Stressors to Imperiled Fishes in the Etowah Basin

Mechanisms, Sources and Management under the Etowah HCP

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Abstract

The Etowah River basin in Georgia, USA, supports nine imperiled fish species that are the object of protection under the proposed Etowah Habitat Conservation Plan (HCP). With urban land cover steadily increasing in the basin at the expense of forest and agricultural land cover, development-related activities and their consequences appear, as a group, to be the major threat to the species. However, urbanization is a complex phenomenon that involves numerous intermediate stressors. The purpose of this study is to review the scientific literature on urban stressors with the goal of identifying the major threats to the survival of fishes so that management strategies may be implemented to avoid or minimize these threats as part of the Etowah HCP. We identify ten potential stressors: sedimentation, hydrologic alteration, extensive riparian buffer loss, contaminants (heavy metals, pesticides, etc.), movement barriers, channelization /piping of streams, invasive species, temperature alteration, loss of woody debris, and eutrophication. For each we review the mechanisms by which the stressors may affect fish, the likely sources of the stressors within the Etowah, and the management strategies to be implemented under the Etowah HCP to address the stressors. We conclude that the first six stressors listed above are likely to be significant threats that must be managed by the Etowah HCP. We identify the most significant *source* of stressors as stormwater runoff from impervious surfaces and the most critical policy as a stormwater management ordinance.

Introduction

The Etowah and its Aquatic Fauna

The Etowah River is a major headwater tributary of the Coosa River system in northern Georgia, USA. The basin is exceptional for its aquatic biodiversity, with 76 extant native fish species (Burkhead *et al.*, 1997), including three species listed under the Endangered Species Act and six others that are considered imperiled but not currently listed (GDNR, 1999). Five federally listed mussel species were once found in the Etowah (Burkhead *et al.*, 1997), although all but one are now considered extirpated. A species of brachycentrid caddisfly also is considered imperiled because it is believed to exist only in the Etowah and Hiawassee Rivers. Table 1 lists all of the Etowah's imperiled species.

Table 1. Imperiled Aquatic Species of the Etowah Basin, including Mussels Considered Extirpated.

Scientific Name	Common Name	Status
Percina antesella	amber darter	Fed. E
Etheostoma etowahae	Etowah darter	Fed. E
Etheostoma scotti	Cherokee darter	Fed. T
Noturus sp. cf. *munitus*	frecklebelly madtom	GA E/ Likely candidate
Etheostoma sp. cf. *brevirostrum* A	holiday darter	GA T/ Likely candidate
Etheostoma sp. cf. *brevirostrum* B	holiday darter	GA T/ Likely candidate
Percina sp. cf. *macrocephala*	bridled darter	GA Rare/Likely candidate
Percina lenticula	freckled darter	GA E/ Likely candidate
Macrhybopsis sp. cf. *aestivalis*	speckled chub	Likely candidate
*Epioblasma metastriata**	upland combshell	Fed. E
*Pleurobema decisum**	southern clubshell	Fed. E
Hamiota altilis	finelined pocketbook	Fed. T
*Ptychobranchus greeni**	triangular kidneyshell	Fed. E
*Medionidus acutissimus**	Alabama moccasinshell	Fed. T
Brachycentrus etowahensis	Etowah caddisfly	Likely candidate

* Believed to be extirpated.

Due largely to its proximity to Atlanta, the Etowah River basin is undergoing rapid development. During the 1990s, the Atlanta metropolitan area added more people than any other region in the U.S. except Los Angeles (McCosh, 2000); in the last decade, counties in the southern portion of the basin have consistently ranked among the most rapidly developing in the nation. Accordingly, urban land cover in the Etowah Basin has increased steadily (Figure 1) (Kramer, 2004), and the pace appears to be accelerating in recent years. This growth has raised concerns within the U.S. Fish and Wildlife that sedimentation, chemical contaminants, and other stressors may threaten the survival of imperiled aquatic species.

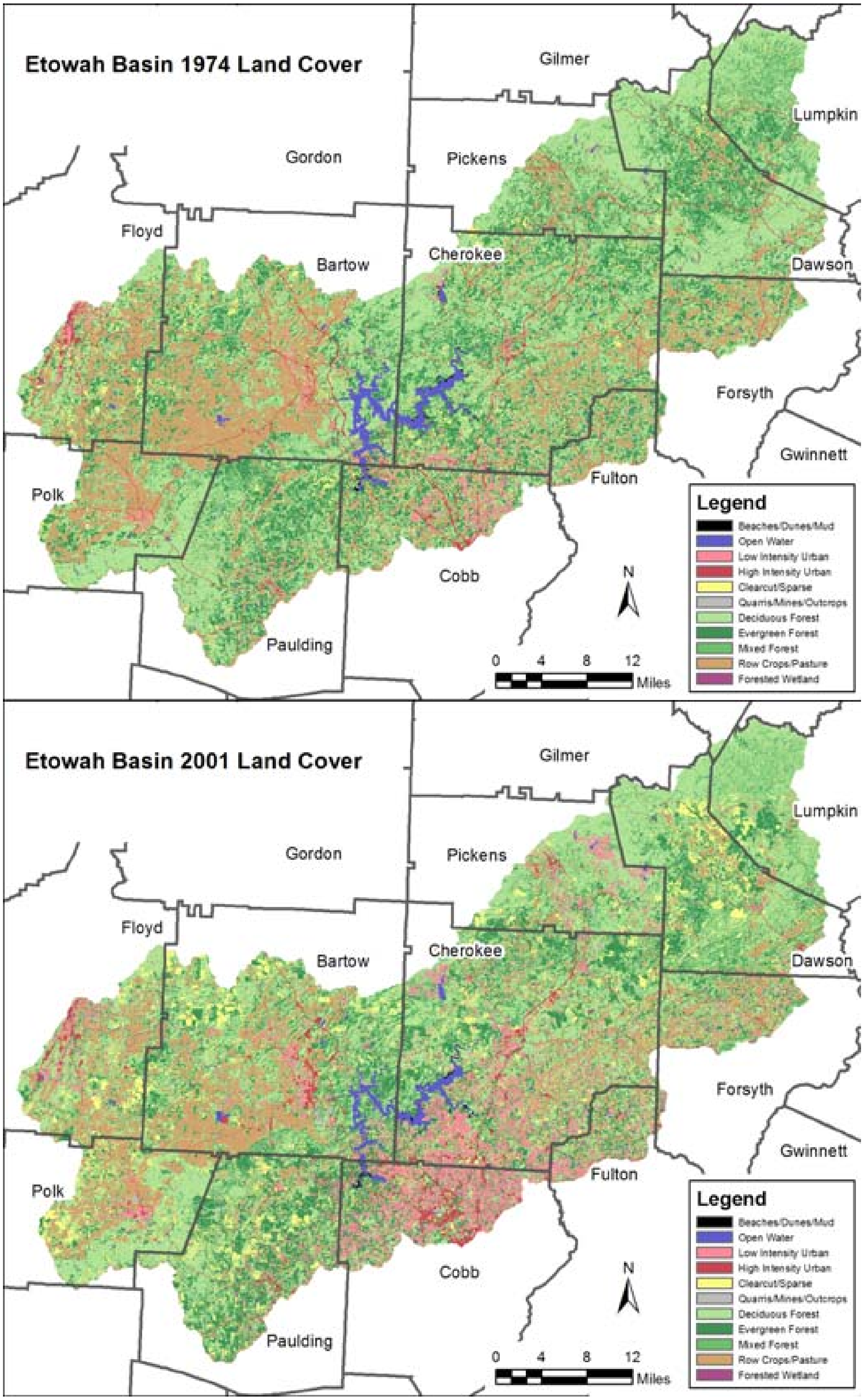
These concerns are the impetus behind the development of the Etowah HCP, which calls for participating local governments to implement a set of growth management policies and ordinances to minimize the impact of future development on aquatic fauna, thus permitting additional growth without impairing survival and recovery of federally protected species. The Etowah HCP Steering Committee voted to focus on urbanization because other sources of stressors (e.g., agriculture and forestry) are declining as urbanization increases (Table 2, Figure 1), and the impacts of urbanization on streams are frequently more extreme than those of agriculture and forestry (Lenat & Crawford, 1994; Wang *et al.*, 2000). The Steering Committee also chose to write the Etowah HCP to cover the nine fish species listed in Table 1, with the understanding that the Etowah caddisfly and the mussel species would also benefit.

This document reviews the scientific literature and recent research on the effects of urbanization and suburbanization on sensitive fish species. It examines both the mechanisms and the sources of stressors, with a focus on the sources found within the Etowah basin itself. The purpose is to identify the key stressors to fish species in the Etowah and the management strategies available to mitigate those threats. As such, this review provides a major part of the scientific basis for the avoidance, minimization, and mitigation policies of the Etowah HCP.

Table 2. Major Land Cover Categories in the Etowah, 1974 and 2001. Data source: National Land Cover Database.

Category	**1974**	**2001**
urban	5%	11%
forest	68%	59%
ag	19%	14%

Figure 1. Land Cover in the Etowah in 1974 and 2001. Data source: National Land Cover Database.



Overview of Stressors

Many studies have demonstrated that fish assemblages respond to a gradient of urbanization, with sensitive fishes disappearing as urbanization increases (Helms *et al.*, 2005; Klein, 1979; Meador *et al.*, 2005; Morgan & Cushman, 2005; Onorato *et al.*, 2000; Roy *et al.*, 2005b; Walters *et al.*, 2005; Walters *et al.*, 2003a; Wang *et al.*, 2001; Wang *et al.*, 2000)[1]. The mechanisms for these changes are not simple. The conversion of a forested or agricultural landscape into parking lots, buildings, and lawns produces a cascade of impacts to stream systems, including changes to hydrology, geomorphology, water temperature, and stream chemistry, as well as inputs of various toxins (for recent reviews, see Allan, 2004; Paul & Meyer, 2001; Walsh *et al.*, 2005b). Here, we organize these effects into ten categories of stressors (Table 3): sedimentation, altered flows, extensive loss of riparian buffers, movement barriers, contaminants, channelization and piping, loss of woody debris, eutrophication, invasive species, and temperature alteration. This list is based in part on a previous review of stressors in the Etowah (Freeman *et al.*, 2002) and the reviews cited above.

In creating this list of stressors, we have taken into consideration certain critical traits of imperiled fish species in the Etowah:

- Most are riffle-dwelling species and tend to be found in association with coarse particles (gravel and cobble).
- Most are high-flow specialists and tend *not* to be found in lentic conditions.
- All are either narrowly distributed (e.g., several are endemic to the Etowah) or are very rare.

We have assumed, for example, that sedimentation of riffles is a threat because so many of the species are found in riffles. Loss of access to lotic habitat is likewise a concern. Conversely, degradation of lentic habitat is given less weight in the review. Some stressors are likely to be most acute at certain life history stages of species; for example, larval fish may be especially sensitive to physical washout from excessive storm flows caused by habitat alteration.

Note that some stressors are best described as direct or proximate stressors, while others are indirect or ultimate stressors. Loss of riparian buffers, for example, generally acts via other stressors (i.e., it is a source of other stressors such as temperature alteration). Some stressors have both direct and indirect effects: for example, altered flows may lead to sedimentation, and general degradation from multiple stressors may facilitate species invasions. For simplicity we treat all stressors in a similar fashion.

Table 3 lists the categories of stressors with their potential sources and the HCP policies designed to avoid, minimize, or mitigate the stressors. The list of potential sources includes those associated with urbanization as well as those associated with agriculture and forestry, although the HCP management policies only address urbanization. This does not mean that agriculture and forestry are not bound by the provisions of the Endangered Species Act; rather, it means that they will not enjoy the benefits of coverage under the Etowah HCP. In addition, there are some other aspects of urbanization that are also not covered by the

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[1] Because effects can occur at relatively low levels of development, "urbanization" is used here to refer to any increase in development, including construction of low density suburban housing.

Etowah HCP. Construction of roads by local, state, and federal governments is not covered, and water and sewer construction and operations are not covered. These were deliberate omissions by the Etowah HCP Steering Committee designed to keep the HCP manageable by limiting its scope.

The next ten sections discuss each of the categories of stressors, including the mechanisms by which they affect fish, their sources, and the HCP management policy designed to address them.

Table 3. Stressors to sensitive aquatic species in the Etowah Basin.

Stressor	Sources	HCP Management Policy
Sedimentation	Construction sites Channel erosion Utility and road crossings Agriculture Forestry Historic land use	Erosion and sedimentation control Stormwater management policy Utility crossing policy
Hydrologic alteration	Stormwater runoff Reservoirs Water withdrawals	Stormwater management policy Water supply planning protocol
Extensive riparian buffer loss	Agriculture Golf courses Other construction	Riparian buffer ordinance
Contaminants (heavy metals, pesticides, etc.)	Point sources Stormwater runoff Agriculture Forestry	Stormwater management policy
Movement barriers	Natural barriers Road crossings Reservoirs and Ponds	Road crossing policy Water supply planning protocol
Channelization / piping	Agriculture Urban channelization Urban piping	Riparian buffer ordinance
Invasive species	Deliberate stocking Baitfish introductions Aquarium introductions Invasion from downstream Hybridization Facilitation by degradation	(none)
Temperature alteration	Loss of riparian buffers Stormwater runoff Reservoirs Water withdrawals Point sources	Stormwater management policy Water supply planning protocol Riparian buffer ordinance
Loss of woody debris	Deliberate removal Loss of riparian buffers Hydrologic alteration Channelization	See: extensive loss of riparian buffers and hydrologic alteration
Eutrophication	Point sources Agriculture Septic systems Sewer systems Stormwater runoff Erosion	Stormwater management policy Erosion and sedimentation control

Sedimentation

Studies have shown that fish richness, density, and species composition in the Etowah Basin are well predicted by stream geomorphic variables, including those reflecting sedimentation (Walters *et al.*, 2003a). Streams draining highly urbanized portions of the Etowah Basin have finer bed texture and higher turbidity, and fewer endemic or sensitive fishes, than those draining less urbanized areas even after accounting for the effect of slope (Walters *et al.*, 2003b). This is significant evidence that sedimentation affects Etowah fish species.

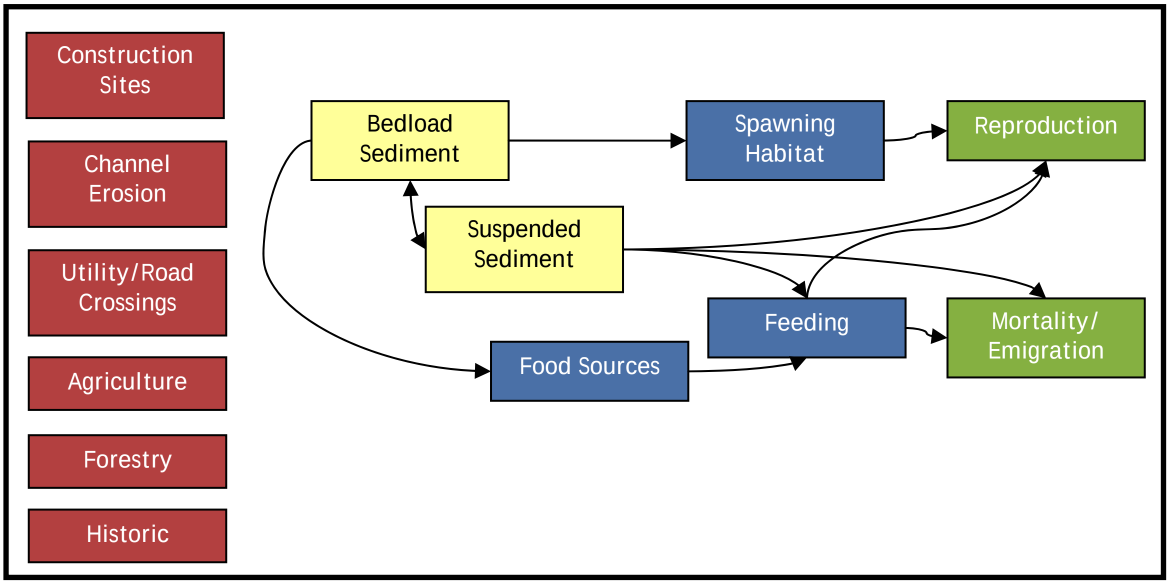
Increased sediment in streams can impact fish in two major ways: (1) bed sediment may degrade physical habitat and reduce productivity, and (2) suspended sediment may cause behavioral, sublethal health effects and mortality. These pathways can be further broken down into five mechanisms (Figure 2):

- Bed sediment can reduce primary and secondary production (Wood & Armitage, 1997) or otherwise modify food webs (Schofield *et al.*, 2004).
- Bed sediment can degrade spawning habitat for crevice and gravel-spawning fishes. Fine sediments can clog the interstices of larger particles, reducing spawning habitat (Berkman & Rabeni, 1987); it can also reduce egg survival.
- Suspended sediment can reduce spawning success. Studies have shown that increasing levels of suspended sediment reduce spawning success of both salmonids and minnows, many of which depend on clear water for visual reproductive cues (Burkhead & Jelks, 2001; Sutherland, 2005).
- Suspended sediment can reduce feeding effectiveness for sight-feeding fishes (Sweka & Hartman, 2003).
- Suspended sediment can cause stress, reduced growth, and physical abrasion to gills and other body parts (Newcombe & MacDonald, 1991; Sutherland, 2005). In a recent study, Sutherland (2005) showed that sediment levels sufficient to cause significant physical and physiological effects can occur in Southern Appalachian rivers more than fifty percent of the time.

Sources of sedimentation associated with urbanization

- Construction sites. Failure to properly install and maintain appropriate best management practices is a highly visible source of sediment to aquatic systems in the Etowah.
- Channel erosion. Runoff from impervious surfaces can lead to increased frequency and magnitude of storm flows in urbanizing streams. This can cause erosion of the stream banks and bed, leading to downstream sedimentation (Arnold *et al.*, 1982; Hammer, 1972; Trimble, 1997). See Hydrologic Alteration.
- Utility and road crossings. Open trenching of utility lines across streams can lead to short-term but severe sedimentation (Reid *et al.*, 2004). Road crossing construction can also lead to short-term sedimentation (Taylor *et al.*, 1999), although literature on the topic appears almost entirely focused on logging roads.

Figure 2. Influence diagram showing how increased sediment affects sensitive fish species in the Etowah Basin. Sources are shown in red, stressors in yellow, mechanisms in blue, and affected vital rates of fish in green.



Other sources of sedimentation

- Dredging and instream mining. A sand and gravel dredging operation in the Etowah near Canton has the potential to produce sedimentation, especially if adequate settling does not occur; however, there is little known habitat for covered species downstream of the operation, so the impacts may not be severe. Amateur gold mining is practiced in the Etowah as well; the impacts of this have not been evaluated, but the extremely small scale of these operations suggests that effects may not be major.
- Agriculture. In the Etowah, sedimentation from modern row crop agriculture appears to be a minor threat, because little row crop agriculture is practiced. However, bank erosion at cattle access points can be readily observed in many areas of the basin.
- Forestry. Forestry operations can result in substantial erosion, especially if best management practices are improperly applied. Reports from the Georgia Forestry Commission say that the most frequently violated BMPs are those for stream crossings (Green, 2003). As a general rule, however, forestry activities produce less sediment than agriculture (Wood & Armitage, 1997).
- Historic land use. Historic agriculture and gold mining deposited large amounts of sediment in stream and river valleys (Leigh, 1994; Trimble, 1970). Some channels may still be readjusting to this massive change, and may be slowly degrading as they cut down through the sediment back to their original channel level.

Depending on extent of urbanization, the dominant source of sediment may shift. Pre-development, agriculturally-derived sediment and historical sediment remobilized in the stream are often dominant sediment sources. As a watershed begins to urbanize, much sediment comes from construction sites. As development progresses, construction sites are replaced with impervious cover, and there is a decrease in sediment delivery to streams; however, scouring flows associated with increased runoff increase the amount of sediment eroding from the bed and banks (Arnold *et al.*, 1982; Doyle *et al.*, 2000; Wolman, 1967). In urbanizing watersheds, this stream channel erosion can be the major source of sediment (Trimble, 1997), and researchers have found a significant sediment supply in streams even in heavily urbanized watersheds (Pizzuto *et al.*, 2000). Streams may reach a new equilibrium after one to two decades, although some may take longer and others have not been found to stabilize in measured time frames (Henshaw & Booth, 2000; Pizzuto *et al.*, 2000).

Management Strategies

There is substantial evidence that sedimentation is a major threat to imperiled fishes of the Etowah, so the Etowah HCP policies address all three of the sources of sedimentation associated with urbanization. Sedimentation from construction sites is managed via a "standard operating procedure" (SOP) for enforcement of existing erosion and sedimentation ordinances by local governments. The Steering Committee approved this approach based on the argument that existing regulations are an adequate basis for an effective program, but the rules are unevenly enforced. An audit of the state Erosion and Sedimentation Control Program by the Georgia Department of Audits and Accounts came to this conclusion in 2001 (Georgia Department of Audits and Accounts, 2001), and local officials confirm that it is still the case in many areas. The SOP is supplemented by a grading ordinance that encourages developers to minimize the amount of exposed soil during site preparation, since the larger the area of exposed soil, the greater the possibility of erosion.

Sedimentation generated during construction of utility crossings is managed with a utility crossing policy that specifies that directional boring be used in preference to other stream crossing methods. Directional boring is a non-invasive alternative to open trenching that is increasingly common in the Etowah. Other approaches are permitted if it can be shown that directional boring is infeasible, except during spawning periods when directional boring is the only permissible option for crossing streams with populations of species covered by the Etowah HCP. The road crossings policy requires that appropriate best management practices be employed to minimize sedimentation during the construction of crossings.

Hydrologic Alteration

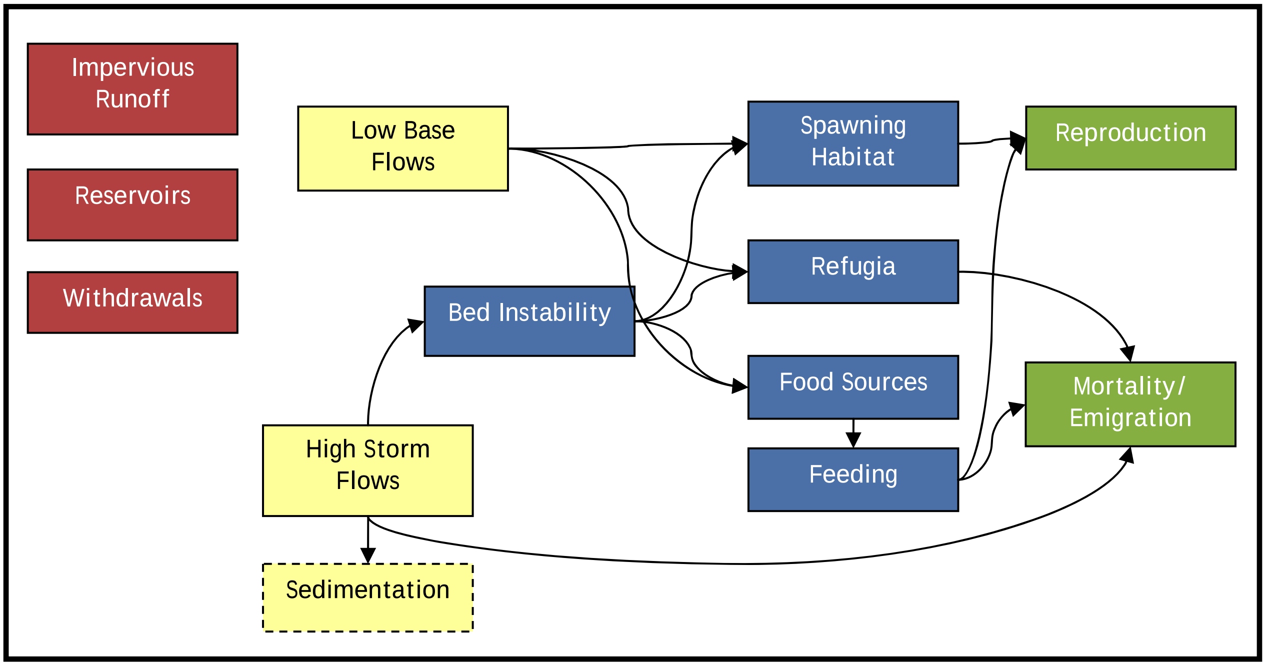
We focus on two aspects of hydrologic alteration: an increase in storm flows and a decrease in base flows, which together create a "flashy" hydrologic regime. There are other potential types of hydrologic alteration, such as daily pulsing of flows below peaking hydroelectric dams, but we focus mainly on flashy stream flows because they are associated with urban runoff, which is arguably the most common source of hydrologic alteration in the Etowah Basin, as well as the one under potential management of the Etowah HCP. There are numerous mechanisms by which altered flows can affect sensitive fish (Figure 3):

- Reduced base flows can reduce lotic habitat, which especially affects high-flow specialists (Armstrong *et al.*, 2001; Freeman & Marcinek, 2004, 2006; Power *et al.*, 1996; Walsh *et al.*, 2004a).
- Increased storm flows will result in channel widening or deepening to accommodate the additional discharge unless the channel is physically constrained (Arnold *et al.*, 1982; Booth, 1990; Doyle *et al.*, 2000; Trimble, 1997; Wolman, 1967). During this process,

which may take years or decades (if hydrologic alteration continues to increase), the bed is likely to be physically unstable at many locations (Booth, 1990; Doyle *et al.*, 2000). This instability may significantly degrade habitat for spawning, feeding, and refugia, especially for riffle-dwelling species.

- The sediment from channel widening and deepening will move through the system, leading to sedimentation of downstream habitat. This may be ephemeral or long term. A higher frequency of storm flows will also increase the amount of time that organisms are exposed to high levels of suspended sediment.
- Increased storm flows can cause physical washout of eggs and larval fishes and stresses on adults as well (Freeman *et al.*, 2001; Power *et al.*, 1996).
- In addition to direct effects on fish, hydrologic alteration may also act via the four mechanisms described above to alter the quantity and quality of primary and secondary production in a stream (Bunn & Arthington, 2002), indirectly affecting many fish species.
- For species that rely on annual hydrologic cycles for spawning or other life history patterns, disruption of the natural flow regime can reduce recruitment or cause other negative impacts (Bunn & Arthington, 2002; Poff *et al.*, 1997).
- Alteration of the natural hydrologic regime can also facilitate invasion by exotic species (Bunn & Arthington, 2002; Fausch *et al.*, 2001).

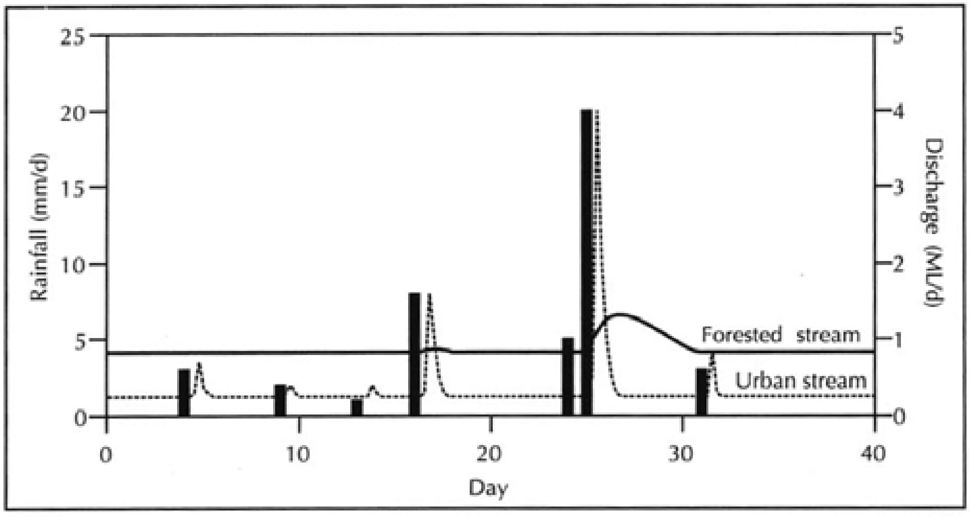
Figure 3. Influence diagram showing how hydrologic alteration affects sensitive fish species in the Etowah Basin. Sources are shown in red, stressors in yellow, mechanisms in blue, and affected vital rates of the fish in green.



Sources

- Stormwater runoff from impervious surfaces. With the possible exception of Allatoona Dam operations (described below), runoff from impervious surfaces is the most significant source of hydrologic alteration in the Etowah basin. Impervious surfaces—roads, parking lots, rooftops, etc.—alter the natural hydrologic cycle. In a natural forested system, much of the stormwater infiltrates into the soil and is carried to the stream via shallow or deep subsurface flow paths. A significant amount evaporates or transpires, and a relatively small amount becomes surface runoff. In an urbanized system with high levels of impervious cover, most stormwater hits impervious surfaces and becomes runoff, which is then channeled quickly to streams via stormwater drain pipes. Relatively little infiltrates into the soil. As a result, storm flows in the stream are higher and more frequent, although briefer in duration, and base flows are lower (Ferguson & Suckling, 1990) (Figure 4). Studies have shown that the storm discharge of urban streams can be twice that of rural streams draining watersheds of similar size (Pizzuto *et al.*, 2000; Rose & Peters, 2000), and the frequency of channel-forming events can be ten times that of the pre-development conditions (Booth & Jackson, 1997).

Figure 4. Diagram of flow response to rainfall (heavy bars) in a stream draining a forested watershed (solid line) versus a stream draining an urban watershed (dashed line). From Walsh et al. (2004a).



Research in the Etowah basin conducted as part of the Etowah HCP demonstrated that watersheds with high imperviousness are flashier and have more frequent discharge events than watersheds with low imperviousness (Roy *et al.*, 2005b). Variables describing hydrologic alteration explained 22-66% of the variation in fish assemblage richness and abundance, demonstrating that hydrologic alteration is indeed a potential mechanism of impacts to fish communities. Flow alteration was most significant during summer and autumn (Roy *et al.*, 2005b).

Many researchers have made the case that the most problematic impervious surfaces are those that are directly connected to streams via drainage and conveyance systems (Alley & Veenhuis, 1983; Booth & Jackson, 1997; Walsh *et al.*, 2004a; Walsh *et al.*, 2005b). Studies have demonstrated that this effective impervious area (EIA) is a better predictor of stream biological and chemical response than total impervious area (TIA) (e.g., Hatt *et al.*, 2004; Walsh *et al.*, 2004b; Wang *et al.*, 2001). A recent study in the Etowah found that EIA was a better predictor of sensitive fish occurrence than TIA

(Wenger *et al.*, in preparation). The implication is that if EIA can be maintained at low levels—by using stormwater infiltration in place of conventional stormwater management systems that pipe runoff to streams—it is possible to maintain healthy aquatic systems while permitting further development of the watershed (Roy *et al.*, 2005b; Walsh *et al.*, 2005a). Through infiltration, EIA can stay nearly constant even while TIA increases.

As part of the Etowah HCP, researchers conducted a study to determine the levels at which sensitive fish species in the Etowah respond to increases in impervious cover. The researchers tested the possibility that other factors, particularly historic land use, could also explain current fish distributions, as they have elsewhere (Harding *et al.*, 1998). A total of 357 fish collections from the Etowah from 1999-2003 were used in the analyses. Five 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, are species covered by the Etowah HCP. The results showed that the Etowah darter and several other species were very sensitive to increasing EIA even when historic land use and other variables were taken into consideration (Figure 5). The Cherokee darter did not show a strong response of occurrence to impervious cover, but it did show a decline in *abundance* as EIA increased (Figure 6). Because of the rarity and limited distribution of the amber darter, the closely related bronze darter was used as a surrogate. Data from the bronze darter were used as a prior [missing word?] and updated with data from the amber darter itself in a Bayesian fashion to produce a model of amber darter response to EIA (Figure 7).

Figure 5. Probability of occurrence of the Etowah darter in response to increasing effective impervious area (EIA). Black line represents a large stream; gray line, a mid-sized stream.

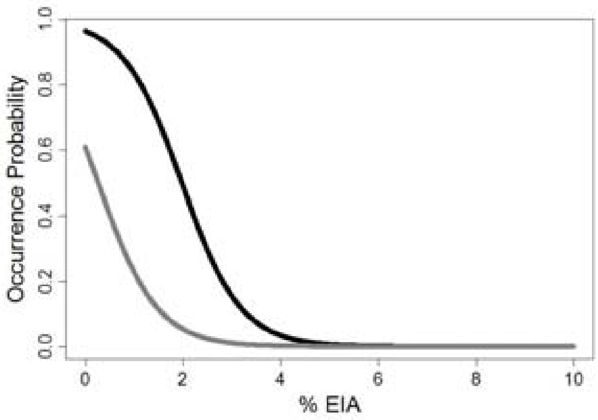


Figure 6. Abundance of the Cherokee darter within standardized stream reaches in response to increasing EIA. The two lines represent different geologic conditions.

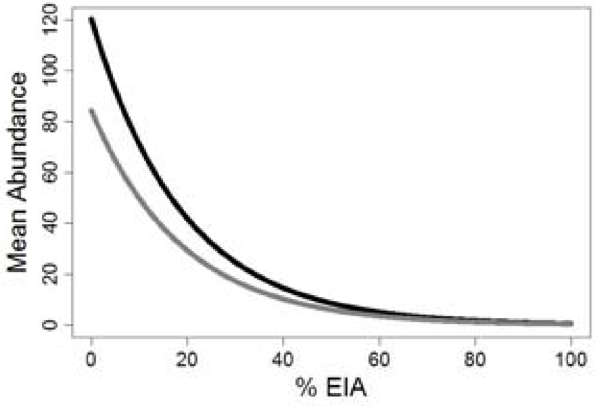
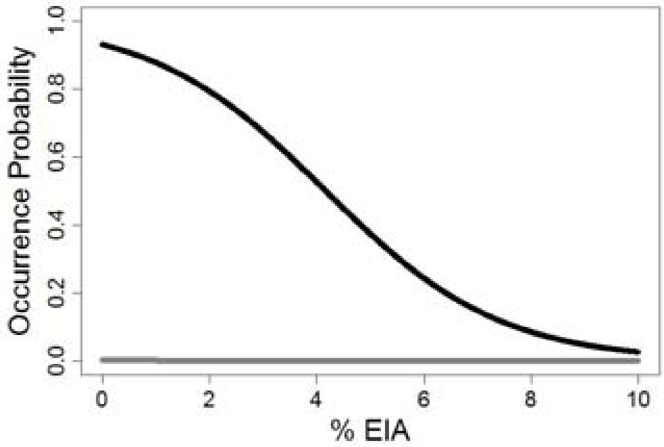


Figure 7. Probability of occurrence of the amber darter in response to increasing effective impervious area (EIA). Black line represents a river of the size of the Etowah mainstem; gray line, a mid-sized stream (too small for amber darters to occupy).



- Reservoirs. Reservoirs can significantly alter hydrology downstream, especially when dams are operated for hydroelectric power generation (Freeman *et al.*, 2001; Power *et al.*, 1996). Hydropeaking dams, such as Allatoona Dam, release high flows only when additional power is needed. This can produce a daily pulsing cycle that is very different from the natural flow regime. Farm ponds and small water supply reservoirs also may substantially alter hydrologic regimes. Even if water is consistently released from a reservoir (e.g., as a minimum flow), the storage created by a reservoir may delay the return of normal or high flows to the stream following drought periods. Water supply reservoirs typically are operated to store water captured during higher flow periods for offstream use during low flow periods, with the effect of dampening moderate to high flows and in some cases augmenting low flows.

The operation of Allatoona Dam as a hydropeaking facility may be a factor explaining the absence of the imperiled fish species of the Etowah in the mainstem below the impoundment. There are several other water supply reservoirs either existing (e.g., Yellow Creek Reservoir) or under construction (e.g., Hickory Log Creek Reservoir) that are large relative to their watersheds and can significantly impact downstream flows.

- Water Withdrawals. Water withdrawals lower downstream water levels, and recent studies in the Georgia Piedmont show that fish assemblage integrity levels decline as water withdrawal levels increase (Freeman & Marcinek, 2006). In the Etowah Basin, there are 21 water withdrawals, with maximum daily withdrawal levels ranging from 0.2 to 86 million gallons per day (mgd) (not counting Georgia Power's Plant Bowen) (Freeman *et al.*, 2005). At present, no one of these appears to be at a level to cause major downstream problems, but further growth in the area will continue to increase pressure for additional water withdrawals.

Management Strategies

There is substantial evidence that hydrologic alteration is a significant threat to imperiled fishes in the Etowah. Management is focused on controlling stormwater runoff from impervious surfaces, which is both the most common source of hydrologic alteration and the one most amenable to management. The principal tool is a stormwater ordinance based on the model ordinance of the Metropolitan North Georgia Water Planning District (the "Metro District") (Metropolitan North Georgia Water Planning District, 2004). The HCP ordinance includes five performance standards, four of which are based on the Metro District ordinance:

- Water quality protection: capture and treat runoff from all storm events of 1.2" or less, as well as the first 1.2" of runoff for all larger storm events.
- Channel protection: 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.

In addition, however, the Etowah HCP model stormwater ordinance includes a fifth requirement: a limit on the total volume of water that can leave a site as surface runoff. This "runoff limit" performance standard requires that excess runoff from small storms be infiltrated back into the soil as close as possible to where it is generated. Essentially, this should limit EIA to levels that are both low and predictable, providing near-natural hydrologic function as well as highly effective pollutant removal. The "runoff limit" standard applies only to watersheds that support populations of the most sensitive imperiled species ("Priority 1" and "Priority 2" areas). The ordinance allows local governments to designate development nodes where less strict runoff limits apply. However, the number and locations of these nodes are limited so that they will not threaten the survival of any of the species covered by the Etowah HCP.

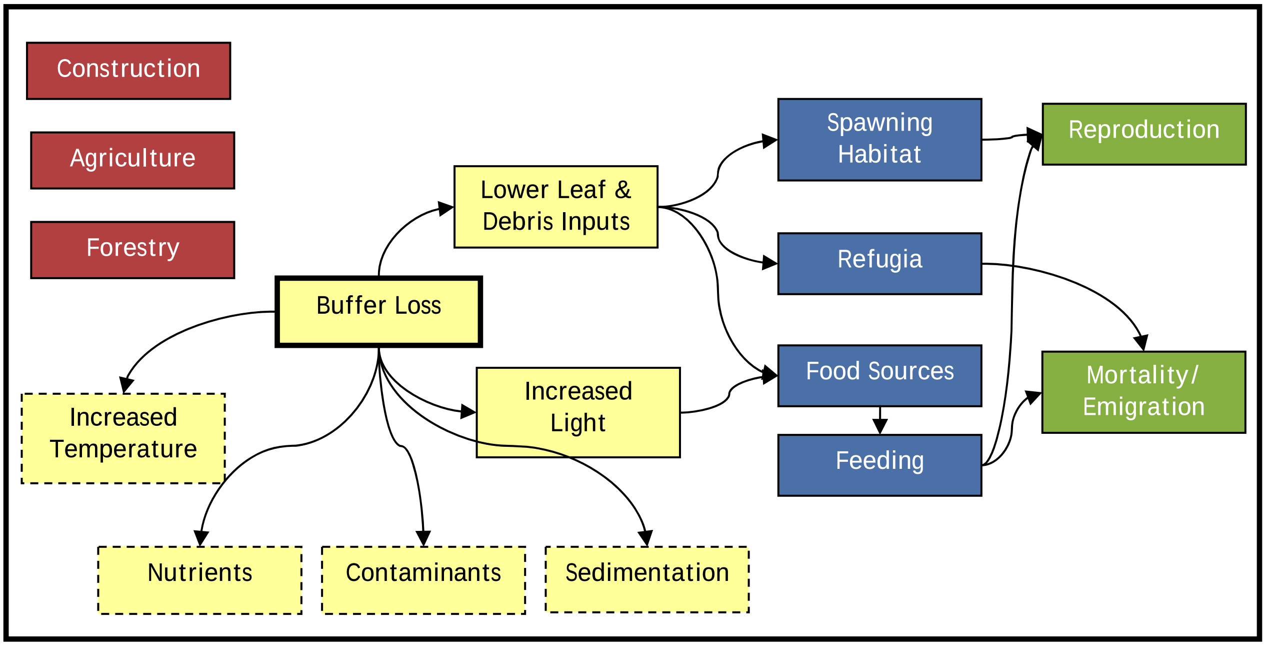
Hydrologic alteration due to the management of Allatoona Dam for hydropeaking power production may be an important factor in making the Lower Etowah uninhabitable for many species. However, operation of the dam is outside the scope of the Etowah HCP. Construction of new water supply reservoirs, however, is addressed in the Etowah HCP in limited form. A protocol has been developed to evaluate potential impacts of competing reservoir locations to ensure that reservoirs are built where they will have minimal impact on the imperiled species of the Etowah (see Movement Barriers for more information).

Extensive Riparian Buffer Loss

Removal of riparian buffers can have a number of effects on streams, including exacerbating several other stressors. Removal can (Figure 8):

- Destabilize stream banks, increasing stream sedimentation (Barling & Moore, 1994; Beeson & Doyle, 1995);
- Reduce capacity for trapping and removing contaminants from runoff (Dillaha *et al.*, 1988; Groffman *et al.*, 1991; Herson-Jones *et al.*, 1995; Lowrance *et al.*, 1997);
- Increase transport of nutrients to streams (Osborne & Kovacic, 1993; Peterjohn & Correll, 1984; Vought *et al.*, 1994);
- Increase water temperature (Barton *et al.*, 1985; Brazier & Brown, 1973; Meyer *et al.*, 2005a; Pusey & Arthington, 2003);
- Increase light penetration to streams, increasing primary production (Noel *et al.*, 1986; Pusey & Arthington, 2003);
- Reduce woody debris inputs, removing a source of aquatic habitat (Karr & Schlosser, 1978);
- Reduce leaf litter and terrestrial invertebrate inputs, decreasing production (Nakano *et al.*, 1999; Pusey & Arthington, 2003; Wallace *et al.*, 1999);
- Decrease stream width, reducing the overall amount of stream habitat (Sweeney *et al.*, 2004).

Figure 8. Influence diagram showing how extensive riparian buffer loss affects sensitive fish species in the Etowah Basin. Sources are shown in red, stressors in yellow, mechanisms in blue, and affected vital rates of the fish in green.



Many of these effects can lead to increased productivity of the stream system, which is not necessarily harmful. However, if loss of riparian buffers is extensive, then the stream can become inhospitable to fish species that depend on natural forested conditions. To better understand the effect of riparian buffer loss in an urban setting, Allison Roy and collaborators conducted a series of studies in the Etowah basin from 2002-2004 in association with the development of the Etowah HCP. They compared paired open and forested reaches along five small streams in suburban catchments (Roy *et al.*, 2005a). They found no differences in overall habitat diversity between the reaches although open reaches had higher amounts of woody debris and increased algal biomass. Open reaches had correspondingly higher densities of fish, especially the algivorous *Campostoma oligolepis*, but assemblages in all reaches appeared to be impaired due to urbanization. They concluded that small gaps in riparian buffers had little effect on biological integrity and that the negative effects of urbanization on streams are primarily due to watershed-scale effects, not local loss of riparian forest (Roy *et al.*, 2005a). Similarly, in a study of 30 small streams along a gradient of impervious cover, they found that land cover at the watershed scale was a filter for sensitive species although loss of riparian cover could lead to higher abundances of some tolerant species (Roy *et al.*, 2006). They concluded that riparian buffers alone are insufficient to maintain healthy fish assemblages in an urban setting where much stormwater runoff is transported to the stream in pipes, bypassing the buffer. Nevertheless, buffers are a necessary component of an overall program of stream ecosystem protection.

Sources

Riparian forests were previously removed on many streams to increase the land available for crop agriculture and to provide cattle with water access. Current pressures to remove riparian forests are likely to be related to new development. Some of the most extensive riparian buffer losses are associated with golf courses, which historically have been able to secure variances from local and state buffer protection regulations to heavily modify streams. Other losses of riparian buffers are associated with piping of small streams for commercial and industrial development (see Channelization and Piping). This is an extreme form of buffer loss where the riparian zone is obliterated and the stream is completely disconnected from the terrestrial system.

Management Strategies

Preservation of riparian buffers is essential to protecting the imperiled species covered by the Etowah HCP. The chief management strategy for protecting riparian forests under the Etowah HCP is a riparian buffer ordinance. The regulations are based on a model ordinance of the Metropolitan North Georgia Water Planning District (Metropolitan North Georgia Water Planning District, 2004) and require, at a minimum, protection of 50 ft naturally vegetated riparian buffers with an additional 25 ft setback for impervious surfaces along all perennial streams. A slightly less restrictive option (without the 25 ft setback) is recommended for Lumpkin County, Pickens County, Dawson County, and Dawsonville, which are outside of the Metro District. The ordinance does not apply to agriculture and forestry lands although appropriate best management practices are strongly encouraged on lands used for those activities.

Contaminants

Aquatic contaminants, including metals, hydrocarbons, pesticides, and other potentially harmful organic and inorganic compounds, are common in urban streams and may be partially responsible for the absence of sensitive fish in those system. Because of the expense of monitoring and experimental study, however, they have not received the attention they deserve. In the past, some studies have dismissed the role of water quality on aquatic species in urbanizing landscapes, but more recently scientists have challenged this view and suggest that contaminants may play a major role (Walsh *et al.*, 2004a). There are a number of mechanisms by which contaminants can affect fish:

- Contaminants can cause direct mortality. Laboratory studies have shown that high levels of metals, pesticides, and other contaminants can cause lesions, deformities, and even mortality in fish (e.g., Meyers & Hendricks, 1982; Woodling *et al.*, 2002). However, most of the acute toxicity studies have been conducted on fish of commercial importance although these may not be good predictors of nongame species responses (Woodling *et al.*, 2002).
- Contaminants can have sublethal effects. Heavy metals—such as mercury, lead, arsenic, selenium, cadmium, and copper—have been found to impair physiological functions of the liver, heart, and kidneys, as well as to impair growth rate, metabolic capacities, and respiration rates (e.g., (Rajotte & Couture, 2002; Rowe *et al.*, 2002) and to cause morphological and morphometric changes to organs (Jagoe *et al.*, 1996). Organic compounds—such as surfactants, PCBs, insecticides (e.g., dioxins, malathion), and fungicides (e.g., imidazole, triazole)—have been found to cause morphological alterations; increased instances of sores, lesions, and fin erosion; impaired reproductive function; and reduced reproductive fitness (e.g., Monod *et al.*, 2004). Endocrine disrupting chemicals can cause subtle changes in fish physiology and sexual behavior or more permanent damage such as sexual differentiation and impairment of reproductive fitness (Carlisle & Clements, 2003; Jobling & Tyler, 2003; Noaksson *et al.*, 2003; Van Der Kraak *et al.*, 2001).

- Contaminants can reduce primary or secondary productivity. Contaminants can impair production and degrade the quality of food sources. Rosi-Marshall (2004) found that the quality of fine particulate matter as a food source was lower in the Chattahoochee River below Atlanta than in a control although she was unable to attribute the reduction to a specific cause. Studies have shown that aquatic invertebrate density, production, and diversity is lower in streams with metal contamination (Maret *et al.*, 2003).

Sources

- Urban Point Sources. The most recent database of point sources permitted under the National Pollution Discharge Elimination System lists 96 wastewater discharges in the Etowah. These include wastewater treatment plants, mines, and industrial facilities. The largest discharge is the cooling water for Georgia Power's Plant Bowen; the next largest discharges are the wastewater treatment facilities for Cobb County, Cartersville, and Rockmart.

  Organic chemical compounds such as polychlorinated biphenyls (PCBs) are found in urban streams, sometimes as a result of point sources. Fish tissue samples from the Coosa River at Rome found levels of PCBs many times greater than the maximum recommended by the National Academy of Science / National Academy of Engineering (Zappia, 2002). This is believed to be a legacy of a General Electric transformer plant in Rome. Because PCBs bioaccumulate and continue to cycle through biota, they can be transported both upstream (into the Etowah) and downstream by the movement of fishes, especially large migratory fish such as striped bass.

- Urban Nonpoint Sources. Pesticides are heavily used in urban and suburban areas, and many of these find their way to streams and groundwater (Schueler, 1995). The highest levels of the pesticides 2,4,D, imazaquin, and malathion recorded nationally in the National Water Quality Assessment program were found in an urban stream in Montgomery, Alabama (McPherson *et al.*, 2003). A comparison of agricultural and urban groundwater quality in the Mobile Basin found a greater variety and frequency of pesticide compounds in the urban groundwater (Robinson, 2003). Chlordane and other now-banned organochlorine pesticides are still common in urban streams, including those in the Mobile Basin (Zappia, 2002). Although most pesticides applied to lawns remain bound to soils or thatch, a significant amount runs off during storm events or infiltrates into shallow groundwater and can be transported to streams (Schueler, 1995).

  Streets and parking lots can contribute large quantities of heavy metals (zinc, cadmium, chromium, nickel, manganese, copper, and others) that are largely derived from automobiles (Bannerman *et al.*, 1993; Muschak, 1990; Van Hassel *et al.*, 1980). Runoff from rooftops is relatively clean although galvanized roofing can contribute large amounts of zinc (Bannerman *et al.*, 1993). Oil and other hydrocarbons are also common constituents in runoff, and the amounts washed into streams and rivers may be massive (Paul & Meyer, 2001). It is generally accepted that most of the contaminants in stormwater are washed off in a "first flush" although there is evidence that, in highly urbanized watersheds, significant contaminants continue to be delivered after the first flush (Goonetilleke *et al.*, 2005; Schueler, 1994).

- Agriculture. Pesticides are frequently found in streams draining agricultural land uses, with herbicides being the most commonly detected (McPherson *et al.*, 2003). Many agricultural streams still contain DDT and its degradation products (Zappia, 2002).

Management Strategies

Although not well characterized, contaminants may be a major threat to the imperiled species covered by the Etowah HCP. Fortunately, the most significant source of contaminants—stormwater runoff—can be managed with the same stormwater ordinance that also controls hydrologic alteration. The ordinance requires that all new development must meet a standard of 80% removal of total suspended solids in the first 1.2" of runoff. This is intended to treat small storms and the first flush of large storms. In addition, under the runoff limits program, new development in Priority Areas 1 and 2 will need to use infiltration practices to meet the volume control performance standard under most circumstances. Pollutant removal performances of infiltration practices are among the highest of any stormwater treatment BMPs (Walsh *et al.*, 2004a). Studies have found nearly 100% removal of metals within bioretention areas (Davis *et al.*, 2003). Studies of infiltration areas in Switzerland and France found that soils effectively trapped heavy metals and other pollutants; concentrations of pollutants decreased rapidly within a short distance in soils, indicating that even after decades of use there was effective treatment and little risk to groundwater (Barraud *et al.*, 2005; Barraud *et al.*, 1999; Mikkelsen *et al.*, 1997). Infiltration areas may be less effective at removing nutrients; see the section on eutrophication.

Management of point sources and agricultural sources are outside the jurisdiction of the Etowah Regional HCP.

Movement Barriers

Many fish species need to move upstream and downstream as part of their natural life cycles. A number of species release larvae in upstream areas, allowing them to drift to favorable downstream habitats (Robinson *et al.*, 1998; White & Harvey, 2003). This is then balanced by upstream movement of adults (Hall, 1972). Movement barriers interrupt this process, fragmenting populations and making them more vulnerable to local extinction.

In addition, connectivity is essential for allowing a species to recover from small-scale disturbances: a local population may be wiped out by a pulse of sediment from a construction site or a chemical spill, but as long as recolonization routes are available, such periodic events may not have long-term impacts. Several authors have reported rapid recovery of defaunated streams (Bayley & Osborne, 1993; Lonzarich *et al.*, 1998; Peterson & Bayley, 1993; Sheldon & Meffe, 1995), suggesting that many species have a natural ability to recover from such impacts, provided that they have an unblocked route for recoloniation. In fact, many fish populations may be best termed metapopulations. According to classical metapopulation theory, a population can persist in numerous patches that are alternately extirpated and recolonized, allowing the overall persistence of the metapopulation even when local patches are inhospitable (Hanski & Simberloff, 1997; Levins, 1969). Metapopulation dynamics of freshwater fish have received only a modest amount of study to date (but see Dunham & Reiman, 1999; Gotelli & Taylor, 1999; Koizumi & Maekawa, 2004) although it is widely thought that metapopulation dynamics do operate on many stream fishes in some fashion (Fagan, 2002; Rieman & Dunham, 2000). If this is so, then it is essential to maintain open pathways connecting population patches to allow recolonization. Because fish movement pathways are confined to the streams themselves (unlike those of amphibians and most aquatic arthropods, for example), fish are highly susceptible to the effects of movement barriers (Charles *et al.*, 1998; Joy & Death, 2001; Koizumi & Maekawa, 2004). We believe that movement barriers play a critical role in determining the likelihood of extinction or persistence of the imperiled fish species in the Etowah.

Sources

Because streams are linear systems, any obstacle or reach of inhospitable habitat can act as a significant barrier to fish movement. Movement barriers can be natural or man-made, partial or complete, one-way or two-way. Natural barriers include waterfalls, riffles, areas of bedrock, and dry stream segments; man-made barriers include culverts and other road crossings, channelized stream segments, dewatered stream segments, and dams.

- Natural Barriers. Movement studies have found evidence that even such natural partial barriers as riffles can inhibit movement although the effect is most severe at low flows. A study of leopard darter (*Percina pantherina*) movement found very little movement across riffles and areas of bedrock (Schaefer *et al.*, 2003) while a pair of short-term movement studies in Arkansas found that five species of cyprinids and centrarchids were three times more likely to cross short riffles (average 8m) than long riffles (average 50m) (Lonzarich *et al.*, 2000). In a series of artificial stream studies, Schaefer (2001) found that shallower, faster riffles were greater barriers than deeper, slower riffles. Fish colonization rates in natural streams also were significantly reduced by the presence of shallow riffles (Lonzarich *et al.*, 1998).

- Culverts. In the study of leopard darter movement discussed above, researchers also examined the effects of culverts (Schaefer *et al.*, 2003). They found no movement upstream and little movement downstream through a culvert. In a series of experimental trials in an artificial stream, the same researchers found that culverts of various types greatly reduced movement of leopard darters although in no case did they block movement entirely (Schaefer *et al.*, 2003). A larger mark-recapture study in small Arkansas streams found that open box culverts and fords were not barriers to fish movement but that pipe culverts and a flat concrete slab road crossing significantly impeded movement (Warren & Pardew, 1998). Researchers found that movement across a potential barrier was negatively correlated with water velocity across the barrier.

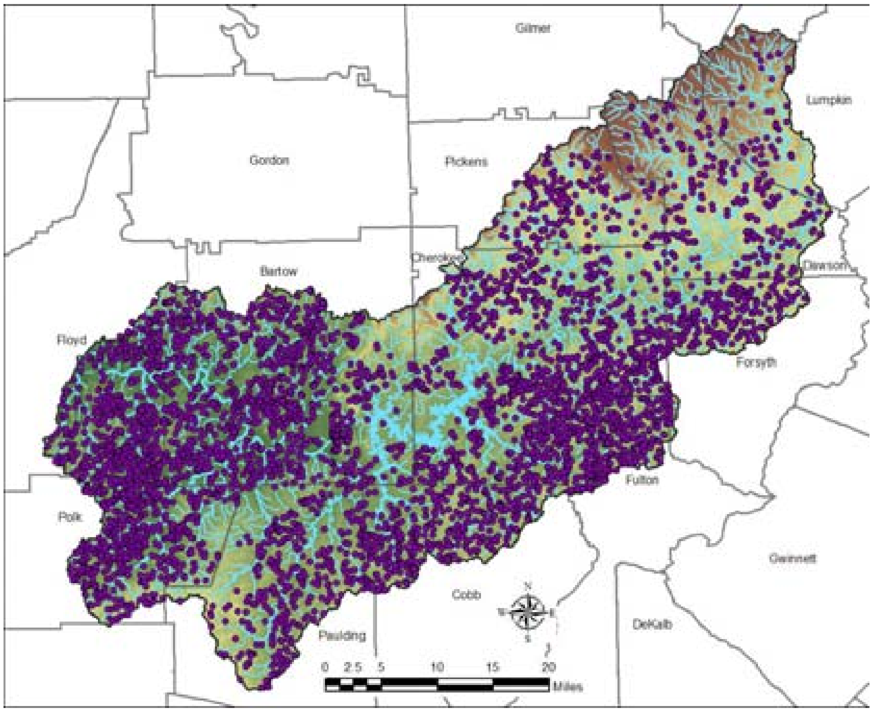
  Culverts are ubiquitous in the landscape and increase in density with urbanization. Unlike riffles, many culverts are permanent barriers: they impede movement at both low and high flows. Most of the culverts that block movement are on small streams, so small stream fish species may be most severely affected. However, larger stream fish species generally have fewer distinct populations (i.e., because there are fewer large streams), so the effect of an individual barrier on a large tributary may be dramatic.

A study of 70 stream crossings in the Etowah River Basin found that 34% of surveyed crossings had characteristics likely to make them impassable to small-bodied fish. Fifty-five percent of pipe culverts were considered impassable (Figure 9). In addition, most of the surveyed culverts appeared to be undersized, which produces high velocities and channel scouring at high flows. A fish movement study in the Etowah basin found that fishes were much less likely to move through pipe or box culverts than stream crossings with bridges. Taken together, research on stream crossings in the Etowah River basin illustrates that as many as one-third or more of the existing crossings on streams draining up to 50 km^2 are likely to impede passage by small fish and that passage problems are likely to occur where pipe, and to a lesser extent, box culverts are used to cross streams.

Figure 9. A typical pipe culvert with a drop to the tailwater surface (Camp Creek, Lumpkin County). Photo by Heidi Millington.

- Reservoirs. The construction of Allatoona Reservoir isolated many populations in previously connected watersheds. This may be a factor in the extirpation of several fish species from small watersheds that are now tributaries to the reservoir rather than the Etowah mainstem. There are over 2000 smaller reservoirs in the Etowah that fragment streams (Figure 10). Most are on small (first or second order) streams, but a number are located on larger tributaries, effectively isolating large sections of headwaters.

Figure 10. Reservoirs and ponds in the Etowah basin. Digitized from USGS topographic maps and aerial photos.



Management Strategies

Movement barriers are a major threat to the species covered by the Etowah HCP. The main policy to manage the threat of movement barriers is the Stream Crossing Policy (referenced elsewhere as the Road Crossing Policy and the Road Crossings of Streams Policy). This policy requires that, for new stream crossings, bridges must be used for streams draining areas of 20mi^2 or greater. Box and pipe culverts may be used on smaller streams, but these must be embedded or bottomless, and sized at 1.2 times the stream width, plus two feet. Multi-barrel pipe culverts are prohibited although multi-barrel box culverts are allowed. These requirements apply to both privately constructed road crossings and those built by city and county governments and their contractors. Only new road crossings are affected, not replacement of existing crossings, except in the case where a bridge is to be replaced by a culvert.

In addition, the Etowah HCP includes a protocol to assist local governments in identifying reservoir locations with the least impact on protected fishes. The protocol is a procedure for evaluating the impacts of potential reservoir locations by examining:

- the number of habitat patches disturbed;
- the habitat quality in patches disturbed;
- the connectivity among patches disturbed; and
- the diversity of patch types disturbed.

These guidelines are intended to avoid conflicts between water resource development and stream conservation by removing from consideration those technically feasible options that would likely jeopardize the survival of the HCP species. The policy will also greatly streamline the reservoir review process by federal agencies, saving considerable time and expense for local governments and water utilities.

Channelization and piping of streams

Channelization includes the straightening, deepening, widening, embanking, stabilizing, and/or clearing of streams and rivers for purposes of flood control, drainage improvement, navigation, and relocation (Brookes, 1988; Simpson *et al.*, 1982; Swales, 1982). *Piping* is the extensive culvertization of a length of stream designed to remove the waterway to allow other land uses, such as large buildings and parking lots. These two stressors are grouped together because both involve direct physical modification of the stream itself:

- Removal of habitat. Straightening, widening, and deepening of channels usually include the physical destruction of riffles and pools (Brookes, 1988). Extreme channelization may replace the stream with a concrete-lined channel; similarly, piping replaces the natural stream channel with a metal or masonry pipe. In most cases, essential elements of habitat are entirely lost from the affected length of stream and the remaining channel is very homogeneous. Channel straightening also reduces the total length of habitat available (Simpson *et al.*, 1982). Loss of habitat affects all aspects of the lives of fish, leading to lack of spawning habitat, refugia, and/or food sources. Studies have shown that lack of habitat is a problem in channelized streams at both low flow (Brookes, 1988; Simpson *et al.*, 1982; Swales, 1982) and high flow (Negishi *et al.*, 2002). Piping a stream "eliminates aquatic habitat" outright (Meyer *et al.*, 2005b).
- Reduction in food sources. Studies have shown that invertebrate biomass and diversity in channelized stream segments are much lower than in natural stream segments (Moyle, 1976). Virtually no organisms can live within a piped stream, and insect diversity downstream from piped segments is greatly reduced (Meyer *et al.*, 2005a).
- Hydrologic alteration. Channelization is often intended to increase the hydraulic efficiency of the channel and increase flow velocity, which results in large increases in peak discharge (Swales, 1982).
- Sedimentation. There are often upstream and downstream geomorphic impacts of channelization and piping. Because the hydraulic efficiency is increased in the affected segment, erosion may occur downstream, resulting in sedimentation (Simpson *et al.*, 1982).
- Downstream effects from loss of headwater streams. It is typically the small, headwater streams that are piped. Meyer and Wallace (2001) documented the important role of headwater streams in maintaining the overall ecological integrity of the aquatic system. Loss of headwater streams through piping may lead to decreased sediment retention; reduced processing of nutrients, contaminants, and organic matter; and hydrologic changes, among other effects (Meyer *et al.*, 2005a).

The effect of channelization on fish populations can be dramatic. Studies have shown that number, biomass, and richness of fish in channelized stream reaches are typically far below that of comparable natural stream reaches (e.g., Huggins & Moss, 1975; Moyle, 1976). The reduction in biomass in channelized streams can be over 90% (Brookes, 1988). The impact of piping appears to be less studied but possibly even more dramatic.

Sources

- Historic agricultural channelization. Most of the existing channelization in the Etowah Basin is probably associated with row crop agriculture. The extent of historic channelization is unknown and likely to be less extensive than in other parts of the country (e.g., the Midwest and lower Mississippi), but examples are evident from aerial photographs and from field observations.
- Urban channelization. Some streams are channelized in urban areas. Such projects are less common today than in the past; today, it appears more common for small streams to be piped and buried while larger streams are better protected.
- Urban piping. Stream piping is common with large commercial and industrial construction projects. Current regulations in Georgia permit the piping of up to 200 ft of small headwater streams without a permit and larger streams and additional length with a permit.

Management Strategies

Piping of streams is common for large construction projects and constitutes a significant threat to the species covered by the Etowah HCP. While there are no management actions under the Etowah HCP explicitly devoted to preventing channelization or piping of streams, riparian buffer regulations prohibit these activities for streams draining more than 20 acres. If buffer ordinances are properly enforced, large streams should be protected. Agriculture and forestry are exempt from these regulations, although they are expected to follow BMPs, which also mandate buffers. Other ordinances, such as conservation subdivision regulations, provide incentives for stream protection. Under the adaptive management provisions of the Etowah HCP, additional measures will be considered if monitoring and research show that channelization and piping remain significant threats in the Etowah Basin.

Invasive Species

The homogenization of fish communities due to the introduction of cosmopolitan species is occurring across the United States, but southeastern fish communities have suffered less than many other parts of the U.S. (Rahel, 2000). Southeastern fish assemblages may be resistant to invasion due to their high diversity: the principle that more diverse communities are less invasible has a long history in the ecological literature (Elton, 1958) and is supported by experimental evidence (Shurin, 2000). However, others (e.g., Moyle & Light, 1996) disagree that aquatic community invasibility is related to diversity. Furthermore, there is ample evidence that southeastern fish communities are at risk of internal homogenization, in which habitat degradation eliminates specialists and local endemics in favor of habitat generalists (Scott & Helfman, 2001; Walters *et al.*, 2003a).

Thirteen non-native species are known from the Etowah (Table 4; Freeman et al. 2002). Of these, the red shiner (*Cyprinella lutrensis)* is considered the species of greatest concern because of its adaptability, tolerance, rapid reproduction, and ability to hybridize with native minnows (Etnier & Starnes, 1993; Marsh-Matthews & Matthews, 2000). The redbreast sunfish, although widely distributed, has long been naturalized in the Etowah system and is not known to have led to declines in native fish species. Non-native trout species are confined to cool headwater streams and other temporary stocking locations. The *Morone* species and threadfin shad are common in Lake Allatoona and the Etowah mainstem but again are not thought to have had a noticeable impact on native species. Carp species are of some concern because of their ability to heavily graze macrophytes. The bluntnose minnow (*Pimephales notatus*) is an uncommon species in the Etowah mainstem.

Table 4. Nonindigenous fishes of the Etowah basin.

Common name	**Family**	**Scientific Name**
threadfin shad	Clupeidae	*Dorosoma petenense*
grass carp	Cyprinidae	*Ctenopharnygodon idella*
red shiner	Cyprinidae	*Cyprinella lutrensis*
common carp	Cyprinidae	*Cyprinus carpio*
bluntnose minnow	Cyprinidae	*Pimephales notatus*
rainbow trout	Salmonidae	*Oncorhynchus mykiss*
brown trout	Salmonidae	*Salmo trutta*
brook trout	Salmonidae	*Salvelinus fontinalis*
white bass	Moronidae	*Morone chrysops*
yellow bass	Moronidae	*M. mississippiensis*
striped bass	Moronidae	*M. saxatilis*
hybrid bass	Moronidae	*M. chrysops* x *M. saxatilis*
redbreast sunfish	Centrarchidae	*Lepomis auritus*

Invasive species impact natives by both replacement and displacement (Helfman, in press). Somewhat more specifically, mechanisms include:

- Competition. Some invasive species are highly aggressive competitors that may exclude native species from feeding, spawning or other essential activities. The red shiner may fall in this category.
- Predation. Introduced predators may eliminate native species by predation on adults, juveniles or eggs.
- Habitat Modification. It is possible that introduced herbivores, such as grass carp and common carp, could reduce native macrophytes, indirectly impacting other fish species. Thus far, there is no evidence of this in the Etowah.
- Hybridization. Invasive species can hybridize with native species, such as has been observed in western sucker species (Scoppettone *et al.*, 1991), and with the red shiner and native *Cyprinella* species where the red shiner has been introduced (Hubbs & Strawn, 1956; Taylor *et al.*, 1994). This is threat is currently under study by David Walters, US EPA, Byron Freeman, Georgia Museum of Natural History, and Noel Burkhead, USGS.

Sources

Listed here are both the sources of non-native species and factors involved in their spread.

- Deliberate stocking. Worldwide, this may be the most common source of invasive species (Helfman, in press). Trout are stocked in tributaries of the Etowah and have established permanent populations in higher-altitude streams with sufficiently cool water. Other species may be stocked in impoundments and subsequently escape upstream or downstream.
- Baitfish introductions. Various non-native species of minnows have been or are currently used for bait in the Etowah. The red shiner is thought to have been introduced as a baitfish.
- Aquarium introductions. Many species have spread as the results of the release of aquarium species (Helfman, in press).
- Invasion from downstream. Some species may not have been introduced locally but may have invaded the basin from downstream after they were introduced elsewhere in the Coosa system.
- Facilitation by degradation. Although the rate of introduction of nonnative fish species has not been found to be closely correlated with human population density (McKinney, 2001), urbanization may indirectly facilitate species invasions by degrading aquatic habitat. Homogenization of fish communities has been observed in highland Southeastern stream systems degraded by deforestation and sedimentation (Scott & Helfman, 2001). Walters et al. (2003a) associated homogenization of fish communities with habitat sedimentation and alteration in the Etowah. In both of these cases, invading species were native downstream or elsewhere in the basin although assumably certain non-native cosmopolitan species would also benefit from the same conditions. Hydrologic alteration (particularly reservoir construction) also has been cited as a factor facilitating the spread of invasive species (Bunn & Arthington, 2002; Meffe, 1991).

Management Strategies

At this time invasive species do not appear to be a major threat to the species covered under the Etowah HCP, and there are no management strategies explicitly devoted to preventing their introduction or spread. Many of the other HCP provisions are intended to prevent degradation of aquatic systems, which should reduce the threat of internal homogenization.

Temperature Alteration

Aquatic organisms are adapted to a limited temperature range. If stream water temperatures are raised or lowered beyond this range, potential effects include:

- Metabolic stress and mortality. Water temperatures outside the thermal tolerances of fish can lead to reduced metabolic activity and mortality. Although the thermal tolerances of many cold-water species have been thoroughly evaluated, those of most warm-water fish are little-studied (Eaton & Scheller, 1996).
- Alteration of spawning times. Changes in water temperature may lead to earlier or later spawning. For example, spawning by river-dwelling basses (*Micropterus*) may vary depending on thermal regime (Graham & Orth, 1986; Peterson & Kwak, 1999), and the duration of spawning by many darter species is regulated by temperature (Hubbs, 1985)

- Temperature shock. Sudden pulses of high or low temperature water may negatively impact fish species that would not be affected by the change if they had time to acclimate.
- Reduction in food sources/alteration in food webs. As with other stressors, temperature alteration may indirectly affect fish by impacting leaf decomposition, invertebrate life history, or otherwise disrupting natural food webs.

Sources

- Loss of riparian buffers. Riparian forests are critical in controlling stream temperature (Barton *et al.*, 1985; Brazier & Brown, 1973; Pusey & Arthington, 2003). Recent studies in North Georgia showed that reduced forest cover in the riparian zone was correlated with increased stream temperatures (Meyer *et al.*, 2005a).
- Stormwater runoff. Stormwater runoff from impervious surfaces tends to be hotter than runoff from natural vegetated soils, leading to elevated water temperatures in urban streams (Hatt *et al.*, 2004; Walsh *et al.*, 2001). Runoff from Atlanta during summer storm events has been associated with trout mortality in the Chattahoochee River, downstream from Buford Dam (John Biagi, pers. com.). Additionally, impervious cover prevents infiltration into shallow groundwater, which under natural conditions buffers stream temperature (Poole & Berman, 2001).
- Reservoirs. Large hydropower dams are typically bottom-release and can maintain downstream water temperatures much lower than natural levels, resulting in such anomalies as the trout fishery of the Middle Chattahoochee in Atlanta, Georgia. In contrast to large dams, most small reservoirs are top-release, which can produce elevated downstream water temperatures.
- Water withdrawals. Reducing the flow in a stream reduces its ability to maintain a consistent temperature (Poole & Berman, 2001).
- Thermal effluent discharges. Point source discharges, especially of power plant cooling water, may be warmer than receiving water bodies.

Management Strategies

At this time there is not evidence that temperature alteration is a major threat to the species covered by the Etowah HCP. The riparian buffer ordinance, stormwater management program, and reservoir siting guidelines should help maintain natural stream temperature regimes essential to persistence of the HCP species.

Loss of Woody Debris

The presence of large woody debris is a critical element in structuring fish assemblages in streams and rivers in many locations, especially those with sandy subtrates. In these locations, removal of woody debris tends to reduce the abundance and diversity of fish (Angermeier & Karr, 1984). Mechanisms include:

- Alteration of channel morphology and habitat. Removal of woody debris can lead to a loss of pool habitat and a homogenization of habitat characteristics, such as water velocity and benthic material (Wallace *et al.*, 1995). Loss of woody debris can eliminate shelter from high-velocity flows (Crook & Robertson, 1999).

- Decreased retention of organic and inorganic matter. Nutrient uptake lengths tend to be shorter in pools behind debris dams (Bilby & Likens, 1980; Wallace *et al.*, 1995), so loss of woody debris tends to decrease the "efficiency" of the stream in processing organic matter. This can decrease the overall productivity of the stream system.
- Loss of food sources/foraging sites. Woody debris provides substrate for invertebrates, which may be especially important in low gradient, sandy-bottom streams lacking other surfaces for attachment (Wallace & Benke, 1984).

Sources

Although it is a problem elsewhere, researchers have not observed a lack of woody debris in Etowah streams, suggesting that this is not a major stressor. However, there are several potential causes of a lack of woody debris:

- Deliberate removal. Woody debris is regularly removed from bridge pilings to prevent excessive scour which could compromise the structures.
- Loss of riparian forests (Karr & Schlosser, 1978). Without a source, woody debris in streams will eventually disappear.
- Hydrologic alteration. Increased magnitude and frequency of stormflows could increase export of woody debris from streams.
- Channelization. By increasing flow velocity and decreasing sinuosity, channelization can increase export of woody debris. However, a stream recovering from channelization may have unstable banks that generate large amounts of woody debris.

Management Strategies

Because lack of woody debris does not appear to be a major stressor at this time, there are no management strategies explicitly focused on this threat. However, the riparian buffer ordinance and stormwater management ordinance are expected to help ensure a supply of woody debris and minimize excessive washout.

Eutrophication

Eutrophication, or excessive nutrient input , is a widespread problem in surface waters of the U.S. (Carpenter *et al.*, 1998). To date, concerns over nutrients in the Etowah basin have focused on the possible eutrophication of Lake Allatoona, the large multipurpose reservoir bisecting the system and providing drinking water to parts of the Atlanta metropolitan area. A comprehensive water quality assessment of Lake Allatoona (Rose, 1999) characterized the impoundment as midway between mesotrophic and eutrophic, and predicted that the reservoir would be unfit for drinking water or recreation within 10 years unless phosphorus inputs were reduced. While nutrient pollution has long been implicated in the degradation of lentic water bodies, its effects on streams and rivers are less studied (Nijboer & Verdonschot, 2004), and we have found few published cases that attribute fish kills or changes in fish assemblages to nutrients. Potential effects of eutrophication that could impact Etowah fish species include:

- Shifts in algal assemblages. It has been noted that there is a weaker causal relationship between nutrients and chlorophyll in streams than in lakes (Dodds *et al.*, 2002). Nevertheless, nutrient enrichment can lead to shifts in the structure of benthic algal communities, as summarized by Carpenter et al. (1998). During low flow periods in recent years, algal blooms in the neighboring Conasauga River have covered shoals in a filamentous slime (Freeman & Wenger, 2001) that may have degraded habitat for benthic fishes. Such blooms have not been described in the Etowah, but a combination of high nutrients and low flows, as occurred in the Conasauga, might permit a similar event.
- Death of *Podostemum*. We hypothesize that dense algal blooms could smother the benthic macrophyte *Podostemum*, which provides cover for benthic fishes as well as increases the productivity of invertebrate prey for stream fishes (Grubaugh & Wallace, 1995; Hutchens *et al.*, 2004).
- Declines in dissolved oxygen. In lentic water bodies, large algal blooms are followed by die-offs, which lead to oxygen sags as microorganisms degrade the dead algal material (Carpenter *et al.*, 1998); this decline in dissolved oxygen can cause fish kills. Under low flow conditions, such events are possible in rivers as well.
- Rapid decomposition of leaves. Small, tree-shaded tributaries are light-limited and are not expected to suffer algal blooms and related problems. However, nutrient enrichment can accelerate decomposition of leaves and other heterotrophic food sources, causing unnatural seasonal shortages of primary food sources for the system (Greenwood, 2004).
- Toxicity. At high concentrations both ammonium and nitrate can be toxic although such cases are rare (Nijboer & Verdonschot, 2004).

Sources

Although both nitrogen and phosphorus can be limiting in freshwater systems (Dodds *et al.*, 2002), Lake Allatoona has been identified as phosphorus-limited (Rose, 1999). Therefore, our focus is on phosphorus sources.

- Point sources. The wastewater treatment plants (WTPs) above Lake Allatoona are permitted for phosphorus loads totaling 67,026 lbs per year (Rose, 1999), although several WTPs do not have phosphorus limits, so their contributions are unknown.
- Agriculture. In the Etowah, the main agricultural sources of phosphorus are likely to be poultry and cattle farming, both of which are still practiced extensively in portions of the basin (Boatright, 2004). It is common practice to dispose of poultry litter by spreading it on pasture, sometimes in excess of the rate that can be used by vegetation or bound by soil. When it rains shortly after application, or when phosphorus accumulates to high levels in the soil, the likelihood that nutrients will be transmitted to surface water is increased (Chapman, 1996).
- Septic systems. Under the right conditions, septic systems achieve very good performance. Studies have found 99% removal of phosphorus within 40 horizontal feet from a drainfield (McNeillie *et al.*, 1994) and total nitrogen reduction of 99% two feet below a drainfield (Anderson *et al.*, 1994). However, improperly located and poorly maintained septic systems can and do contribute to surface water pollution, and some consider septic systems the greatest threat to groundwater (Nizeyimana *et al.*, 1996). Much of the population of the Etowah basin is served by septic systems

although the exact proportion has not been determined and the proportion of failing systems has also not been estimated.

- Sewer systems. A sewer collection system conveys wastewater to a treatment plant, where the effluent becomes a point source (see above). Along the way, however, there are opportunities for leakage, especially at pump stations and other junctures. While septic system failures usually discharge partially treated wastewater, sewer line failures result in raw wastewater discharges, usually in close proximity to streams. The frequency of sewer line failures in the Etowah is unknown.
- Stormwater runoff. Urban runoff can be high in nutrients. The ultimate sources of nutrients in runoff are likely to include lawn fertilization, pet waste, and atmospheric deposition although partitioning contributions of these sources is difficult. Homeowners often apply lawn fertilizers at much higher rates than are required or specified, often exceeding agricultural rates (Barth, 1995). In suburban areas, the great majority of nutrients in shallow groundwater may originate as lawn fertilizers (Flipse *et al.*, 1984). Although pet waste in urban areas is thought to be a significant source of microbial pollution (Schueler, 1998), its contribution to nutrient loading is unknown, though possibly significant. Atmospheric deposition on impervious surfaces is likely to result in nutrients reaching surface waters with little processing.
- Erosion of phosphorus-rich soils. Construction activities may mobilize soils saturated in phosphorus as a result of previous agricultural activities (Bennett *et al.*, 1999).

Management Strategies

Because there is not strong evidence that nutrient pollution is an immediate threat to the imperiled species covered by the Etowah HCP, there are no management policies explicitly devoted to its control. The Steering Committee considered strategies focused on sewer and septic systems but ultimately voted not to include them in the plan. Lawn fertilization and pet waste are difficult to regulate and are likely to be of secondary importance, so they are also not included in the management strategy. Point sources and agricultural activities are not covered under the Etowah HCP.

Nutrients in stormwater runoff may be trapped and removed by stormwater management practices. The emphasis of the Etowah HCP is on infiltration practices, which appear to have mixed success in terms of nutrient removal performance. Studies of bioretention areas found only moderate removal rates for ammonia and little to no removal of phosphorus (Dietz & Clausen, 2005, 2006) although a study of porous pavers showed significant removal of both phosphorus and nitrogen for stormwater passing through pavers (Dreelin, 2006).

In short, nutrient pollution may not be well managed by the Etowah HCP. Because there is currently little evidence that eutrophication is a problem for the imperiled species covered by the plan, this omission may not be too damaging. If future research should prove otherwise, however, additional measures—outside of the Etowah HCP—may need to be taken.

Conclusions

It should be evident from this review that some stressors are more of a threat than others. Sedimentation, hydrologic alteration, extensive riparian buffer loss, contaminants, movement barriers, and channelization & piping all appear to be significant threats that must be managed by the Etowah HCP. Other stressors—invasive species, temperature alteration, loss of woody debris, and eutrophication—appear to be less immediate or severe threats at this time, based on existing evidence. However, most of these other stressors are also reduced incidentally by the management policies of the Etowah HCP.

Certain sources of stressors also demand more attention than others. In particular, stormwater runoff is implicated more than anything else as a source of significant stressors. This is consistent with other findings. In a recent paper evaluating the impacts of urbanization on streams—termed the "urban stream syndrome"—the authors concluded that stormwater runoff was the dominant source of impairment: "The mechanisms driving the [urban stream] syndrome are complex and interactive, but most impacts can be ascribed to a few major large-scale sources, primarily urban stormwater runoff delivered to streams by hydraulically efficient drainage systems" (Walsh *et al.*, 2005b).

For this reason, the stormwater management policy of the Etowah HCP is absolutely critical. In particular, the runoff limits performance standard that requires the use of infiltration is essential for reducing hydrologic alteration and contaminants from runoff. Five other major policies are essential components of the Etowah HCP: erosion and sedimentation control, the stream buffer ordinance, road crossings of streams, utility crossings of streams, and the water supply planning protocol. We believe that if properly implemented and supported by adaptive management when necessary, these policies will be sufficient for maintaining healthy populations of the imperiled fish species covered by the Etowah HCP.

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