BACTERIOLOGICAL WATER QUALITY OF FORESTED AND PASTURED STREAMS RECEIVING LAND-APPLIED POULTRY LITTER

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ABSTRACT: Poultry production is a growing industry in East Texas, generating about 360,000 m tons of broiler litter each year as a by-product for application on pasturelands. Grab samples of fecal coliform (FC) and fecal streptococcus (FS) were collected monthly between March and December 1996 and FC and E-coli samples were collected weekly between July and October 2001 at six sites on the Waffelo and Terrapin Creeks in Nacogdoches County, Texas to assess possible impacts of poultry litter application on bacterial water quality. Sites were grouped by three pairs with each pair consisting of one upstream site in predominantly forested area and one downstream site in a pastured area receiving land application of poultry litter. All pastured watersheds had a 10 to 150 m buffer of riparian forest and/or unfertilized pasture between the stream and areas on which broiler litter was applied.

FC concentrations exceeded the 200 cfu/100 ml contact recreation standards in more than 50% of observations, regardless of forested or pastured conditions. E-coli samples did not violate standards and has been shown to be a better indicator of fecal contamination. Current broiler litter land-application rates on pasturelands did not cause significantly higher FC concentrations than natural wildlife activities on forested watersheds. Water pH was the only parameter significantly correlated ($r > 0.50$) with FC in the study areas. No significant correlations were detected between FC and other aquatic parameters including stream discharge, temperature, salinity, specific conductance, and dissolved oxygen. The study suggests that background variation in bacteriological parameters may mask land-use practices, though a longer period of observations with greater sampling frequency at more study sites may reduce observed variation in the present study.
KEY TERMS: poultry litter, bacteria, fecal coliform, *Escherichia coli*, water quality, East Texas.

INTRODUCTION

Agricultural nonpoint source pollution is a major water quality problem in the United States. USEPA (1998) cited it as a factor in impairing water quality for 25% of rivers and 19% of lakes that were surveyed. One potential source of agricultural pollution is the land application of poultry litter. The poultry industry has expanded tremendously since the 1990s. Texas currently ranks six in broiler production in the nation with about 90% of the broilers produced in Texas come from East Texas with revenues exceeding $1 billion annually. The poultry industry in East Texas produces about 400 million broilers that generate 364,000 m-ton/year of broiler litter. More than 90% of this litter is applied to pastures and hay meadows as a fertilizer substitute with a rate typically at about 6.5 – 11.0 m-ton/ha/yr (Young et al., 1996). The potential impact of poultry litter land-application on receiving water quality has generated concern, especially after some East Texas water bodies were placed on EPA's 303d list as being impaired due to bacteria. Impacts of poultry litter application on surface runoff and chemical water quality in receiving streams were reported in Young et al. (1996), Cochran et al. (1998), and McBroom et al. (1999).

BACKGROUND

Fecal coliform (FC), fecal streptococcus (FS), and *Escherichia coli* (E-coli) are bacteria always present in the intestinal tracts of warm-blooded animals. They are eliminated in fecal wastes and do not generally multiply outside the intestines. Contamination of excessive nutrients in surface streams and groundwater may result in chronic effects, but contamination of human pathogens can have acute effects, making people ill within hours of exposure in some cases. Numerous diseases are transmitted by fecal contact. Waters contaminated with fecal wastes are unsafe for contact recreation and drinking. The Texas Commission on Environmental Quality (TCEQ) standard for water contact use for FC is 200 colony-forming units (cfu) per 100 ml of water and for E-coli the contact standard is 126 cfu as a 5-sample geometric mean over a 30-day period.

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The impact of grazing and manure application on bacteriological water quality has been studied by many investigators in different parts of the U.S. Mean FC concentrations in runoff from grazed pasture fields were 5-10 times greater than from un-grazed pasture fields in Nebraska (Doran et al., 1981). Significant increases in FC concentrations were also reported in, Idaho (Stephenson and Street, 1978), Colorado (Gary et al., 1983), Oregon (Tiedemann et al., 1987), Arkansas (Edwards et al., 1997), and Kentucky (Edwards et al., 2000). However, some studies showed grazing caused no significant changes or only slight increases in FC concentrations (Pasquarell and Boyer, 1995; Skinner et al., 1974; Buckhouse and Gifford, 1976; Jawson et al., 1982). Concentrations of enteric bacteria are affected by an array of environmental and management factors such as streamflow (Stephenson and Street, 1978), water temperature and grazing strategy (Tiedemann et al., 1988), seasons (Doran et al., 1981), timing and rate of manure deposition (Edwards et al., 2000), and best management practices (Boyer and Pasquarell, 1999). Management factors such as grazing density, duration, and management schemes often increase variation in bacterial concentrations in streams causing assessment and comparisons to be difficult. Coupling the uncertainties created by the management factors with limited understanding on bacteria routing and residence time in watershed systems make it difficult to establish the relationships between bacteriological water quality and grazing/manure application. Edwards et al. (1997) stated that the majority of information on bacteria concentrations is empirical, and frequently contradictory.

METHODS OF STUDY

The study area was located in the 1,680 km^2 Attoyac River watershed in East Texas (Figure 1). In the Attoyac watershed, four sampling sites on the Waffelo and two sites on Terrapin Creeks, about 24 km east of the City of Nacogdoches, were selected for the study. These sites were grouped in three pairs with each pair consisting of an upstream-forested site ("A" Site) without litter application and a downstream pastured site ("B" site) with litter application. All pastured watersheds had a 10 to 150 m buffer of riparian forest and/or unfertilized pasture between the stream and areas on which broiler litter was applied. Study watersheds ranged from 230 and 4,580 ha in size, 63 and 183 m in elevation, and level to 12% in slope. Broiler houses have been in production in the pastured watersheds since the late 1960s. Litter has been routinely applied on pastures since then with application rates of about 6.5 – 11.0 m ton/ha/yr (Young et al., 1996). Waffelo creek is listed on EPA's 303d list as impaired due to bacteria.

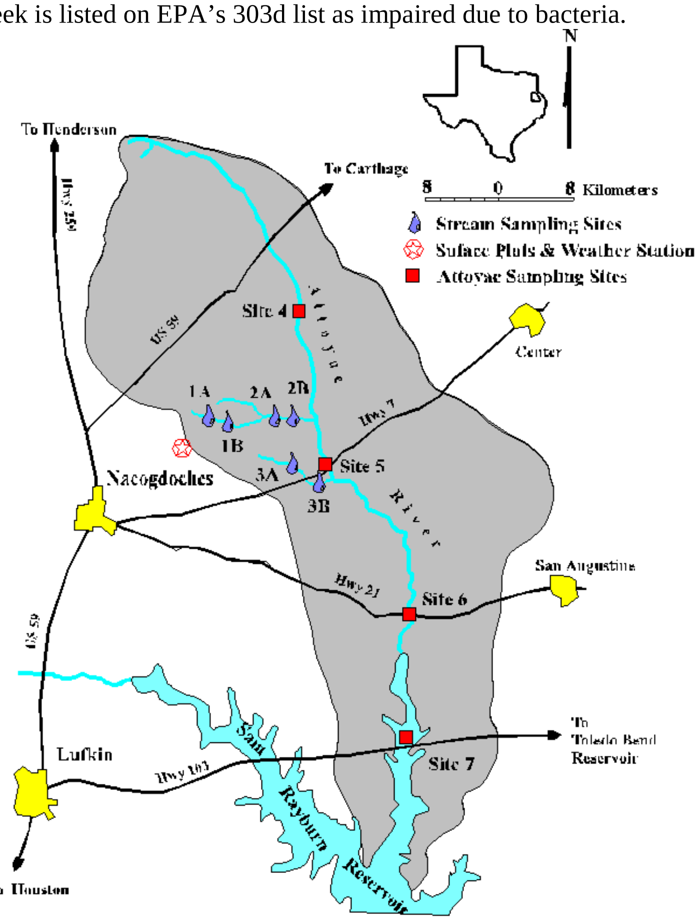

Figure 1. Map of sampling sites on the Waffelo and Terrapin Creeks in the Attoyac River Watershed in East Texas.

Grab water samples at the six study sites were collected monthly between March and December 1996 and weekly between July and October 2001. Samples were brought to SFASU on ice for analyses of bacteriological water quality parameters within 24 hours. Bacterial enumeration followed the membrane filtration method as described in Standard Methods by APHA (1995).

Stream discharge and six water quality parameters were also measured at the time of water sample collection using a Marsh-McBirney flow meter and an YSI #610 DM multi-probe water monitoring system. The six water-quality parameters included dissolved oxygen (DO), temperature, specific conductance (EC), salinity, total dissolved solids (TDS), and pH. Because of the small sample size, the Wilcoxon signed rank test was employed to test differences in concentrations between upstream and downstream. The associations of bacteria with physical water quality parameters were examined by the simple correlation analysis.

RESULTS AND DISCUSSION

Bacterial Concentrations

Overall FC ranged from 5 to 4,300 cfu/100 ml with medians equal to or exceeding the standard 400 cfu/100 ml water for contact use for single grab samples at all six sites (Table 1). About 36 to 79% of the observed FC concentrations exceeded the contact standard. In addition, the contact standard also requires that concentrations not exceed 400 cfu/100 ml in more than 10% of all samples (TNRCC, 1995). In the study watersheds, 37 to 79% of the observed FC concentrations at the six watersheds exceeding the 400 cfu/100 ml level. The contact standard is also base on a five-sample, 30-day geometric mean concentration less than 200 cfu/100 ml. Two 30-day periods were analyzed, from 7/31/01 to 8/28/01, and 9/11/01 to 10/9/01. No FC samples exceeded the TCEQ 30-day geometric mean standard of 200 cfu/100 ml during these periods on Terrapin Creek. However, on Waffelo Creek, which is on EPA's 303d list, site 1B was in violation for both periods and site 2A, a forested site, was in violation from 9/11/01 to 10/9/01.

Similar high concentrations were also reported in many other studies (Doran and Linn, 1979; Edwards et al., 1997; Howell et al., 1995; Lindsey, 1975; Richardson, 1975; Robbins et al., 1972). Sherer et al. (1992) attributed erratic FC concentrations to animal traffic that caused increases in turbulence and re-suspended sediment bound enteric bacteria. In Nebraska, Doran et al. (1981) stated that standards developed for point source pollution might be inappropriate for nonpoint source pollution for FC from pasture because wildlife alone can contribute fecal bacteria exceeding recommended water quality standards. There, both FC concentrations in grazed and ungrazed pastures exceeded the 200 cfu/100 ml criterion more than 90% of the time. In the current study area, cattle had direct access to streams at all pasture sites. Significant wildlife activities, especially wild hog rooting and wallowing, were noted in creek channels at both forested and pastured sites.

Table 1. Descriptive Statistics for fecal coliform (FC) and E-coli (E-C) concentrations (cfu/100 ml) for three pairs of upstream forested (A) and downstream pastured (B) sites in the Attoyac River Watershed in East Texas.

	1A		1B		2A		2B		3A		3B	
Statistic	FC	E-C	FC	E-C	FC	E-C	FC	E-C	FC	E-C	FC	E-C
Mean	200	19	550	67	560	81	245	30	308	16	260	21
Median	660	3	733	15	755	26	569	14	560	6	595	12
Std. Dev.	1060	46	988	154	610	118	653	39	756	28	752	34
Minimum	10	1	59	2	15	4	17	6	35	0	5	1
Maximum	4300	150	3140	504	1950	368	2100	116	2870	94	2800	114
N	19	10	19	10	19	10	19	10	19	10	19	10
% Obs. > TCEQ Std*	42.1	0	52.6	10	78.9	0	47.4	0	36.8	0	52.6	0

*TCEQ primary contact standard for FC is 400 cfu and 394 cfu for E-coli for a single sample.

E-coli has been reported as a more reliable indicator of bacterial contamination than FC (USEPA, 1986). Only one sample collected from 7/31/01 to 10/9/01 exceeded the TCEQ single sample criteria of 394 cfu/100 ml. This was at site 1B where homes were close enough to the stream for possible septic system contamination. E-coli concentrations are typically evaluated based on a geometric mean of 5 samples over a 30-day period. Two 30-day periods were analyzed, from 7/31/01 to 8/28/01, and from 9/11/01 to 10/9/01. No E-coli samples exceeded the TCEQ 30-day standard of 126 cfu/100 ml during these periods. E-coli concentrations were not significantly different between monitoring sites. E-coli data displayed less overall variation between sites (Table 1) and tended to be more reflective of land use conditions indicating that E-coli may be a better indicator of fecal contamination.

Broiler Litter/Grazing Impacts

Differences on FC concentrations between upstream forested and downstream pastured sites were not significant at the 95% probability level for Pair #2 and #3 as analyzed by the Wilcoxon sighed rank test (nonparametric test for related samples). The medians for upstream sites were even higher than for the downstream sites in these two pairs. Although FC concentrations at 1A (Pair #1) were significantly lower than those at 1B, the overall differences were insignificant when all three A (forested) sites were compared with all three B sites. The means were 659 and 699 cfu/100 ml for all A sites and B sites, respectively, while the medians were 450 and 340 cfu/100 ml, in the same order. In southeastern West Virginia, FC concentrations in karst groundwater in forested (80% of total land area) watersheds were not significantly different from those in livestock production watersheds (79%) (Pasquarell and Boyer, 1995).

The two sites of pair #1 were located on a second-order channel along Waffelo Creek. The area above 1A was fully covered by mature southern pine forests with only natural bacterial sources. Distance between 1A and 1B was about 0.6 km with open pastureland on both sides of stream channel. Impacts of grazing and broiler litter applications on bacteria water quality were clearly demonstrated at these two sites. However, site 1A had observed 4,300 cfu/100 ml on September 4, 1996, greater than its downstream pasture site by about 8 times and the highest concentration in the entire study. This indicates that forested watersheds do not necessarily have lower FC concentrations than other land uses at all times. Wildlife activities can cause FC concentrations in forested watersheds to be similar to pastured watersheds with grazing activities. In a six- year study conducted in eastern Oregon, Tiedemann et al. (1987) reported that although the mean FC concentration for forested watersheds with no grazing (strategy A, 2.9; cfu/100 ml) was significantly lower than the other forested watersheds with grazing (strategy C; 5.7 cfu/100 ml), the un-managed forest watersheds could have FC concentrations exceeding 500 cfu/100ml.

Median FC concentrations at forested sites 2A and 3A were higher than those at pastured sites 2B and 3B. Small areas of pasture existed in the headwaters of 2A and 3A. If those small pasturelands in relatively remote areas had significant contributions to the high FC concentrations at sites 2A and 3A, then the FC should route to their downstream pastured sites 2B and 3B, only 1.5 km in distance. In this case, FC at sites 2B and 3B should be higher than sites 2A and 3A because of the additional contributions of FC from the B sites. Apparently, the patched pastures nested in forested areas could not provide satisfactory explanations for higher FC concentrations at the forested sites. This leads to the contribution of FC by wildlife activity in the forested areas as a cause, evidenced by the frequent sighting of wild hog rooting and wallowing and the highest values observed at 1A. It may suggest that, with riparian vegetation strips on both sides of stream, the current broiler litter land-application rates on pasturelands did not cause FC concentrations significantly higher than the wildlife activity would do to forested watersheds. No differences in E-coli concentrations were observed between sites, indicating that it may be the better criteria for evaluating potential bacteriological contamination.

Sources of Contamination

The fecal coliform/fecal streptococcus (FC/FS) ratio may be used as an indicator for possible sources of bacteria contamination -- human sources for FC/FS ratios > 4.0, domestic animal sources for ratios 0.1 - 0.7, and wildlife sources for ratios < 0.1 (Geldreich, 1976). Howell et al. (1995) used a FC/FS ratio of 0.1 to 4.0 to indicate domestic animal contamination. However, ratios greater than 2.5 had also been used as an indication of the contamination sources as predominantly human wastes (Gary et al., 1983).

Mean FC/FS ratios ranged from 0.93 at 1A to 3.1 at 1B, indicating domestic sources of contamination at all sites based on Geldreich (1976) and Howell et al. (1995). Site 1A was fully covered by mature southern pine forests with no potential sources of bacteria other than wildlife. Therefore, a FC/FS ratio of less than 0.1 was expected. However, the FC/FS ratio was never less than 0.1, indicating that the calculated source of contamination by FC/FS ratio was inconsistent with land use at this site. On the other hand, a FC/FS ratio greater than 4.0 occurred in three out of nine months or 30% of the observations at site 1B, suggesting possible sources of human contamination. There were residences immediately upstream of the 1B sampling-site. The domestic sewage disposal systems of these residences could bacteriologically contaminate streamflow through underground drainage, overland runoff, and sediment movement.

These results indicate that there were variations in the consistency of FC/FS ratios as indicators for sources of bacteria contamination in the study areas. Many other studies have also reported that the FC/FS ratio is questionable in distinguishing contamination between human and non-human sources (Doran and Lin, 1979; Howell et al., 1995; Edwards et al., 1997; Boyer and Pasquarell, 1999). This is due to FC/FS levels different from levels at defecation because of: 1) different mortality rates of FC and FS, 2) distance of animal activity to stream channels, 3) rainfall and runoff, 4) watershed characteristics, and 5) regrowth and residence durations. In the present study, if a ratio of 2.5 was used as the human contamination criterion instead of 4.0, this would provide a more realistic indication for these study watersheds. However, this study covered only nine monthly measurements at six sampling site along three stream channels and all samples were collected during baseflow periods. Data were sufficient to characterize bacteria water quality conditions, but not sufficient to make reassessments of the FC/FS ratio criteria.

Aquatic Environment and Bacteria

Simple correlation coefficients (r) between FC concentrations and other streamflow characteristic parameters including discharge rate, water temperature, DO, salinity, EC, and pH were low, ranging from 0.027 to –0.587. Water pH was the only parameter with significant r-values (-0.509 for A sites and –0.587 for B sites) at the 95% probability level. None of the other five parameters had r-values higher than 0.16. Studies on five stream characteristics in Oregon also reported that pH and turbidity were significant, while discharge, conductivity, and temperature were not correlated with FC concentrations (Tiedmann et al., 1987).

In Idaho, Stephenson and Street (1978) reported that, except for water temperature and possibly chloride, total and FC concentrations did not show a definitive relationship with physical and chemical parameters in the Reynolds Creek watershed. Edwards et al. (1997) also reported that runoff has no effect on FC, but a relationship between bacterial concentrations and hydrologic regime was demonstrated by Robbins et al. (1972).

The relationships between FC concentrations and hydrologic characteristics cited above were quite varied, reflecting the complexity of bacterial production, transport, and life span in conjunction with livestock management, litter application rate and schedule, precipitation and overland flow, soil conditions, and aquatic environment. In many cases, the sampling schemes used in enumerating bacteria concentrations are not sufficient to describe the temporal and spatial variation in a consistent manner. As stated by Stephenson and Street (1978), variations in livestock management along the streams often overshadowed the effects of aquatic parameters. These make general relationships between bacterial pollution and grazing difficult to define and predictive models are difficult to develop (Edwards et al., 2000).

CONCLUSIONS

Fecal coliform concentrations exceeded the 200 cfu/100 ml contact recreation standards in more than 50% of the observations in the study watersheds, regardless of whether forested or pastured conditions, with or without poultry applications. With riparian vegetation strips on both sides of stream, the current broiler litter land-application rates on pasturelands did not cause FC concentrations significantly higher than the wildlife activity in forested watersheds. E-coli concentrations were found to be below TCEQ standards, displayed less variation between sites, and are perhaps a better indicator of bacteriological contamination. Analyses of the FC/FS ratios showed inconsistency in reflecting the sources of bacterial contamination, suggesting the necessity for reassessment of the ratio's applicability. Water pH was the only parameter significantly correlated ($r > 0.50$) with FC concentrations in the study areas. No significant correlation could be detected between FC concentrations and other aquatic parameters including stream discharge, temperature, salinity, specific conductance, and dissolved oxygen. The study covered only limited sample periods at six sites, a longer period of observations with greater sampling frequency at more study sites is necessary to address some variation observed in the present study.

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