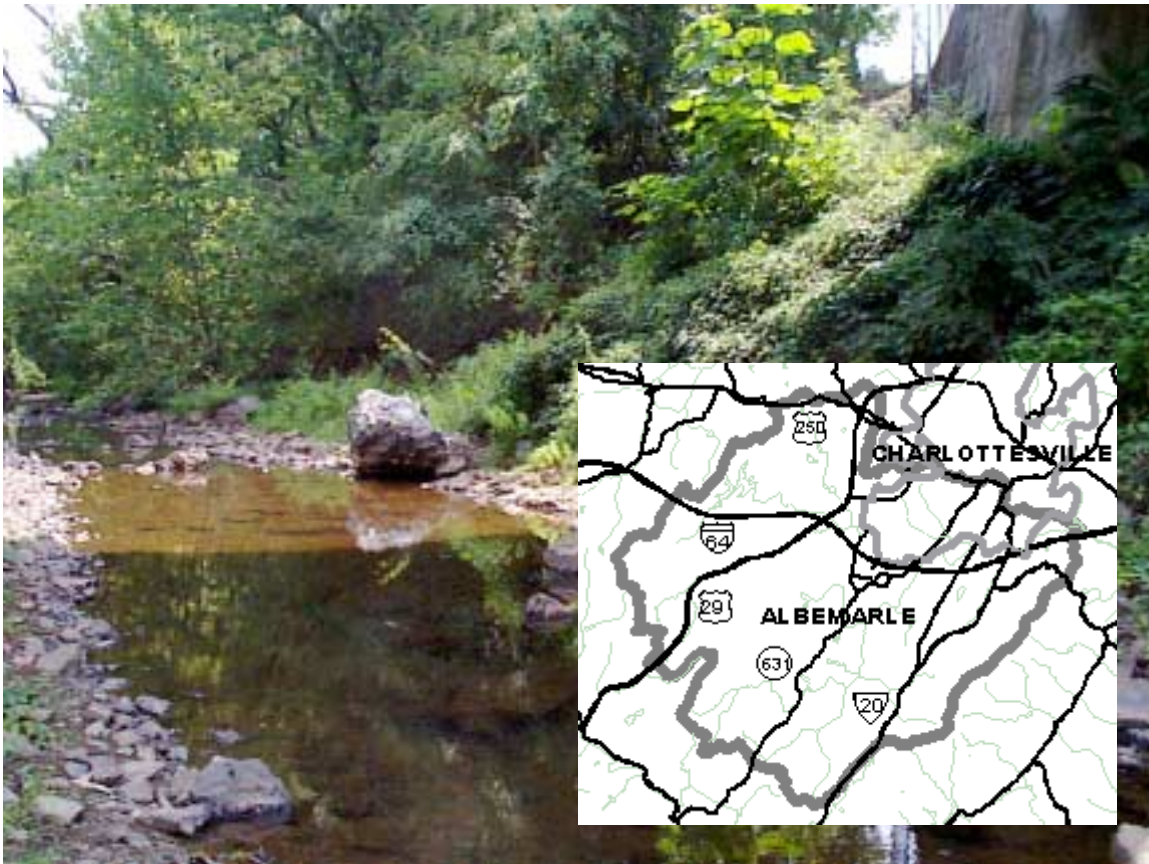


The Fecal Coliform Problem in Moore's Creek Watershed: Understanding the Sources, Finding the Solutions

A Clean Water Act Section 604(b) project submitted to the
Virginia Department of Environmental Quality by the
Thomas Jefferson Planning District Commission
in conjunction with
James Madison University and the United States Geological Survey

June 2002



The Rivanna River Basin, which covers 766 square miles of farm, forest, city and suburb in the heart of Central Virginia, contains three segments of river or creek which appear on the 1998 303(d) Total Maximum Daily Load Priority List for fecal coliform contamination (as well as two others that violate the general standard for benthic macroinvertebrates). Of the three segments listed for fecal coliforms, the one with the smallest watershed, 35 mi², is that of Moore's Creek (which has 6.37 miles that are listed as impaired, from the intersection of Rts. 29 and 1106 to the confluence with the Rivanna River). In spite of its size, it is a diverse watershed which reflects the diversity of the Rivanna Basin. It includes a wide range of land cover, from forested to rural to urban, covering part of Albemarle County and the City of Charlottesville. Figure 1 shows the land cover for the Moore's Creek watershed (as developed by the TJPDC for the Moore's Creek TMDL). The upstream portions of the watershed are primarily forested, with some

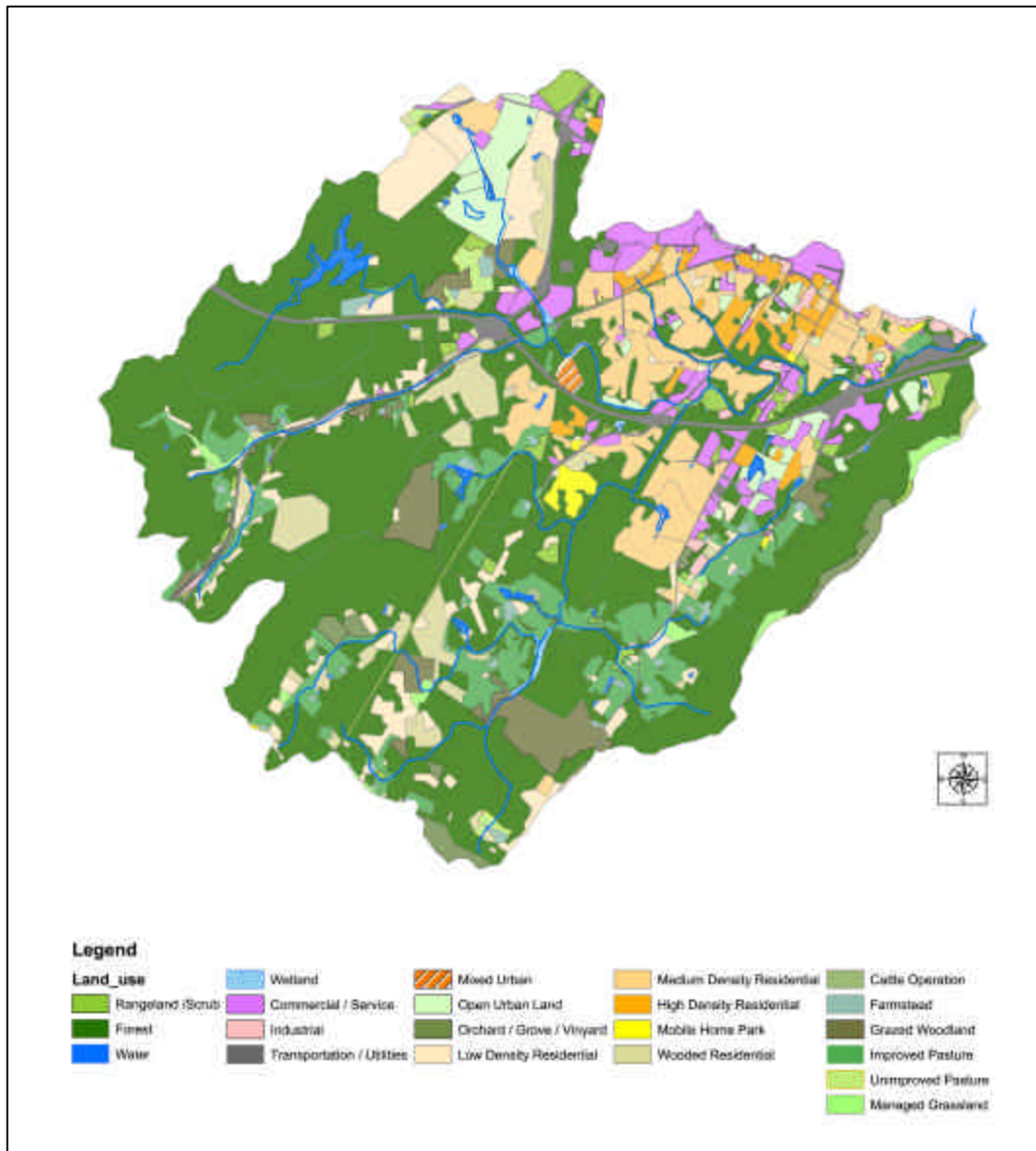


Figure 1: Land Cover for Moore's Creek Watershed.

pasture and residential. Downstream portions are largely urban but include a stockyard and a popular park for walking dogs. The Ragged Mountain reservoir, a source of the area's drinking water, is located in the creek's headwaters, and the Rivanna Water and Sewer Authority's Moore's Creek Wastewater Treatment Plant is located near its mouth. A small, privately operated wastewater treatment plant at the Southwood Mobile Home Park is also located in the watershed. The varied nature of the Moore's Creek watershed made it an excellent candidate for a bacterial source tracking study, as no single source seemed obviously preeminent. Potential sources of fecal coliform in the watershed included wildlife, failing septic systems, leaking sewer pipes, pets, and livestock, and it was felt that further information was needed to help determine the most important sources. Further, its status as a microcosm of the Rivanna watershed made it seem a good place to begin TMDL work in the basin.

For those reasons, the Thomas Jefferson Planning District Commission applied for and received funding from the U.S. Environmental Protection Agency Clean Water Act Section 604(b) program, administered through the Virginia Department of Environmental Quality. The project began in January 2000. Its primary purpose was to lay the groundwork to do a fecal coliform TMDL for Moore's Creek (which was successfully completed in May 2002 in partnership with Dr. Teresa Culver of the University of Virginia), and to that end four tasks were laid out:

1. Perform preliminary sampling to determine the most impaired segments.
2. Identify sources of fecal coliforms through genetic fingerprinting techniques.
3. Use educational tools to increase public awareness of the problem.
4. Work with stakeholders, through the Rivanna River Basin Roundtable, to determine the feasible plans of action for the reduction of fecal coliform pollution.

Task 1: Perform preliminary sampling to determine the most impaired segments.

Eight sampling sites were chosen based on watershed coverage and accessibility. The sites are shown in Figure 2 (the relationship of which relative to the watershed is shown in Fig. 3) and were named as follows:

Moore's Creek @ Goodwin Farm Rd. (farthest upstream site)
"Ragged Mountain Creek" (actual creek name unknown)
Morey Creek @ Fontaine Research Park
Moore's Creek @ Azalea Park
Rock Creek near Fifth St. Ext.
Cow Branch near Monticello Visitor's Ctr.
Biscuit Run @ Foxcroft
Moore's Creek @ RWSA bridge (farthest downstream site)

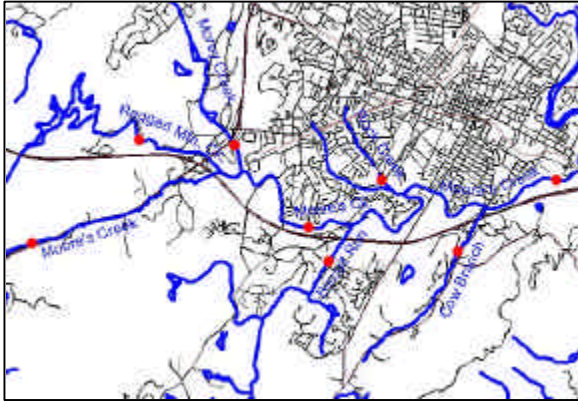


Figure 2: Preliminary sampling sites.

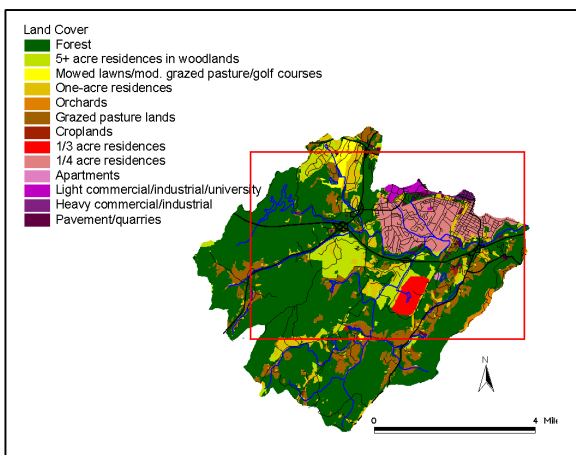


Figure 3: Approximate area of preliminary sampling site map. Land cover shown is from a map developed for the Rivanna River Basin Project by the VA DMME Division of Mineral Resources.

Samples were taken upon three occasions, focusing on storm flow because the work of the Rivanna River Basin Project (*State of the Basin: 1998*) found that fecal coliform concentrations throughout the Rivanna watershed were many times higher during storm flow than during base flow. Samples were taken two days after a major storm, during a storm, and immediately after a storm. Fecal coliform counts were done by the Rivanna Water and Sewer Authority using the membrane filtration method. The results obtained are shown in Table 1 on the following page.

Table 1: Preliminary sampling results.

	Two days after storm	During storm	Immediately after storm
	(all in cells/100 mL)		
Moore's Creek @ Goodwin Farm Rd.	360	5700	6000
Ragged Mtn. Creek	191	270	360
Morey Creek @ Fontaine Research Park	100	430	2900
Moore's Creek @ Azalea Park	290	4900	4800
Rock Creek near Fifth St. Ext.	380	28000	3700
Cow Branch near Monticello Visitor's Ctr.	350	5700	13000 (est.)
Biscuit Run @ Foxcroft	280	6000	2600
Moore's Creek @ RWSA bridge	280	22000	7818 (est.)

With the exception of Ragged Mountain Creek, all sites exceeded the 1000 cell/100 mL Virginia instantaneous water quality standard for secondary contact at least once. It also appears that fecal coliform concentrations drop relatively quickly after a storm; although two days after the storm, flows still appeared elevated relative to base flow, counts were all well under the 1000 cell/100 mL standard. These sites represent a great diversity of land cover. The most forested watershed is that of Ragged Mountain Creek, which may be reflected in its low coliform counts (it is also downstream of a pair of the Ragged Mountain drinking water reservoirs). The Goodwin Farm Road site has the most adjacent pasture land, although Biscuit Run and Cow Branch also have pasture land within their watersheds. Rock Creek is the most urbanized site and a concern had been raised that there could be contamination from a leaking sewer line, but Charlottesville Department of Public Works staff were unable to confirm that. All of the tributaries except Rock Creek have septic systems in their watersheds as well as sewer lines. Because the results showed that all sites except Ragged Mountain Creek exceeded the 1000 cell/100 mL standard, and these sites represented relatively good coverage of the watershed, the decision was made to continue using most of them for the next phase of the project, the bacterial source tracking study. The Ragged Mountain Creek site was discontinued (although samples were taken from one of the reservoirs as described in the next section), and the Goodwin Farm Road site was discontinued in favor of a site closer to the start of the section formally classified as impaired. Two other sites were added, for reasons described in the following section.

Task 2: Identify sources of fecal coliforms through genetic fingerprinting techniques.

Although the project proposal called for the use of genetic techniques, investigation of available techniques led to the conclusion that antibiotic resistance techniques have a similar success rate and are less expensive, therefore allowing for the identification of more isolates for the same amount of money. We submitted recent articles by Dr. Charles Hagedorn of Virginia Tech and Dr. Bruce Wiggins of James Madison University to Roger Stewart of DEQ, and he agreed that antibiotic resistance techniques would be

appropriate for this study. TJPDC accepted Dr. Wiggins' proposal to do the bacterial source tracking study, which commenced June 1, 2000 and ran through May 31, 2001.

As mentioned previously, for the source tracking study two sites were added to those used in the preliminary study, one was discontinued, and one was moved. A site near the mouth of the creek was added, to better correspond to the boundaries of the TMDL. Also added was a site at the Carleton Bridge Condos, which are just upstream of the livestock yard located on Moore's Creek, to better judge the effect of the stockyard (the existing site at the Moore's Creek Wastewater Treatment Plant is just downstream of the stockyard). The Goodwin Farm Road site was moved downstream to behind the Hickory Hill gas station, which was the closest accessible point to the start of the section classed as impaired. Although Ragged Mountain Creek was not sampled in this study, samples were taken at the lower reservoir in order to get upstream of all non-wildlife influences (the reservoir watershed is entirely forested, but the original site was downstream of some horse pasture and septic systems). Samples collected there were considered to be representative of a wildlife mixture (in other words, reservoir samples were being used as a "known" for wildlife). "Known" samples were also collected from beef cattle, dairy cattle, goats, horses, dogs, geese, a duck, an aquatic mammal, and the primary influent to the Rivanna Water and Sewer Authority's Moore's Creek Wastewater Treatment plant. "Unknown" samples from the creek and its tributaries were sampled eight times, five of those during storm events. The antibiotic resistance profiles of the unknown samples were compared to the known samples in various groupings. Overall, it was found that wild animal sources, including geese, were the major sources of fecal pollution in Moore's Creek, and were particularly dominant in the summer. Human pollution was also a significant contributor to fecal contamination, particularly in the winter. Contributions from dogs, cattle, and goats were also notable, however. Dr. Wiggins' full report is attached as Appendix A, and a map with charts that was created by TJPDC staff as an aid to interpretation of the study data is attached as Appendix B.

An additional aspect of Task 2 was the initiation of gaging on Moore's Creek at the bridge at RWSA's wastewater treatment plant (which serves as the VA DEQ sampling station and is also the site at which RWSA takes a weekly sample to test for background levels of fecal coliform). This was deemed critical to the modeling effort anticipated as part of the TMDL. It was additionally felt that it would be of assistance in understanding other pollutant problems in Moore's Creek, as found in the *Moore's Creek Watershed Study* (an EPA Section 319-funded study performed by Dewberry & Davis in 1996). The gaging of flow data was recommended in that report as part of its Stormwater Management Plan.

The original proposal called for instantaneous gaging, but budget constraints required that a staff gage be installed instead. This was performed by the U.S. Geological Survey in May 2000 and a rating table was established by them and delivered in March 2001. The rating table is attached as Appendix C. Issues regarding the limited extent of this rating table (covering stage heights from 1.36 feet to 3 feet) unfortunately were never resolved due to lack of staff availability at USGS. Gage readings were taken for six of the eight unknown sampling runs in the bacterial source tracking study. Gage readings were

commenced by RWSA when taking their sample for fecal coliforms on Wednesdays, volunteers were recruited to read the gage on other days, and Dr. Culver's students took some readings as well. In all, about 125 gage readings were made before the TMDL was complete. Although the brief period of record coupled with drought conditions during the course of the TMDL necessitated simulation methods to cover a full range of hydrologic conditions, the gage readings still played an important role in the calibration of the model.

Task 3: Use educational tools to increase public awareness of the problem.

A variety of tools were used to publicize the 303(d) listing, the source tracking study and the forthcoming TMDL. These included:

- Mailings to the Rivanna River Basin Roundtable mailing list (which included both members and friends of the Roundtable);
- E-mail updates to the Rivanna River Basin Roundtable and Natural History Roundtable e-mail lists;
- An article in the Thomas Jefferson Soil and Water Conservation District newsletter;
- A display at the Rivanna River Festival, attended by about 3,000 people;
- An article in the Belmont Neighborhood Association's *Belmont Bulletin* (circulation 2,000);
- Discussions with and distribution of information to an interested planning class at the University of Virginia;
- Posting of information, including quarterly reports, study results, and watershed maps, to the TJPDC website;
- A display at the Rivanna kiosk at Darden Towe Park in Albemarle County.

Interest in doing a story was expressed by both a reporter at WVIR-TV (Channel 29, Charlottesville) and a reporter from the C-Ville Weekly, but unfortunately, despite two interviews and a field trip with the C-Ville Weekly reporter, no story was ever produced or published.

Task 4: Work with stakeholders, through the Rivanna River Basin Roundtable, to determine the feasible plans of action for the reduction of fecal coliform pollution.

The Rivanna River Basin Roundtable had initially expressed great interest in the project, which was in keeping with their recommendations in *State of the Basin: 1998* to "determine the origin of the fecal coliform found in the waters of the basin" and "develop and implement TMDLs for the designated 303(d) listed streams and rivers in the basin to assure good water quality for people and aquatic life." As it turned out, however, the Roundtable's energy was dissipating as this project began, and the stakeholders' committee that was formed was separate from the Roundtable. Committee members were found through a combination of the publicity given the project and active recruitment. Ultimately 12 people were named to the committee by the TJPDC, including representatives from Albemarle County, the City of Charlottesville, the Rivanna Water and Sewer Authority, the Thomas Jefferson Soil and Water Conservation District, the Albemarle County Farm Bureau, the Southern Environmental Law Center, the Fry's Springs and Belmont Neighborhood Associations, and several other interested citizens.

Through the publicity efforts previously mentioned, some prospective members of the committee were attracted to the project early on. A watershed tour was conducted, and e-mail updates on the progress of the bacterial source tracking study were sent out periodically. However, recruitment efforts did not begin in earnest until the tracking study was nearing completion. Many committee members attended the first public meeting for the TMDL on June 7, 2001. The committee met formally for the first time on September 21, 2001. Ground rules were established, and the nature of the watershed, the results of the typing study, and topics for future meetings were discussed. An attempt to organize a tour of the watershed for those who had missed the first one failed, but several members toured the watershed individually using directions and maps provided. The second public meeting for the TMDL was held on November 15, 2001, and again many committee members were in attendance. They met again on November 27, 2001, to discuss the public meeting and to hear a presentation by Jim Palmborg of the City of Charlottesville on recent and planned work by the City on sewer lines within the watershed. Dr. Culver's forthcoming TMDL loading assumptions were anticipated eagerly by the committee, which agreed to meet again after they became available. In late January 2002, the committee received the loading assumptions. They met February 12, 2002 to discuss the assumptions, and two pages of comments were typed up by TJPDC staff, reviewed by the committee, and submitted to Dr. Culver. The draft TMDL was made available to the committee two weeks in advance of the final public meeting on March 25, 2002, which again had many committee members in attendance. Their final meeting was on March 26, 2002, to discuss their remaining concerns with Dr. Culver. A few more adjustments were made to the loading assumptions and submitted to the committee for a last review. The comments from that meeting were submitted to DEQ to be part of the public comment record.

Because the TMDL began before the bacterial source tracking study was even complete, the work of the committee was much more focused on the TMDL than had originally been envisioned in the project proposal. Also due to the close timing of the TMDL with the BST study, a separate public meeting, as had been envisioned in the proposal for this project, was never held. The three public meetings required for the TMDL were felt to be sufficient given the limited time frame in which to finish the project, and the BST study results were discussed by Dr. Culver at the second public meeting. However, the committee finished the project eager to take on the task of crafting an implementation plan for the Moore's Creek TMDL. The TJPDC intends to seek funding to enable them to do so.

References

Dewberry & Davis, 1996, *Moore's Creek Watershed Study*, Albemarle County and City of Charlottesville.

Rivanna River Basin Roundtable, 1998, *Rivanna River Basin Project – State of the Basin, 1998*, Thomas Jefferson Planning District Commission.

University of Virginia and Thomas Jefferson Planning District Commission, 2002, *Development of the Total Maximum Daily Load (TMDL) for Fecal Coliform Bacteria in Moore's Creek, Albemarle County, Virginia*. Submitted by the Virginia Department of Environmental Quality and Virginia Department of Conservation and Recreation.

APPENDIX A: BACTERIAL SOURCE TRACKING STUDY

Use of Antibiotic Resistance Analysis (ARA) to Identify Nonpoint Sources of Fecal Contamination in the Moores Creek Watershed

Final Report presented to the Thomas Jefferson Planning District Commission

Bruce A. Wiggins*

May 31, 2001

The antibiotic resistance analysis (ARA) method of determining the sources of fecal contamination in natural waterways was applied to the Moores Creek watershed. ARA involves isolation of indicator bacteria (enterococci) from different known fecal samples, as well as from unknown water samples. Source identification is accomplished by using the statistical method of discriminant analysis to classify each isolate extracted from water by comparing its antibiotic resistance patterns with the resistance patterns of isolates taken from known fecal samples. The potential sources of fecal contamination in Moores Creek that were tested were livestock (cattle, goats, horses), dogs, humans, and geese and other wild sources. Nine water samples were collected at stations along Moores Creek eight times during the past year. The samples were processed using ARA, and fecal coliform counts were measured to evaluate the quantity of fecal material in the water. The results indicate that wild animal sources, including geese, are the major sources of fecal pollution in Moores Creek, and that human pollution is also a significant contributor to fecal contamination.

Introduction

Fecal contamination in natural waterways can lead to several problems, including an increased incidence of pathogens (5). Additionally, the increased levels of phosphorous and nitrogen in natural waterways due to fecal pollution can lead to algal blooms that, when degraded, result in deoxygenation of waterways (1). This situation is currently leading to a deterioration of the aquatic environment in the Chesapeake Bay. Fecal contamination in waterways has consistently been demonstrated by the presence of indicator organisms such as fecal coliforms or enterococci (5). However, differentiation of the sources of fecal contamination in waters receiving mixed agricultural and human waste is more difficult. Knowledge of the source of fecal contamination is important because humans are more susceptible to infections by pathogens found in human feces (5). Once the source is identified, steps can be taken to control the influx of fecal pollution.

Several approaches have been developed for the source identification of fecal contamination. The ratio of fecal coliforms to fecal streptococci, and the presence of certain bacteriophages as source indicators have been used (7). Another method involves DNA “fingerprinting” of fecal coliforms using pulsed field gel electrophoresis (PFGE) analysis to differentiate between the variations in restriction fragments of bacteria that are found in the feces of different hosts (2). Ribotyping uses the slight differences in ribosomal RNA in *E. coli* isolated from the feces of different hosts to identify the source of fecal pollution (2).

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Antibiotic resistant bacteria can develop in animals and humans as a result of treatment with antibiotics. Several methods of source identification are based on differences in antibiotic resistance among bacteria from different sources. Krumperman developed multiple antibiotic resistance (MAR) indexing as a method of quantifying the frequency of occurrence of multiple antibiotic resistant *E. coli* in fecal material (4). He was able to demonstrate a difference in MAR indices of *E. coli* isolated from wild sources with those isolated from humans or poultry. Similarly, Kaspar et al. (3) were able to demonstrate a difference in MAR indices from rural and urban sources.

Our laboratory has developed antibiotic resistance analysis (ARA), which uses enterococci as an indicator organism in identification of sources of fecal contamination (7). Enterococci are a group of gram-positive, catalase-negative cocci that hydrolyze esculin, and are capable of growing at 6.5% NaCl and at 45°C. Enterococci are used because they survive well in natural waters and can be isolated from all potential sources of fecal pollution (7, 8). In this approach, enterococci are isolated from known fecal sources, and grown on plates containing various concentrations of 16 different antibiotics. The resulting antibiotic resistance patterns of each isolate are then analyzed using discriminant analysis, a multivariate statistical method. The results are pooled to form a "known library" of antibiotic resistance patterns from different fecal sources. Resistance patterns of isolates from natural waterways are then compared with this known library to determine the source(s) of fecal pollution in that waterway (7, 8).

In this report, ARA and fecal coliform counts were used to draw conclusions about the source(s) of fecal contamination in the Moores Creek watershed. Moores Creek is located in Albemarle County and the City of Charlottesville, Virginia, and is highly polluted with fecal matter. Moores Creek feeds the Rivanna River and flows eventually into the Chesapeake Bay. The possible sources of fecal contamination in the Moores Creek watershed have been identified as beef cattle, dogs, failing septic systems or sewer lines ("human"), goats, horses, and geese and other wild animals.

Eight sampling trips were taken during the course of 10 months during 2000-2001 in an effort to monitor the influx of fecal contamination found at each site, and to determine if any seasonal patterns were present.

Materials and Methods

Sample Collection:

Known fecal samples. Beef, dairy, and goat fecal samples were collected from grazing areas and from a stockyard located in the watershed (just upstream from Station #8). Horse fecal samples were collected from the polo grounds near Biscuit Run. No horses were present at the Holiday Trails Camp. Dog feces were obtained from the dog exercise area in Azalea Park (near Station #3). Geese droppings were obtained from ponds in the watershed. For these samples, material from at least three animals were mixed in each sample to increase representativeness. Human samples were taken from the primary influent to the Rivanna Water and Sewer Authority plant. One duck sample was collected from the stockyard, and one sample of aquatic mammal scat was collected from along the stream. Additionally, several water samples were collected from the Ragged Mountain Reservoir. The bacteria isolated from this pristine water were called "wild", as the reservoir receives no human or agricultural input. All known samples (except the reservoir samples, which were collected in sterile 2L bottles) were collected in sterile whirl-pack bags. The numbers and sources of the samples are shown in Table 1.

Stream samples. Nine sites were sampled along Moores Creek during each sampling event (Table 2 and Figure 1). Stream (unknown) samples were collected on 6/6/00, 6/19/00, 6/28/00, 7/11/00, 9/19/00, 2/2/01, 2/9/01, and 3/30/01. A major goal of this project was to collect samples during or right after storm events, to obtain samples that contained fecal material carried into the stream by the rain. The 6/6/00, 6/19/00, 6/28/00, 9/19/00, and 3/30/01 samples were collected during or immediately after a rain event.

A total of 72 stream samples were collected. Unknown samples were collected in sterile containers (using a bucket when necessary). The goal was to test 46 isolates from each sample, resulting in a precision of approximately 2%. Because of low counts, fewer isolates were analyzed for some samples. Some of the 2/2/01 samples had very low numbers of isolates, so a repeat trip was made on 2/9/01.

Isolation of enterococci:

Varying amounts of fecal samples (0.1 – 0.5 g) were suspended in 50 ml of saline buffer. The sample was mixed vigorously before filtering through 0.45- μ m pore-size filters. Varying volumes of unknown water samples were filtered using the same filters. The filters were placed in 50 mm petri dishes containing 5 ml of m-Enterococcus agar. The petri dishes were incubated at 37°C for 48 hours. After incubation, isolated colonies were selected (48 for unknown samples, and 12-24 for known samples) and transferred to 96-microwell plates containing 0.2 ml of Enterococcosel broth. The microwell plates were incubated at 37°C for 48 hours. Esculin-negative isolates were not analyzed.

Antibiotics:

Isolates from the 96-microwell plate were transferred to antibiotic-containing Trypticase Soy agar (TSA) plates using a sterile 48-prong replica-plater. Various concentrations of 16 antibiotics were used (51 concentrations total) (9). The isolates were also replica-plated to two TSA plates that did not contain antibiotics as a control. All TSA plates were incubated at 37°C for 48 hours. After incubation, the growth of each isolate on each concentration of each antibiotic was determined, and the resulting antibiotic resistance patterns were combined to form a library of known sources.

Statistical Analysis:

The results from resistance testing were entered into the SAS statistical program where they were analyzed using the DISCRIM procedure, which produces a classification table. The average rate of correct classification (ARCC) is the average rate that known isolates are correctly classified, and was used to measure the reliability of the known library. The Minimum Detectable Percentage (MDP) for each source type was determined by averaging the percentages of other source types that were misclassified as that type. This value is the minimum percentage for each particular source that can be detected in a stream sample.

Fecal Coliform Counts:

Fecal coliform (FC) counts were performed by filtering various volumes of all unknown stream samples (as described above). The filters were then placed in 50 ml petri-dishes containing 1.9 ml of

m-FC broth. The petri dishes were incubated in a water bath at 44.5°C for 18 – 24 hours. After incubation, the number of blue colonies were enumerated and recorded. In the tables, the values in the "average" rows are geometric means.

Stream Height Measurements

Stream height was determined by reading the gauge located at Station #8. No readings were taken for the first two sampling trips.

Results

Two-way Classification of Isolates: Human vs. Animal

To determine if the pollution in Moores Creek was from humans or animals, a library was created where all animal sources were pooled together. The average rate of correct classification (ARCC) of this library was 85%, which was well above the background level of 50%, and the Minimum Detectable Percentage (MDP) was 22% for animals and 7% for humans (Table 3).

Using this library, the 72 stream samples were classified. The results are shown in Tables 4 (listed by collection date) and 5 (listed by sample site). Both human and animal sources were identified in the stream. There was variation from station to station, and from day to day, but some clear trends are evident:

1. On average, all stations are polluted primarily by animals, although human pollution is present as well. The MDP for humans in this library is 7%. This means that if human pollution is present at more than 7%, it is unlikely to be a result of misclassification of the animal sources. All eight sampling days showed both human and animal sources present at average levels above the MDP.
2. On average, animal sources were dominant on all eight sampling days, and at all nine stations. The proportion of animal was above the MDP in 71 of 72 samples, and animal was the major source in 62 of 72 samples.
3. On average, human sources were not dominant on any sampling day, or at any station. However, the proportion of human was above the MDP in 42 of 72 samples that were processed, and human was the major source in 12 of 72 samples. On average, human fecal pollution was present at all locations except Station #2 (Morey Creek).
4. The amount of rain did not affect the proportion of animal vs human. All samples (both rain-event and non-rain-event) were dominated by animal (except the 2/2/01 sample, which may be anomalous because of the difficulty in finding enough isolates to test).

Four-way Classification of Isolates: Dog vs Human vs. Livestock vs. Wild

To determine which animal sources are contributing to the pollution in Moores Creek, a four-way library was created. For this library, the beef, dairy, goat, and horse isolates were pooled as

livestock, and the duck, goose and "wild" isolates were pooled as wild. The ARCC of this library was 72%, which was well above the background level of 25% (Table 6). The MDPs for livestock and wild were the highest (11%), and the other two were below 10%.

Using this library, the stream samples were classified. The results are shown in Tables 7 (listed by collection date) and 8 (listed by sample site). All four source types were found in Moores Creek. Again, there was variation from station to station and from day to day, and again, some clear trends are evident:

1. On average, wild sources were identified as the major source on all eight days and at all nine sites. In 69 of the 72 samples, the proportion of wild was above the MDP, and wild was the dominant source in 47 of those samples.

2. Wild sources were much more dominant during the summer and fall samples. Of the 45 samples taken during the summer and fall, only 6 samples did not have wild as the major source. In the winter and spring samples, there was no single dominant source (wild was dominant in only 7 of 27 samples).

3. Human sources were present in many samples. The proportion of human was above the MDP in 31 of 72 samples, and human was the dominant source in 9 of those samples.

4. Dog sources were also present in many samples. The proportion of dog was above the MDP in 44 of 72 samples, and dog was the dominant source in 5 of those samples.

5. Livestock sources were also present in many samples. The proportion of livestock was above the MDP in 46 of 72 samples, and livestock was the dominant source in 11 of those samples.

Seven-way Classification of Isolates: Cattle vs Dog vs Goat vs Goose vs Horse vs Human vs. Wild

To determine which of the merged animal sources are contributing to the pollution in Moores Creek, a seven-way library was created. For this library, the beef and dairy isolates were pooled as cattle, the one duck sample was pooled with the geese, and the aquatic mammal was pooled with the "wild" isolates. The ARCC of this library was 64%, which, even though lower than the other libraries because of the many possible categories, was still well above the background level of 14% (Table 9). The MDPs for cattle and geese were the highest (11% and 10%), and the rest were around 5%.

Again, the stream samples were classified using this library. The results are shown in Tables 10 (listed by collection date) and 11 (listed by sample site). All seven source types were found in Moores Creek. Again, there was variation from station to station and from day to day, and again, some clear trends are evident:

1. Wild and geese isolates continued to be the dominant source, especially in the summer samples. On average, wild was dominant on 3 of 8 days, and geese were dominant on 1 of 8. On average, wild or goose sources were dominant at all locations. In 62 of the 72 samples, the proportion of wild was above the MDP, and wild was the dominant source in 23 of those samples. The proportion of geese was above the MDP in 56 of 72 samples, and geese was the dominant source in 18 of those samples.

2. Human sources were present in many samples. The proportion of human was above the MDP in 29 of 72 samples, especially in the winter months. Human was the dominant source in 6 of those samples (although 2 of those samples have very low numbers of isolates). On average, human was never the dominant source for any day or at any location. However, on average, human isolates were present above the MDP for every station except Station #2.

3. Dog sources were also present in many samples. The proportion of dog was above the MDP in 43 of 72 samples, and dog was the dominant source in 6 of those samples (all in winter samples). On average, dog was the dominant source for 2 days (in February) but not at any location. Dog sources seemed to be at higher proportions in the winter months.

4. Cattle sources were also present. The proportion of cattle was above the MDP in 31 of 72 samples, and cattle was the dominant source in 8 of those samples. On average, cattle was the dominant source for one day (March 30), but not at any location.

5. Goat sources were present as well. The proportion of goat was above the MDP in 44 of 72 samples, and goat was the dominant source in 10 of those samples. On average, goat was the dominant source for one day (July 11), but not at any location.

6. Horse sources were very rare. Only 3 samples showed any isolates that were classified as horse, but horse was the dominant source for each of them. On average, horse was never the dominant source for any day or at any location.

7. The averages for all sample sites are plotted in Figure 2. Geese and wild sources are dominant in the summer months (except for one day when goat was highest). In the winter, dog, cattle, and human sources are higher.

Levels of Fecal Coliforms

Fecal coliform levels varied by sampling day and by sampling location (Tables 4, 5, 7, 8, 10, & 11). Individual values ranged from as low as 2 to as many as 58,000 FC/100 ml. A total of 30 of the 72 samples had FC levels that were greater than the standard of 1,000 FC/100 ml. All of the nine sites had geometric means greater than the standard of 200 FC/100 ml. Stations 5, 6, and 9 had geometric mean values close to or above 1,000 FC/100 ml. Counts tended to be higher in the summer months, and lower in the winter. A geometric mean of 10,273 FC/100 ml was recorded for 9/19/00. Fecal coliform counts were much higher on days after heavy rains.

Discussion

These results show that animals are the major sources of pollution in Moores Creek. However, human sources are a low but significant contributor as well. Every station (except Station #2) had an average percentage of human that was above the minimum detectable level.

Of the animal sources, the dominant source is wild animals, including geese. Dogs, cattle, and goats are also present. Table 12 shows the major source of fecal contamination at each sample site. The two most common sources in the stream are wild (the majority source in 23 of 72 samples) and

geese (dominant in 19 of 64). Goat is dominant in 10 samples, and cattle in 8 samples. Human contamination is found at lower levels (dominant in 6 samples), as was dog contamination (6 samples). Pollution from horse sources was rare, and was found in only 3 samples (but was the dominant source in all three).

These results indicate that the source of fecal influx at each sampling site is not consistent over time. As seen in Table 12, it was typical to find three or more of the possible sources dominant at any given sample site at different times during the course of the year. Also, many of the dominant sources were found at relatively low proportions, indicating that many other sources were present in those samples as well. This suggests that Moores Creek is polluted by several sources, and that the influx of fecal contamination from each source varies.

There were not higher levels of dog sources directly below the dog walking area in Azalea Park (Station #3). This shows that the park is not a major contributor to pollution in Moores Creek. Similarly, fecal coliform levels were not higher, nor were livestock source proportions higher, at the station below the stockyard (Station #8). This suggests that this facility is not a significant source of fecal pollution to the creek.

There seems to be no relationship between the fecal coliform levels and the dominant source of fecal contamination in the stream. However, there does seem to be a relationship between rainfall and fecal coliform levels. When the rainfall levels are very high, there are much higher levels of fecal contamination in the stream.

Perhaps the most surprising result of this study is the high proportions of wild isolates, including many of the samples with extremely high fecal coliform counts. Given that the numbers of these isolates in the known reservoir samples were very low, it seems surprising that they would be in such high levels downstream. One of the limitations of the use of discriminant analysis is the composition of the library of known isolates. The identification of unknown isolates is only reliable if the library is representative of the watershed. Because the program can assign unknowns only to those types of sources that are present in the library, if other sources are present in the stream they would be incorrectly classified. Although we sampled what we felt were the major possible fecal sources, there may be other sources in the watershed that were not sampled, and the high levels of "wild" sources might really be these other sources. The "wild" isolates probably include contributions from deer scat, and deer may be in higher numbers than were estimated when the study was begun. Another explanation is that the number of known samples in the library was not great enough to account for all of the antibiotic resistance patterns that are present in the watershed. Perhaps development of alternative analysis methods (currently underway) may help determine the identity of these wild bacteria.

In conclusion, Moores Creek receives high levels of fecal pollution, especially during the summer months. The sources of this pollution include geese and other wild animals, and to a lesser extent, humans, dogs and livestock.

Acknowledgments

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References

- 1) **Alliance for the Chesapeake Bay.** 1993. Nutrients and the Chesapeake: Refining the bay cleanup effort.
- 2) **Hagedorn, C.** Bacterial source tracking (BST): Identifying sources of fecal pollution.
http://www.bsi.vt.edu/biol_4684/BST/BST.html
- 3) **Kaspar, C. W., J. L. Burgess, I. T. Knight, and R. R. Colwell.** 1990. Antibiotic resistance indexing of *Escherichia coli* to identify sources of fecal contamination in water. *Can. J. Microbiol.* 36:891-894.
- 4) **Krumperman, P. H.** 1983. Multiple antibiotic resistance indexing of *Escherichia coli* to identify high-risk sources of fecal contamination of foods. *Appl. Environ. Microbiol.* 46:165-170.
- 5) **Sinton, L. W., A. M. Donnison, and C. M. Hastie.** 1993. Faecal streptococci as faecal pollution indicators: a review. II. Sanitary significance, survival, and use. *N. Z. J. Mar. Freshwater Res.* 27:117-137.
- 6) **Stevens, E., and B. A. Wiggins.** 2000. Use of Antibiotic Resistance Analysis to Determine the Effect of Stream Water Exposure in the Identification of Nonpoint Sources of Fecal Pollution. Honors Thesis submitted to James Madison University.
- 7) **Wiggins, B. A.** 1996. Discriminant analysis of antibiotic resistance patterns in fecal streptococci, a method to differentiate human and animal sources of fecal pollution. *Appl. Environ. Microbiol.* 63:3997-4002.
- 8) **Wiggins, B. A., R. W. Andrews, R. A. Conway, C. L. Corr, E. J. Dobratz, D. P. Dougherty, J. R. Eppard, S. R. Knupp, M. C. Limjoco, J. M. Mettenburg, J. M. Rinehardt, J. Sonsino, R. L. Torrijos, and M. E. Zimmerman.** 1999. Use of Antibiotic Resistance Analysis to Identify Nonpoint Sources of Fecal Pollution. *Appl. Environ. Microbiol.* 65:3483-3486.
- 9) **Wiggins, B. A.,** 2001. Procedures and protocols for antibiotic resistance analysis (ARA). Laboratory for Riparian Microbiology, James Madison University.

Table 1. Numbers of known fecal samples and isolates used in this study.

Source	Number of Samples	Total Number of Isolates
Beef Cattle	20	287
Dairy Cattle	2	22
Horses	5	58
Dogs	14	174
Sewage influent	9	134
Geese	13	159
Ducks	1	11
Goats	6	67
Aquatic Mammals	1	12
Wild	4	56
Totals	75	980

Table 2. Location and description of sampling sites in the Moores Creek watershed.

Site	Coordinates	Description
1	38°00.97N 78°32.90W	Moores Creek (Hickory Hill Gas Station)
2	38°01.36N 78°31.79W	Morey Creek (Fontaine Research Park)
3	38°00.58N 78°30.82W	Moores Creek (Azalea Park)
4	38°00.20N 78°30.51W	Biscuit Run (Foxcroft Village)
5	38°01.07N 78°29.83W	Rock Creek (Cleveland Ave)
6	38°00.35N 78°28.85W	Cow Branch (Monticello Visitors Center)
7	38°00.99N 78°28.15W	Moores Creek (Linden Apts)
8	38°01.09N 78°27.61W	Moores Creek (Sewage Treatment Plant)
9	38°01.15N 78°27.26W	Moores Creek (above Rivanna confluence)

Table 3. Classification of 980 isolates of enterococci from known animal and human sources in the Moores Creek watershed. Correctly-classified isolates are shown in bold. The ARCC for this analysis is 85%.

SOURCE	Number (and Percent) of Isolates Classified As:	
	<u>ANIMAL</u>	<u>HUMAN</u>
ANIMAL (n = 846)	785 (93)	61 (7)
HUMAN (n = 134)	30 (22)	104 (78)
MDP	22	7

Table 4. Two-way classification of sources of fecal pollution in Moores Creek, listed by collection date.

Values in red are the major source. Values in blue are above the MDP.

A. Samples collected on 6/6/00. The gauge height for this day was not recorded.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml
1	45	100	0	ND
2	46	93	7	ND
3	34	50	50	ND
4	46	48	52	ND
5	46	89	11	ND
6	46	78	22	ND
7	46	80	20	ND
8	46	98	2	ND
9	46	98	2	ND
Average		82	18	ND

B. Samples collected on 6/19/00. The gauge height for this day was not recorded.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml
1	46	87	13	4,450
2	46	96	4	5,750
3	46	85	15	7,700
4	46	80	20	3,450
5	46	85	15	58,000
6	46	72	28	6,500
7	46	87	13	10,350
8	46	80	20	10,350
9	46	46	54	12,750
Average		80	20	8899

C. Samples collected on 6/28/00. The gauge height for this day was 2.10.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml
1	43	95	5	18,000
2	42	100	0	3,550
3	46	100	0	3,550
4	46	96	4	1,650
5	44	93	7	6,050
6	46	78	22	8,600
7	46	85	15	4,800
8	46	85	15	4,750
9	46	100	0	2,700
Average		92	8	4736

Table 4 (cont.)

D. Samples collected on 7/11/00. The gauge height for this day was 1.52.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml
1	46	65	35	215
2	46	85	15	135
3	46	100	0	120
4	26	58	42	285
5	46	100	0	395
6	46	100	0	220
7	45	98	2	260
8	46	96	4	380
9	46	100	0	485
Average		89	11	252

E. Samples collected on 9/19/00. The gauge height for this day was 2.70.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml
1	46	89	11	4,850
2	46	93	7	4,300
3	46	96	4	4,300
4	46	52	48	16,200
5	46	83	17	4,050
6	46	67	32	22,500
7	46	100	0	21,000
8	46	96	4	23,500
9	46	98	2	19,500
Average		86	14	10273

F. Samples collected on 2/2/01. The gauge height for this day was 1.55.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml
1	36	31	69	30
2	4*	50*	50*	71
3	17	41	59	2
4	6*	33*	67*	3
5	46	0	100	44
6	40	42	58	42
7	20	80	20	14
8	33	91	9	21
9	14	93	7	14
Average		54	46	17

* low number of isolates (not included in the average)

Table 4 (cont.)

G. Samples collected on 2/9/01. The gauge height for this day was 1.49.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml
1	43	91	9	15
2	46	98	2	12
3	46	54	46	2
4	46	41	59	33
5	46	93	7	76
6	46	85	15	56
7	46	87	13	64
8	44	93	7	22
9	41	66	34	36
Average		79	21	24

H. Samples collected on 3/30/01. The gauge height for this day was 2.85.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml
1	38	100	0	270
2	46	98	2	745
3	46	91	9	625
4	46	98	2	230
5	46	87	13	505
6	46	96	4	2,800
7	46	76	23	645
8	46	43	56	1,950
9	46	39	61	5,300
Average		81	19	866

Table 5. Two-way classification of sources of fecal pollution in Moores Creek, listed by sample site. Values in red are the major source. Values in blue exceed the MDP.

A. Samples collected at site 1.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	Gauge
6/6/00	45	100	0	ND	ND
6/19/00	46	87	13	4,450	ND
6/28/00	43	95	5	18,000	2.10
7/11/00	46	65	35	215	1.52
9/19/00	46	89	11	4,850	2.70
2/2/01	36	31	69	30	1.55
2/9/01	43	91	9	15	1.49
3/30/01	38	100	0	270	2.85
Average		82	18	519	

B. Samples collected at site 2.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	Gauge
6/6/00	46	93	7	ND	ND
6/19/00	46	96	4	5,750	ND
6/28/00	42	100	0	3,550	2.10
7/11/00	46	85	15	135	1.52
9/19/00	46	93	7	4,300	2.70
2/2/01	4*	50*	50*	71	1.55
2/9/01	46	98	2	12	1.49
3/30/01	46	98	2	745	2.85
Average		95	5	497	

* low number of isolates (not included in the average)

C. Samples collected at site 3.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	Gauge
6/6/00	34	50	50	ND	ND
6/19/00	46	85	15	7,700	ND
6/28/00	46	100	0	3,550	2.10
7/11/00	46	100	0	120	1.52
9/19/00	46	96	4	4,300	2.70
2/2/01	17	41	59	2	1.55
2/9/01	46	54	46	2	1.49
3/30/01	46	91	9	625	2.85
Average		77	23	231	

Table 5 (cont.)

D. Samples collected at site 4.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	Gauge
6/6/00	46	48	52	ND	ND
6/19/00	46	80	20	3,450	ND
6/28/00	46	96	4	1,650	2.10
7/11/00	26	58	42	285	1.52
9/19/00	46	52	48	16,200	2.70
2/2/01	6*	33*	67*	3	1.55
2/9/01	46	41	59	33	1.49
3/30/01	46	98	2	230	2.85
Average		68	32	346	

* low number of isolates (not included in the average)

E. Samples collected at site 5.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	Gauge
6/6/00	46	89	11	ND	ND
6/19/00	46	85	15	58,000	ND
6/28/00	44	93	7	6,050	2.10
7/11/00	46	100	0	395	1.52
9/19/00	46	83	17	4,050	2.70
2/2/01	46	0	100	44	1.55
2/9/01	46	93	7	76	1.49
3/30/01	46	87	13	505	2.85
Average		79	21	992	

F. Samples collected at site 6.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	Gauge
6/6/00	46	78	22	ND	ND
6/19/00	46	72	28	6,500	ND
6/28/00	46	78	22	8,600	2.10
7/11/00	46	100	0	220	1.52
9/19/00	46	67	32	22,500	2.70
2/2/01	40	42	58	42	1.55
2/9/01	46	85	15	56	1.49
3/30/01	46	96	4	2,800	2.85
Average		77	23	1090	

Table 5 (cont.)

G. Samples collected at site 7.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	Gauge
6/6/00	46	80	20	ND	ND
6/19/00	46	87	13	10,350	ND
6/28/00	46	85	15	4,800	2.10
7/11/00	45	98	2	260	1.52
9/19/00	46	100	0	21,000	2.70
2/2/01	20	80	20	14	1.55
2/9/01	46	87	13	64	1.49
3/30/01	46	76	23	645	2.85
Average		87	13	767	

H. Samples collected at site 8.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	Gauge
6/6/00	46	98	2	ND	ND
6/19/00	46	80	20	10,350	ND
6/28/00	46	85	15	4,750	2.10
7/11/00	46	96	4	380	1.52
9/19/00	46	96	4	23,500	2.70
2/2/01	33	91	9	21	1.55
2/9/01	44	93	7	22	1.49
3/30/01	46	43	56	1,950	2.85
Average		85	15	876	

I. Samples collected at site 9.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	Gauge
6/6/00	46	98	2	ND	ND
6/19/00	46	46	54	12,750	ND
6/28/00	46	100	0	2,700	2.10
7/11/00	46	100	0	485	1.52
9/19/00	46	98	2	19,500	2.70
2/2/01	14	93	7	14	1.55
2/9/01	41	66	34	36	1.49
3/30/01	46	39	61	5,300	2.85
Average		80	20	980	

Table 6. Classification of 980 isolates of enterococci from known dog, human, livestock, and wild sources in the Moores Creek watershed. Correctly-classified isolates are shown in bold. The ARCC for this analysis is 72%.

<u>SOURCE</u>	Number (and Percent) of Isolates Classified As:			
	<u>DOG</u>	<u>HUMAN</u>	<u>LIVESTOCK</u>	<u>WILD</u>
DOG (n = 174)	123 (71)	28 (16)	10 (6)	13 (7)
HUMAN (n = 134)	15 (11)	97 (72)	10 (8)	12 (9)
LIVESTOCK (n=434)	37 (8)	14 (3)	311 (72)	72 (17)
WILD (n=238)	12 (5)	6 (2)	47 (20)	173 (73)
MDP	8	7	11	11

Table 9. Classification of 980 isolates of enterococci from known cattle, dog, goat, goose, horse, human, and wild sources in the Moores Creek watershed. Correctly-classified isolates are shown in bold. The ARCC for this analysis is 64%.

<u>SOURCE</u>	Number (and Percent) of Isolates Classified As:						
	<u>CATTLE</u>	<u>DOG</u>	<u>GOAT</u>	<u>GOOSE</u>	<u>HORSE</u>	<u>HUMAN</u>	<u>WILD</u>
CATTLE (n = 309)	217 (70)	28 (9)	17 (5)	35 (11)	0 (0)	1 (1)	11 (4)
DOG (n = 174)	6 (3)	102 (59)	6 (3)	12 (7)	12(7)	27 (16)	9 (5)
GOAT (n=67)	12 (18)	3 (4)	44 (66)	2 (3)	0 (0)	1 (2)	5 (7)
GOOSE (n=170)	25 (15)	8 (4)	12 (7)	109 (64)	1 (1)	1 (1)	14 (8)
HORSE (n=58)	2 (4)	3 (5)	1 (2)	13 (22)	36 (62)	0 (0)	3 (5)
HUMAN (n=134)	7 (5)	11 (8)	13 (10)	5 (4)	0 (0)	89 (66)	9 (7)
WILD (n=68)	15 (22)	1 (2)	0 (0)	7 (10)	0 (0)	2 (3)	43 (63)
MDP	11	5	5	10	1	4	6

Table 12. The dominant source (and %) of fecal contamination found in each sample site during each sampling event. **C**=cattle; **D**=dog, **Gt**=goat, **Gs**=goose, **Hr**=horse, **Hu**=human; **W**=wild. Values with an asterisk represent proportions of very small numbers of isolates.

<u>Site</u>	<u>Sample Date</u>							
	6/6/00	6/19/00	6/28/00	7/11/00	9/19/00	2/2/01	2/9/01	3/30/01
1	W (71)	Gs (33)	W (46)	Gt (63)	W (37)	Hu (42)	C (39)	C (53)
2	Hr (44)	C (46)	Gs (45)	Gt (61)	C (37)	Hu (50*)	Gs (48)	Gs (35)
3	W (38)	W (61)	C (43)	Gs (54)	Gs (33)	Gs (53)	Hu (35)	C (33)
4	W (68)	W (37)	Gs (72)	Gt (81)	W (48)	Hu (50*)	D,W (30)	D (30)
5	W (46)	W (74)	Gt, W (34)	Gt (93)	W (46)	D (67)	Gt (39)	Gs (28)
6	W (54)	W (55)	W (74)	Gs (61)	W (56)	Hu (35)	Gs (37)	C (61)
7	W (35)	Hr (65)	W (41)	Gs (47)	Gs (28)	D (40)	Gt (30)	Gs (24)
8	W (52)	Gt (43)	Gs (50)	Gs (48)	Gs (41)	W (34)	Hr (57)	Gt (37)
9	W (41)	Hu (35)	Gs (65)	Gs, W (41)	C (33)	D (36)	D (24)	Gt (33)

Table 7. Four-way classification of sources of fecal pollution in Moores Creek, listed by collection date.

Values in red are the major source. Values in blue are above the MDP.

A. Samples collected on 6/6/00. The gauge height for this day was not recorded.

Site #	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml
1	45	9	0	4	87	ND
2	46	7	0	30	63	ND
3	34	9	20	15	56	ND
4	46	4	16	4	76	ND
5	46	7	4	13	76	ND
6	46	7	10	7	76	ND
7	46	13	6	11	70	ND
8	46	9	4	37	50	ND
9	46	15	2	22	61	ND
Average		9	7	16	68	ND

B. Samples collected on 6/19/00. The gauge height for this day was not recorded.

Site #	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml
1	46	11	7	28	54	4,450
2	46	0	2	46	52	5,750
3	46	11	4	17	68	7,700
4	46	28	4	9	59	3,450
5	46	11	9	6	74	58,000
6	46	13	7	6	74	6,500
7	46	9	13	74	4	10,350
8	46	7	17	43	33	10,350
9	46	11	50	17	22	12,750
Average		11	13	27	49	8899

C. Samples collected on 6/28/00. The gauge height for this day was 2.10.

Site #	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml
1	43	5	2	14	79	18,000
2	42	0	2	24	74	3,550
3	46	0	0	46	54	3,550
4	46	6	2	20	72	1,650
5	44	11	2	32	55	6,050
6	46	0	7	2	91	8,600
7	46	9	15	22	54	4,800
8	46	0	4	2	94	4,750
9	46	9	0	15	76	2,700
Average		4	4	20	72	4736

Table 7 (cont.)

D. Samples collected on 7/11/00. The gauge height for this day was 1.52.

Site #	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml
1	46	2	17	7	74	215
2	46	7	9	6	78	135
3	46	4	0	18	78	120
4	26	19	35	31	15	285
5	46	0	0	87	13	395
6	46	0	0	2	98	220
7	45	27	0	0	73	260
8	46	0	4	15	81	380
9	46	15	0	2	83	485
Average		8	7	19	66	252

E. Samples collected on 9/19/00. The gauge height for this day was 2.70.

Site #	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml
1	46	2	9	22	67	4,850
2	46	9	4	50	37	4,300
3	46	4	0	24	72	4,300
4	46	9	33	6	52	16,200
5	46	19	9	20	52	4,050
6	46	9	9	0	82	22,500
7	46	22	0	26	52	21,000
8	46	7	4	37	52	23,500
9	46	19	2	33	46	19,500
Average		11	8	24	57	10273

F. Samples collected on 2/2/01. The gauge height for this day was 1.55.

Site #	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml
1	36	11	56	11	22	30
2	4*	25*	50*	0*	25*	71
3	17	0	29	0	71	2
4	6*	17*	66*	0*	17*	3
5	46	70	30	0	0	44
6	40	35	38	7	20	42
7	20	45	0	25	30	14
8	33	12	12	24	52	21
9	14	43	7	29	21	14
Average		31	25	14	31	17

* low number of isolates (not included in the average)

Table 7 (cont.)

G. Samples collected on 2/9/01. The gauge height for this day was 1.49.

Site #	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml
1	43	14	7	44	35	15
2	46	28	0	9	63	12
3	46	28	35	28	9	2
4	46	30	30	0	40	33
5	46	52	7	26	15	76
6	46	4	18	13	65	56
7	46	13	9	48	30	64
8	44	14	7	41	38	22
9	41	24	20	32	24	36
Average		23	15	27	35	24

H. Samples collected on 3/30/01. The gauge height for this day was 2.85.

Site #	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml
1	38	10	0	53	37	270
2	46	15	0	28	57	745
3	46	22	7	43	28	625
4	46	37	2	28	33	230
5	46	22	11	22	45	505
6	46	13	0	61	26	2,800
7	46	19	20	22	39	645
8	46	17	37	11	35	1,950
9	46	2	48	4	46	5,300
Average		17	14	30	38	866

Table 8. Four-way classification of sources of fecal pollution in Moores Creek, listed by sample site. Values in red are the major source. Values in blue are above the MDP.

A. Samples collected at site 1.

Date	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml	Gauge
6/6/00	45	9	0	4	87	ND	ND
6/19/00	46	11	7	28	54	4,450	ND
6/28/00	43	5	2	14	79	18,000	2.10
7/11/00	46	2	17	7	74	215	1.52
9/19/00	46	2	9	22	67	4,850	2.70
2/2/01	36	11	56	11	22	30	1.55
2/9/01	43	14	7	44	35	15	1.49
3/30/01	38	10	0	53	37	270	2.85
Average		8	12	23	57	519	

B. Samples collected at site 2.

Date	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml	Gauge
6/6/00	46	7	0	30	63	ND	ND
6/19/00	46	0	2	46	52	5,750	ND
6/28/00	42	0	2	24	74	3,550	2.10
7/11/00	46	7	9	6	78	135	1.52
9/19/00	46	9	4	50	37	4,300	2.70
2/2/01	4*	25*	50*	0*	25*	71	1.55
2/9/01	46	28	0	9	63	12	1.49
3/30/01	46	15	0	28	57	745	2.85
Average		9	2	28	61	497	

* low number of isolates (not included in the average)

C. Samples collected at site 3.

Date	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml	Gauge
6/6/00	34	9	20	15	56	ND	ND
6/19/00	46	11	4	17	68	7,700	ND
6/28/00	46	0	0	46	54	3,550	2.10
7/11/00	46	4	0	18	78	120	1.52
9/19/00	46	4	0	24	72	4,300	2.70
2/2/01	17	0	29	0	71	2	1.55
2/9/01	46	28	35	28	9	2	1.49
3/30/01	46	22	7	43	28	625	2.85
Average		10	12	24	55	231	

Table 8 (cont.)

D. Samples collected at site 4.

Date	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml	Gauge
6/6/00	46	4	16	4	76	ND	ND
6/19/00	46	28	4	9	59	3,450	ND
6/28/00	46	6	2	20	72	1,650	2.10
7/11/00	26	19	35	31	15	285	1.52
9/19/00	46	9	33	6	52	16,200	2.70
2/2/01	6*	17*	66*	0*	17*	3	1.55
2/9/01	46	30	30	0	40	33	1.49
3/30/01	46	37	2	28	33	230	2.85
Average		19	17	14	50	346	

* low number of isolates (not included in the average)

E. Samples collected at site 5.

Date	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml	Gauge
6/6/00	46	7	4	13	76	ND	ND
6/19/00	46	11	9	6	74	58,000	ND
6/28/00	44	11	2	32	55	6,050	2.10
7/11/00	46	0	0	87	13	395	1.52
9/19/00	46	19	9	20	52	4,050	2.70
2/2/01	46	70	30	0	0	44	1.55
2/9/01	46	52	7	26	15	76	1.49
3/30/01	46	22	11	22	45	505	2.85
Average		24	9	26	41	992	

F. Samples collected at site 6.

Date	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml	Gauge
6/6/00	46	7	10	7	76	ND	ND
6/19/00	46	13	7	6	74	6,500	ND
6/28/00	46	0	7	2	91	8,600	2.10
7/11/00	46	0	0	2	98	220	1.52
9/19/00	46	9	9	0	82	22,500	2.70
2/2/01	40	35	38	7	20	42	1.55
2/9/01	46	4	18	13	65	56	1.49
3/30/01	46	13	0	61	26	2,800	2.85
Average		10	11	12	67	1090	

Table 8 (cont.)

G. Samples collected at site 7.

Date	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml	Gauge
6/6/00	46	13	6	11	70	ND	ND
6/19/00	46	9	13	74	4	10,350	ND
6/28/00	46	9	15	22	54	4,800	2.10
7/11/00	45	27	0	0	73	260	1.52
9/19/00	46	22	0	26	52	21,000	2.70
2/2/01	20	45	0	25	30	14	1.55
2/9/01	46	13	9	48	30	64	1.49
3/30/01	46	19	20	22	39	645	2.85
Average		20	8	29	44	767	

H. Samples collected at site 8.

Date	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml	Gauge
6/6/00	46	9	4	37	50	ND	ND
6/19/00	46	7	17	43	33	10,350	ND
6/28/00	46	0	4	2	94	4,750	2.10
7/11/00	46	0	4	15	81	380	1.52
9/19/00	46	7	4	37	52	23,500	2.70
2/2/01	33	12	12	24	52	21	1.55
2/9/01	44	14	7	41	38	22	1.49
3/30/01	46	17	37	11	35	1,950	2.85
Average		8	11	26	54	876	

I. Samples collected at site 9.

Date	# of isolates	%DOG	%HUMAN	%LIVESTOCK	%WILD	# FC/100ml	Gauge
6/6/00	46	15	2	22	61	ND	ND
6/19/00	46	11	50	17	22	12,750	ND
6/28/00	46	9	0	15	76	2,700	2.10
7/11/00	46	15	0	2	83	485	1.52
9/19/00	46	19	2	33	46	19,500	2.70
2/2/01	14	43	7	29	21	14	1.55
2/9/01	41	24	20	32	24	36	1.49
3/30/01	46	2	48	4	46	5,300	2.85
Average		17	16	19	47	980	

Table 10. Seven-way classification of sources of fecal pollution in Moores Creek, listed by collection date.

Values in red are the major source. Values in blue are above the MDP.

A. Samples collected on 6/6/00. The gauge height for this day was not recorded.

Site #	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml
1	45	0	9	2	18	0	0	71	ND
2	46	2	0	2	15	44	0	37	ND
3	34	3	9	26	12	0	12	38	ND
4	46	4	4	13	9	0	2	68	ND
5	46	11	4	6	33	0	0	46	ND
6	46	0	7	30	9	0	0	54	ND
7	46	4	9	26	26	0	0	35	ND
8	46	19	0	9	20	0	0	52	ND
9	46	11	13	13	22	0	0	41	ND
Average		6	6	14	18	5	2	49	ND

B. Samples collected on 6/19/00. The gauge height for this day was not recorded.

Site #	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml
1	46	22	9	2	33	0	4	30	4,450
2	46	46	0	0	22	0	0	32	5,750
3	46	20	6	0	13	0	0	61	7,700
4	46	17	11	7	26	0	2	37	3,450
5	46	7	4	4	7	0	4	74	58,000
6	46	4	13	2	24	0	2	55	6,500
7	46	9	2	11	0	65	6	7	10,350
8	46	24	7	43	6	0	9	11	10,350
9	46	6	9	26	13	0	35	11	12,750
Average		17	7	11	16	7	7	35	8899

C. Samples collected on 6/28/00. The gauge height for this day was 2.10.

Site #	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml
1	43	12	2	12	28	0	0	46	18,000
2	42	14	3	24	45	0	0	14	3,550
3	46	43	0	0	37	0	0	20	3,550
4	46	17	9	0	72	0	2	0	1,650
5	44	9	2	34	21	0	0	34	6,050
6	46	0	0	17	9	0	0	74	8,600
7	46	9	7	28	13	0	2	41	4,800
8	46	0	0	11	50	0	0	39	4,750
9	46	0	9	24	65	0	0	2	2,700
Average		12	4	17	38	0	0	30	4736

Table 10 (cont.)

D. Samples collected on 7/11/00. The gauge height for this day was 1.52.

Site #	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml
1	46	0	2	63	17	0	9	9	215
2	46	0	2	61	26	0	0	11	135
3	46	0	0	44	54	0	0	2	120
4	26	0	4	81	4	0	11	0	285
5	46	0	0	93	7	0	0	0	395
6	46	0	0	4	61	0	0	35	220
7	45	0	27	4	47	0	0	22	260
8	46	13	2	2	48	0	2	33	380
9	46	2	16	0	41	0	0	41	485
Average		2	6	39	34	0	2	17	252

E. Samples collected on 9/19/00. The gauge height for this day was 2.70.

Site #	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml
1	46	17	0	9	33	0	4	37	4,850
2	46	37	7	13	30	0	2	11	4,300
3	46	22	4	11	33	0	0	30	4,300
4	46	9	2	22	6	0	13	48	16,200
5	46	4	11	11	22	0	6	46	4,050
6	46	0	0	22	13	0	9	56	22,500
7	46	26	22	0	28	0	0	24	21,000
8	46	35	7	2	41	0	4	11	23,500
9	46	33	17	2	26	0	2	20	19,500
Average		20	8	10	26	0	4	31	10273

F. Samples collected on 2/2/01. The gauge height for this day was 1.55.

Site #	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml
1	36	8	8	11	17	0	42	14	30
2	4*	0*	25*	25*	0*	0*	50*	0*	71
3	17	0	0	6	53	0	29	12	2
4	6*	0*	16*	0*	17*	0*	50*	17*	3
5	46	0	67	0	0	0	33	0	44
6	40	5	25	0	15	0	35	20	42
7	20	25	40	0	5	0	5	25	14
8	33	27	6	9	18	0	6	34	21
9	14	29	36	7	14	0	7	7	14
Average		13	26	5	17	0	22	16	17

* low number of isolates (not included in the average)

Table 10 (cont.)

G. Samples collected on 2/9/01. The gauge height for this day was 1.49.

Site #	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml
1	43	39	12	0	7	0	7	35	15
2	46	9	28	2	48	0	0	13	12
3	46	18	24	15	4	0	35	4	2
4	46	3	30	2	9	0	26	30	33
5	46	11	37	39	11	0	2	0	76
6	46	18	2	2	37	0	15	26	56
7	46	22	13	30	13	0	7	15	64
8	44	2	2	7	11	57	7	14	22
9	41	10	24	22	19	0	15	10	36
Average		15	19	13	18	6	13	16	24

H. Samples collected on 3/30/01. The gauge height for this day was 2.85.

Site #	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml
1	38	53	5	13	11	0	0	18	270
2	46	24	17	13	35	0	0	11	745
3	46	33	17	15	24	0	2	9	625
4	46	20	30	7	26	0	2	15	230
5	46	22	22	2	28	0	9	17	505
6	46	61	13	4	4	0	0	18	2,800
7	46	13	17	11	24	0	18	17	645
8	46	7	11	37	17	0	24	4	1,950
9	46	2	2	33	20	0	30	13	5,300
Average		26	15	15	21	0	9	14	866

Table 11. Seven-way classification of sources of fecal pollution in Moores Creek, listed by sample site.

Values in red are the major source. Values in blue are above the MDP.

A. Samples collected at site 1.

Date	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	Gauge
6/6/00	45	0	9	2	18	0	0	71	ND	ND
6/19/00	46	22	9	2	33	0	4	30	4,450	ND
6/28/00	43	12	2	12	28	0	0	46	18,000	2.10
7/11/00	46	0	2	63	17	0	9	9	215	1.52
9/19/00	46	17	0	9	33	0	4	37	4,850	2.70
2/2/01	36	8	8	11	17	0	42	14	30	1.55
2/9/01	43	39	12	0	7	0	7	35	15	1.49
3/30/01	38	53	5	13	11	0	0	18	270	2.85
Average		19	6	14	21	0	8	33	519	

B. Samples collected at site 2.

Date	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	Gauge
6/6/00	46	2	0	2	15	44	0	37	ND	ND
6/19/00	46	46	0	0	22	0	0	32	5,750	ND
6/28/00	42	14	3	24	45	0	0	14	3,550	2.10
7/11/00	46	0	2	61	26	0	0	11	135	1.52
9/19/00	46	37	7	13	30	0	2	11	4,300	2.70
2/2/01	4*	0*	25*	25*	0*	0*	50*	0*	71	1.55
2/9/01	46	9	28	2	48	0	0	13	12	1.49
3/30/01	46	24	17	13	35	0	0	11	745	2.85
Average		19	8	16	32	6	0	18	497	

* low number of isolates (not included in the average)

C. Samples collected at site 3.

Date	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	Gauge
6/6/00	34	3	9	26	12	0	12	38	ND	ND
6/19/00	46	20	6	0	13	0	0	61	7,700	ND
6/28/00	46	43	0	0	37	0	0	20	3,550	2.10
7/11/00	46	0	0	44	54	0	0	2	120	1.52
9/19/00	46	22	4	11	33	0	0	30	4,300	2.70
2/2/01	17	0	0	6	53	0	29	12	2	1.55
2/9/01	46	18	24	15	4	0	35	4	2	1.49
3/30/01	46	33	17	15	24	0	2	9	625	2.85
Average		17	8	15	29	0	10	22	231	

Table 11 (cont.)

D. Samples collected at site 4.

Date	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	Gauge
6/6/00	46	4	4	13	9	0	2	68	ND	ND
6/19/00	46	17	11	7	26	0	2	37	3,450	ND
6/28/00	46	17	9	0	72	0	2	0	1,650	2.10
7/11/00	26	0	4	81	4	0	11	0	285	1.52
9/19/00	46	9	2	22	6	0	13	48	16,200	2.70
2/2/01	6*	0*	16*	0*	17*	0*	50*	17*	3	1.55
2/9/01	46	3	30	2	9	0	26	30	33	1.49
3/30/01	46	20	30	7	26	0	2	15	230	2.85
Average		10	13	19	22	0	8	28	346	

* low number of isolates (not included in the average)

E. Samples collected at site 5.

Date	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	Gauge
6/6/00	46	11	4	6	33	0	0	46	ND	ND
6/19/00	46	7	4	4	7	0	4	74	58,000	ND
6/28/00	44	9	2	34	21	0	0	34	6,050	2.10
7/11/00	46	0	0	93	7	0	0	0	395	1.52
9/19/00	46	4	11	11	22	0	6	46	4,050	2.70
2/2/01	46	0	67	0	0	0	33	0	44	1.55
2/9/01	46	11	37	39	11	0	2	0	76	1.49
3/30/01	46	22	22	2	28	0	9	17	505	2.85
Average		8	18	24	16	0	7	27	992	

F. Samples collected at site 6.

Date	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	Gauge
6/6/00	46	0	7	30	9	0	0	54	ND	ND
6/19/00	46	4	13	2	24	0	2	55	6,500	ND
6/28/00	46	0	0	17	9	0	0	74	8,600	2.10
7/11/00	46	0	0	4	61	0	0	35	220	1.52
9/19/00	46	0	0	22	13	0	9	56	22,500	2.70
2/2/01	40	5	25	0	15	0	35	20	42	1.55
2/9/01	46	18	2	2	37	0	15	26	56	1.49
3/30/01	46	61	13	4	4	0	0	18	2,800	2.85
Average		11	8	10	22	0	8	42	1090	

Table 11 (cont.)

G. Samples collected at site 7.

Date	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	Gauge
6/6/00	46	4	9	26	26	0	0	35	ND	ND
6/19/00	46	9	2	11	0	65	6	7	10,350	ND
6/28/00	46	9	7	28	13	0	2	41	4,800	2.10
7/11/00	45	0	27	4	47	0	0	22	260	1.52
9/19/00	46	26	22	0	28	0	0	24	21,000	2.70
2/2/01	20	25	40	0	5	0	5	25	14	1.55
2/9/01	46	22	13	30	13	0	7	15	64	1.49
3/30/01	46	13	17	11	24	0	18	17	645	2.85
Average		14	17	14	20	8	5	23	767	

H. Samples collected at site 8.

Date	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	Gauge
6/6/00	46	19	0	9	20	0	0	52	ND	ND
6/19/00	46	24	7	43	6	0	9	11	10,350	ND
6/28/00	46	0	0	11	50	0	0	39	4,750	2.10
7/11/00	46	13	2	2	48	0	2	33	380	1.52
9/19/00	46	35	7	2	41	0	4	11	23,500	2.70
2/2/01	33	27	6	9	18	0	6	34	21	1.55
2/9/01	44	2	2	7	11	57	7	14	22	1.49
3/30/01	46	7	11	37	17	0	24	4	1,950	2.85
Average		16	4	15	26	7	7	25	876	

I. Samples collected at site 9.

Date	# of isolates	%CATTLE	%DOG	%GOAT	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	Gauge
6/6/00	46	11	13	13	22	0	0	41	ND	ND
6/19/00	46	6	9	26	13	0	35	11	12,750	ND
6/28/00	46	0	9	24	65	0	0	2	2,700	2.10
7/11/00	46	2	16	0	41	0	0	41	485	1.52
9/19/00	46	33	17	2	26	0	2	20	19,500	2.70
2/2/01	14	29	36	7	14	0	7	7	14	1.55
2/9/01	41	10	24	22	19	0	15	10	36	1.49
3/30/01	46	2	2	33	20	0	30	13	5,300	2.85
Average		12	16	16	28	0	11	18	980	

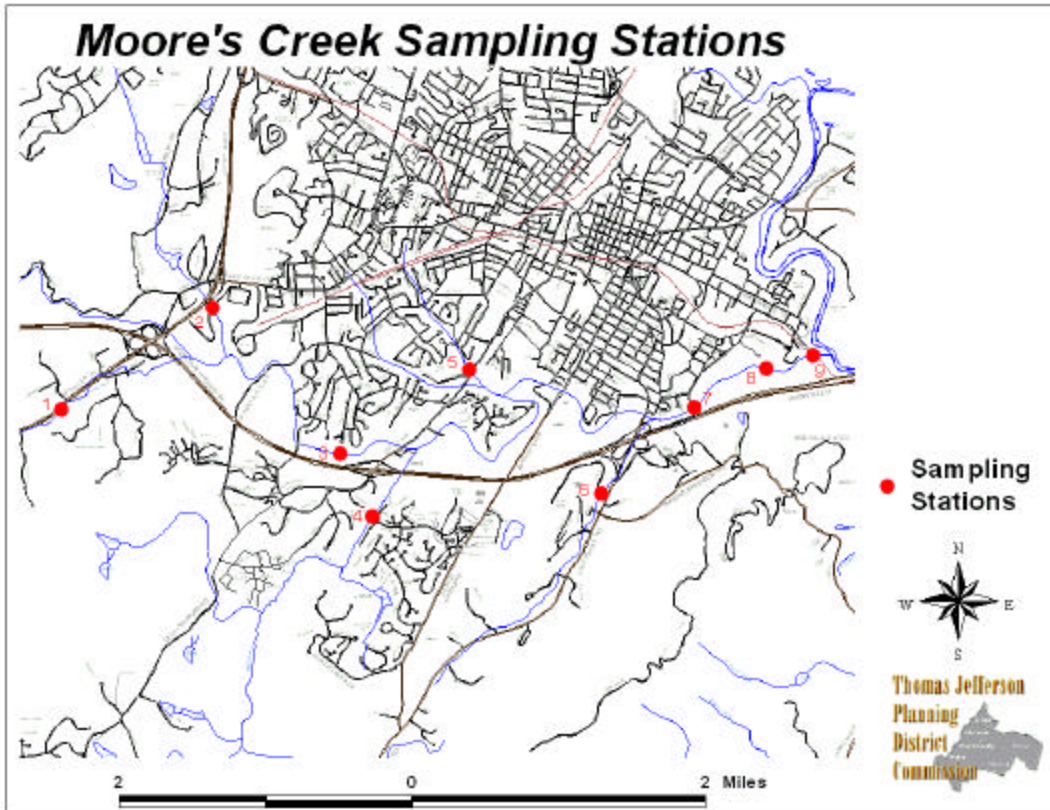
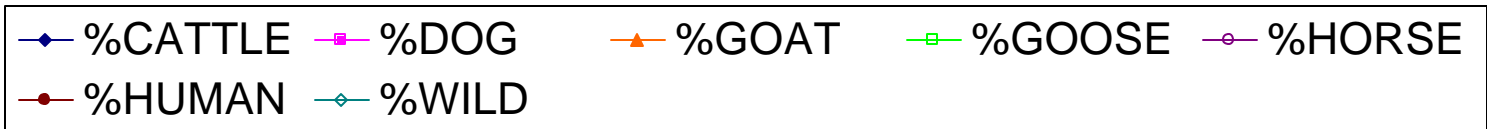
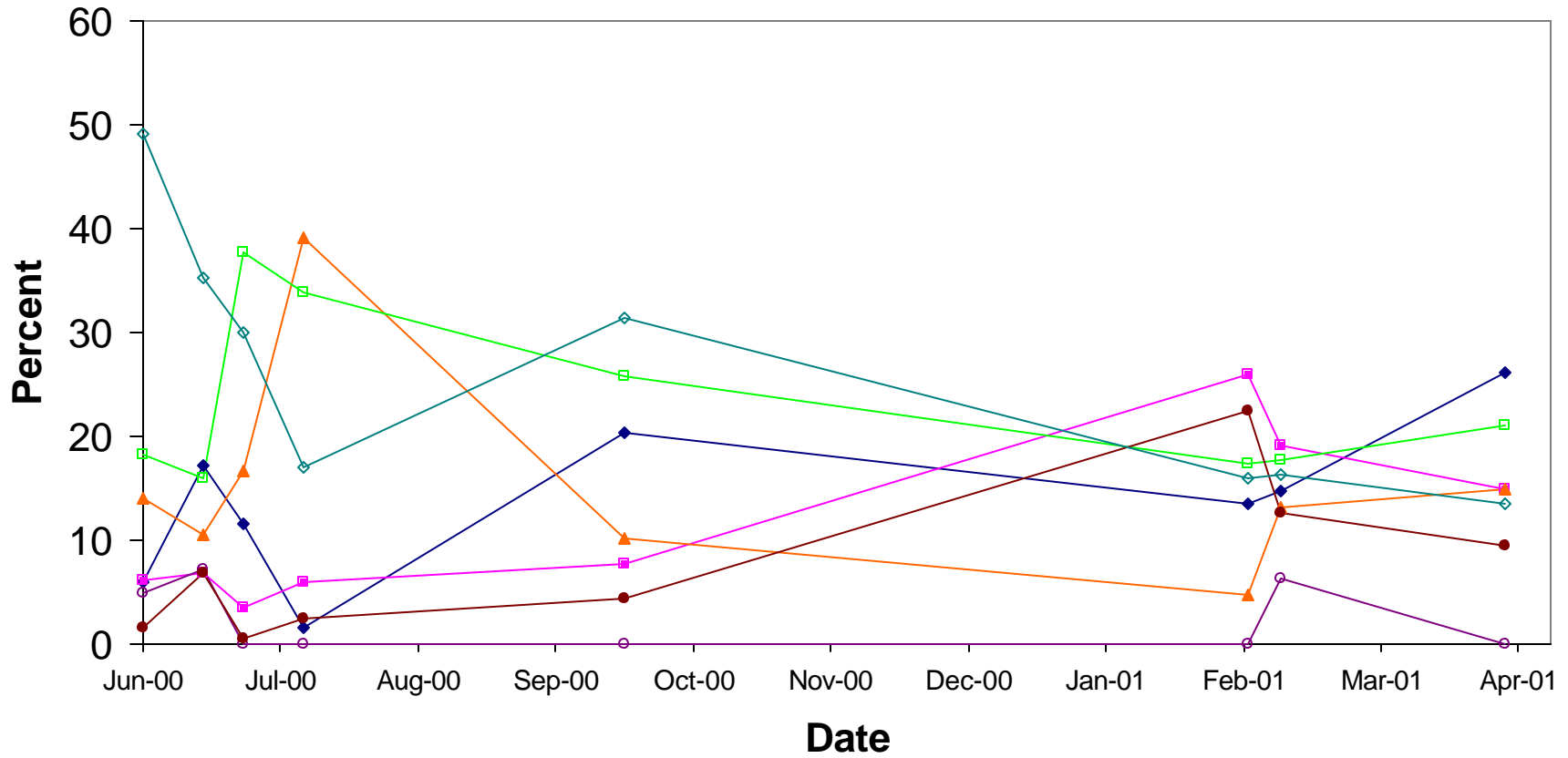


Figure 1: Sampling sites in the Moores Creek watershed.

Figure 2. Sources of Fecal Pollution in Moores Creek
(averages of all sites)



Appendix 1 Sample numbers used in this report

Sample numbers according to type used in these analyses.

Aquatic mammal: 1089

Beef: 990 1051 1052 1077 1078 1093 1102 1103 1115 1116 1125 1129 1130 1136 1137
1142 1143 1176 1179 1237

Dairy: 1055 1090

Dog: 922 962 987 1060 1061 1095 1122 1123 1124 1173 1174 1230 1231 1232

Duck: 1085

Goat: 989 992 1058 1059 1092 1131

Goose: 924 925 994 1062 1087 1088 1097 1177 1178 1234 1235 1236 1239

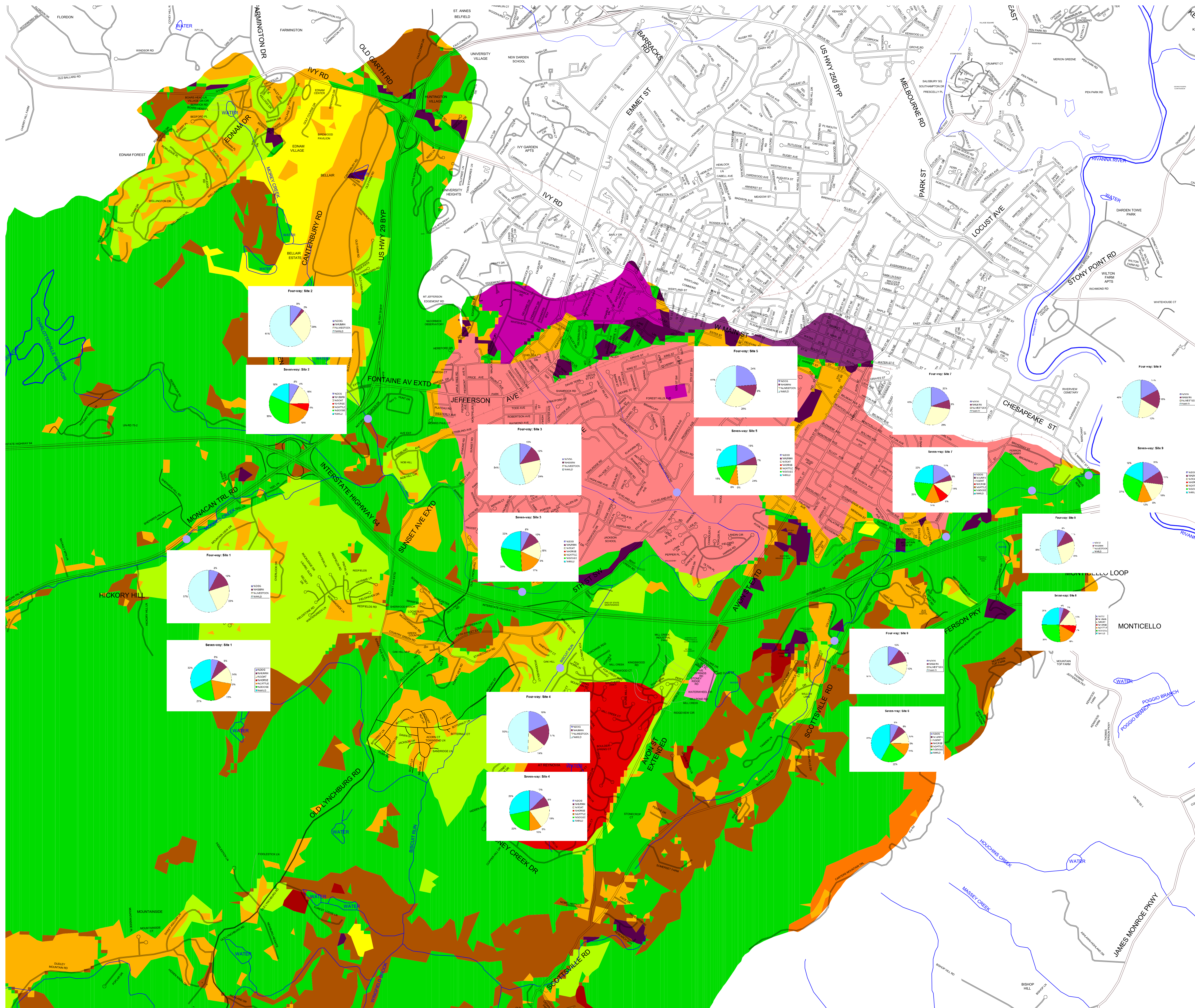
Horse: 1054 1063 1064 1065 1126

Human: 923 963 988 1053 1086 1121 1128 1175 1233

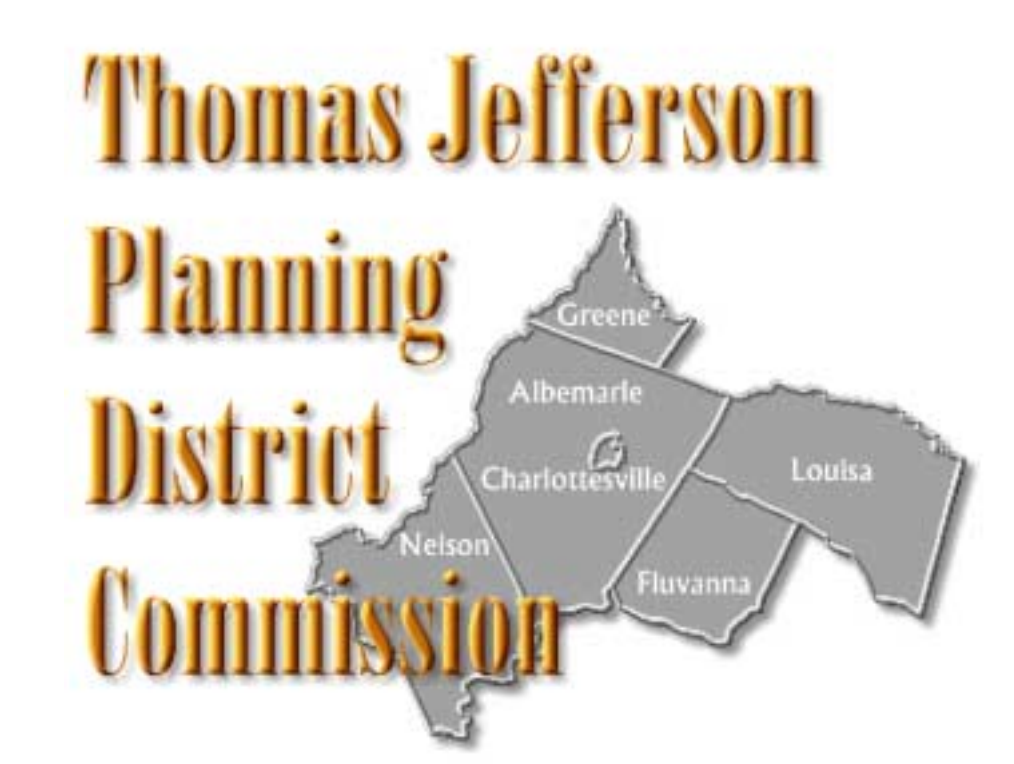
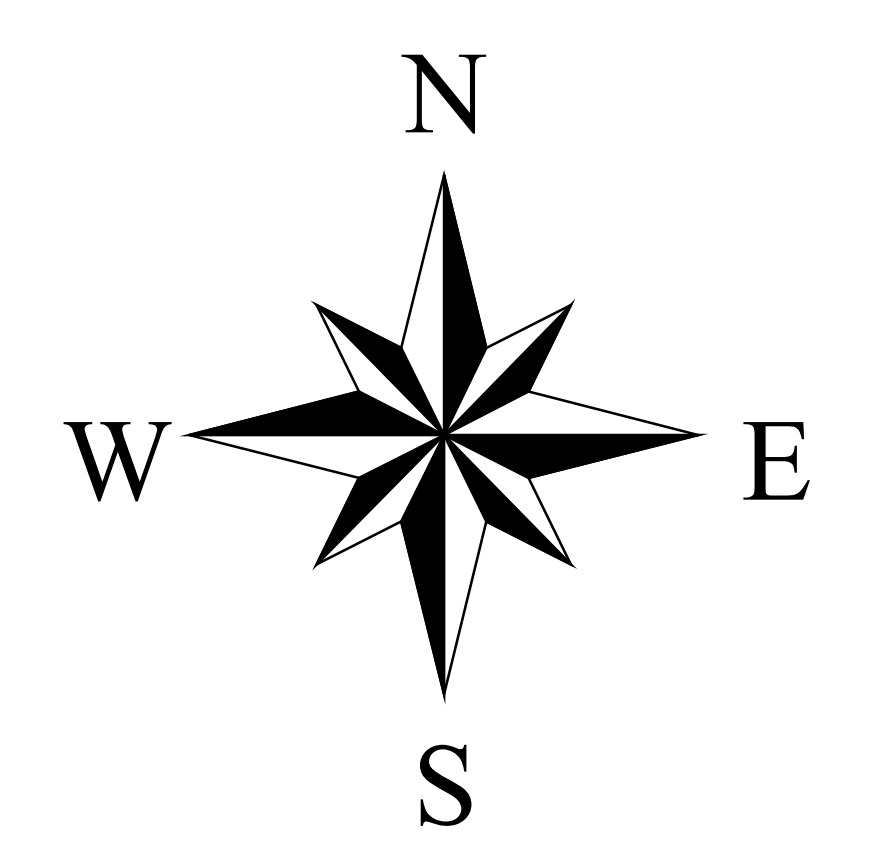
Wild (reservoir): 1066 1096 1180 1238

**APPENDIX B:
CHARTS OF BACTERIAL SOURCE TRACKING STUDY RESULTS
WITH MOORE'S CREEK LAND COVER MAP**

Moore's Creek Typing Study Results



- Tracking Study Sampling Stations
- Moorecreekimperv_stateplane.shp
- Forest - 0% impervious
- 5+ acre residences in woodlands - 3% impervious
- Mowed lawns, moderately grazed pasture, and golf courses - 10% impervious
- One-acre residences - 10% impervious
- Orchards - 12.5% impervious
- Grazed pasture lands - 15% impervious
- Croplands - 25% impervious
- 1/3 acre residences - 30% impervious
- 1/4 acre residences - 35% impervious
- Apartments - 70% impervious
- Light commercial/industrial/schools/university - 70% impervious
- Heavy commercial/industrial - 90% impervious
- Pavement/quarries - 100% impervious



Prepared by the Thomas Jefferson Planning District Commission
 Landcover source: VA DMM Division of Mineral Resources
 d:\moores_creek\moores_with_graphsandcover.apr rrg

APPENDIX C: RATING TABLE ESTABLISHED BY U.S. GEOLOGICAL SURVEY FOR MOORE'S CREEK

1 UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION PAGE 1
 EXPANDED RATING TABLE
 2033495 DATE PROCESSED: 03-17-2001 @ 12:16 BY rkwhite TYP E: LOG
 MOORES CREEK AB STP NR CHARLOTTSVILLE, VA DD: 1 TYPE: 001 RATING NO: 001
 OFFSET: 1.00 ST ART DATE/ TIME: 10-01-1999 (2000)

BASED ON _____ DISCHARGE MEASUREMENTS, NOT _____, AND _____, AND IS _____ WELLS DEFINED BETWEEN _____ AND _____ CFS
 CO MP BY _____ DATE _____ CHK. BY _____ DATE _____

GAGE HEIGHT (FEET)	DISCHARGE IN CUBIC FEET PER SECOND (EXPANDED PRECISION)											DIFF IN Q PER TENTH FT
	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	
1.3							0.5	0.649	0.836	1.07	2.152	
1.4	1.361	1.721	2.163	2.706	3.366	4.168	5.135	6.3	7.108	8	7.502	
1.5	8.863	9.8	10.47	11.16	11.89	12.66	13.46	14.29	15.15	16.06	8.137	
1.6	17	17.52	18.04	18.58	19.12	19.66	20.22	20.78	21.34	21.92	5.5	
1.7	22.5	23.09	23.68	24.28	24.89	25.51	26.13	26.76	27.39	28.03	6.18	
1.8	28.68	29.34	30	30.69	31.38	32.09	32.8	33.52	34.24	34.97	7.03	
1.9	35.71	36.46	37.21	37.97	38.74	39.52	40.3	41.09	41.89	42.69	7.79	
2	43.5	44.32	45.14	45.98	46.82	47.66	48.52	49.38	50.24	51.12	8.5	
2.1	52	53.15	54.32	55.51	56.71	57.92	59.15	60.4	61.66	62.94	12.23	
2.2	64.23	65.53	66.86	68.19	69.55	70.92	72.3	73.7	75.12	76.55	13.77	
2.3	78	79.86	81.76	83.68	85.63	87.61	89.63	91.67	93.75	95.86	20	
2.4	98	100.5	103	105.6	108.2	110.9	113.6	116.4	119.2	122.1	27	
2.5	125	128	131	134.1	137.2	140.4	143.6	146.9	150.2	153.6	32	
2.6	157	161.5	166.1	170.7	175.5	180.4	185.4	190.5	195.7	201	49.4	
2.7	206.4	212	217.6	223.4	229.3	235.3	241.4	247.7	254.1	260.6	60.8	
2.8	267.2	274	280.9	287.9	295.1	302.4	309.9	317.5	325.2	333.1	73.9	
2.9	341.1	349.3	357.6	366.1	374.7	383.5	392.5	401.6	410.9	420.4	88.9	