evapotranspiration BMPs are excellent ways to meet the water quality treatment standard, and reducing the volume of runoff can eliminate the need for channel protection volume control. In many cases a detention pond will still be required to meet the downstream flooding standard, but it can be signficantly reduced in size.

Fish distributions and priority areas
The runoff limits are based on tolerances of sensitive fish species in the Etowah basin, and vary geographically based on the distribution of imperiled species (see Appendix for a summary of how fish sensitivities were determined. Fish distribution maps are available on the Etowah HCP web site, *www.etowahhcp.org*). Priority One areas (Figure 1), have the strictest runoff limits. These areas support populations of the Etowah darter, which appears to be very sensitive, and other imperiled fishes that are presumed to be equally sensitive. Priority Two areas, which have slightly less restrictive limits, are important for protecting downstream habitat and populations of less sensitive imperiled fishes, such as the Cherokee darter. Priority Three areas support none of the species covered under the Etowah HCP, or only very small populations of Cherokee darters, and therefore have no runoff limits. Local governments can establish development nodes within Priority One and Priority Two areas to allow high-intensity land uses, such as commercial, industrial and high-density residential developments. Development nodes have much less restrictive runoff limits.

Figure 1. Priority Areas in the Etowah Basin. Areas in light green are extensions of Priority 1 proposed by a scientific review panel on October 24, 2005, and not yet officially adopted.



Runoff Limits for Priority Areas

The runoff limit for a site in Priority One areas is equal to that of an undeveloped, forested site. That is, the volume of runoff for a site in Priority One areas must not exceed the volume of runoff that would occur under a forested condition, for small storms, given the soils present. Of course, there will still be some impact on these streams. Existing impervious areas will continue to produce runoff, and any designated development node will produce significant runoff as well. Predictive modeling shows, however, that the levels of runoff will be low enough that species such as the Etowah darter will continue to survive, even after accounting for the impacts of existing impervious areas and development nodes.

Runoff limits in Priority 2 areas are set at the equivalent of 5% total impervious cover. Therefore, new development must employ stormwater management practices that make the site act as if it had no more than 5% impervious cover (and the remainder forested). Again, existing imperviousness and development nodes will increase the overall impervious cover in these areas. However, the moderate runoff limit in Priority 2 areas will help ensure that tributaries to the Etowah do not act as conduits for toxins and sediment that might degrade mainstem habitat. In addition, forest cover should remain at levels high enough to ensure healthy populations of Cherokee darters across the basin.

Development nodes

Development nodes are mapped locations in Priority 1 and Priority 2 areas where higher volumes of runoff are permitted. The purpose of development nodes is to accommodate commercial, industrial and high-density residential development in areas where the current zoning, comprehensive plans and infrastructure support it. The size of these nodes must be limited, however, to ensure that impacts to the imperiled fish species are minimal and localized. This is especially true in Priority 1 areas. In Priority 2 areas there is more flexibility for nodes to be larger and to occupy more space. The runoff limits for development nodes are set at one half the actual impervious cover for the site. For example, a site with 60% impervious cover must reduce the runoff to the amount expected from the site if it had only 30% impervious cover (and the remainder were forested).

The size and locations of development nodes will be determined by local governments, with assistance from the HCP Advisory Committee. Potential locations for development nodes may be based on current zoning and future land use maps, or otherwise established through local planning processes. Local governments may also choose to reserve some capacity to assign additional nodes in the future. The HCP Advisory Committee will work with the local governments to determine the total capacity for nodes, based primarily on the sensitivities of imperiled fish species, and will model the impact of proposed node placement to ensure that the impacts on species are acceptable. Once an appropriate development node scenario is finalized, each jurisdiction will map node boundaries and incorporate this map into their comprehensive plan and zoning code, as appropriate.

Applying Runoff Limits: Calculations and engineering specifications

Estimating the runoff volumes under forested and developed conditions requires only simple, commonly-employed hydrologic modeling based on the Soil Conservation Service Runoff Curve Number method (SCS 1986). Curve numbers are a measure of the runoff potential of a site, with higher curve numbers used for surfaces that produce more runoff given local soil conditions. Impervious surfaces are given a curve number of 98. The curve number of a forested site in good condition with type "C" soils—typical of the Etowah—is 70. These numbers are used in an equation to estimate the volume of runoff for storms of different sizes.

Applying the performance standard to a site is a straightforward three-step process:

(1) Calculate the volume of runoff from the site using the curve number of a forest in good condition and existing soils on site for the regional two-year, 24-hour design storm. This is the runoff limit.
(2) Calculate the volume of runoff from the site using the curve numbers of the post-development conditions for the regional two-year, 24-hour design storm.
(3) If the volume from step two exceeds the runoff limit, then best management practices must be used to decrease the volume so that it meets the limit. Practices can include

implementation of better site design principles to reduce the volume of stormwater generated, and use of infiltration and evapotranspiration stormwater structures to return the runoff to the soil or the air.

The above procedure applies to Priority One areas. The same procedure is used for Priority Two areas and development nodes, except that the calculation in step 1 is modified appropriately. Detailed instructions on calculations, including examples, will be provided in the Etowah HCP Runoff Limits Manual, currently under development by the Runoff Limits Technical Committee.

Forested condition, not current condition, serves as the basis of the runoff limits. This makes it more difficult to meet the runoff limits on agricultural sites than forested sites; in fact, for sites currently in agricultural use, development may result in a net *decrease* in runoff from current conditions. Given the extreme sensitivity of the imperiled fish species of the Etowah, this improvement in conditions on agricultural land is necessary to offset the runoff from development nodes. To make this rule less burdensome, credit will be given to developers of agricultural sites who reforest portions of the land. Newly planted areas may be counted as if they were fully forested in runoff calculations, reflecting their future condition rather than current condition.

The preceding calculations determine the capacity of the infiltration or evapotranspiration stormwater structures used on a site. These BMPs should be integrated into a comprehensive system that is designed in accordance with two general requirements:

- Regardless of the runoff limits, the treatment system shall be designed so that the initial flush of stormwater runoff passes into infiltration or evapotranspiration stormwater structures. Runoff from a part of a site cannot be shunted to detention ponds or offsite without the opportunity to pass through infiltration BMPs. This applies to development nodes as well as priority areas. If properly implemented, this requirement will ensure that there is minimal increase in the frequency of runoff-generating events, a critical indicator of effective stormwater management (Walsh et al. 2004a).
- Runoff shall be managed as close as possible to the point where it is generated, using many small structures rather than few large structures, to the extent feasible. This is critical to maintaining near-natural hydrologic function.

These requirements will be elaborated in the Etowah HCP Runoff Limits Manual.

For developers to effectively meet runoff limits, they must have access to good engineering design specifications for infiltration and evapotranspiration stormwater BMPs. The Georgia Stormwater Management Manual has specifications for some of these, including infiltration trenches and bioretention areas. Manuals for other states and regions add additional practices, such as dry wells, infiltration basins and vegetated roof cover. Further resources are available from independent sources, such as the Center for Watershed Protection (*www.cwp.org*). The best and most relevant of these engineering specifications will be included in the Etowah HCP Runoff Limits Manual.

The Runoff Limits Manual will help ensure that BMPs are designed to meet the performance standards and match the goals of the runoff limits program. For example, many design specifications for bioretention areas assume that the practice is for water quality treatment, not infiltration; however, other specifications for the BMP are designed to provide both services.

The purpose of the Runoff Limits Manual is not just to collect good design specifications, but to steer practitioners away from specifications that, although similar, may not effectively meet the performance standards. Dr. Rose Mary Seymour, an engineer on faculty at the University of Georgia, is overseeing the development of the engineering specifications.

Feasibility of Infiltration

Infiltration best management practices have been employed successfully in the Etowah basin, even in areas of poor soils. The Upper Etowah River Alliance worked with the Etowah Water and Sewer Authority (EWSA) to construct a raingarden and infiltration trench to infiltrate runoff from the parking lot and rooftop at EWSA's headquarters in Dawsonville. The Cherokee County Water and Sewerage Authority, in conjunction with Environmental Impact Assessment, LLC, built a raingarden to infiltrate and treat runoff from an office building and parking lot. Other examples of infiltration BMPs can be found at The Estates at Brooke Park in Canton, Black's Mill Elementary School in Dawsonville, Teasley Middle School in Canton, the Glade Marina on Lake Allatoona, and many private residences.

Alfie Vick, an assistant professor at the University of Georgia School of Environmental Design, redesigned the stormwater management system for a 98-acre residential development in Dawsonville, Georgia, to replace the conventional design with one that meets the runoff limits. He demonstrated that it was feasible to add bioretention and infiltration areas to each residence without altering the site design. With this approach he was able to meet the Priority Area 1 runoff limits standards for a residential development with an average density of 2.4 units per acre (a report on the demonstration study will be available in November, 2005). This demonstrates the kind of densities that are feasible for new developments in Priority 1 areas. For Priority 2 areas greater densities are possible, and development nodes allow for small areas of even higher density. Given current zoning in the Etowah basin, the runoff limits program is not expected to constrain densities or significantly limit developer flexibility.

Cost estimates for the use of bioretention and other infiltration practices vary greatly. The Etowah HCP Advisory Committee is in the process of preparing a report that assembles cost estimates and reviews the available studies, including comparisons of infiltration versus conventional stormwater management. It is anticipated that on the average, the cost of implementing infiltration practices required to meet the runoff limits will be more expensive than practices needed to meet conventional stormwater regulations, for a given site design. However, sites that follow Better Site Design principles to minimize impervious area can greatly reduce the volume of runoff generated, reducing the need for structural controls and frequently reducing construction costs as well. In addition, use of infiltration allows for significant reductions in the size of detention basins. In some cases detention ponds may be eliminated entirely and the conveyance network greatly reduced, adding further savings.

Implementation

Pickens County recently became the first jurisdiction to complete the process of identifying development nodes. Dawson County and Cherokee County have begun the process and the other jurisdictions are expected to follow soon after. The Runoff Limits Manual will be completed in spring, 2006. Training courses for county staff and for private development industry professionals will begin shortly thereafter, and local governments are expected to adopt the ordinance provisions implementing the runoff limits program by summer, 2006.

References

Allan, J. D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution and Systematics* 35: 257-284.

Bannerman, R., D. Owens, R. Dodds, and N. Hornewer. 1993. Sources of pollutants in Wisconsin stormwater. *Water Science and Technology* 28: 241-259.

Booth, D. B., and C. R. Jackson. 1997. Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation. *Journal of the American Water Resources Association* 33: 1077-1090.

Ferguson, B. K., and P. W. Suckling. 1990. Changing rainfall-runoff relationships in the urbanizing Peachtree Creek watershed, Atlanta, Georgia. *Water Resources Bulletin* 26: 313-322.

Harding, J. S., E. F. Benfield, P. V. Bolstad, G. S. Helfman, and E. B. D. Jones. 1998. Stream biodiversity: The ghost of land use past. *Proceedings of the National Academy of Sciences of the United States of America* 95: 14843-14847.

Hatt, B. E., T. D. Fletcher, C. J. Walsh, and C. M. Taylor. 2004. The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams. *Enviromental Management* 34: 112-124.

Klein, R. D. 1979. Urbanization and stream quality impairment. *Water Resources Bulletin* 15: 948-963.

Kramer, L. 2004. Georgia Land Use Trends (GLUT) Program. *http://narsal.ecology.uga.edu/glut.html*. Georgia Land Use Trends Program, Athens, GA.

McCosh, J. 2000. Growth puts area near 4 million people. Pages D1. *Atlanta Journal Constitution*, Atlanta.

Metropolitan North Georgia Water Planning District. 2004. Model Stormwater Management Ordinances. *Available online at http://www.northgeorgiawater.com/*.

Paul, M. J., and J. L. Meyer. 2001. Streams in the urban landscape. *Annual Review of Ecology, Evolution and Systematics* 32: 333-365.

Rose, S., and N. E. Peters. 2000. Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach. *Hydrological Processes* 15: 1441-1457.

Trimble, S. W. 1970. Culturally accelerated sedimentation on the Middle Georgia Piedmont. University of Georgia, Athens, GA.

Walsh, C. J., A. W. Leonard, A. R. Ladson, and T. D. Fletcher. 2004a. *Urban Stormwater and the Ecology of Streams*. Cooperative Research Center for Freshwater Ecology, Canberra, Australia.

Walsh, C. J., P. J. Papas, D. Crowther, P. Sim, and J. Yoo. 2004b. Stormwater drainage pipes as a threat to a stream-dwelling amphipod of conservation significance, *Austrogammarus australis*, in South-eastern Australia. *Biodiversity and Conservation* 13: 781-793.

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, and P. M. Groffman. 2005. The urban stream syndrome: current knowledge and the search for a cure. *Journal of the North American Benthological Society* 24: 706-723.

Walters, D. M., D. S. Leigh, and A. B. Bearden. 2003. Urbanization, sedimentation, and the homogenization of fish assemblages in the Etowah River Basin, USA. *Hydrobiologia* 494: 5-10.

Wang, L. Z., J. Lyons, and P. Kanehl. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management* 28: 255-266.

Appendix: Summary of Modeling to Determine Fish Sensitivity and Set Runoff Limits

In order to recommend appropriate runoff limits, researchers with the HCP Advisory Committee first determined the tolerances of sensitive fish species to impervious cover in the Etowah. They did this by analyzing fish distribution patterns to determine whether fish occurrences were negatively related to impervious cover, and to determine the strength of those relationships. They examined relationships with both total impervious area (TIA) and effective impervious area (EIA). Effective impervious area refers to only those impervious surfaces that are connected to the drainage network; previous studies have found that EIA is a stronger predictor of impacts to streams than is TIA (e.g., Hatt et al. 2004, Walsh et al. 2004b, Wang et al. 2001). The researchers also evaluated urban land cover and forest cover as alternative indicators of current land use. All imperviousness and land cover data were based on 2001 satellite imagery.

The researchers also tested the possibility that other factors, particularly historic land use, could better explain current fish distributions. Large portions of the Etowah were formerly in cotton agriculture, which caused massive sedimentation (Trimble 1970) and could have led to extirpations of fish species (Harding et al. 1998). Additionally, numerous reservoirs were built on these same agricultural lands, which might also have had negative impacts on species. All of these factors were tested to be certain that any observed relationships between impervious cover and fish occurrence were not legacies of historic activities, or of natural landscape characteristics.

A total of 357 fish collection from the Etowah from 1999-2003 were used in the analyses. Nine species of fish thought to be sensitive to urban or other stressors were evaluated. Two of these species, the Etowah darter and the Cherokee darter, were species covered by the Etowah HCP. The other species covered by the Etowah HCP were too rare to analyze, because there were not sufficient data over a range of conditions to establish relationships. The seven other sensitive species were used as surrogates to indicate the possible responses of the HCP species.

Results are shown in Table 2. For all species, the best model for predicting probability of occurrence was the one that included current land use (and not historic) or both historic and current land use. In other words, most species evaluated did appear to respond to impervious cover, even after the complicating factor of historic land use was taken into account.

The species varied in the strengths of their responses to impervious cover. The Etowah darter, bronze darter, tricolor shiner and riffle minnow were among the most sensitive. Figure 1 shows the probability of occurrence of the Etowah darter in response to increasing effective impervious area (EIA) for two different sized streams. The heavy line indicates the response in a large stream (36 square miles drainage area), while the fine line indicates the response in a mid-sized stream (13 square miles drainage area). Because the Etowah darter is much more likely to be found in a large stream, its probability of occurrence is significantly higher, but in both cases the response to imperviousness is strong: when effective impervious area reaches six percent, the probability of species occurrence approaches zero. The Cherokee darter, on the other hand, is more likely to be found in smaller streams. Although it does not show a strong response to impervious cover, it is more likely to be found in forested watersheds than unforested.

Table 2. Summary of Best-Supported Model by Species. "EIA" means effective impervious area. "TIA" means total impervious area.

Species	Best Model	Best Current Land Use Predictor
Alabama shiner	Current	EIA in watershed
Tricolor shiner	Current + Historic	EIA within 1.5 km
Riffle minnow	Current + Historic	EIA within 2 km
Speckled madtom	Current + Historic	EIA within 1 km
Sculpin	Current + Historic	EIA within 1 km
Etowah darter	Current	EIA within 1.5 km
Cherokee darter	Current	Forest in watershed
Speckled darter	Current	TIA within 500 m
Bronze darter	Current + Historic	EIA within 500 m

Figure 1. Probability of occurrence of the Etowah darter in response to increasing Effective Impervious Area (EIA). Dark line represents a large stream; fine line, a mid-sized stream.

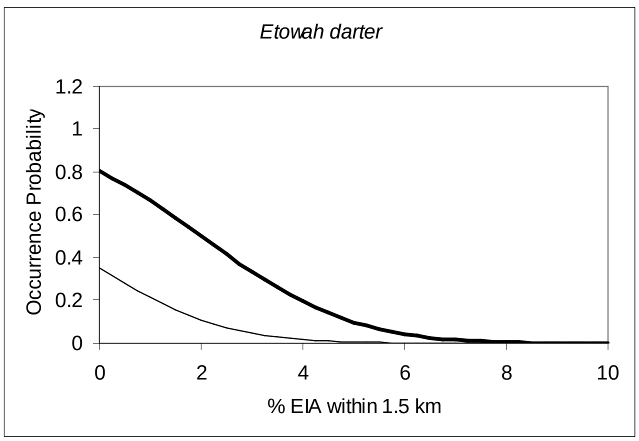


Figure 2. Probability of occurrence of the Cherokee darter in response to increasing forest cover. Dark line represents a large stream; fine line, a mid-sized stream.