# Scientific Basis for Bacterial TMDLs in Georgia



Cover photo of Mountain Creek in Harris County, GA by Bill Bumback Layout and design by Bonnie Jackson, Georgia Conservancy

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A white paper submitted to the Georgia Environmental Protection Division to support the Assimilative Capacity Technical Advisory Committee as part of the Georgia Statewide Water Planning process. www.gadnr.org/gswp/Documents/info\_req.html

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### Acronyms and Abbreviations

ARC	Atlanta Regional Commission
BASINS	Better Assessment Science Integrating Point and Non-point Sources
BMPs	Best Management Practices
BST	bacterial source tracking
CAFOs	Concebtrated Animal Feeding Operations
CES	Cooperative Extension Service
EPA	(U.S.) Environmental Protection Agency
EPD	(Georgia) Environmental Protection Division
EQIP	Environmental Quality Incentives Program
FC	fecal coliforms
GM	geometric mean
HSPF	Hydrologic Simulation Program Fortean
LA	load allocations
MOS	margin of safety
MS4	municipal separate stormwater sewer systems
NRCS	National Resources Conservation Service
RDC	Regional Development Center
SM	single maximum
SQAP	sampling and quality assurance plan
TAG	Technical Advisory Group
TMDL	Total Maximum Daily Loads
cfu	colony-forming units
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WLA	wasteload allocations

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TMDL forum in March of 2002 identified the establishment and implementation of bacterial TMDLs as one area most in need of scientific input. The University of Georgia River Basin Center and the Georgia Conservancy worked together to form a Technical Advisory Group (TAG) that met on nine occasions in six different locations across the state from October 2002 to February 2005. The TAG heard from scientific experts on bacteria, and local officials and stakeholders involved in bacterial TMDL implementation. This is a summary of the TAG's findings and recommendations (in bold). The findings and recommendations are those of the authors and do not necessarily represent a consensus of all 60 participants.

There are a number of scientific issues related to the state water quality standard for bacteria used to list waters for TMDL development. The current standard for fresh and marine waters is based on fecal coliforms (FC). Fecal coliforms are a broad group of nonpathogenic bacteria whose presence indicates that fecal matter from warmblooded animals may have been in contact with the water. The standard varies with the designated use of the water, which is fishing for most streams and rivers in Georgia. For this use, the standard is a FC concentration not to exceed a geometric mean of 200 colony-forming units per 100 ml (cfu/100 ml) for the months of May through October, and 1,000 cfu/100 ml for the months of November through April. The geometric mean is based on at least four samples collected over a 30-day period at intervals not less than 24 hours. During November through

April, a single sample standard also applies to fishing waters: no sample should have FC concentrations more than 4,000 cfu/100 ml.



Jennifer McDonald (Marine Extension Service, University of Georgia) sampling a small tidal tributary to Postell Creek on St. Simons Island, GA.

#### **Recommendation I:**

In 1986 and again in 2002, EPA published guidance that recommended states adopt a water quality standard for fresh water based on *Escherichia coli* (*E. coli*) instead of FC because studies had shown that the rate of gastrointestinal illnesses among swimmers was better correlated with *E. coli* concentrations in the water at the time of exposure than to FC concentrations (USEPA, 1986, 2002). For marine waters, EPA guidance recommended that states adopt a standard based on fecal enterococci instead of FC for similar reasons.

Georgia should follow the recommendations from EPA to adopt new bacterial standards for freshwaters (using *E. coli*) and marine waters (using fecal enterococci).

#### **Recommendation 2:**

In contrast to many other states, Georgia does not designate waters as primary or secondary contact recreation. Primary contact recreation includes swimming and other activities where contact and immersion in the water is likely. Secondary contact recreation includes fishing and other activities where full immersion is unlikely. Georgia designates waters that are recreational use and these could be subdivided into primary and secondary primary contact recreation waters. Most of these waters are lakes and estuaries, although in the case of the Chattahoochee they include extensive headwater areas.

Georgia should divide the current list of recreational fresh waters into primary and secondary contact waters with different standards. Primary contact recreational waters should be high-use recreational waters such as beaches and parks, and the most stringent standard should be applied to these waters (risk of 8 illnesses per thousand swimmers and an *E. coli* standard of 126 cfu/100 ml for fresh waters). This division should also be done for marine waters, but the TAG does not have a recommendation on what numbers of fecal enterococci should be used for the standard.

#### **Recommendation 3:**

Studies have shown that *E. coli* tend to survive better in warm weather. As a result, background concentrations of bacteria in Georgia due to wildlife may exceed the level associated with 8 ill-nesses per thousand swimmers on occasions (and especially during storms).

An E. coli standard associated with 12 illnesses per thousand swimmers (336 cfu/100 ml) or 14 illnesses per thousand swimmers (548 cfu/100 ml) should be used for secondary contact waters as background concentrations are unlikely to exceed these standards. Recreational marine waters should also be divided into primary and secondary contact, but the TAG does not have a recommendation on what numbers of fecal enterococci should be used for the standard.

#### **Recommendation 4:**

New methods have been developed for enumerating *E. coli* that are more rapid than traditional membrane filtration and most probable number methods. One popular method is produced by IDEXX Laboratories (Westbrook, ME). This method is ideal for use in bacterial source tracking to find possible sources of bacteria. However, a study has shown that this method tends to overestimate *E. coli* concentrations compared to the traditional methods (which were used in the epidemiological studies to develop the association between illnesses and bacteria concentrations).

### Further studies should be done to determine if there is a bias toward higher numbers of *E. coli* with the IDEXX method than for traditional methods.

#### **Recommendation 5:**

The 1986 EPA document allowed a less stringent standard for watersheds where no human sources were likely (USEPA, 1986). The 2002 EPA document eliminated this provision because many pathogenic organisms are of animal origin (USEPA, 2002a). To date, it appears that Georgia continues to use the less stringent standard for waters with nonhuman sources.

The provision for a less stringent standard when nonhuman sources of bacteria are present should be dropped to conform with the new recommendations from EPA. In waters where wildlife may be the source of contamination, the state should file for classification of the waters as "Wildlife Impacted Recreation." These waters will require site-specific supporting data.

#### **Recommendation 6:**

The current method used to calculate TMDLs, based largely on monitoring results, is reasonable, given the uncertainty in computer models that predict bacterial loads.

More intensive analysis using watershed models should be considered where a TMDL is being developed for several pollutants in an extensive area (such as a lake watershed) where the consequences of the TMDL will have a large economic impact.

#### **Recommendation 7:**

One of the most difficult problems in bacterial TMDLs is determining the source of bacteria, especially when non-point sources predominate. Library-based methods of bacteria source tracking were once thought of as promising methods that might be widely used to distinguish between sources. However, library methods are likely to be too expensive for identifying bacterial sources in most watersheds. In most cases, targeted sampling, as a prelude to bacterial source tracking, is the least expensive and the most promising method for determining bacterial sources. Local jurisdictions should take advantage of volunteer groups such as Adopt-A-Stream for assistance in targeted sampling since the data are used to determine sources, not to list or de-list a stream.

#### **Recommendation 8:**

In 2003 GA EPD began including a Waste Load Allocation from municipal separate stormwater sewer systems (MS4) in the TMDL equation.

The assumptions that new MS4 systems will capture 70% of runoff and result in bacterial concentrations in storm water that meet the state standard should be tested by studies that measure MS4 discharge volumes and bacterial concentrations.

#### **Recommendation 9:**

The two most common questions local stakeholders ask about TMDLs are where were the samples taken and where are the data. It would assist stakeholder involvement to include this information in the TMDL documents.

**TMDL** documents should include a table that clearly identifies the sampling location and sample data that were used to list a particular waterbody. While some data are included in the current TMDL documents, the associated stream segment is not always clear.

#### **Recommendation 10:**

Atlanta Regional Commission staff have found errors in the landuse/landcover descriptions for stream segment watershed in the development of TMDLs.

# TMDL documents should include landuse category definitions or descriptions of how the landuse categories were developed.

#### **Recommendation 11:**

Many different approaches to implementing bacteria TMDLs are being taken across the diverse regions of Georgia. The TAG found examples of success stories and examples where little progress was being made. By 2004, approximately 60% of the TMDL implementation plans required by the federal court order had been completed. EPD is now placing emphasis on improving water quality instead of expending time and resources to finish implementation plans within short time periods. In most cases, the Regional Development Centers (RDCs) are responsible for writing implementation plans based on templates EPD developed. The implementation plans provide little specific guidance on recommended approaches to improving water quality. In addition, the bulk of the implementation strategy relies on regulations, local ordinances, and programs already in place. EPD has a staff dedicated to TMDL outreach and the TAG heard how helpful this arm of the agency has been in providing technical assistance regarding TMDL implementation in some cases. However, many local governments seem to be unaware of the availability of such assistance and have searched elsewhere in frustration. Funding seems to be a tremendous obstacle to implementation at the local level. Although limited funding is available through a variety of federal and state and federal programs such as Clean Water Act Section 319, the application process for these funds is onerous and takes several years from the time the application is submitted to the time the funds become available.

### Executive Summary

In addition to applying for funding from state and federal programs, low interest loans are also available through the Georgia Environmental Facilities Authority program. However, local authorities are often reluctant to take on loans. Overall, the TMDL implementation process needs to be improved. Regional Development Centers have insufficient resources to identify sources of bacteria and develop an implementation plan that will achieve the large reductions in bacterial concentrations called for in bacterial TMDLs.

Increased funding should be provided to EPD and to local jurisdictions to support implementation programs that focus on a two-pronged approach: 1) identifying existing sources of water quality impairment, and 2) addressing existing and future land use practices that are potential sources in a comprehensive basin-wide fashion through policy changes and public outreach. Local and private matching funds may be provided through collaboration of existing analytical local and private analytical labs and monitoring efforts.

#### **Recommendation 12:**

More technical assistance and outreach on TMDL implementation strategies are needed as well as better coordination among entities working in this arena to serve the local jurisdictions charged with implementation.

Perhaps a single point of contact can be established and an awareness campaign launched to raise awareness of available resources and make requesting assistance easier. Watershed-based extension personnel may play a key role in linking local jurisdictions to needed technical and funding resources.

#### **Recommendation 13:**

One of the best ways to improve performance of septic systems is through regular inspection and maintenance such as pumping of septic tanks. By State statue, however, County Boards of Health cannot require periodic maintenance of non-mechanical onsite systems.

State legislation (O.C.G.A. § 31-3-5(b)(6)) should be changed to provide local health departments that currently hold permitting authority for nonmechanical residential sewage management systems with enforcement authority to perform inspections and require repairs and maintenance on these systems as necessary to prevent significant pollution contributions from these sources. Adequate resources and funding mechanisms should also be made available to health departments to enable them to exercise this authority.

#### **Recommendation** 14:

Lastly, the TAG discussions identified a number of scientific issues that need further research; these are listed at the end of this report. More funding sources should be identified to conduct studies on a number of regional, mixed-use watersheds typical of local land use and geology. These studies should use bacterial source tracking (BST), intensive monitoring, and watershed-scale modeling of the watersheds to identify and quantify sources of bacteria. The monitoring should also assess water quality improvement during the implementation phase. The results from these studies could then guide bacterial TMDL implementation in other similar watersheds.

#### TAG Participants

A total of 60 university, state, and federal scientists, local officials, and members of nonprofit groups participated in one or more of the TAG meetings. The opinions expressed by these individuals at the meetings were their own and were understood to not necessarily represent the policy of the organizations to which they belonged. These individuals are:

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#### Background

here are over 800 stream, river, and lake segments that require TMDLs in Georgia. The largest category of pollutant is fecal coliform (FC). At a TMDL forum in March of 2002, a protocol for establishing bacterial TMDLs was identified as one of two areas where scientific input was most needed (the other area was implementation of TMDLs for all of the various pollutants that are common). The University of Georgia River Basin Center and the Georgia Conservancy worked together to form a Technical Advisory Group (TAG) that met for the first time in October 2002. At this meeting, the TAG identified the following issues as the most important topics to be explored:

- Bacterial water quality standard
- Identification of sources of bacterial contamination
- Method for calculating bacteria TMDLs
- Implementing bacteria TMDLs

The TAG met nine times from October 2002 to February 2005. Meetings were held in six Georgia locations: Athens, Atlanta, Macon, Newton, Savannah, and Tifton. The meetings usually consisted of presentations from experts on a particular topic and from local officials involved in TMDL implementation accompanied by discussion. From the material presented at these meetings, the discussions, and the scientific literature, the authors developed a draft white paper that was sent out to all the participants for comment in January, 2006. Comments were received by the end of March and revisions were completed in June, 2006.

Although it was not the original intent, the timing was such that the authors were able to submit the white paper in response to the request for information to support the Assimilative Capacity Technical Advisory Committee as part of the statewide water planning process in the spring 2006 (www.gadnr.org/ gswp/Documents/info\_req.html).

The findings and recommendations are those of the authors and do not necessarily represent a consensus of the other 60 TAG participants.



The Amicalola River in Dawson County provides as example of the important wildlife habitat, natural water purification processing, water supply delivery and recreational opportunities that are among Georgia's most valuable assets.

#### Current Georgia Water Quality Standard

The current Georgia bacterial standard for fresh water is based on FC and varies with the designated use of the water. Fecal coliforms are used as indicator bacteria. As a broad group of nonpathogenic bacteria, their presence was thought to indicate that fecal matter from warm-blooded animals has been in contact with the water. However, recent studies have shown that they include bacterial species that may not necessarily come from these animals, but also from plants and soil (Doyle and Erickson, 2006). Nonetheless, studies have shown a correlation between the presence of FC and human gastrointestinal illnesses (USEPA, 2002a). Standards are given in terms of a geometric mean of at least four samples collected from a given sampling site over a 30-day period at intervals of not less than 24 hours. In some cases, a single sample maximum is also specified. The six "designated uses" in the state and their associated FC standards are (GAEPD, 2004):

- Recreation: Not to exceed a geometric mean of 100 colony forming units (cfu)/100 milliliter (ml) for coastal waters or 200 cfu/100 ml for all other recreational waters.
- Drinking water supplies: For the months of May through October, not to exceed a geometric mean of 200 cfu/100 ml. For the months of November through April, not to exceed a geometric mean of 1,000 cfu/100 ml and not to exceed a single sample maximum of 4,000 cfu/100 ml.
- Fishing:<sup>5</sup> Same as drinking water

standard.

- Wild River: No alteration of natural water quality from any source.
- Scenic River: No alteration of natural water quality from any source.
- Coastal Fishing: Same as drinking water standard.

For recreation, drinking water supplies and fishing waters, there is an additional provision (GAEPD, 2004):

"Should water quality and sanitary studies show fecal coliform levels from non-human sources exceed 200/100 ml (geometric mean) occasionally, then the allowable geometric mean fecal coliform shall not exceed 300 per 100 ml in lakes and reservoirs and 500 per 100 ml in free flowing freshwater streams."

Most streams and rivers in Georgia have fishing as the designated standard.

The geometric mean standard of 200 cfu/100 ml is common among states and was based on studies by the Department of the Interior in the 1940s and 1950s (USEPA, 1986). Fresh water studies were conducted at two beaches on Lake Michigan in Chicago (one with good water quality and one with poor water quality) and on one beach on the Ohio River in Kentucky (one with a poor water quality; a good water quality beach site could not be found). Each location was chosen because there was a large residential population nearby that used the beaches. Cooperating families used a calendar system that asked them to record their swimming activity and illnesses on a daily basis for an entire summer. Water quality was measured on a routine basis using total coliforms

 $^{5}$  The full title is "Fishing, propagation of fish, shellfish, game, and other aquatic life."  $_{Pa}$ 

as the indicator bacteria. Both studies showed a significantly higher number of illnesses among individuals who swam during a period when the geometric mean total coliforms were above 2300 cfu/100 ml compared to non swimmers. This became the Department of Interior's recommended water quality standard.

In the 1960s, the Department of Interior converted their recommended standard from total coliform to FC. At the same location on the Ohio River where the original study was conducted, FC and total coliform were measured and FC were about 18% of total coliforms. Taking 18% of 2300, a value of 414 was obtained. Because this value represented the concentration at which a risk was detectable and the FC standard was designed to prevent this risk, half the value was taken and rounded off to 200 FC cfu/100 ml. According to EPA, the risk associated with this standard was approximately 8 illnesses per 1,000 swimmers (USEPA, 1986).

#### Listing and Delisting Waters

River segments representing over 71,000 river miles (18-20% of the total) have been sampled by the Georgia Environmental Protection Division (EPD) or an authorized sampling unit. Every two years, EPD publishes the 305 (b) report (so called because this is the section of the Clean Water Act that requires the report) on the quality of all navigable state waters. The report lists waters that do not meet the state water quality standard for bacteria, as well as many other pollutants. Estimates of environmental impact and socioeconomic costs of achieving the water quality standards and a description of the nature and extent of non-point sources of pollutants, and recommended programs to address each category of pollutant source must be included in the report.

The 303(d) list (required by this section of the Clean Water Act) is the list of waters that either partially support or do not support their designated use (a component of the 305(b) report) and require TMDL development. Waters are listed as "supporting," "partially supporting," or "not supporting" their designated use. EPD uses bacterial geometric mean (GM) data when available. In the absence of sufficient GM data to assess a water body for 303 (d) listing, the EPD uses the single maximum (SM) standard to evaluate sample results. The SM standard is evaluated along with all other available bacterial data. Waters are placed on the partially supporting list if the standard is exceeded in one GM out of four quarterly GMs collected in one year. Waters are placed on the not supporting list if the standard is exceeded in two or more GMs out of four quarterly GMs. In an earlier period when the SM standard was used for listing, some streams were added to the list based on a single sample that exceeded the SM water quality standard.

The sampling requirements to remove a stream from the 303(d) list are the same as those for listing a stream: enough samples to calculate at least four quarterly GMs in one year would be needed and less than 25% of the GMs could exceed the water quality standard. While the term "delisting" is commonly used, this term is inaccurate because

once a water body has meet its water quality goal, it remains on the list, only its evaluation changes from "not supporting" or "partially supporting" to "supporting." EPD has a document that describes how a unit can gain approval for monitoring waters and submitting data for listing or delisting waters (GAEPD, 2003a). A unit must submit a Sampling and Quality Assurance Plan for concurrence prior to monitoring.

There seems to be an issue about holding times for bacteria samples related to listing and delisting streams. The authors' understanding is that when EPD monitors streams for listing, whether the samples are collected by EPD personnel or USGS personnel, they are usually shipped by express mail to a lab for analysis. This procedure means that the samples are not being analyzed within six hours, but rather within 24 hours of being collected. A study needs to be done to see what effect a 24-hour vs. 6-hour hold time for stream samples has on E. coli bacterial concentrations.

## EPA Recommendations in 1986 and 2002

In 1986, EPA released a document in which they encouraged states to change from a fresh water standard based on FC to one based on *Escherichia coli* (or *E. coli*) (USEPA, 1986). The basis for this recommendation was a series of freshwater studies conducted in the 1970s at beaches on Lake Erie at Erie, Pennsylvania, and on Keystone Lake near Tulsa, Oklahoma. Two public beaches were selected at each site, one with little or no contamination and one with barely acceptable water quality. The contamination at the barely acceptable beaches was due to a pointsource discharge. Water quality was measured on weekends using multiple indicator organisms including FC and *E. coli*. Individuals at the beach on the days when measurements were made were approached as they left and asked if they would participate in the survey. Volunteers who had been swimming during the previous week were excluded from the survey. After 7 to 10 days, the volunteers were contacted to determine their health status since the swimming event.

Control non-swimmers, usually a member of the volunteer's family, were also interviewed. Volunteers were asked if they experienced "highly credible" gastrointestinal symptoms, including any one of the following:

- (1) vomiting,
- (2) diarrhea with fever or a disabling condition (remained home, remained in bed, or sought medical advice),
- (3) stomach ache or nausea accompanied by a fever.Individuals experiencing such symptoms were considered to have acute gastroenteritis.

The swimming-associated illness rate was obtained by subtracting the nonswimmer illness rate from the swimmer illness rate using data collected over a summer. The studies were conducted for three years at the Lake Erie beaches and two years at the Keystone Lake beaches.

The data were grouped by location and season. Each season at a beach was averaged into one paired data point consisting of an average illness rate and a geometric mean of the indicator organism concentration. These data points were plotted to determine the relationship between illness rate and geometric mean indicator concentration. Both *E. coli* and enterococci showed a highly significant correlation with swimmer illness rate (*E. coli*  $r^2 = 0.80$ , enterococci  $r^2 = 0.74$ ), but FC showed no correlation ( $r^2 = -0.08$ ).

Based on these data and the statistical relationships, EPA concluded that *E. coli* was the preferred indicator organism for fresh waters. Using an illness rate of 8 illness per 1,000 swimmers (the estimated rate associated with the FC standard of 200 cfu/100 ml), the regression line was used to find the associated concentration. This associated concentration for *E. coli* was a GM of 126 cfu/100 ml.

Using the standard deviation of the *E. coli* samples collected and assuming a log-normal distribution, various percentiles of the upper range of the distribution of the *E. coli* associated with this illness rate were estimated (Table 1).

In the 1986 document entitled "Ambient Water Quality Criteria for Bacteria -1986," EPA urged states to drop the FC standard and adopt the new E. coli standard for "primary contact" waters (USEPA, 1986). These are water bodies "where people engage, or are likely to engage, in swimming, water skiing, kayaking, and other activity where contact and immersion in the water is likely." The report also suggested that various upper percentile confidence limits could be used for single sample maximum standards or for secondary contact water where full immersion was less likely.

Parameter	Geometric Mean <i>E. coli</i> Concentration (cfu/100 ml)
Mean value (primary contact geometric mean standard)	126
Upper 75% confidence limit (single sample maximum standard for desig- nated beach area)	235
Upper 82% confidence limit (secondary contact single sample maximum standard for moderate full body contact recreation)	298
Upper 90% confidence limit (secondary contact single sample maximum standard for lightly used full body contact recreation)	410
Upper 95% confidence limit (secondary contact single sample maximum standard for infrequent full body contact recreation)	576

**Table 1.** *Escherichia coli* water quality criteria for primary contact water and upper confidence limits at various percentiles that could be used for secondary contact waters issued in 1986 (USEPA, 1986).

Most states (including Georgia) did not make the change from FC to E. coli. In 2002, EPA released a new document entitled "Implementation Guidance for Ambient Water Quality Criteria for Bacteria," again urging states to change to the new standard (USEPA, 2002a). This is a draft document published to solicit comments and EPA is expected to provide a final guidance document in the future. In the draft document, EPA stated that it had reviewed the original studies supporting the 1986 recommendation and the literature on epidemiological research studies conducted since these studies were conducted.

Based on these reviews, EPA's 2002 report stated:

The epidemiological studies conducted since 1984, which examined the relationships between water quality and swimming-associated health effects, have not established any new or unique principles that might significantly affect the current guidance EPA recommends for maintaining the microbiological safety of marine and freshwater bathing beaches. Many of the studies have, in fact, confirmed and validated the findings of the U.S. EPA studies.

The EPA used the data from the studies supporting the 1986 recommendations

**Table 2.** *Escherichia coli* water quality criteria associated with various illness rates for primary contact water and upper confidence limits (C.L.) at various percentiles that could be used for secondary contact waters issued in 2002 (USEPA, 1986).

	Geometric Mean Concentration (cfu 100 / ml)	Single Sample Maximum Concentration					
Illness Per I,000 Swimmers		Designated Beach Area 75% C.L.	Moderate Full Body Contact 82% C.L.	Lightly Used Full Body Con- tact 90% C.L.	Infrequently Used Full Body Contact 95% C.L.		
8	126	235	298	410	576		
9	206	300	381	524	736		
10	206	383	487	669	941		
11	263	490	622	855	1,202		
12	336	626	795	1,092	1,536		
13	429	799	1,016	1,396	1,962		
14	548	1,021	1,298	I,783	2,507		

to calculate the geometric mean and upper confidence limit concentrations for a range of illness rates (not just 8 illnesses per 1,000 swimmers as was done in the 1986 document); (Table 2). Similar values were given for an enterococci standard (not shown).

These observations are based on contamination with human feces, but the state is establishing a standard for areas that reflect microbes from wildlife and domestic stock that may not follow the same relationship. This point is addressed in the section on Human vs. Nonhuman Sources. EPA recommended that states adopt an *E. coli* or enterococci standard for primary contact freshwater associated with an illness rate no greater than 14 illnesses per 1,000 swimmers.

They recommended that states adopt both a GM and a SM standard (a water body fails the standard if either the GM or SM concentration is exceeded):

For waters that are known to be heavily used swimming areas and where necessary to protect downstream primary contact recreation uses, states and authorized tribes should consider

**Table 3.** EPA's recommendations for fresh water recreation use categories and associated water quality criteria (USEPA, 2002a).

Designated Use	Water Quality Criteria			
Identified/Popular Beach Areas	Criterion based on risk levels of 8 or fewer illnesses per 1000 swimmers.			
Other Primary Contact Recreation Waters	Criterion based on risk level not greater than 14 illnesses per 1000 swimmers.			
Seasonal Recreation Use	Primary contact recreation criteria apply during specified recreational season; secondary contact recreation criteria apply rest of year. <sup>1</sup>			
Recreational Use Subcategories				
Exceptions for High Flow Events	Exceptions to meeting criteria at high flows are to be determined on a water body-by-water body basis and based on flow statistic or number of exceedances allowed. <sup>1</sup>			
Wildlife Impacted Recreation	Criterion to reflect the natural levels of bacteria while providing greater protection than criteria adopted to protect a secondary contact recreation use. <sup>1</sup>			
Other Categories of Recreation				
Secondary Contact Recreation	Criterion sufficient to protect the use. May use numeric criterion (suggest specifying criterion as SM maximum value or GM five times the primary contact recreation GM value) or narrative criterion. <sup>1</sup>			

<sup>1</sup> Supporting analysis is required for this category.

using more conservative approaches, such as adopting criteria based on lower illness rates (e.g., 8 illnesses per 1,000 swimmers for fresh waters) or a more conservative single maximum (e.g., single sample maximum values based on 75% confidence level).

Further, EPA recommended that states adopt subcategories of recreation uses to recognize seasonal uses and exceptions for high flow events and wildlife-impacted waters, providing supporting analysis was provided. EPA recommendations are summarized in Table 3.

#### Proposed Georgia Water Quality Standard

In the fall of 2002, the Georgia Environmental Protection Division (EPD) proposed a new freshwater bacteria standard for the state based on *E. coli* (GAEPD, 2002a). EPD received significant stakeholder input on the proposed criteria and did not move forward to promulgate the proposed criteria based on three major stakeholder issues:

- test methods for *E. coli* and enterococci in ambient freshwater an estuarine/marine water had been proposed by EPA, but were not yet approved.
- test methods for *E. coli* and enterococci in wastewater effluents had not been proposed or approved by EPA.
- EPA document "Implementation Guidance for Ambient Water Quality Criteria for Bacteria, May 2002 Draft" (USEPA, 2002a) had not been finalized.

As of today, the test methods for ambient waters have been approved (Federal Register, 2003) and the test methods for wastewater effluents have been proposed (Federal Register, 2005). The USEPA document (2002a) has not yet been finalized. When the state develops a new standard, there are a number of scientific issues that should be considered:

- What should the state consider as primary contact waters?
- How to compare the proposed *E. coli* standard with the current FC standard?
- Should different standards apply to base-flow and storm-flow conditions?
- What are background (natural) levels of *E. coli* in Georgia waters?
- Does the risk level associated with the *E. coli* standard developed by EPA apply to waters where the source of *E. coli* is not likely to be human sources?
- What have other states adopted as an *E. coli* standard?

These questions are now considered in order below.

#### **Primary Contact Waters**

Currently, Georgia does not designate waters as primary or secondary contact *per se.* Waters designated as recreation should be considered as primary contact, and waters designated as drinking and fishing waters could be considered secondary contact waters. A list of the waters in Georgia that are designated as recreation is shown in Table 4. Most of these waters are lakes and estuaries, although in the case of the Chattahoochee they include extensive headwater areas. A primary contact

### Water Quality Standard

Table 4. List of waters with designated use of "Recreation" in Georgia (compiled from GAEPD, 2004).

Water body	Section
Tallulah River	Headwaters Lake Burton to Chattooga River
Tugaloo River	Confluence of Tallulah and Chattooga to Yonah Lake Dam
Savannah River	Hwy. 184 to Clark Hill Dam
	Fort Pulaski to open sea
Ogeechee River	US Hwy. 17 to open sea
Little Ogeechee River	South end of White Bluff Road to open sea
Oconee River	GA Hwy. 16 to Sinclair Dam
Jackson Lake	South River at GA Hwy. 36; Yellow River at GA Hwy 36; Alcovy River at Newton Factory Road Bridge to Lloyd Shoals Dam
Towaliga River	GA Hwy. 36 to High Falls Dam
Tobesofkee Creek	Lake Tobesofkee
Altamaha River	Littoral waters on ocean side of St. Simons, Sea and Sapelo Islands
Satilla River	Littoral waters on ocean side of Cumberland and Jekyll Islands
St Marys River	Littoral waters on ocean side of Cumberland Island
Flint River	GA Hwy. 27 to Georgia Power Dam at Lake Worth
	US Hwy 84 to Jim Woodruff Dam, Lake Seminole
Chattahoochee River	Headwaters to Buford Dam
	Buford Dam to Atlanta (Peachtree Creek)
	New River to West Point Dam
	Osanippa Creek to Columbus (North Highland Dam)
	Cowikee Creek to Great Southern Division of Great Northern Paper Company
	GA Hwy. 91 to Jim Woodruff Dam
Coosawattee River	Confluence of Mountaintown Creek to Carters Dam
Etowah River	GA Hwy. 20 to Allatoona Dam
Coosa River	At the Alabama state line
Nottely River	Headwaters to GA-NC state line
Toccoa River	Headwaters to GA-TN state line (including Lake Blue Ridge)

standard could apply to all of these waters, or the state could consider creating a subcategory within the recreation waters where there is very high recreation use (such as the "Identified/Popular Beach Areas" in Table 3). For example, Colorado uses three categories (USEPA, 2002a):

- Recreation Use 1A: GM = 126 cfu/100 ml
- Recreation Use 1B: GM = 205 cfu/100 ml
- Secondary Contact Recreation Use: GM = 630 cfu/100 ml.

# Comparing E. coli and Fecal Coliforms

How should a new *E. coli* standard be compared to the current FC standard? Escherichia coli are clearly a subset of FC, so one would expect a new E. coli water quality standard concentration to be equal to or less than the FC water quality standard concentration assuming the standards use the same risk for illness. The question is what risk is associated with the current FC standard (FC GM of 200 cfu/100 ml). According to the 2002 EPA document, the FC standard is associated with a risk of 8 illnesses/1,000 swimmers (USEPA, 2002). A new *E. coli* standard that would be equivalent to the current standard in terms of risk would be 126 *E. coli* cfu/100 ml (Table 2).



**Figure 1.** *Escherichia coli* concentration measured by membrane filtration versus *E. coli* concentration measured by the IDEXX method on 250 samples collected from six headwaters streams in the Oconee River Basin. The regression line with 95% confidence limits (dotted lines) and the 1:1 line are shown.

The method of measuring *E. coli* may be important. This is illustrated in a recent study by Dr. Radcliffe and others where 250 samples were collected from six headwater streams in the Oconee River watershed and analyzed for E. *coli* using the traditional membrane filtration method on mTEC agar (USEPA, 1985) and a popular new colorimetric method developed by IDEXX Laboratories (Westbrook, ME). In Figure 1, E. coli concentrations measured on the same sample using the two methods are shown along with a regression line through the data with 95% confidence lines on either side of the regression line. The data were log-transformed for statistical purposes so a log scale is used. The 1:1 line is shown and if there was no bias between the two methods, then the 1:1 line would lie with the confidence limits of the regression line. However, the regression line and its confidence limits fall below the 1:1 line indicating that *E*. coli measured using the IDEXX method resulted in a statistically significant higher concentration compared to the membrane filtration method.

This difference may be because the IDEXX *E. coli* procedure is not as stressful for bacteria that are shocked by treatment or handling as the traditional membrane filtration *E. coli* procedure. Therefore, viable but not culturable *E. coli* may be detected by the IDEXX method but not by the membrane filtration method. If this is the case, the estimated number of *E. coli* by the IDEXX method may be greater than the estimated number of FC.

This difference is also important point

in deciding how to convert from a FC standard to an *E. coli* standard. If the new standard is chosen so that the risk stays the same as the current FC standard (8 illnesses per 1,000 swimmers), then the limit for primary contact waters would be 126 cfu/100ml for *E. coli* based on the EPA studies conducted in the 1970s. However, these studies used membrane filtration to



Recreation occurs even under stormflow conditions on many water bodies such as on the Etowah River in Dawson County, GA.

measure *E. coli* (USEPA, 1986). The IDEXX method for determining *E. coli* has become popular because of the relative ease and shorter time for analysis. If it is used to compare to the standard, one can expect the IDEXX method to produce a higher concentration than would be measured with membrane filtration.

Further studies should be conducted to compare IDEXX and membrane filtration methods. The IDEXX method is still ideal for bacteria source tracking (see page 41) because of its convenience. A bias towards slightly higher *E. coli* concentrations compared to the membrane filtration method should not prevent the use of this method to stream reaches with very high bacterial concentrations compared to other stream reaches.

#### Base-flow vs. Storm-flow Conditions

Do bacteria concentrations in streams and rivers change during storms and if so should the bacteria standard apply to these conditions? These conditions occur in streams during and shortly after storms when water levels rise due to water entering the stream from overland flow, lateral flow from perched water tables, and ground water flow. Baseflow conditions are reestablished in streams shortly after storms when overland flow and lateral flow from perched water tables ceases. Under these conditions, the only input of water to the stream is ground water. Bacteria from point sources such as wastewater treatment plants can enter under both base-flow and storm-flow conditions.

However, bacteria from non-point sources are generally thought to enter streams only via overland flow (and perhaps to some extent via shallow lateral flow from perched water tables) so this would occur during storm-flow. Exceptions would be livestock and wildlife defecating in a stream during base-flow conditions.

As a result, most studies on streams in watersheds where non-point sources dominate have shown that bacteria concentrations increase during, and for some time after, storms. An example is seen in Figure 2 which is reproduced from a study by Fisher et al. (2000) conducted at the USDA-ARS J. Phil Campbell, Sr. Natural Resource Conservation Center in Watkinsville, GA.



**Figure 2.** Most Probable Number (MPN) of *E. coli* in surface water samples from watersheds with cattle (Pasture) and without (Wooded). Rains occurred on 24 Dec and 7 Jan. The dashed line indicates the maximum limit of detection for the assay. Vertical lines indicate the 95% confidence intervals when the interval is greater than the size of the symbol. From Fisher et al. (2000).

In this study, samples were collected at two-week intervals from two creeks at the Center. Both creeks had springs and the pasture creek fed into a pond. Rains occurred on 24 December (99 mm) and 7 January (46 mm). As a consequence, *E. coli* concentrations increased during this period in all of the waters sampled except one spring.

The EPA standard was clearly developed to protect swimmers. If swimming is less likely to occur during storms, then perhaps the standard should not apply during these periods. This raises an interesting question regarding the GM and SM standards. It is unlikely that one will get a GM sample (collected from a given sampling site over a 30-day period at intervals of not less than 24 hours) where all the samples were taken during storm-flow.

However, the SM standard could be collected during or shortly after a storm and reflect storm-flow conditions. The EPA recommends using a SM standard as well as a GM standard (USEPA, 2002a). The problem in doing this is that it might result in a stream being placed on the 303(d) list based on only one sample (this has been a source of concern among some stakeholders).

One way to approach the problem would be to have a high-flow cutoff on the standard (e.g., the water quality standard would not apply during storm-flow or, in the case of marine waters, during spring high tides). This cutoff could apply to all waters that are not used for recreation during storms and high flow. However, certain water bodies that are popular kayaking, canoeing, and rafting segments would not have the high-flow cutoff. Unfortunately, EPA (2002a) requires a site-by-site justification for using the high-flow cutoff.

#### **Background Levels of Bacteria**

Some states have suggested that background levels of bacteria might be higher in sub-tropical waters because *E. coli* survive longer than expected in these waters (Solo-Gabriele et al., 2000; Desmarais et al., 2002; USEPA, 2002a). The EPA studies that form the basis for the *E. coli* standards were at sites in Pennsylvania and Oklahoma. The TAG-studied data were from Piedmont and Coastal Plain streams by USDA-ARS and UGA scientists. Some of these data sets included streams that were primarily forested land and therefore might be considered reference streams with background concentrations of bacteria.

From the same study described earlier, the FC concentrations measured over a three-year period on two Piedmont headwater streams in the Oconee River basin are plotted in Figure 3. (D. Radcliffe, unpublished data, 2006) These first-order streams drain watersheds that are entirely forested so they represent background conditions. The streams were designated "BF1 Forest Control" and "BF1 Forest Treatment" in that they were paired watersheds on unnamed tributaries of Big Indian Creek in a study of the effect of timber harvest in the BF Grant Forest in Putnam County. Fecal coliform GM concentrations (solid and dashed lines) were usually below the current state standard for fishing waters: 200 cfu/100ml in the summer and 1.000 cfu/100ml in the winter. However, the standard was exceeded on six occasions.



**Figure 3.** Fecal coliform concentrations measured in two headwater forested streams in the Oconee River basin. (D. Radcliffe, unpublished data, 2006) The current standard for fishing waters is shown by the red line.

Most of the samples were collected during base-flow conditions and there was no relationship between concentration and stream flow. These data come from small streams (watershed areas of 32 and 43 ha).

UGA scientist Dr. George Vellidis and USDA-ARS scientist Dr. Richard Lowrance from the Southeast Watershed Research Laboratory have collected samples from six streams in the Piscola Creek watershed of the Suwanee River basin. Five of these streams drained areas with differing levels of animal production and one stream could be considered a reference stream in that it was mostly forest. Grab samples were taken every two weeks for three to six years, depending on the site. Geometric mean values were computed each year for the winter months (November through April) and for the summer months (May through October). For the reference stream, the summer means ranged from 67 to 211 FC cfu/100ml and the winter means ranged from 102 to 145 FC cfu/100ml.

Dr. Dwight Fisher from the USDA-ARS J. Phil Campbell, Sr. Natural Resource and Conservation Center in Watkinsville, GA presented data he and others have collected in the Upper Oconee River Basin. They measured E. coli concentrations over a two-year period at 18 stream sites from headwaters north of Athens to tributaries entering Lake Oconee. Grab samples were taken about every two weeks. Most of the samples were taken during base-flow conditions, but some samples were taken under storm-flow conditions. The mean E. coli concentrations ranged from 232 to 917 cfu/100 ml. During his presentation to the TAG, Dr. Fisher suggested that the E. coli concentrations below 350-400 cfu/100 ml probably represented background.

Overall, these data indicate that the GM for reference streams are usually below the current FC standard of 200 cfu/100 ml and the equivalent *E. coli* primary contact standard of 126 cfu/100 ml, but will exceed the limit on occasions (especially during storm-flow). If most of these waters are not considered primary contact, then a standard of 12 or 14 illnesses per 1,000 swimmer could be used (E. coli concentrations of 336 or 548 cfu/100 ml, Table 2). It may well be that in the southeastern United States streams have background levels above the proposed standard for 8 illnesses/1,000 swimmers, which means that the background risk is higher in this region than in other regions.

#### Human vs. Nonhuman Sources of Bacteria

The 1986 EPA document allowed a less stringent standard for watersheds where no human sources were likely (USEPA, 1986). The 2002 EPA document

eliminates this provision and points out that many pathogenic organisms are of animal origin (USEPA, 2002a; as discussed in the section on Bacteria and Pathogens in Animal Manures). However, in the EPA's new recommendations for fresh water recreation use categories (Table 3), they allow a recreation use subcategory of "Wildlife Impacted Recreation," but this category must be assigned on a case-bycase basis with supporting data.

Georgia appears to be still using the less stringent standard for waters with nonhuman sources in that the standard includes the provision that for recreation, drinking water supplies, and fishing waters (GAEPD, 2004):

"Should water quality and sanitary studies show fecal coliform levels from non-human sources exceed 200/100 ml (geometric mean) occasionally, then the allowable geometric mean fecal coliform shall not exceed 300 per 100 ml in lakes and reservoirs and 500 per 100 ml in free flowing freshwater streams."

This provision should be dropped to conform with the new recommendations from EPA (USEPA, 2002a). In waters where wildlife are thought to be the source of contamination, the state should file for classification of the waters as "Wildlife Impacted Recreation," but this classification will require site specific supporting data.

The EPA standard is based on studies where the contamination came from point sources (wastewater treatment plants) that were likely dominated by human waste. Apparently, no studies have been done that show what the illness rate would be for a given *E. coli* concentration in streams where the sources were predominantly non-point and non-human. Also, studies have not been done to determine if there is a relationship between *E. coli* and pathogenic bacteria and viruses in these types of waters.

In Virginia, state regulations address wildlife sources in the following way (Benham et al., 2005):

"While managing over-populations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL. In such a case, after demonstrating that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs, the state may decide to redesignate the stream's use for secondary contact recreation or to adopt site-specific criteria based on natural background levels of bacteria. The state must demonstrate that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs through a so called Use Attainability Analysis."

# Standards Adopted by Other States

Thirteen states have adopted an *E. coli* standard for freshwaters (Table 5). In the southeastern United States, only Tennessee has adopted an *E. coli* standard for freshwater. All of the states except Vermont have adopted a GM standard for primary contact that is equal to or slightly above the concentration (126 cfu/100ml)

associated with the lowest risk (8 illness/1000 swimmers). Vermont has not adopted a GM, but uses a low SM concentration.



Waterfront development such as these homes on St.Simons Island, GA, places human settlement in close proximity to water resources, increasing the potential for sewage leaks, septic failures and other contaminant sources to negatively impact waterways.

#### Marine Water Quality Standard

The TAG did not spend as much time examining the issues related to the bacteria standard for marine waters as for fresh waters. EPA has recommended that states adopt enterococci as the indicator bacteria to replace FC for marine waters. The initial recommendation from EPA in 1986 suggested a geometric mean enterococci concentration of 35 cfu/100 ml as the new standard (USEPA, 1986). This concentration was associated with an illness rate of 19 per 1,000 swimmers, an approximation of the protection previously provided by a FC standard of 200 cfu/100 ml. In 2002, EPA recommended that states use approximately the same risk in terms of illness rates for fresh and marine waters (USEPA, 2002).

Approximately two years ago, EPA mandated that coastal states either adopt

### Water Quality Standard

State	Water Class	GM (cfu/100ml)	SM (cfu/100ml)
Arizona	Full Body Contact	130	580
California Regional Board 2	REC-I	126	235-576'
California Regional Board 7	REC-I	126	400
	REC-2	630	2000
Colorado R.	REC-I	126	235
	REC-2	630	1175
California Regional Board 9	REC-I	126	235-576'
Colorado	Rec Use IA	126	
	Rec Use IB	205	
	Secondary Contact	630	
Idaho	Primary Contact	126	406
	Secondary Contact	126	576
Indiana	Total Body Contact <sup>2</sup>	125	235
Maine	В	64	427
	С	142	949
Michigan	All Waterbodies <sup>3</sup>	130	300
New Hampshire	A	47	153
	В	126	406
	B (beaches)	47	88
Ohio	Lake Erie and Ohio R.	126	<b>235</b> ⁴
	Primary Contact	126	298 <sup>4</sup>
	Secondary Contact	126	576⁴
Oklahoma	Lakes and High Use	126	235
	Primary Contact	126	406
Oregon	All Waterbodies	126	
Tennessee	Recreation Waters	126	
Texas	Contact Recreation	126	394
	Noncontact Recreation	605	
Vermont	Α		18
	В		77

Table 5. Freshwater E. coli standards adopted by states (USEPA, 2002).

<sup>1</sup>April through October. <sup>2</sup>May through October at minimum. <sup>3</sup>Depends on frequency of use. <sup>4</sup>No more than 10% of samples should exceed the concentration shown.

their own *Enterococcus* standard for marine waters or implement the EPA standard for issuance of beach health advisories. Although the state has not promulgated a new standard, the Coastal Resources Division (CRD) of DNR uses a GM standard of 35 and a SM standard of 104 enterococci cfu/100ml. The Department of Human Resources issues advisories based on the sample results from the CRD. of sand (46.9%) than sediments from New Hampshire (7.2%) or Georgia (9.1%). Soils with a high percentage of sand dry faster and have poorer bacterial survival than soils with a high percentage of clay (Hartel and Alexander, 1986).

According to the definition in *Standard Methods for the Examination of Water and Wastewater* (Clesceri et al., 1998),

**Table 6.** Log<sub>10</sub> Most Probable Number (MPN) of fecal enterococci per g of sediment obtained with the Enterolert system (IDEXX, Westbrook, ME) at two sampling times (summer, winter) from the sediment of a) Academy Creek, Georgia b) Bunker Creek, New Hampshire, and c) Chun-Chin Creek, Puerto Rico. Statistical analysis deleted for clarity.

Condition	Acader	my Creek	ek Bunker Creek		Chun-Chin Creek	
	Winter	Summer	Winter	Summer	Winter	Summer
log <sub>10</sub> MPN g <sup>-1</sup> sediment						
Moist sediment	3.50	4.12	2.36	2.02	2.20	2.24
After 2 days of drying	4.23	2.72	2.19	2.34	1.98	1.46
After 30 days of drying	2.71	3.03	1.61	1.38	1.81	0.60
After 60 days of drying	3.08	2.60	2.48	1.80	1.22	0.20

An important issue related to the marine water quality standard is survival of fecal enterococci during desiccation and rewetting of sediments. Data from a study by Hartel et al. (2006a) suggest that fecal enterococci survived desiccation in sediment after rewetting (Table 6). The most reasonable explanation for this survival is the ability of the fecal enterococci to tolerate the high salt concentrations in sediment during drying. Fecal enterococci can tolerate 6.5% NaCl (USEPA, 2002a). Fecal enterococcal survival was poorest in Puerto Rican sediment, likely because of differences in sand and clay content. Puerto Rican sediment contained a higher percentage

fecal indicator bacteria should not persist in the environment. Survival of fecal enterococci violate this criterion. Furthermore, this survival affects bacterial source tracking results because the bacteria may represent a source of long past fecal contamination. These results reaffirm that an ideal fecal indicator bacterium does not exist, and care should be taken in interpreting fecal enterococcal data.

When Hartel et al. (2006b) conducted a similar experiment to determine if *E. coli* survived in three desiccated and subsequently rewetted sediments, the bacterium survived longer in one sediment, but not in the other two

(Table 7). They tried a similar *E. coli* experiment in marine sediments and obtained similar results (Hartel, unpublished). The common feature for both experiments was that E. coli survived better only in sediments below wastewater treatment plants. One reasonable explanation is that E. coli survived because of the nutrients associated with the wastewater plant effluent and some E. coli recovered from chlorine exposure. Recovery of E. *coli* following chlorine exposure has been observed in microcosm studies (Bolster et al., 2005). Nevertheless, E. coli declined below the limit of detection in all sediments by 60 d. thereby conforming to the American Public Health definition (Clesceri et al., 1998) that a fecal indicator bacterium not persist in the environment.

A Georgia study by McDonald et al. (2006b) compared three methods of measuring fecal enterococci concentrations in samples collected from Georgia's coastal waters from May 2003 to October 2003. The methods compared were IDEXX Enterolert method, the EPA membrane filtration Method 1600, and the traditional multiple tube technique. A significant difference was found among the three methods. Due to the subjectivity of assessing positive wells, the Enterolert method produced significantly higher numbers of enterococci organisms from split samples when completed by two coastal laboratories. The values of the multiple tube method were consistently lower than that of the other two methods. The Enterolert assay exhibited the most false positives, (37%), followed by membrane filtration, (18%), and finally the multiple tube technique (12%). Each method offers advantages and disadvantages. The Enterolert method is rapid, but has the highest incidence of false positive results. Membrane filtration is rapid, has a much lower incidence of false positives, but is affected by sediment loads, a common component in Georgia's estuarine waters. The multiple tube number method has the lowest incidence of false positives, is not influenced by sediment load, but is much more timeconsuming and labor-intensive than the other methods.

**Table 7.**  $Log_{10}$  Most-Probable-Number (MPN) of *Escherichia coli* per g of sediment obtained from: 1) below the outfall of the Griffin Wastewater Treatment Plant on Potato Creek (Griffin), 2) above the intake for the Thomaston Water Treatment Plant on Potato Creek (Thomaston), and c) Dean Creek, a Potato Creek tributary, below Thomaston. Statistical analysis deleted for clarity.

Condition	Griffin	Thomaston	Dean Creek	
	log <sub>10</sub> MPN g <sup>-1</sup> sediment			
Moist sediment	4.11	3.23	3.29	
After 2 days of drying	3.07	1.74	1.85	
After 30 days of drying	1.94	<1.00	<1.00	
After 60 days of drying	<1.00	<1.00	<1.00	

#### Bacteria and Pathogens in Animal Manures

s one might expect, animal A manures are high in FC. Barker et al. (1994) gave typical FC counts for different types of animal manure including beef cattle, dairy cattle, layer hens, broiler chickens, and swine; they ranged from  $1,170,000 (1.17 \times 10^6)$  to  $4,800,000 (4.8 \times 10^6)$  cfu per gram dry weight of manure. Bacteria from manures can reach streams a) from manure that is applied to fields, b) from manure deposited on fields where animals are grazing, or c) manure from animals deposited in streams where they have access. Since fecal bacteria are adapted to conditions found in the intestines of animals and humans (high temperature and moisture, no ultraviolet radiation from sunlight), they do not survive for long in a field. The greatest danger occurs when fresh manure is applied to a field and a storm occurs within days after application. In Georgia, poultry litter that is composted or stock piled (in "stack houses") for more than a few days had low levels of FC (Hartel et al., 2000).

A number of studies have measured FC concentrations in runoff or in streams from agricultural areas are listed in Table 8 along with the average FC concentrations. Runoff from fields that received manure were usually on the order of  $10^6$  FC cfu/100 ml shortly after manure application. These levels drop to about  $10^3$  to  $10^4$  cfu/100 ml within 30-100 days after application. Concentrations in streams near fields that received manure or were grazed were generally lowest,  $10^2$  to  $10^3$  cfu/100 ml. Pathogens as well as indicator bacteria are present in animal

manure (Dr. Michael Jenkins, J. Phil Campbell, Jr. Conservation Research Center, personal communication). Zoonotic pathogens from cattle that cause human disease are Salmonella enterica, Campylobacter spp., Escherichia coli O157:H7, Listeria monocytogenes, Clostridium perfringens, and the protozoa Cryptosporidium parvum and Giardia *lamblia*. All of these pathogens cause gastroenteritis and can be a serious problem for those who are immunocompromised. Prevalence of any one of these pathogens in a herd of cattle can range from less than 10 to greater than 80%. Infected cattle can shed as many as a million or more infectious agents in one gram of feces, and the infectious dose of these pathogens for humans can be a few thousand to less than 200 infective agents. Because these pathogens can survive several weeks in soil and can be transported by rain events into surface and ground water where they can survive for several weeks, infected cattle can present a serious risk to human health. The development of best management practices (BMPs) to control the dissemination of pathogens from cattle, and the development of methods for identifying bovine sources of pathogens in surface and groundwater, therefore, is a paramount concern for the protection of the public health.

#### Livestock Access to Streams

Several studies in Georgia have examined the effects of livestock access on stream water quality. Streams are attractive to livestock because they offer a source of water, and often shade. This is especially true in the summer with beef cattle gazing fescue pastures. **Table 8.** Studies that have measured average FC concentrations in runoff from plots or fields thatreceived manure or were grazed, or in streams near fields that received manure or were grazed.BMP = Best Management Practices

Study description	Fecal coliforms (cfu/100 ml)	Reference
Runoff from plots receiving broiler ma- nure	2.5 × 10 <sup>6</sup>	Edwards & Daniel, 1994
Runoff from plots receiving layer manure	3.3 x 10 <sup>6</sup>	Edwards & Daniel, 1994
Runoff from beef cattle feedlot	7.6 x 10 <sup>6</sup>	Young et al., 1980
Runoff from incorporated layer manure	1.0 × 10 <sup>6</sup>	Coyne et al., 1998
Runoff from cattle manure 30 days after deposition	$4.0 \times 10^4$	Thelin & Gifford, 1983
Runoff from cattle manure 100 days after deposition	4.2 × 10 <sup>3</sup>	Thelin & Gifford, 1983
Runoff from grazed pastures	$1.1 \times 10^{5}$ 2.6 x $10^{2}$ to $1.5 \times 10^{3}$	Doran & Linn, 1979 Jawson et al., 1982
Runoff from ungrazed pastures	$1.3 \times 10^4$ 4.0 x 10 <sup>0</sup> to 4.7 x 10 <sup>2</sup>	Doran & Linn, 1979 Jawson et al., 1982
Runoff from grazed fields receiving fertil- izer	8.7 x $10^3$ to 2.7 x $10^4$	Edwards et al., 1997b
Runoff from grazed fields receiving poul- try litter	5.5 × 10 <sup>4</sup>	Edwards et al., 1997b
Runoff from grazed fields receiving poul- try manure	3.7 × 10 <sup>3</sup>	Edwards et al., 1997b
Agricultural stream before BMPs	1.0 x 10 <sup>6</sup> to 1.0 x 10 <sup>8</sup>	Cook et al., 1998
Agricultural stream after BMPs	< 1.0 x 10 <sup>6</sup>	Cook et al., 1998
Stream through cattle grazing area	> $2.0 \times 10^{3}$ 1.0 x 10 <sup>3</sup> 6.0 x 10 <sup>0</sup> to 1.8 x 10 <sup>2</sup>	Stephenson & Street, 1978 Tiedemann et al., 1988 Gary et al., 1983
Stream through poultry and cattle grazing area during base-flow	$1.8 \times 10^2$ to $3.1 \times 10^2$	Edwards et al., 1997a
Stream through poultry and cattle grazing area during storm-flow	peak values 1.0 x 10 <sup>4</sup>	Edwards et al., 1997a
Streams, ditches, & ponds in agricultural areas in Finland	3.8 × 10 <sup>3</sup>	Niemi & Niemi, 1991
Fescue is usually infected with an endophyte which causes a low grade fever in cattle and causes them to overheat (Hoveland, 2003). All these studies show that bacteria concentrations are high when livestock have access to streams. In Figure 2, taken from the study by Fisher et al. (2000), showed that *E. coli c*oncentrations increased during storms. In that study, beef cattle had access to



Uncontrolled access of cattle to waterways poses a threat to water quality through the resulting stream bank destabilization and direct input of animal waste.

the pasture creek and *E. coli* concentrations reached the microbial assay's upper limit of detection (about 2,500 cfu/100 ml) during a wet period. By comparison, the maximum *E. coli* concentration in the wooded creek with no cattle was about 1,000 cfu/100ml.

The data collected by USDA-ARS scientist Dr. Richard Lowrance and UGA scientist Dr. George Vellidis from Coastal Plain streams were also mentioned in the discussion on background levels of bacteria. In addition to the reference streams, they also sampled two streams where cattle and goats had direct access to streams. The seasonal average FC concentration for the winter season (November to April) ranged from 675 to 1,703 cfu/100 ml and from 647 to 6,771 cfu/100 ml for the summer season (May to October) for one watershed. For the other watershed, the seasonal averages were 2,289 to 25,923 cfu/100 ml for winter and 9,957 to 19,736 cfu/100 ml for summer.

A recent UGA project studied at the effect of fencing dairy cattle out of streams (Thomas, 2002) (Fig. 4). The study was performed at a commercial dairy near Eatonton, Georgia. Samples were taken from a small stream above (reference site) and below (pasture site) where it bisected a pasture. The dairy herd had unrestricted access to the stream. Samples were collected for 18 months starting in April, 1999. Then the cattle were fenced out of the stream and monitoring continued for another 18 months. The results showed a dramatic improvement in stream water quality in the second period when cattle access was restricted. Before the fencing was closed, FC concentrations averaged over 51,000 cfu/100 ml. After the fencing was closed, FC concentrations averaged 258 cfu/100 ml.

Other BMPs such as supplying alternative sources of water and shade may reduce bacterial loading to streams without requiring fences. In a recent UGA study, Global Positioning System (GPS) collars determined how much time cows spent in the riparian zone (Byers et al., 2005). Daily time spent in

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**Figure 4.** Average FC concentrations at a reference sampling site (upstream of the field) and pasture sampling site (downstream of the field) in the before and after fencing cattle out of the stream (Thomas, 2002).

the riparian area varied between 5 and 10% during warm months, and between 2 and 3% during cold months. There was a linear relationship between time spent in the riparian area and a temperature humidity-index, which suggested that cattle went to riparian areas in response to environmental stress. More time was spent in the riparian area in the pasture and less in non-riparian shade. In that pasture, providing cattle with water troughs reduced time spent in riparian areas by 40 to 96%, depending on the time of year.

## Septic Systems

The TAG relied heavily on information from Dr. Larry West at the University of Georgia in regard to septic systems and their influence on bacteria TMDLs. In 1990, more than 38% of the housing units in Georgia (999,960 units) relied on onsite wastewater management systems (septic systems) to dispose of and treat household waste (Bureau of Census, 1993). Since that date, about 50,000 new onsite systems have been installed each year, which would bring the current number of onsite systems being used in the State to more than 1.5 million. Although firm data are not available, this number probably represents more than 40% of the homes in Georgia. When properly sited, designed, installed, and maintained, onsite systems effectively reduce or eliminate most human health or environmental threats posed by various substances in the wastewater, and the USEPA considers onsite systems to be a permanent part of the nation's wastewater management infrastructure (USEPA, 1997; 2002b).

A typical onsite system consists of a septic tank, a drainfield, and the soil. The function of the septic tank is to provide primary wastewater treatment by removing large organic solids. The quiet water environment of the septic tank also allows fat, oil, and grease (FOG), which are less dense than water, to rise to the surface of the liquid in the tank where they form a solidified layer. Because of its anaerobic environment, only 60 to 70% of the organic solids collected in the septic tank decompose, and the remainder accumulates at the bottom of the tank. Over time, accumulation of solids at the bottom of the tank and FOG at the liquid surface will fill the tank and reduce the residence time of the wastewater. This filling may result in movement of solids into the drainfield where they will clog

soil pores and cause hydraulic failure of the system. Thus, the septic tank must be periodically emptied (pumped) to remove solids and FOG as part of a regular maintenance program.

The wastewater flows from the septic tank into the drainfield, which consists of a series of underground trenches where the wastewater is distributed over a sufficiently large area of soil to allow complete infiltration. The soil transmits the wastewater from the drainfield to ground and/or surface water and is the treatment medium where organic material, nutrients, toxic substances, and pathogenic organisms are removed.

Typical household wastewater contains about  $10^6$  to  $10^8$  FC cfu/100 ml. The septic tank will reduce these numbers and septic tank effluent typically has about  $10^5$  to  $10^7$  FC cfu/100 ml (USEPA, 2002b). Aerobic and anaerobic treatment units between the septic tank and drainfield will reduce coliform concentrations by another 100to 1000-fold, but these are typically only used for systems where rock, seasonal water tables, or other soil limitations reduce the thickness of unsaturated soil available for treatment. Thus, the concentration of coliform bacteria in septic tank effluent entering the soil is at least  $10^4$  cfu/100 ml and, more commonly,  $10^5$  to  $10^7$  cfu/100 ml.

When enteric bacteria enter the soil, they are subjected to stresses not encountered in their host: lower temperatures, fewer nutrients and energy sources, suboptimal pH, insufficient moisture for growth and survival, and predation by indigenous soil microflora (Gerba et al., 1975; USEPA, 2002b). These stresses reduce bacterial survival times to typically less than 20 days (USEPA, 2002b) although longer survival times may occur under certain soil conditions (Pekdeger, 1984).

For surviving bacteria moving with water through unsaturated soil, the main mechanisms of bacterial retention are filtration and adsorption (Bicki et al., 1984; Cantor and Knox, 1985; Gerba et al., 1975). Most bacteria are 0.001 to 0.005 mm in size. Thus, if the size of soil pores through which water is moving is smaller, bacteria will be filtered and retained. In relatively dry soil or soils with low permeability, water movement will be dominantly through small pores and appreciable filtration would be expected. However, under saturated or near saturated conditions, much of the water movement is through larger pores in the soil, and bacterial retention by filtration would be reduced.

Bacteria may also be adsorbed to clays and other charged soil components such as Fe oxides and organic matter (USEPA, 2002b). Bacteria are negatively charged at the pH range of acid soils, and clay and organic matter are also negatively charged at these ranges of pH. Thus, adsorption of bacteria to clay and organic matter by electrostatic attraction would not be expected for most soils in Georgia. Other mechanisms may allow absorption of negatively-charged bacteria to negatively-charged surfaces, however, including cation-bridging, van der Waals forces, coordination bonding, and hydrogen bonding (Hartel, 2005). At pH ranges below 7 to 8, Fe oxides and oxyhydroxide minerals have

appreciable positive charge. (Bigham et al.,2002). Thus, in soils containing Fe minerals (soils with red or yellowish brown subsoils), including most soils in Georgia, adsorption to Fe mineral surfaces may be an important mechanism for retention of bacteria. The most notable exception is soil in the Coastal Plain and Coastal Flatwoods regions of the state that have sandy textures to depths of 1 m or more.

Bacteria removal by soils receiving wastewater is enhanced by development of a biomat at the drainfield trench-soil interface. The biomat is formed as pores in the soil are clogged as the soil filters suspended organic solids in infiltrating wastewater. Subsequent growth of microorganisms in this high organic matter zone results in greater clogging of soil pores. Thus, after a few weeks to months of wastewater infiltration, pores in a thin soil zone immediately below the wastewater infiltrative surface in the trench become clogged that appreciably reduces the rate of wastewater infiltration into the soil (Seigrist, 1987; Finch et al., 2005). For this reason, biomat formation is considered to be a limitation for the long-term hydraulic function of onsite systems; however, biomats also enhance wastewater purification by removing bacteria from the percolating wastewater. Van Cuyk et al. (1999) evaluated FC concentrations in septic tank effluent that had been leached through lysimeters filled with 60 to 90 cm of sand. During the first 10 weeks of the experiment, FC concentrations in the lysimeter leachate ranged from  $10^2$  to  $10^5$  cfu/100 ml. After 28 weeks of wastewater additions and during which a biomat had developed, FC concentrations in the leachate were less

than 10 cfu/100 ml. Sampling of the sand in the lysimeters after 48 weeks of wastewater addition indicated that no coliform bacteria were present more than 30 cm below the infiltrative surface and the greatest bacteria population was in the upper 8 cm of the sand.

These results are consistent with the results from other studies that have generally found no or low bacterial populations deeper than 30 to 60 cm below the wastewater infiltrative surface in onsite systems with mature biomats (Bouma et al., 1972; Brown et al., 1978; Kristiansen, 1991; Anderson et al., 1994; Stevik et al., 1999). The impact of the biomat on bacterial retention on the soil has been mostly attributed to enhanced filtration as the soil pores become clogged with organic matter and to increased predation from elevated populations of microorganisms.

However, if soils have seasonal water tables above or at a shallow depth below the wastewater infiltrative surface there is an increased potential for long distance subsurface movement of bacteria as indicated by several studies. This is especially true for soils with high rates of water movement (e.g., sandy textures). Fecal coliform concentrations as high as  $10^5$  cfu/100 ml were found up to 28 m from onsite system drainfields in soils with seasonal water tables at or a short distance below the base of the drainfield trenches (Reneau and Pettry, 1975). Similar bacterial concentrations and travel distances have been reported for onsite systems installed in soils with 15 cm or less separation between seasonal water tables and the wastewater infiltrative surface (Reneau, 1978; Viraraghavan, 1978).

Most soils in Georgia have hydraulic properties that make them suitable for onsite systems. Although renovation capacity is not considered as criteria in assessments of soil suitability for onsite systems, most soils that are hydraulically suitable for an onsite system have a high capacity for retaining potential ground and surface water contaminants. As population and number of houses in Georgia continue to increase, however, soils with shallow seasonal water tables are more commonly being used for onsite systems. A shallow water table reduces the thickness of unsaturated soil available for wastewater treatment and may also retard the hydraulic performance of the onsite system. Because of these limitations, Georgia regulations for anerobically treated wastewater require 60 cm of separation between the wastewater infiltrative surface (bottom of the trench) and the seasonal water table. If aerobic treatment is included in the onsite system, this separation requirement is reduced to 30 cm. With these separation distances, subsurface movement of bacteria to ground water is expected to be minimal.

The region of the State with the greatest potential for bacterial movement to ground water is the Atlantic Coast Flatwoods. Soils in this region are often sandy and often have seasonal water tables within 30 to 60 cm of the soil surface. Because of their shallow water tables, these soils are considered as unsuitable for a conventional onsite system with the base of the drainfield trench below the soil surface. To overcome the water table limitation, onsite system drainfields are installed in sand-textured fill mounded 90 to 120 cm above the soil surface. Fill thickness and position of drainfield trenches are designed to provide at least 60 cm of unsaturated soil between the wastewater infiltrative surface and the seasonal water table. For mound systems with similar fill depths in Wisconsin, Converse et al. (1994) found low concentrations of FC at the base of the fill and no bacteria at a depth of 25 cm in the natural soil.

Only if an onsite system is hydraulically failing with partially treated wastewater rising to the soil surface would the potential exist for appreciable amounts of bacteria from onsite systems to reach surface water. This is often referred to as surfacing or hydraulic failure. Under these conditions, surface runoff may transport bacteria from the area of the failing drainfield to streams and other surface water bodies. While this potential exists, indications are that the rate of hydraulic failure of onsite systems in Georgia is very low, although data on failure rates in the State are limited and probably vary with regional soil and hydraulic conditions.

In some cases, older homes may not have a septic tank or drainfield and instead discharge directly to a nearby ditch or stream. These are referred to as "straight pipes." In a Virginia study, investigators assumed that 10% of old houses and 2% of middle-aged houses within 45 m of streams used straight pipes (Benham et al., 2005).

Gwinnett County has used color infrared aerial photography as a tool for identify failing septic systems that result in a discharge of effluent to the surface

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of the ground (Steve Leo, Gwinnett County Department of Public Utilities, personal communication). This technique relies on the variations in the green coloration of the vegetation on the ground surface surrounding the point at which the failure manifests. Color film sensitive to near-infrared wavelengths of the electromagnetic spectrum has the ability to highlight these changes in vegetation coloration, thereby providing a visual indicator of differences in plant vigor due to differences in water or nutrient availability. In cases of severe failure, vegetation is severely damaged at the point where the wastewater surfaces. This creates a dead patch of grass surrounded by lush vegetation. In other instances, malfunctioning onsite systems may result in areas of lush vegetation in an area of less vigorous growth because of additional water and nutrients from the onsite system. These characteristics, when captured on color infrared film and when cross-referenced with other environmental and land use data, allow a photo analyst to remotely identify a spectral signature or coloration pattern caused by a failing or stressed system.

Gwinnett County estimates that there are up to 100,000 septic systems in the county. About 14% of parcels in the county were obscured by tree canopy, but the study was applied to the whole land mass of the county including incorporated areas. The project identified 121 instances of systems that were classified as "surface failures." These failures would represent less than 1% of the total septic systems in the county. A surface failure is characterized by the upward and/or lateral movement of partially processed



The evidence of septic system failures can be subtle, only visible in this example by the increased moisture, temperature and nutrient content of the soil resulting in increased vegetative growth as seen from the ground (bottom) or as it may stand out more clearly in the color infrared aerial photograph (top).

or unprocessed effluent that results in an accumulation on the ground surface. Dead vegetation or bare ground may also be present. Successful ground verification site inspections were completed on a randomly selected 37 of these 121 sites. These inspections verified that 34 of the 37 sites with remotely identified failing systems were actually failing on the ground. This translates to a 92% accuracy rate for identification of this category of failure.

In addition, two other less serious system-status categories were also established, namely seasonal failure and seasonal stress, and the study remotely identified 508 and 449 instances of these system-status types, respectively. Ground verification on these categories resulted in identification accuracy rates of 61% and 76%, respectively. The reduced accuracy of ground verification of these other system-status categories may reflect environmental conditions (specifically rainfall and groundwater levels) that result in intermittent failure. Another indicator of the intermittent nature of septic system failure is that 15% of the ground verified sites were either upgraded or downgraded to another system-status category.

Although the methodology has some limitations, Gwinnett county has found the study helpful in identifying failing systems that otherwise would not have been identified. The percentage of failures identified was less than those found in a comprehensive study of onsite system failure rates in North Carolina (Uebler et al., 2006). The statewide percentage of malfunctioning onsite systems less than 12 years in age reported in this study was 8.4%. Percentages of failing systems for the Piedmont and Coastal Plain regions were 9.8 and 11.7%, respectively, and these failure rates were higher than the 3.9% of systems malfunctioning in the Blue Ridge Mountain region of the State. The proportion of malfunctioning systems in Georgia may be similar to that found in North Carolina, but could be less because of differences in siting criteria between the two states. North Carolina regulations require 30 cm of separation between the drainfield trench bottom and the seasonal high water table as compared to the more restrictive 60 cm required in Georgia.

In 1998, Georgia instituted new regulations governing all aspects of onsite installation and use in the State. These regulations include relatively stringent requirements for soil and site suitability; certification of County Board of Health Environmental Health Specialists, site evaluators, installers, and pumpers including requirement for continuing education; and establishment of a review process before onsite system equipment is approved for use in the State. These new regulations and procedures are expected to improve long-term onsite system performance and reduce instances of system malfunction.

Two programs that would substantially improve onsite system performance and reduce system malfunction are public education and system maintenance. To ensure long-term performance with minimal environmental degradation, onsite systems require periodic maintenance including pumping of solids from the septic tank and system inspection. By State statue, however, County Boards of Health cannot require periodic maintenance of nonmechanical onsite systems. A few County Boards of Health require annual maintenance of systems with mechanical components, but in much of the State onsite system maintenance is an optional responsibility of the homeowner. Because few homeowners understand the function and maintenance needs of onsite systems (many do not know they use an onsite system to manage their wastewater), maintenance is sporadic and often only is done when there is a problem with the system. A comprehensive public education program coupled with required maintenance of onsite systems would be expected to appreciably reduce environmental degradation and

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homeowner dissatisfaction associated with onsite systems.

### **Urban Sources**

Urban sources of fecal coliform contamination can be divided into those sources that dominate during base-flow conditions and those that are contributed by storm-flows (Carroll and Rasmussen, 2005). Base-flow contamination is likely caused by:

- leaking, failing, or overflowing sanitary sewer lines
- leaking, failing, or overflowing lift stations
- illegal direct sewage discharges from apartments and industries
- illegal connections or discharges to storm sewers
- inadequate treatment at wastewater treatment plants
- legal (permitted) discharges
- poorly installed or maintained onsite wastewater treatment systems.

These sources provide direct routes for poorly or untreated wastes to enter local rivers, lakes, and streams. Storm-flow sources include:

- fecal wastes from pets (e.g., cats, dogs), farm animals (e.g., chickens, pigs), and wildlife (e.g., pigeons, gulls, ducks, geese and other waterfowl, rats, raccoons, possum, squirrels, beaver, muskrats, deer)
- overflowing sanitary sewer lines caused by conveyance systems that exceed capacities
- releases of partially or un-treated sewage by wastewater treatment facilities due to insufficient storage capacity
- anticipated releases from combined

sewer overflow (CSO) systems

• discharges from dumpsters and landfills.

Fecal coliform concentrations in domestic sewage are typically 100-to 1000-fold higher than stormwater



Broken household sewer line over Potato Creek in Griffin, GA.

runoff, and 10,000- to 100,000-fold higher than forest runoff influenced only by wildlife sources, which means that even small sewage leaks can cause substantial increases in fecal concentrations. Tracking urban sources requires a systematic approach that monitors a wide range of sites on a quarterly schedule, with additional, targeted sampling in those areas that show elevated readings. Scheduled monitoring should be performed for a wide range of hydrologic conditions, including base- and storm-flows.

Once an elevated site has been identified, focused sampling requires that additional upstream and tributary samples be taken. Concomitant sampling for total dissolved solids (or specific conductance) and total suspended solids (or turbidity) allows for some source identification (i.e., domestic sewage discharges are indicated by higher dissolved solids, while storm-flows are indicated by elevated suspended solids). Introducing additional flows and tracers into suspect waste streams is another method for isolating specific input locations.

### **Bacterial Source Tracking**

One of the most difficult aspects of bacterial TMDLs is identifying the source of bacterial contamination, especially when it is likely to be a nonpoint source of pollution. "Bacterial source tracking"<sup>2</sup> (BST) is a potential solution to this problem. A good resource document is "Microbial Source Tracking Guide Document" published by USEPA (2005). Information on BST is also available in a Southern Regional Water Quality Program Bulletin entitled "Bacterial Source Tracking (BST)" available online at www.pubs.caes.uga.edu/caespubs/pubs/ PDF/B1242-7.pdf.

The basis for BST is that specific isolates (subspecies) of a single bacterial species (for example, *E. coli*) are found only in specific warmblooded animal species. If a person has a way of identifying these subspecies, then it is possible to identify the source (e.g., human or nonhuman animal). Once the source is known, it can be cleaned up (e.g., malfunctioning septic tanks) or not (e.g., wildlife). identify bacteria: phenotypically or genotypically. A phenotypic method is based on something a bacterium does that is usually easy to see. For example, if an antibiotic is added to a solid medium and a bacterium grows on it (forms a colony), then the bacterium is antibiotic resistant. Antibiotic resistance is a phenotypic characteristic. Because certain warm-blooded animals (like cows) are exposed to different antibiotics than humans, it is not surprising that the bacteria in cow manure are resistant to different antibiotics than humans. BST exploits this difference; if bacteria from a water source are resistant to antibiotics typically given to cows, then the bacteria are more likely to come from cows than humans.

In contrast to phenotypic identification, a "genotypic" method is based on DNA. Generally, DNA is isolated from bacteria and, with the help of a special enzyme that cuts DNA in specific places (a restriction enzyme), the DNA is run on a gel to yield a "fingerprint." Again, because specific isolates of fecal bacteria are only found in specific animal species, most DNA fingerprints of bacteria are specific to that animal. All that is really needed then is a way to match fecal bacteria from humans and other warm-blooded animals to fecal bacteria from water. In most BST methods, this matching is done with a "host origin library" or "host origin database."

In BST, there are two main ways to

It is important to note that a third way to identify sources of fecal bacteria exists:

<sup>2</sup> Some microbiologists use viruses instead of bacteria to identify host sources; in this case, the best term is "viral source tracking." When the type of microorganisms isn't specified, the best term is "microbial source tracking." Since only bacteria were used here, "bacterial source tracking" is the term used throughout the report.

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chemical methods. However, these methods do not depend on identifying bacteria but rather on chemicals directly or indirectly associated with fecal bacteria. These chemicals, like caffeine, are usually associated with human sewage. The most welldeveloped chemical method is fluorometery, which is associated with optical brighteners in laundry and dishwater detergents. Flurometry offers good promise to identify malfunctioning septic systems and sewer lines (McDonald et al., 2006a).

A less expensive alternative to creating a permanent host origin database is to use targeted sampling (EPD prefers to use the term "screening sampling") as a prelude to BST, and use a BST method only when necessary (Figure 5). This method was originally developed in Georgia with EPD funds (Kuntz et al., 2003). The first step of targeted sampling is to divide the sampling into two parts, one for base-flow and another for storm-flow. This division reduces the problem of different sources coming into play during different weather conditions.

The second step is to talk with the locals or other knowledgeable people (e.g., Adopt-A-Stream, riverkeeper, state and federal agencies) about the water source. Many people have a good idea about the source(s) of fecal contamination. Potential human fecal



Figure 5. Decision tree for targeted sampling. (Kuntz et al., 2003).

sources have the highest priority because they are easiest to control; wildlife has the lowest priority because control is difficult.

The third step is to combine the local knowledge with a general survey of the contaminated waterway, collecting between 50 and 100 water samples from the mainstem and all tributaries (as appropriate) in one day.

The data are combined with GPS data to ensure that the sample locations are accurate. The amount of fecal contamination is plotted on a map and hotspots identified.

The fourth step repeats the third step except that only the immediate area around the hotspots with the highest priority are sampled. This targeted sampling yields either a low or high fecal count. Low counts are likely transient sources of fecal contamination (e.g., illegal dumping of boat wastes). Persistent high counts must be coming from somewhere. In the case where the source is a pipe or something equally obvious, then there is no need for further sampling. If the source is still unknown, then this requires the fifth step.

The fifth step is BST. There are generally only two or three likely sources of fecal contamination in hotspot areas. A third and final sampling involves a one-day sampling of these few potential host sources combined with sampling the contaminated water. Because the number of samples is small, it is possible to obtain a reasonable number of isolates from each source. These isolates are then matched genotypically or phenotypically. Costs for targeted sampling are much more reasonable because no permanent host origin database is established, and bacterial changes with time and geography are minimized because the sampling is limited to one day in a restricted geographic area.

Targeted sampling is much like the children's game of "hot" and "cold," and it makes it easy to identify persistent sources of fecal contamination. A recent UGA study on Jekyll Island by McDonald et al. (2006b) illustrates the use of target sampling. In the case of one estuarine area, St. Andrews Park, the most likely major source of fecal contamination during stormy conditions was bird feces from Beach Creek (Fig. 6). No fecal contamination was observed in waters outside the park during calm or stormy conditions, therefore sources of fecal contamination must be near or inside the park. During calm conditions, no sources of fecal contamination were observed in the water either near or inside the park except for the extreme upper reach of Beach Creek. However, during stormy conditions with an ebbing spring tide, large numbers of fecal enterococci were observed in the water coming from Beach Creek into St. Andrews Park. Fecal enterococcal numbers decreased north and south of the creek, and most of St. Andrews Park was in violation of the state standard (>104 fecal enterococci per 100 mL). Runoff and tidal forcing likely caused this pulse of fecal contamination from Beach Creek. Fecal bacteria typically increase 10- to 100-fold after stormy conditions in estuarine conditions (Solo-





**Figure 6**. Location of sampling sites at St. Andrews Park on Jekyll Island during A) calm and B) stormy conditions. Each location shows the site number (boldface top number), turbidity (middle number), and number of fecal enterococci per 100 mL (bottom number). If the number of fecal enterococci exceeds the maximum allowable for a grab sample (>104 fecal enterococci per 100 mL), then the bottom number is shaded. White areas define beach, light gray areas define seawater, medium gray areas define marsh, and the dark gray areas define land (McDonald et al., 2006b).

Gabriele et al., 2000), and after tidal forcing, where feces deposited above the normal, but below the maximal, high tidemark are brought into the water by ebbing spring tides (Boehm and Weisberg, 2005).

As noted in the section above on listing and delisting streams, EPD has a process whereby an organization or lab can gain approval for monitoring waters and submitting data for listing or delisting waters (GAEPD, 2003a). However, organizations and labs do not have to be certified to perform BST where the purpose is to identify sources. Any resources including volunteers and programs such as Adopt-A-Stream can be used for this purpose.

Sediments have long been known as reservoirs of fecal bacteria (Stephenson and Rychert, 1982). Large numbers of fecal bacteria in the sediment may potentially create advisories when the sediments are disturbed (e.g., Clean Beaches Council, 2005). Therefore, sediments should be considered in bacterial source tracking studies whenever they are relevant.

Based on this work, several conclusions can be drawn:

- Targeted sampling is an inexpensive method as a prelude to BST to identify persistent sources of fecal contamination that should be part of TMDL Implementation Plans for waters exceeding limits for fecal contamination. (Northeast Georgia and McIntosh Trail RDCs are already using this method.)
- Based on changes of bacterial subspecies with geography and time, construction of a *permanent* host origin database for BST in Georgia is not recommended.
- Sediments should be considered as sources of fecal contamination if the sediments are disturbed.
- Similarly, survival of fecal enterococci in air-dried and subsequently rewetted sediments can be expected.



Peter Hartel sampling Academy Creek, near Brunswick, GA.

eorgia is on a five-year rotating Georgia is on a management of basin schedule for monitoring streams and establishing and implementing TMDLs. The state has been divided into five large river basins: Altamaha-Oconee-Ocmulgee, Chattahoochee-Flint, Coosa-Tallapoosa-Tennessee, Savannah-Ogeechee, and Suwanee-Satilla-Ochlocknee-St. Mary's. Each basin follows a five-year process. In the first year of a cycle, water segments (streams, rivers, and lakes) that are on the 303(d) impaired list in a given basin are monitored by the USGS under a contract with EPD for one year. In the second and third year, EPD establishes the TMDL. In the fourth and fifth year, an implementation plan is developed, usually by regional development centers under contract with EPD. The first fiveyear rotation was completed in 2003 (Phase I) and Georgia is now in the second five-year rotation.

The monitoring data collected by the USGS consist of a series of measurements designed to produce a monthly GM for four months during the year (two winter months and two summer months). Samples are collected during a given month at four regularly scheduled times, separated by 24 hours. Since the schedule is fixed, samples may be collected under storm-flow conditions, but are more likely to be collected under base-flow conditions.

The Georgia EPD has been responsible for establishing all of the bacterial TMDLs in the State (all TMDL documents are available on the EPD website under Technical Guidance Documents, GAEPD, 2005). This process includes calculating the TMDL and the current load. The bacterial TMDL for a stream is an estimate of the number of bacteria the stream can assimilate and still meet water quality standards. It is EPA's position that this load does not have to be calculated on a daily basis (it can be a monthly or annual load) as long as the period covers the critical conditions (the period when risk is the greatest). The TMDL must be allocated between point source loads (known as wasteload allocations, WLA) and all non-point source loads (known as load allocations, LA). The TMDL must also include a margin of safety (MOS) to account for the uncertainty in the estimate:

### $\mathbf{TMDL} = \mathbf{WLA} + \mathbf{LA} + \mathbf{MOS}$

The first bacterial TMDLs developed by EPD were published in 2000 and covered streams in the Ochlocknee. Satilla, St. Mary's, and Suwanee River Basins. For these streams, EPD published a separate document for each stream (a total of 28 documents) and used a dynamic watershed scale model known as the Hydrologic Simulation Program Fortran (HSPF; Bicknell et al., 2001) to calculate the current loads and to estimate the TMDL. Dynamic watershed models have been developed in recent years to predict stream daily flow and pollutant concentrations at the outlet of a river basin. Essentially, the model "interpolates" between the measured values of FC (which are usually few in number) and predict what the highest FC concentration would have been under critical conditions. This concentration is then used to calculate the current load. The model is also used to determine what level of point and non-point source loads would

result in a maximum FC concentration that would meet the state water quality standard. This is the TMDL. HSPF is part of the Better Assessment Science Integrating Point and Non-point



Sarah Hemmings (top) and Gwyneth Moody (bottom) beginning a targeted sampling of Potato Creek near Meansville, GA.

Sources (BASINS) analysis system designed by EPA for use in developing TMDLs. Part of this system includes the Bacteria Indicator Tool that is used to develop parameter values for HSPF when modeling bacteria. HSPF requires a large number of parameters, most of which were unknown for the streams analyzed in 2000. For example, the number of domesticated and wild animals (i.e., cattle, poultry, swine, and deer) and septic systems (and their failure rate) in each watershed was required. Census data are available for some of these parameters on a county basis but not on a watershed basis. The model also required information on the survival rates of bacteria in fields and streams and these data were not available. Like all dynamic watershed models, HSPF had to be calibrated by adjusting the parameters values (such as the number of cattle or the failure rate

of septic systems) to get a "best-fit" of the model to measured values of stream flow and FC concentrations. In many of these streams, daily water flow had not been measured or was not available at the point where FC concentrations were measured. Also, there were few measurements of FC to use for calibration. As a result, there was a great deal of uncertainty in the model predictions and unrealistic values of some of the parameters were required to get the best fit.

Starting with the bacterial TMDLs published in 2001, EPD developed a new watershed approach in which all of the streams in a given basin were published in a single document. They also abandoned the use of HSPF. Instead of using a model to "interpolate" between measured concentrations of FC to get daily concentrations. EPD has used the USGS data to calculate a geometric mean monthly FC concentration ( $C_{\text{geometric}}$ ) for each of the months sampled (two winter and two summer months). They have also used estimates of stream flow at the time of sampling (provided by the USGS) to calculate a monthly arithmetic average stream flow ( $\mathbf{Q}_{mean}$ ). With these data they calculate an average FC load (counts per 30 days) for each month sampled. The month in which the geometric mean concentration exceeds the state standard by the greatest amount is the current load under critical conditions and is calculated as the product of the FC concentration and mean flow:

$$\mathbf{L}_{\text{critical}} = \mathbf{C}_{\text{geometric}} * \mathbf{Q}_{\text{mean}}$$

To calculate the TMDL, the geometric

mean FC concentration corresponding to the state standard (200 cfu/100 ml or 1,000 cfu/100 ml, depending on the designated use and time of year,  $C_{standard}$ ) is substituted into a similar equation using the same value for monthly mean flow:

 $TMDL_{critical} = C_{standard} * Q_{mean}$ 

The load reduction is calculated as the difference between the current critical load and the TMDL, expressed as a percentage of the current load:

 $\begin{array}{l} \mbox{Load Reduction} = 100 * (\mbox{L}_{critical} \mbox{-} \\ \mbox{TMDL}_{critical}) \ / \ \mbox{L}_{critical} \end{array}$ 

If the designated use of the stream is drinking water and any of the samples collected during the period November to March had a concentration that exceeded 4,000 cfu/100 ml (the state standard for single samples which only applies to drinking water steams during this period), then the current load is calculated for a single day, as well as the monthly mean. Whichever estimate of the current load (single daily value or monthly mean) produces the greatest load reduction, is used to calculate the current critical load and load reduction.

The WLA to all point sources is calculated as the sum of the allowed monthly discharge rate times the allowed FC concentration (usually 200 cfu/100 ml) for each point source according to its NPDES permit. If a permitted facility expands its capacity and the permitted flow increases, the WLA for the facility will increase in proportion to the flow. If there are combined sewer overflows (CSOs), these discharges must meet the FC concentration standard but no attempt is made to calculate a WLA because the discharge volume is not measured. In 2003, GA EPD began including a WLA from municipal separate stormwater sewer systems (MS4) in the TMDL equation. The first TMDLs developed with this new addition were the Chattahoochee and Flint River Basin TMDLs in 2003. The allocation for MS4 must meet the FC standard and is calculated assuming 70% of the storm water runoff from regulated urban areas is collected by the stormwater systems. An allocation is made to safety MOS equivalent to 10% of the TMDL. The remaining load is allocated to the nonpoint sources.

Using the TMDL for the Chattahoochee River Basin (published in January 2003) as an example, 79 stream segments were identified for establishment of TMDLs (GAEPD, 2003b). The average overall load reduction was 58% and ranged from 0 to 99%. The load reduction was not broken down between point and non-point sources. However, since the monthly average discharge and FC concentrations (taken from the Discharge Monitoring Reports for 2000) showed that the point sources were within their permitted limits, most of the load reduction fell on non-point sources. An exception would be the CSOs and MS4s where the current load is unknown but FC concentrations are likely to exceed the state standard.

The watershed approach EPD is now using to publish TMDLs is an improvement over the earlier method where each stream TMDL was published as a separate document. The new method EPD is using to calculate

current loads and TMDLs, which does not use a model, is justified. In most cases, there are insufficient data on sources of bacteria to support the use of a dynamic watershed-scale models such as HSPF. EPD's approach to rely entirely on monitoring to calculate the current load and the load reductions is appropriate. There may be some cases in the future where a TMDL is being developed for several pollutants in an extensive area such as a lake watershed and the consequences of the TMDL will have a large economic impact. In these limited cases, the use of a dynamic model may be appropriate. The assumptions that 70% of the storm water runoff from regulated urban areas is collected by the MS4 systems and that the new MS4 requirements will result in FC concentrations that meet the state standard should be validated by measurements of MS4 discharge volumes and bacterial concentrations.



Karen Rodgers (University of Georgia) sampling a small tributary to Potato Creek near Meansville, GA.

any different approaches to Limplementing bacteria TMDLs have been taken across the diverse regions of Georgia. Over the duration of this TAG, information on TMDL implementation was solicited from relevant branches of federal and state agencies as well as local governments and the RDCs they often rely on for planning assistance from across the state. All meetings were advertised and open to anyone wishing to contribute information. A special effort was made to contact appropriate staff members of local governments and RDCs in advance to notify them of meetings and encourage their attendance. The TAG heard from a variety of participants involved in TMDL implementation throughout the state. Included here is a summary of the role of the State EPD in the implementation process, the common obstacles to achieving effective implementation, and a regional compilation of the approaches being taken across the state.

## Role of EPD

Under EPD's Watershed Protection Branch, the TMDL Implementation program works with contractors around the state to develop implementation plans and improve local water quality. The program works on plan implementation and facilitates watershed remediation through education, outreach, and funding.

The EPD is responsible for developing a template for an implementation plan and hiring a contractor to write the plan. In most cases, contracts are made with the RDCs to write the implementation plans. The RDCs involve stakeholders

and are responsible for education and outreach. They also submit the plan to EPD for review. As previously stated, EPD has divided Georgia's 14 main river basins into five groups:

- 1. Chattahoochee / Flint
- 2. Coosa / Tallapoosa /Tennessee
- 3. Savannah / Ogeechee
- 4. Ochlockonee / St. Marys / Satilla / Suwannee
- 5. Oconee/ Ocmulgee / Altamaha

A rotating basin approach is used to focus on these groups every five years for developing TMDLs, planning, monitoring, modeling, permitting, and addressing water quality concerns. TMDL implementation plans are also developed on a five-year cycle that follows TMDL development by approximately two years.

Starting in 2004 with the Chattahoochee and Flint River basins, EPD began using a tiered approach to the implementation process with each tier requiring different levels of effort and associated costs.

- Tier 3 plans are developed in-house by EPD personnel. Tier 3 includes streams that are "impaired" due to natural conditions, legacy sediments, and those streams that partially support designated uses because they have excessive FC bacteria.
- Tier 2 plans require more effort and are plans that are contracted to the RDCs including plans for those streams that do not support designated uses that are listed for FC bacteria.
- Tier 1 plans will have everything a Tier 2 plan has and will delve further

into non-point source identification and BMP selection. It is EPD's intent for the final Tier 1 plan report to serve as supporting documentation for application by local government for 319(h) grant funding.

A total of 385 FC implementation plans have been completed. These include Tier 2 plans, inventories converted to plans, delisted plans, partially supporting Tier 3 plans and others. A total of 313 Tier 2 plans have been completed.

EPD is now placing emphasis on improving water quality instead of expending time and resources to finish implementation plans within short time periods. According to EPD, local responsibilities include:

- implementing non-point activities for MS4 Phase I and II permits;
- funding local activities, including adequate funding of the wastewater treatment infrastructure;
- working with the RDCs and encouraging citizen involvement;
- raising public awareness.

EPD's goal is to tie 319(h) Non-Point Source grants together with the TMDL process. A common complaint is that the 319 grant awarding process is too long and documentation requirements for spending funds of awarded grants are too onerous. In response, EPD says the grants must be detailed due to the federal requirements and the risk of being audited. These grants require a 40% local matching funds. The funding provided to develop one TMDL implementation plan is approximately \$4,500. EPD advises grant applicants to:

- ensure that all parts of government are working together;
- provide examples of how municipalities do things right to demonstrate the economic benefits (i.e., real estate values);
- understand that funding is dependent upon an annual budget, which may be problematic in times of tight budget and different priorities at the federal, state, and local levels;
- emphasize the economic impact of water quality (e.g., 1 million Georgians fish an average of 14 days per year which can equal \$500 million in direct funds).

EPD is partnering with other agencies to leaverage resources for TMDL implementation involving agricultural and forestry operations. Contracts have been awarded to:

- the USDA-NRCS to undertake two watershed assessments, the Upper Alapaha and Withlacoochee Watersheds in the Suwanee River Watershed, in order to acquire USDA EQIP funds (up to \$5 million per watershed) for farmspecific agricultural BMPs;
- the Georgia Department of Agriculture to inspect confined animal feeding operations (CAFOs) and associated land application activities related to CAFO byproducts such as poultry litter;
- the Soil and Water Conservation Commission to train construction site managers and equipment operators in erosion and sedimentation control;
- the Georgia Forestry Commission to

train foresters and harvesters in timber harvest BMPs and certification of "Green" timber harvest operations;

• the Georgia Forestry Commission to conduct spot audits of timber harvest operations, with particular emphasis on those operations in watersheds of sediment or related biota impaired waters.

EPD is also initiating work with poultry integrators such as Gold-Kist and Sanderson Farms to develop BMPs for their growers.

### **Barriers to Implementation**

Although designated water uses, water quality standards, and TMDLs for impaired waterbodies have been developed for Georgia's waters at the federal and state levels, much of the responsibility for TMDL implementation planning and actual onthe-ground implementation actions falls on the shoulders of Georgia's local governments. This responsibility, although not new (having been in existence since the passage of the Clean Water Act in 1972), has recently risen in priority as a result of litigation. Since TMDL implementation has not comprised a significant portion of local government budgets in the past, funding can be a tremendous obstacle to implementation at the local level. Although limited funding is available through a variety of federal and state programs such as Clean Water Act Section 319(h) funds and Georgia Environmental Facilities Authority low interest loan programs, lack of funding continues to be an obstacle. The TAG repeatedly heard the

complaint that little watershed-specific guidance is provided by the implementation plans on how to improve water quality. This complaint appears to be warranted because many of the implementation plans point to reliance on regulations, local ordinances, and programs already in place to comprise the bulk of the implementation strategy. Although many TMDL implementation plans call for increased infrastructure inspection and maintenance that may lead to identify infrastructure failures and needed repairs, these activities are ones that would have been conducted anyway. If existing measures were adequate to achieve water quality improvement, the affected waterbodies should meet water quality standards. Where new additional action is recommended, the recommendations are often described in general terms without specifying locations to target or quantifying their application. For example, the Revised TMDL Implementation Plan for the Oconee River and Cedar Creek calls for the "implementation of BMPs specific to the identified sources, including septic tank maintenance and sewer leak detection." The implementation plans sometimes go as far as to specifically state that action should not be required until additional monitoring has been conducted. For example, the Revised TMDL Implementation Plan for the Oconee River and Cedar Creek recommends that "the extent of the contribution from specific sources be identified before remedial action is advised." In fact, one of the most difficult issues for local officials is determining the sources of pollution and little guidance is provided in the

implementation plans on how to do this.

EPD has expressed strong disagreement with the suggestion that there is often little guidance provided by the implementation plans in recommended approaches to improving water quality. EPD points to the evolution of guidance for developing implementation plans that has been dispensed annually to its contractors responsible for constructing the implementation plans. EPD states that the guidance for and preparation of fiscal year 2005 implementation plans will substantially exceed past expectations for implementation plans, despite numerous constraints. However, EPD cautions that continued progress towards quantitative evaluation of the efficacy of management measures in achieving necessary load reductions will be contingent on overcoming several additional practical constraints. EPD has also instituted the recommended adaptive management approach to TMDL implementation by instituting a periodic review of plan implementation and subsequent revision of plans, as necessary.

In many cases, there also appears to be a lack of available technical assistance or, at least, a disconnect between technical knowledge and local agencies charged with TMDL implementation. Most water quality violations requiring TMDL implementation are the cumulative result of pollutant contributions from non-point sources and sometimes point sources. The Georgia EPD has a staff dedicated to TMDL outreach and the TAG has heard how helpful this arm of the agency has been in providing technical assistance regarding TMDL implementation. However, many local governments seem to be unaware such assistance is available and have searched elsewhere in frustration. There seems to be a need for outreach and technical training programs to make end-users aware of technical resources.

Identification of potential pollution sources can be time-consuming and expensive, requiring a combination of high-tech remote sensing and mapping methods and on-the-ground field inspection. Many of Georgia's water quality impairments are cumulative effects of widely dispersed non-point sources. By their nature, non-point sources can be difficult to pinpoint and quantify. Even when specific sources can be identified, local authorities may have limited regulatory power to force remedial action. For example, in the case of failing on-site sewage management systems, existing state legislation confers regulatory authority over on-site sewage management systems to local health departments except in the case of nonmechanical residential sewage management systems, which is the most common type of on-site system (O.C.G.A. § 31-3-5(b)(6)).

The following subsections outline the general approaches to TMDL implementation being taken in different regions of the state as reported to the TAG.

# Bacteria TMDL Implementation

### Upper Altamaha River Watershed, Initiative for Watershed Excellence

In an effort to address the needs of watershed-based stakeholder groups and local governments for cost-effective technical assistance, the River Basin Center at the University of Georgia has initiated a targeted outreach effort focused on stakeholders in the Upper Altamaha River Watershed. This project, The Initiative for Watershed Excellence (IWE), Upper Altamaha Pilot Project, is possible through support from EPD and EPA. The Upper Altamaha River Watershed is defined as the drainage area above the confluence of the Oconee and Ocmulgee Rivers. This outreach effort links technical resources available through academic institutions and government agencies to local governments and watershed groups throughout the watershed organized around common needs within subbasins of impaired waterbodies to accomplish TMDL implementation. The project pilots the concept of Watershed Management Support Institutes covering specific geographic areas designed to provide technical, organizational, and legal assistance to stakeholder groups in order to increase their capacity to enhance and protect water quality. The IWE has the following objectives related to water quality and TMDL implementation:

- to provide residents with information on the quality of the natural resources of their community and possible stresses that may lead to their degradation;
- to aid communities in developing and implementing local solutions once

they have determined the problems that threaten their economic and/or environmental sustainability;

- to provide training and technical assistance to local and regional government officials and staff, nongovernmental organizations, business interests and other stakeholders on topics of watershed concern; and
- to draw upon other local, state, and federal resources and expertise to avoid duplication of efforts and maximize effective investment in the watershed.

The IWE is more than a UGA outreach effort. Key academic institutions within the watershed including Georgia College and State University, Georgia State College, Mercer University, and others will work in collaboration with UGA to involve graduate and undergraduate students working closely with staff to meet the needs of local watershed stakeholders. This collaboration will be accomplished through service learning classes, where students receive academic credit for real watershed protection projects. This approach provides a cost-efficient method of providing outreach and provides students invaluable applied interdisciplinary experience that will make them more effective environmental professionals upon graduation. Linking with other colleges and universities throughout the watershed will draw on existing water resource protection expertise and increase the capacity of the local institutions to work within their communities to enhance local water quality. Many of these institutions already have strong stakeholder

partnerships throughout the watershed and these partnerships will save time, money and effort in identifying key stakeholders, project challenges, and opportunities, as well as making contacts and building relationships.

In addition to partnering with other academic institutions, collaboration with the UGA Cooperative Extension Service (CES) has led to the creation of

a watershed agent position. The watershed agent has been hired to work within the current CES framework to provide watershed management educational programming in the tencounty Upper Oconee watershed (Barrow, Clarke, Greene, Hall, Jackson, Morgan, Oconee, Oglethorpe, Putnam. and Walton counties). The overall objective is to develop educational initiatives that reflect local needs and bring watershed stakeholders together to find collaborative

solutions for water resource protection and restoration. As part of a concerted effort to develop mechanisms for local governments to address challenges associated with TMDL implementation, this individual will serve as a link to the IWE and provide local government access to IWE resources and programs. If successful, this position may be replicated throughout the state for service in other areas where CES is currently working, and may bolster the ability of CES to address water quality challenges on a watershed scale, in addition to that of the existing county/ district scale.

The IWE is currently in its first of three funded years. The UGA River Basin Center staff developed a stakeholder survey to determine the specific needs of each community throughout the Upper Altamaha's 52 counties and numerous cities. The team then tailors the outreach to each community rather than taking a standardized 'cookiecutter' approach, addressing needs as identified by local community leaders.



This unnamed tributary to the Middle Oconee River and surrounding forest in Athens, GA, provides an example of a common Piedmont stream.

### **Piedmont Approach**

The Northeast Georgia RDC has taken an approach to TMDL implementation that attempts to narrow the identification of potential sources of non-point source water pollution down to specific activities occurring at specific locations in the watershed of an impaired water body through a combination of targeted (they use the term "strategic") sampling under baseflow conditions and watershed based land use assessment. The procedure for identifying such activities begins with identifying the upper reach of water quality impairment, then collecting water samples and analyzing the sample for fecal bacteria. Moving upstream and sampling at strategic, yet convenient, points such as road crossings and points where tributaries enter the stream yields a water quality profile for the fecal contamination that should indicate where numbers begin to increase. These increases indicate a bacterial source upstream of that sampling point but downstream of samples that showed lower numbers. The land use in the contributing drainage area can then be examined either from recent aerial photography or by ground reconnaissance to identify specific sites with potential contributing land use practices.

Key features of this targeted sampling approach include low cost sample collection and analysis methods. By sampling at road crossings, assuming there are enough road crossings to make this practical, the high personnel costs of accessing different reaches of the stream network on foot, by boat, or other means is reduced. Targeted sampling to identify hot spots is a screening procedure, a coarse filter, for further investigation and not a data collection tool to support regulatory action. Thus, the water quality sampling and analysis methods need not be the same as that required in an approved protocol for evaluating water quality for regulatory compliance but can be a lower cost, less time consuming method. The Northeast Georgia RDC uses the commercial most probable number (MPN) method (IDEXX Laboratories, Westbrook, ME). Water sample analysis results obtained

using this approach are helpful in characterizing water quality conditions to inform management decisions. However, they cannot be used to change designations under sections 303(d) and 305(b) of the Clean Water Act unless the organization taking and analyzing the samples has been approved by EPD for this purpose (see the section on Listing and Delisting Streams starting on page 14). This fact may help ease concerns of landowners who are reluctant to grant access for fear of regulatory action since sampling results cannot trigger regulatory action. The test kits are relatively inexpensive, faster to use, and require less technical expertise and laboratory equipment than other methods. Alternatively, most municipal wastewater treatment facilities have labs that routinely run FC or E. coli tests using membrane filtration.

Another example of targeted sampling is the investigation undertaken on Potato Creek between Griffin and Thomaston, GA (Hartel et al., 2006b). All major and most minor tributaries of Potato Creek above Thomaston were sampled for E. coli. Fluorometry, Enterococcus speciation, and detection of the enterococcal surface protein gene found in Enterococcus faecium were the methods used to distinguish human from nonhuman sources of contamination. Sources of E. coli identified through this investigation were wildlife, cattle, pets, and a leaking sewer line. Appropriate recommendations were made to the EPD regarding bacterial sampling and to the McIntosh Trail RDC regarding specific actions that should be taken to address the identified sources. The

recommendations regarding bacterial sampling have been covered in the section of this report on Bacterial Source Tracking (page 41). The recommendations on specific remedial actions included repairing the broken sewer line, encouraging residential pet waste clean up while discouraging the dumping of pet waste into waterways, and encouraging appropriate agricultural BMPs to keep cattle out of riparian areas and waterways.

### South-Central Coastal Plain Approach

The approach taken on the south Georgia Coastal Plain in the area under the South Georgia RDC has been focused on public education and outreach efforts. The RDC has hosted public events and participated in events hosted by others focused on water quality education. The RDC has been successful in involving and obtaining support of local governments in their region for outreach efforts including storm-drain stenciling events, stream clean-up events, and distributing informational materials explaining water quality issues through utility bill inserts and door hangers. Due to the intimate, rural character of the area, good media coverage of events and water quality issues can carry a high profile. A greater understanding of human effects on natural systems is needed in the broader public for those issues to become important to the community. Efforts such as those being undertaken by the South Georgia RDC and its partners seem to be reaching a significant portion of the local population and raising awareness among the community.



The Georgia mountains are characterized by forested uplands and agricultural valleys such as this valley in Union County.

#### Northwest Georgia Approach

In northwestern Georgia, the Coosa Valley RDC encountered significant public resistance during the process of developing implementation plans for seven impaired streams in its region. Much of this resistance seemed to stem from a perceived weak justification for the listing of some streams from an early (1996) single SM water quality point. Many participants in the implementation plan development process advocated voluntary implementation measures and a process of working informally with landowners along impaired waterways. At the time of the TAG discussion of implementation in the this region, the planned implementation approach consisted of developing a sampling and quality assurance plan (SQAP) to pinpoint pollution sources to be addressed as appropriate and developing an online database to track changes to implementation plans and retain sampling results.

## **Georgia Mountains Approach**

Major issues of concern in the context of TMDL implementation in the north Georgia mountains are potential water impairments resulting from septic systems; sediment from forestry activities, construction and roads; agricultural practices; and recreational activities such as gold dredging, hunting and fishing, swimming, and river tubing. Ideas discussed with the TAG included working with existing USDA, NRCS and Georgia Department of Agriculture programs to improve agricultural practices on a farm-by-farm basis and possibly working with poultry integrators to advocate participation in these programs as well as encouraging voluntary improvements outside of such assistance programs.

### Atlanta Metropolitan Area Approach

In the ten-county Atlanta Metropolitan Area, the approach to developing TMDL implementation plans has been one of verifying and updating the information found in the TMDL documents, educating stakeholders, and working with local governments to enact local ordinances regulating potential sources of pollution. The Atlanta Regional Commission (ARC) has been integral in coordinating this process.

The first step ARC staff takes in developing TMDL implementation plans is verifying the information found in the TMDL documents developed by EPD. ARC staff have found errors in the landuse/landcover descriptions for stream segment watersheds in the TMDLs. As a result, they always delineate the stream segment watersheds before proceeding with the development of the implementation plans. ARC staff believe the most important steps in the TMDL implementation plan are involving stakeholders and identifying potential pollutant sources. However without correctly identifying (delineating) the watershed affecting the particular listed waterbody, ARC can not effectively conduct these steps.

Local ordinances are encouraged and included in the TMDL implementation plans which cover issues of stormwater control, illicit discharge detection, water quantity and quality control of construction site runoff, grease trap inspections, septic installation and repairs. Septic-to-sewer transition programs and/or a prohibition on septic tank installations is also encouraged and have been included in TMDL implementation plans. Successes experienced so far in this region include local government coordination and cooperation and reaching stakeholder groups with water quality educational messages. Some frustrations include building interest among the community and attracting attendees to public meetings and getting local businesses involved.

## Georgia Coast and Eastern Coastal Plain Approach

There are many physical and social characteristics of the Georgia coast which complicate efforts to implement TMDLs in that region. Most tidal streams, estuaries, and waterbodies along the immediate coast can are fairly



Clean coastal waters are important for a variety of organisms from fish and shellfish to the birds that rely on them as a food source.

accessible by boat from one of the many public boat ramps and marinas in the region, and these coastal waterways have been the targets of several monitoring and research efforts by UGA's Dr. Peter Hartel. Marine Extension Service, and others. However, access to waterbodies further inland can be highly restricted due to thick vegetation and swampy conditions. Reliance on volunteer labor can be hampered by a lack of public enthusiasm for working in an area perceived as containing many natural hazards such as alligators and poisonous snakes. This perception makes monitoring more difficult and expensive as it often becomes impractical to rely on Adopt-A-Stream programs or other volunteers. Surface water on the coast does not always flow in a unidirectional fashion but may sit in stagnant pools, flow in interconnected and braided channels at very low velocity or fluctuate in direction under tidal influence. These flow problems complicate predicting pollutant transport and establishing monitoring regimes. Local governments in this region are often limited in resources due to small tax bases, minimal staff, and few local regulatory controls.

### Southwest Georgia Approach

It was difficult for the TAG to assess TMDL implementation in southwest Georgia. The local governments and the regional development center solicited for participation in the TMDL TAG had not been heavily involved in the development of the TMDLs or associated implementation plans for waters in their region. Their knowledge of TMDLs and their implementation responsibilities was more limited than in other parts of the state and it seems that implementation efforts have yet to come to this part of the state. Local scientific experts communicated to the TAG that many of the water quality issues in this part of the state are related to agriculture and groundwater influences. Local governments and communities in southwest Georgia



Upper Tired Creek, Grady County, GA.

would likely benefit from focused technical assistance and outreach efforts.

### Implementation Conclusions

From the TAG's discussion of TMDL implementation approaches, the best approach appears to be a two-pronged approach: one involving targeted sampling to identify quantifiable sources and the other involving broader policy changes and public education programs addressing land use activities present in a watershed that are generally known as a non-point sources of pollution. The first is more reactive and better suited to identifying existing hotspots and infrastructure failures. The second is more proactive, providing a way to reduce cumulative impacts of non-point source contributions throughout a basin. The reactive approach is to go out and look for all the current problems attacking the largest ones first and working down to the small ones. This is the intensive sampling and monitoring approach. It eliminates identifiable sources. It is a good approach for identifying sources such as leaking sewer lines, failing septic systems, cattle in the stream, NPDES permit violations, failing sewage lift stations, and other point sources of pollution.

Non-point sources are by definition, a cumulative effect of diffuse sources scattered across the basin. An effective way to address cumulative effects is to take a comprehensive basin-wide approach to managing the present land use activities that current research has shown generally contribute to these effects. Most of Georgia's water quality impairments are due to nonpoint sources so as much, if not more, focus should be placed on these sources as is placed on point sources. Many of the point sources should be dealt with by programs already in place, such as NPDES permitting and enforcement. and local infrastructure inspection and maintenance. More focus on point

sources is needed but additional monitoring alone is not implementation. The data will never be perfect or complete. At some point, a decision must be made that the contributing factors to poor water quality are known with enough certainty to start controlling them to the extent that is practical. The best approach is a combination of the two approaches, but so far there has been little focus on additional sampling and monitoring and even less focus on better site design standards, better land use controls, better inspection and maintenance programs, and better enforcement of existing regulations. Many of the existing TMDL plans call for more monitoring before implementation can occur, but then name all the existing plans and policies that will eliminate or remedy the problem. If more monitoring is needed to further define the nature of the problem before implementing any remedial action, what evidence is there that the existing plans and policies will fix the problem? Many current implementation plans rely on existing knowledge of activities that contribute to the types of water quality problems observed and readily point to existing mechanisms for addressing the problem. The reality is that if these programs were adequate, there would not be a water quality problem in many of these cases given that existing programs have been in place for many years. If there is enough existing knowledge about water quality problems to claim that existing programs will fix these problems, then there should be enough existing knowledge to look for other approaches and additional actions that can be taken.

Our discussions have helped identify a number of research issues that are important to the development and implementation of bacterial TMDLs in Georgia. These are listed below.

- Most bacterial implementation plans developed so far do not identify or quantify specific sources of bacteria beyond suggesting broad categories, especially with non-point sources. Local governments tasked with implementing these TMDLs do not, in many cases, have the funding and technical expertise necessary to identify and quantify specific sources, either. The state should fund studies on a number of regional mixed use watersheds of an intermediate size that are thought to be typical of local land use and geology. These studies would use BST, intensive monitoring, and watershed-scale modeling of the watersheds to identify and quantify sources of bacteria. The results from these studies could then be used to guide bacteria TMDL implementation in other similar watersheds.
- More research is needed to determine the reference stream background ("natural") number for fecal bacteria in Georgia. These numbers need to be compared to values used for freshwater *E. coli* standards from other states. It is possible that *E. coli* standards should be higher than other states due to warmer temperatures and higher wildlife numbers.
- Additional studies are needed to bridge the gap between the few studies relating human fecal contamination and human illness and the probably differing relationship of wildlife and domestic livestock fecal

contamination and human illness.

- The potential bias toward higher readings with the IDEXX method compared to the traditional membrane filtration method of measuring *E. coli* should be further investigated.
- The relationship between bacterial concentrations and stream size should be investigated.
- The impact of stream impoundments (ponds and lakes) on indicator and pathogenic bacteria should be investigated.
- Fecal enterococci have regrowth potential in coastal subtropical environments and thus indicate that they may fail as an indicator to bacterial TMDLs in the southeast. More research must be done in marine and freshwater systems on the coast to determine if this is a factor.
- A study needs to be done to see what effect a 24-hour vs. 6-hour hold time for stream samples has on *E. coli* bacterial concentrations.
- Further research on detection methods for identifying failing septic systems is needed. Fluorometry may be one such method.



An example of membrane filtration.

# Recommendations

The authors make the following recommendations to improve establishment and implementation of bacterial TMDLs in Georgia.

### **Recommendation 1:**

Georgia should follow the recommendations from EPA to adopt new bacterial standards for freshwaters (using *E. coli*) and marine waters (using fecal enterococci).

### **Recommendation 2:**

Georgia should divide the current list of recreational fresh waters into primary and secondary contact waters with different standards. Primary contact recreational waters should be high-use recreational waters such as beaches and parks and the most stringent standard should be applied to these waters (risk of 8 illnesses per thousand swimmers and an *E. coli* standard of 126 cfu/100 ml for fresh waters). This should also be done for marine waters, but the TAG does not have a recommendation on what numbers of fecal enterococci should be used for the standard.

### **Recommendation 3:**

An *E. coli* standard associated with 12 illnesses per thousand swimmers (336 cfu/100 ml) or 14 illnesses per thousand swimmers (548 cfu/100 ml) should be used for secondary contact waters as background concentrations are unlikely to exceed these standards. Recreational marine waters should also be divided into primary and secondary contact, but the TAG does not have a recommendation on what numbers of fecal enterococci should be used for the standard.

### **Recommendation 4:**

Further studies should be done to determine if there is a bias toward higher numbers of *E. coli* with the IDEXX method than for traditional methods.

### **Recommendation 5:**

The provision for a less stringent standard when nonhuman sources of bacteria are present should be dropped to conform with the new recommendations from EPA. In waters where wildlife may be the source of contamination, the state should file for classification of the waters as "Wildlife Impacted Recreation," but this designation will require site-specific supporting data.

### **Recommendation 6:**

The current method used to calculate TMDLs, based largely on monitoring results, is reasonable. More intensive analysis using watershed models should be considered where a TMDL is being developed for several pollutants in an extensive area (such as a lake watershed) where the consequences of the TMDL will have a large economic impact.

### **Recommendation 7:**

Library-based methods of bacterial source tracking are likely to be too expensive for identifying bacteria sources in most watersheds. In most cases, targeted sampling, as a prelude to bacterial source tracking, is the least expensive and the most promising method for determining bacterial sources.

### **Recommendation 8:**

The assumptions (made in calculating TMDLs) that the new MS4 systems will capture 70% of storm water runoff and contain bacterial concentrations that meet the state standard should be tested by studies that measure of MS4 discharge volumes and bacterial concentrations.

### **Recommendation 9:**

The two most common questions local stakeholders ask about TMDLs are where the samples were taken and where are the data. It would assist attempts to involve stakeholders if this information was included in the TMDL documents. TMDL documents should include a table that clearly identifies the sampling location and sample data that were used to list a particular waterbody. While there is some data included in the current TMDL documents it is not clear which stream segment it is associated with.

### **Recommendation 10:**

TMDL documents should include landuse category definitions or descriptions of how the landuse categories were developed.

#### **Recommendation 11:**

Overall, the TMDL implementation process needs to be improved. RDCs and local governments generally have insufficient resources to identify sources and develop an implementation plan that will achieve the large reductions called for in bacterial TMDLs.

### **Recommendation 12:**

More technical assistance and outreach on TMDL implementation strategies are needed, as well as better coordination among entities working in this arena to serve the local jurisdictions charged with implementation. Perhaps a single point of contact can be established and a campaign launched to raise awareness of available resources and make requesting assistance easier. Watershed-based extension personnel may play a key role in linking local jurisdictions to needed technical and funding resources.

#### **Recommendation 13:**

State legislation (O.C.G.A. § 31-3-5(b)(6)) should be changed to provide local health departments that currently hold permitting authority for nonmechanical residential sewage management systems with enforcement authority to perform inspections and require repairs and maintenance on these systems as necessary to prevent significant pollution contributions from these sources. Adequate resources and funding mechanisms should also be made available to health departments to enable them to exercise this authority.

### **Recommendation 14:**

More funding sources should be identified to conduct studies on a number of regional, mixed-use watersheds typical of local land use and geology. These studies should use bacterial source tracking, intensive monitoring, and watershed-scale modeling of the watersheds to identify and quantify sources of bacteria. The monitoring should also assess water quality improvement during the implementation phase. The results from these studies could then guide bacterial TMDL implementation in other similar watersheds where such intensive methods are too expensive.

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