Water Resources Research Institute
of The University of North Carolina

Report No. 398

EVALUATION OF SMALL MARINA IMPACTS ON BACTERIAL CONTAMINATION OF ESTUARINE WATERS

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July 2004

UNC-WRRI-398

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The research on which this report is based was supported by funds provided by the North Carolina Water Quality Workgroup Initiative. Contents of the publication do not necessarily reflect the views and policies of the State of North Carolina or the Department of Environmental and Natural Resources, nor does mention of trade names or commercial products constitute their endorsement by the State of North Carolina

This report fulfills the requirements for a project completion report of the Water Resources Research Institute of The University of North Carolina. The authors are solely responsible for the content and completeness of the report.

WRRI Project No. 50320
Agreement No. AE1002
July 2004

ACKNOWLEDGMENTS

The authors would like to thank the following individuals for their technical help in the field and laboratory: Karineh Samkian, Clifton Cameron, Jamie Kelly, and Daniel Govoni.

We thank the Water Quality Working Group of the Department of the Environment and Natural Resources funding the project and the Water Resources Research Institute for administering that funding.

ABSTRACT

A study of the cumulative impact of docking facilities on fecal coliform (FC) bacterial counts was done in the Broad Creek estuary of Pamlico County, North Carolina from April 2002 through March 2003. Six sites were selected and included an area of older suburban development, an undeveloped shoreline, two sites with adjacent docking facilities of < 10 slips each (pseudomarinas: one with six docks and a total of 11 slips and another with 4 docks and 24 slips), a marina with 22 slips and a site with new suburban development along the shore. Five locations were sampled within each site. Sampling was conducted on Thursdays and again the following Mondays to capture any effects of weekend use of the docks. This paired temporal sampling was conducted monthly for April, September – March and twice monthly for May – August for a total of 32 dates. All samples were analyzed for FC and *E. coli*. The middle location at each of the five sites was also sampled for water depth, secchi depth, surface and bottom oxygen, salinity and temperature and surface turbidity, flow speed and flow direction. During this study almost all the FC were positive for *E.* coli. Analysis of mean FC at each site on each date (Wilcoxon Signed-Rank) yielded the following significant differences: Old development (OD) > new development (ND) = real marina (RM) > pseudomarina 1 (P1) = pseudomarina 2 (P2) > no development. Mean FC MPN (most probable number) counts were 43.3, 13.0, 12.7, 6.6, 6.1, and 4.5 respectively. There were no significant differences between paired Thursday and Monday samples when data was analyzed from the entire year or the summer only. Positive correlations of FC with water depth were noted for three sites (OD, UD, and P2) suggesting increases in counts as adjacent shorelines flooded. The year was moderately wet with one year rainfall for the period 3/15/-2 – 3/14/03 of 65.7 inches. Average annual rainfall is approximately 55 inches. Positive correlations in FC as a function of rainfall occurring on the day of sampling or the previous day were noted for the OD and ND sites while positive correlations of FC with rainfall were noted for the UD, P1 and P2 sites when the rain had fallen 2 – 3 days prior to sampling. These data suggested that the areas of developed shoreline experienced increased FC due to local immediate runoff while the other sites had increases due to more remote sources of runoff. No strong correlations of FC as a function of environmental variables measured were noted except that counts increased at the OD site as sampling progressed upstream in the small embayment at that location.

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SUMMARY AND CONCLUSIONS

The Broad Creek estuary in Pamlico County, North Carolina is undergoing shoreline development typical for estuaries of the southeastern United States. Rapid growth in waterfront homes with their associated boat docks and increased surface runoff is coinciding with the proliferation of multiple docking facilities ("pseudomarinas") of less than ten slips each as well as permitted larger facilities. Such shoreline development and small docking facilities can be sited in estuarine shellfishing waters as a part of a general permitting process. Docking facilities of > 10 slips requires a more stringent permit review process as such facilities cause an automatic closure of the adjacent areas to shellfishing. The results of the research reported here suggest that the increasing areas of shellfish closures in estuarine waters is the result of all suburban development and that the degree of shoreline development is more significant than simply increased numbers of boat slips. Whether such conclusions can be extrapolated other similar estuarine areas requires additional information.

RECOMMENDATIONS

Based upon the results of this study we provide the following recommendations to the State of North Carolina:

1. To keep estuarine waters open for shellfishing, development along estuarine shorelines immediately adjacent to shellfish beds should not include piers and docking facilities and should require complete control (elimination) of surface runoff from adjacent shoreline as development proceeds.

2. If additional studies find that the cumulative impact of the < 10 slip marinas (pseudomarinas) is no greater than that of new development with individual docks then the focus of regulatory changes should probably be on total docking area per foot of shoreline as opposed to number of slips.

3. Although this study did not address the ongoing discussions of “oyster gardening” off private docks, the data do suggest that the waters under and adjacent to private docks may well have FC counts that exceed standards for shellfish consumption. Prior to harvest for human consumption shellfish from such sources should be tested for FC and consumption prohibited if they exceed the sanitary standard.

INTRODUCTION

Elevated fecal coliform bacteria counts in estuarine surface waters are associated with multiple forms of anthropogenic disturbances of the adjacent shoreline (Kirby-Smith and Barber 1979, Paerl 1990, EPA 1993, NCDEHNR 1993, NCDEHNR 1994, APES 1994, White et al. 1999a, White et al., 1999c) and wildlife (Presnell and Miescier 1971, Simmons et al. 1995, Kirby-Smith 1994, Desper 1997). Increasing development and population growth along the North Carolina coast has been accompanied by the proliferation of full-sized marinas around which elevated levels of fecal coliform and *E. coli* bacteria have been observed (Garreis et al. 1979, Fisher et al. 1987, Australian Environment Council 1988, NCDEM 1990, Ott 1992). In 2000 the coastal waters of North Carolina currently had 227 CAMA permitted marinas, defined as having more than 10 boat slips, and 421 CAMA permitted boat docking facilities with less than 10 slips (Lopazanski 2000). The North Carolina Department of Environment and Natural Resources (NCDEH) Shellfish Sanitation and Recreational Water Quality Section (SSRWQ) automatically closes the waters for shellfishing around > 10 slip CAMA permitted marinas according to a formula which includes marina type and number of boat slips. The <10 slip docking facilities, which are the focus of this study, are not classified as marinas and are permitted in open shellfish waters. However, SSRWQ reports that an increase in close proximity of <10 slip facilities in combination with increased development may cause subsequent closure of additional acreage to shellfishing (Gilbert 2000). This project addressed the question of whether waters around these <10 slip boat docking facilities should also be automatically closed to shellfishing. Furthermore, the possible discharge of raw sewage at developed sites without septic systems is a serious health concern, and since the proliferation of <10 slip boat docking facilities is also associated with increased recreational uses of the water, this may be a policy standard that shellfish management needs to review to adequately protect human health and estuarine water quality. In this report these boating facilities are referred to as “pseudomarinas”.

METHODS

The study site was selected in consultation with the North Carolina Shellfish Sanitation and Recreational Water Quality Section (SSRWQ) and the North Carolina Division of Water Quality (DWQ). The goal was to intensively sample an estuarine creek system containing a spectrum of development including a marina, less-than 10 slip dock facilities and undeveloped areas. The site was also to have known elevated fecal coliform bacteria counts as measured by the SSRWQ (Gilbert 2000). Following consultation and a field survey with SSRWQ, Broad Creek estuary in Pamlico County was selected. Broad Creek has a broad spectrum of land use and boat docking facilities. The watershed is woodland with some agricultural operations and includes an increasing number of subdivisions, marinas and docking facilities.

The study site is located within an area classified as *Area F-5* by the SSRWQ. They have sampled this area for fecal coliform bacteria since the 1970's, and in the most recent Report of Sanitary Survey prior to the start of this project (April 2000), 9 of 19 sampling stations were closed to shellfish harvesting due to elevated levels of fecal coliform bacteria. Fifteen of 19 stations demonstrate further water quality degradation since the last triennial survey report in 1998. In addition, the number of acres of water open to shellfishing at this site has declined in recent years as development, including boat docking facilities, has increased (Gilbert 2000).

Within Broad Creek six sampling areas were selected: (1) An older suburban development along the water referred to in this report as OD; (2) Area of undeveloped shoreline referred to here as UD; (3) An area with multiple adjacent <10 slip docking facilities referred to here as pseudomarina 1 or P1; (4) A second area with multiple adjacent <10 slip docking facilities referred to here as pseudomarina 2 or P2; (4) An area of shoreline with obviously newly built homes referred to here as new development or ND; (5) A CAMA permitted >10 slip marina referred to here as real marina or RM.

Within each of the sites, five locations were identified to collect samples and their location defined by global positioning satellite (Table 1). The locations were regularly spaced along the shoreline. The old development site was in a small embayment with modest wood frame and concrete block residences. There were approximately 10 docks scattered throughout the area with several small commercial fishing vessels tied or onshore. The sampling locations were approximately 50 feet offshore near the junctions of smaller tributaries of the embayment. The undeveloped shoreline was located on the south shore of the lower part of the estuary in an area with no development. Sampling locations were widely spaced and located approximately 75 – 100 feet offshore. Pseudomarina 1 was located on the north shore and consisted of six very long adjacent docks but with only a few slips (11) located at the ends of the docks. Samples were taken between the adjacent docks about halfway out or approximately 100 feet off shore. Pseudomarina2 was located further upstream in Broad Creek at a location much narrower than pseudomarina 1. At this site there were fewer docks (4) but they were shorter and contained a larger number of slips (24) taking up over half the length of the docks. Samples were taken just outside and between the adjacent docks approximately 100 feet offshore. The new development area was located along the western shore of the lower part of Brown's Creek tributary. The entire shoreline has been subdivided and many of the lots have homes with small docks, each with one or two slips for small boats. The real marina was located at the junction of Browns Creek and the main axis of Broad Creek and extended approximately 400 ft. into the channel. There were approximately 22 slips suitable for large sail or power boats. Samples here were taken on either side of the marina and near the tip of the marina. We estimated that during the course of the study approximately 50 – 75% of the slips in all three docking facilities were occupied by large boats but there were few if any “live aboards”.

Table 1. Sampling locations (Latitude and longitude) in Broad Creek, Pamlico County, North Carolina.

OD1	35 5.829 76 36.430	UD1	35 5.387 76 36.342	P11	35 5.512 76 37.555
OD2	35 5.814 76 36.494	UD2	35 5.209 76 36.475	P12	35 5.507 76 37.506
OD3	35 5.811 76 36.530	UD3	35 5.258 76 36.628	P13	35 5.498 76 37.473
OD4	35 5.778 76 36.518	UD4	35 5.283 76 36.809	P14	35 5.491 76 37.442
OD5	35 5.731 76 36.502	UD5	35 5.259 76 36.998	P15	35 5.491 76 37.407
P21	35 5.406 76 38.166	DS1	35 5.802 76 38.165	RM1	35 5.605 76 37.749
P22	35 5.412 76 38.105	DS2	35 5.801 76 38.135	RM2	35 5.580 76 37.749
P23	35 5.424 76 38.082	DS3	35 5.761 76 38.102	RM3	35 5.559 76 37.735
P24	35 5.434 76 38.051	DS4	35 5.725 76 38.080	RM4	35 5.579 76 37.720
P25	35 5.441 76 38.025	DS5	35 5.677 76 38.066	RM5	35 5.601 76 37.722

The sampling strategy was to visit the Creek on Thursday and again on Monday with these paired sample dates done monthly in the cooler months and biweekly in the summer from Memorial Day through Labor Day weekends. Sampling began in April, 2002 and was completed in March, 2003. There were 32 dates sampled or sixteen Thursday Monday pairs. The intent in the temporal pairing was to examine possible increases in fecal coliform bacteria that might be associated with increased weekend use of the vessels. At each of the 5 locations in the 6 areas water samples were taken approximately 10 cm below the surface. Samples for bacterial analysis were collected in sterile 125-ml plastic bottles while water for the other analyses was collected in 500 ml bottles. Samples were placed on ice in a cooler and returned to the laboratory for analysis.

A recording tide gage was placed on a dock at the junction of Brown’s Creek with Broad Creek. The recorder operated from late May, 2002 to early February, 2003. The relative water level was recorded every 10 minutes and the data for each day averaged. Rainfall was obtained from NOAA for Bayboro, NC, located approximately 10 miles northwest of Broad Creek.

Bacterial analysis was conducted according to *Standard Methods* (American Public Health Association 1995) using the five tube dilution method with A-1 media to which Mug had been added. From these analyses we obtained most probable numbers (MPN) for both fecal coliform bacteria and for those that tested positive (almost all) as *E.* coli. In the field salinity, temperature and dissolved oxygen was measured near the surface and near the bottom using Yellow Springs Instrument meters. Water depth and Secchi depth were determined and water current speed and direction were measured with a Marsh-McBirney velocity meter. Turbidity was measured in the laboratory with a Hach nepholometer.

Statistical analysis was done using Statmost® analytical software.

RESULTS

The results of the marina study fall into two major categories; those associated with the fecal coliform bacteria counts relative to land/water use categories, referred to here as sites (Appendix 1) and those associated with the environmental variables measured (Appendix 2).

Within Site Comparisons (Table2)

Table 2 . Within Site Comparisons. Wilcoxon Signed-Rank "p" values comparing all dates sampled(n= 32) for fecal coliform bacteria MPN for five locations within an adjacent land use (sites) and the geometric means of each of the five locations for each date for the six land uses. OD = old suburban development, UD = undeveloped shore, P1 = pseudomarina 1, P2 = pseudomarina 2, ND = new suburban development, and RM = real marina.

Site	OD1	OD2	OD3	OD4	OD5	Site	UD1	UD2	UD3	UD4	UD5
OD2	<.001					UD2	0.31				
OD3	<.001	0.44				UD3	0.71	0.95			
OD4	<.001	0.74	0.37			UD4	0.55	0.98	0.78		
OD5	<.001	0.04	0.03	0.09		D5	0.07	0.01	0.04	0.08	
GM	114	45	40	38	19	GM	4.0	4.3	4.1	4.4	6.0
Site	P11	P12	P13	P14	P15	Site	P21	P22	P23	P24	P25
P12	0.15					P22	0.01				
P13	0.74	0.65				P23	0.14	0.12			
P14	0.74	0.14	0.67			P24	0.28	0.01	0.54		
P15	0.75	0.62	0.97	0.37		P25	0.25	0.19	0.66	0.66	
GM	6.2	7.4	7.2	5.9	6.5	GM	7.6	4.9	6.3	6.3	5.8
Site	ND1	ND2	ND3	ND4	ND5	Site	RM1	RM2	RM3	RM4	RM5
ND2	0.22					RM2	0.05				
ND3	0.08	0.95				RM3	0.03	0.91			
ND4	0.07	0.63	0.42			RM4	0.68	0.02	0.01		
ND5	0.15	0.88	0.82	0.68		RM5	0.55	0.1	0.02	0.83	
GM	17.8	11.5	11.7	12.7	12.3	GM	13	9.6	9.6	16.3	16.6

The geometric mean fecal coliform MPN's at the site with mostly older homes (OD) ranged from 19 to 144 (Table 2). The site was in a small enclosed embayment with limited circulation. The innermost location (OD1) had significantly higher mean bacterial counts (MPN 114) than any of the other four locations ($p<0.001$) while the outermost site had significantly lower counts (MPN 19) compared to the other four locations ($p<0.10$). As might be expected in a small estuarine creek surrounded by residential development, there was a regular decrease in FC-MPN as we sampled from the inner-most site at the junction of two small upstream basins (OD1), out to the mouths of two other small basins (OD2, OD3), to a point halfway out the embayment (OD4), and ending at the embayment mouth (OD5). There were no significant differences in MPN among middle sites OD2, OD3, and OD4.

The geometric mean fecal coliform counts were low along the undeveloped shoreline (UD), ranging from a geometric mean of 4.0 to 6.0 MPN(Table 2). Location UD5 had significantly higher counts MPN 6.0) than the other four locations ($p< 0.10$). There were no significant differences among the other locations.

The geometric mean fecal coliform MPN's within the first pseudomarina (P1) were low, with geometric means ranging from 5.9 – 7.4 (Table 2). The site was in open waters with the multiple docking facilities extending out into the estuary. There were no significant differences among the five locations sampled.

The geometric mean fecal coliform MPN's within the second pseudomarina (P2) ranged from 4.9 to 7.6 (Table 2). This site was upstream from the P1 site where the estuary was considerably narrower. Site P21 had significantly higher counts than site P22 ($p = 0.01$) and site P24 had significantly higher counts than site P22 ($p = 0.01$). None of the other sites were significantly different than each other.

The geometric mean fecal coliform MPN's along the newly developed (ND) shoreline ranged from 11.5 to 17.8 (Table 2). The area sampled was up into Brown Creek in an area approximately the same width as P2 but oriented north to south. Most of the shoreline of the creek had recently built homes with a lot of trees and shrubs left on the lots. Most of the homes had a small dock extending a short distance into the estuary. The sampling locations were along in the middle of this shoreline. Location ND4 was significantly higher than ND1 ($p = 0.07$), otherwise there were no significant differences among the locations.

The geometric mean fecal coliform MPN's at the real marina (RM) sampling locations ranged from 9.6 to 16.6 (Table 2). The marina extended several hundred feet into the estuary and perpendicular to the shoreline. The sampling locations were located at the end of the marina (RM3) and along either side (RM1 and RM2 to the west, RM4 and RM5 to the east). There were a number of cases where MPN's were significantly different among the locations but they did not form a consistent hierarchy in these comparisons. RM5 was significantly higher than RM3 but not RM2 while RM4 and RM1 were both significantly higher than both RM2 and RM3.

Among Site Comparisons (Table 3)

Table 3. Among site Comparisons. Wilcoxon Signed-Rank “p” values comparing all dates sampled (n= 32) for fecal coliform bacteria MPN for the geometric means of five locations within an adjacent land use (Sites). OD = old suburban development, UD = undeveloped shore, P1 = pseudomarina 1, P2 = pseudomarina 2, ND = new suburban development, and RM = real marina.

Land Use	**OD**	**UD**	**P1**	**P2**	**ND**	**RM**
UD	<.001					
P1	<.001	<.001				
P2	<.001	0.05	0.80			
ND	<.001	<.001	.002	.004		
RM	<.001	<.001	.004	<.001	0.93	
Geomean	43.3	4.5	6.6	6.1	13.0	12.7

The hierarchy of significant differences in MPN’s based on adjacent land use was “Old Development” > “New Development” and “Real Marina” > “Pseudomarina 1” and “Pseudomarina 2” > “No Development”. The old development site (OD) stood out from the others in its high geometric mean MPN (43.3: Table 3). This relatively high count is not surprising in that the site was a very small embayment, surrounded by houses with septic systems and domestic pets, and with lawns slopping to the waters edge. Many of these lawns had no fringe marsh or other vegetated buffer and most of the houses had small docks. There is limited water circulation within the embayment. There were no “live aboard” boats and many of the vessels appeared to be use in small commercial fishing operations.

The second highest geometric mean FC MPN (13.0; Table 3) was the new development (ND) located on the lower part of the western shore of the Brown Creek tributary of Broad Creek. In this location the estuary is approximately 750 ft. wide and both shores upstream and downstream of the site sampled have a number of houses along the shore. Along the opposite or eastern shore is a “pseudomarina” that was not sampled in this study. The second place ranking of FC MPN was not expected. In selecting the site we had hypothesized the presence of recently installed septic systems and the presence of significant marsh and/or vegetated buffers might have meant MPN counts in adjacent waters that were lower that waters adjacent to the other land uses (except for OD). Most of the houses along the shore were set back somewhat from the shore. However, all along both shores most of the houses docks that could accommodate several small boats. Because of it openness to wind stress water circulation was good although probably not as good at the other sites except OD.

The real marina (RM) had the third highest geometric mean FC MPN (12.7; Table 3) was essentially the same as the ND site. The counts were generally much lower than we expected. When we picked the site we believed that there would be a significant number of larger recreational vessels with a significant “live aboard” population for short periods in the warmer months. This marina had 43 slips with 70 – 90% occupied, mainly by relatively large recreational vessels (sail and power) which would have had heads. There is no pump out facility on site. The marina is located in a very open site and has very good water circulation which may account for the relatively low MPN's.

The two pseudomarina sites (P1, P2) had essentially the same FC MPN (6.6, 6.1; Table 3). The P1 site has 6 very long docks approximately 11 slips while P2 has 4 shorter docks with approximately 24 slips. Both were designed for large recreational boats. As with the real marina the counts at P1 and P2 were much lower than we had expected. Like the real marina. P1 area is very open while P2 is in a much narrower section of the creek. Both have very good water circulation.

As expected, the undeveloped shoreline site (UD) had the lowest count, a geometric mean FC MPN of 4.5 (Table 3). The sampling locations were located approximately the same distance from land as the P1, P2, and ND sites but along the southern shore of the lower part of the Broad Creek estuary. The site was undeveloped forest land owned by Weyerhaeuser Company. During the course of the study a few signs of the new Gum Branch development appeared in the form of survey markers and a single narrow clearing perpendicular to the shore but not reaching the shore.

The results of the analysis of the paired Thursday with Monday sampling (Table 4) suggest there was no difference between FC counts before and after weekends, even in the summer when we expected significantly more boating activity associated with weekends. For the whole year analysis there were higher counts for the Thursday versus the Monday samples for 'All" data together ($p = 0.10$) and for the old development ($p = 0.03$) but there were no differences approaching significance for the summer only data..

Table 4. Geometric mean FC MPN and "p" values Wilcoxon Signed-Rank for a comparison of samples collected on Thursday with those collected the following Monday, April 2002 – March 2003. Summer is defined as May 15 - September 14. For "All Year" individual sites n = 80 (16 pairs for each site X 5 stations per site), for "All Year" "All Sites" n = 480 (16 pairs for each site X 5 locations per site X 6 sites), for "Summer" individual sites n = 40 (8 pairs for each site X 5 stations per site), and for "Summer" "All Sites" n = 240 (8 pairs for each site X 5 locations per site X 6 sites). OD = old suburban development, UD = undeveloped shore, P1 = pseudomarina 1, P2 = pseudomarina 2, ND = new suburban development, and RM = real marina.

All Year	**OD**	**UD**	**P1**	**P2**	**ND**	**RM**	**All Sites**
Thursday	53	4.7	6.6	6.1	15	15	11
Monday	35	4.3	6.6	6.2	10	10	9.5
"p" =	0.03	0.92	0.14	0.97	0.23	0.49	0.10

Summer	**OD**	**UD**	**P1**	**P2**	**ND**	**RM**	**All Sites**
Thursday	48	3.8	4.1	4.3	9.1	8.6	7.9
Monday	55	4.2	5.9	4.4	10	8.3	8.9
"p" =	0.29	0.90	0.55	0.97	0.88	0.50	0.29

Water Level and Current Velocity

Figure 1. Average daily water level recorded in Broad Creek from 5/02 to 2/03.

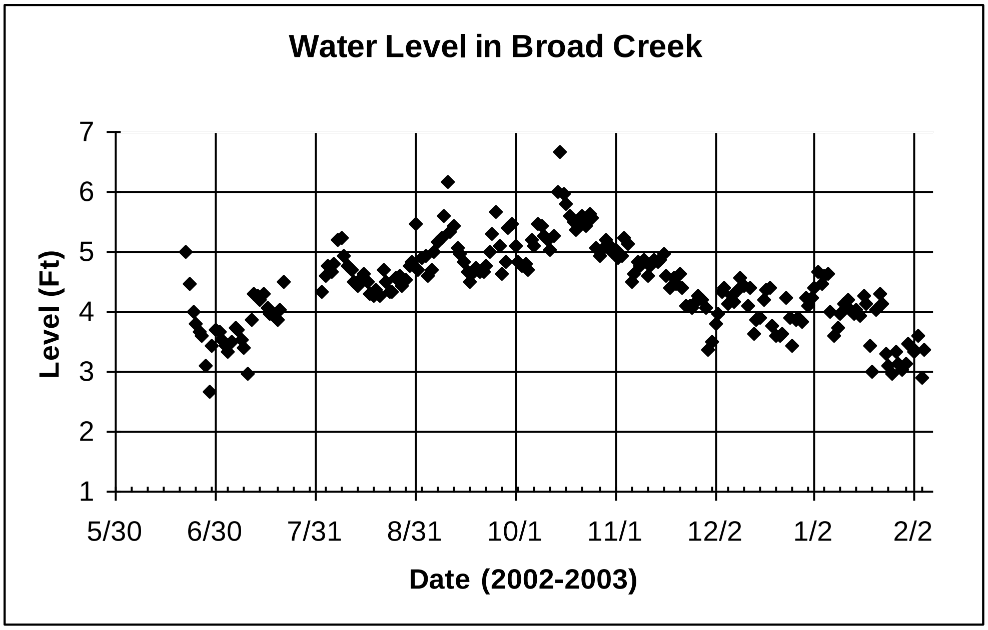


Table 5. Spearman correlation coefficients (CC) and probability (p) for fecal coliform bacteria MPN as a function of water levels recorded in Broad Creek from June 2002 – February 2004 (n= 17) and current velocities from April, 2002 – March, 2003 (n=28). OD = Old Development, UD = Undeveloped shore, P1 = Pseudomarina 1, P2 = Pseudomarina 2, ND = New Development, RM = Real Marina.

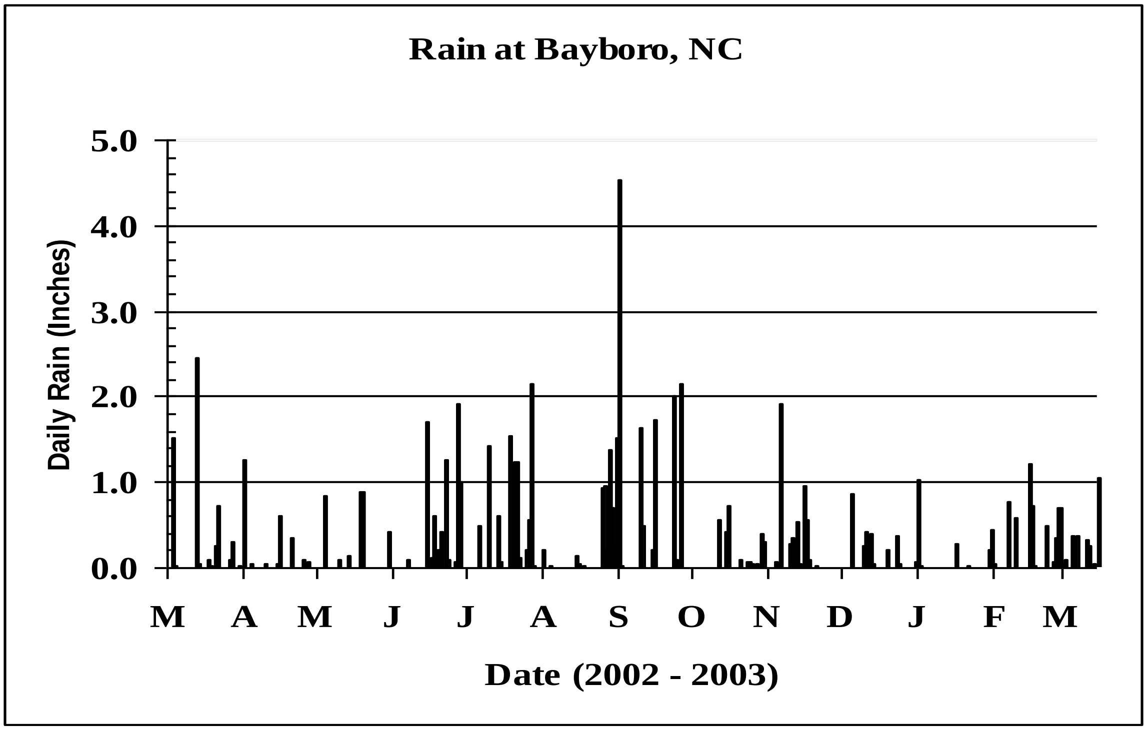
	Water Level		**Current Velocity**	
Site	**CC**	**p**	**CC**	**P**
OD	0.48	0.05	-0.09	0.66
UD	0.50	0.04	-0.09	0.65
P1	0.07	0.80	0.13	0.50
P2	0.63	0.01	-0.17	0.38
ND	0.37	0.14	0.39	0.04
RM	0.29	0.25	0.15	0.45

The water level recorder was installed in Broad Creek in the late spring of 2002 and provided a continuous record (level every 10 minutes) until February 2003. The data, averaged for each day (Figure 1), had a range of approximately 4 feet. Maximum depths were in the summer and early fall with minimum depths in winter and spring with an average difference of approximately 2 feet. Within each period there were oscillations of level of approximately 1 – 2 feet. The water level in Broad Creek is controlled by wind direction and responds to change in level in the Pamlico Sound caused by these winds. Wind from the west, northwest, north and northeast lower water levels while winds from the east (very infrequent), southeast, south and southwest cause water levels to increase.

Moderately strong correlations were observed between fecal coliform bacteria counts and water level at three sites (OD, UD, P2)(Table 5). It is possible that these are sites where significant fecal material deposited at the waters edge is brought into suspension. Alternately it may just mean tat at these sites highest counts were generally in the late summer coincident with highest seasonal water levels due to south west winds.

<u>Rainfall</u>

Figure 2. Total daily rainfall collected by NOAA at Bayboro, NC approximately 10 miles north west of Broad Creek.



During the course of the study, rainfall (Figure 2; Appendix 3) was frequent. Measurable rainfall occurred on 108 days with the majority days totals being less than 0.5 inches. The total rainfall for the period 3/15/02 – 3/14/03 was 65.7 inches. The one year average for eastern North Carolina is approximately 55 inches. The greatest daily rainfall during the project occurred on September 1 (4.53 inches) and followed rain of 1.53 inches on August 31 for a two day total of 6.06 inches. Over the one year project period there were 21 days with rainfall greater than 1.0 inches and 4 days with totals greater than 2 inches.

Correlation analysis was done to see what, if any, relationship existed between FC and previous day's rainfall (Table 6). The patterns of fecal coliform counts relative to rainfall fell into several distinct temporal and land use categories. In the old development and new development counts were moderately positively correlated with rainfall on the day of sampling and increased in correlation on day 1. Correlations decreased on day 2 but increased again for day 3 totals before tapering off for day 4 and 5. At the undeveloped site and the two pseudo-marinas there was no correlation with rainfall on the day of sampling and day 1 but on day 2 the correlation was extremely high, reaching 0.94 at the undeveloped site and 0.86 and 0.70 at the two pseudomarinas. On day three the correlation remained relatively high but then decreased to little or no correlation on days 4 and 5. At the real Marina site there was only a slight positive correlation of fecal coliform counts with rainfall, peaking on day 2 at 0.18.

Table 6. Correlation coefficients comparing fecal coliform counts with same day and prior day's rainfall. 0 Day = day sample was collected, OD = Old Development, UD = Undeveloped shore, P1 = Pseudomarina 1, P2 = Pseudomarina 2, ND = New Development, RM = Real Marina.

Correlations for each day's rainfall total separate from other days

	OD	UD	P1	P2	ND	RM
0 Day	0.467	-0.071	-0.099	-0.026	0.318	0.065
1 Day	0.631	-0.026	-0.033	0.092	0.393	0.042
2 Day	0.364	0.936	0.862	0.695	0.064	0.176
3 Day	0.450	0.496	0.479	0.526	0.606	0.161
4 Day	0.289	0.105	0.073	0.031	0.005	-0.030
5 Day	0.134	0.166	0.131	0.060	0.026	-0.055

Correlation for cumulative rainfall with preceding days added together

	OD	UD	P1	P2	ND	RM
0 Day	0.467	-0.071	-0.099	-0.026	0.318	0.065
1 Day	0.648	-0.047	-0.064	0.058	0.415	0.058
2 Day	0.648	0.806	0.733	0.644	0.259	0.186
3 Day	0.637	0.768	0.709	0.664	0.420	0.195
4 Day	0.650	0.738	0.677	0.627	0.394	0.177
5 Day	0.595	0.740	0.676	0.598	0.332	0.145

Correlations of fecal coliform counts with cumulative rainfall (Table 6) exhibited similar patterns to those for the days separately except that the correlation tended to remain high as the total rainfall amounts can only remain the same or increase in a cumulative analysis, tending to keep the correlations higher.

Water Quality Variables

The possible relationship between fecal coliform bacteria and water quality variables measure was examined by determination of correlation coefficients of FC with each variable at all sites lumped together as well as each site separately (Table 7). Environmental variables were measured at location 3 for each site so these data were paired with the FC counts from location 3 for correlation analysis. Overall there were no strong correlations that could be used to provide predictive value in interpreting fecal coliform counts

For "All" sites combined the correlation coefficients were extremely weak. The greatest positive correlation (0.20) of FC was with turbidity while the largest negative correlation (-0.18) was with depth.

Table 7. Correlation coefficients for fecal coliform bacteria MPN (FC) with the environmental variables measured for data from all sites together (ALL) and for each site separately (OD = Old Development, UD = Undeveloped, P1 = Pseudo-marina 1, P2= Pseudomarina 2, ND = New Development, RM = Real Marina, Tur = turbidity, S Su = surface salinity, S Bt. = bottom salinity, T Su. = surface temperature, T Bt. = bottom temperature, O Su = surface oxygen, O Bt = bottom oxygen, D = water depth meters, SD = Secchi depth meters. For each location the data are sorted from the greatest negative correlation coefficient to the greatest positive value.

All		OD		UD	
Tur	0.20	Tur	0.48	D	0.44
S Bt	0.15	S Bt	0.28	S Bt	0.16
S Su	0.07	S Su	0.21	T Su	0.15
O Bt	0.07	D	0.20	T Bt	0.11
O Su	0.04	T Bt	0.10	O Su	-0.09
T Bt	-0.03	T Su	0.08	Tur	-0.19
T Su	-0.04	O Bt	-0.06	SD	-0.22
SD	-0.10	O Su	-0.08	O Bt	-0.24
D	-0.18	SD	-0.12	S Su	-0.27

P1		P2		ND		RM	
O Su	0.25	S Bt	0.44	O Bt	0.28	D	0.34
O Bt	0.23	D	0.23	O Su	0.25	O Su	0.30
S Bt	0.17	Tur	0.15	D	0.16	SD	0.28
S Su	0.15	T Su	0.07	SD	0.10	O Bt	0.27
D	0.04	T Bt	0.04	S Bt	-0.04	S Bt	0.23
SD	0.01	SD	-0.01	S Su	-0.18	S Su	0.06
Tur	-0.19	O Su	-0.05	T Bt	-0.18	Tur	-0.11
T Bt	-0.33	S Su	-0.06	T Su	-0.21	T Bt	-0.18
T Su	-0.34	O Bt	-0.14	Tur	-0.26	T Su	-0.21

For the OD site the greatest positive correlation (0.48) was with turbidity was due to the fact that one of the higher FC counts (490) coincided with the greatest turbidity (25 NTU) measured at this site, a value more than double the next highest turbidity observed. The negative correlations of FC with environmental variables were all extremely weak.

For the UD site the greatest positive correlation (0.44) was FC with depth. The only really high counts at this site occurred on 9/3/2002 (MPN = 240) on the same day as the maximum depth (1.95 m) was measured for this site. A slight negative correlation was observed between FC counts and surface salinity (-0.27o/oo).

For the P1 site the greatest positive correlation of FC (0.25, 0.23) was with surface and bottom oxygen while the largest negative correlation (-0.33, -0.34) was with surface and bottom temperature. Since cold water has higher oxygen concentrations this inverse relationship is not surprising. These high and low correlations were due to one extremely high FC count (540) that occurred on 12/4/2002, a day with unusually low temperature (7.5^{o}C) for the season following a northeast storm.

For the P2 site the relatively high positive correlation of FC with bottom salinity (0.44) was due to the highest FC count at this site (79) occurring on the day (9/3/2002) with the highest bottom salinity (24.3o/oo).

For the ND site the correlations were similar to those observed at P1 with a direct correlation with oxygen and an inverse correlation with temperature. However, it the case of ND the correlations appeared related to the generally higher FC counts at this location during the cooler months.

For the RM site a single high FC count (170) on 1/10/2003 appeared to cause the same direct and inverse correlation patterns with oxygen and temperature as was observed at P1 and ND.

Differences in mean current velocity (Table 8) probably indicate relative water exchange at each of the sites such that sites with significantly higher velocities have higher exchange rates. Significant differences existed among the sites with ND, RM, and P2 > P1 > UD > OD. The marinas (RM, P1, and P2) and the new development (ND) shorelines had significantly greater water exchange than the old development (OD) or the undeveloped shoreline (UD). The weak positive correlations of FC with current speed at the ND and RM sites suggest that FC at these sites might be coming from outside of the immediate area. If FC bacteria are originating within a sampling area we would expect increased current velocities (thus exchange) to cause the FC counts to decrease. The very weak negative correlations at P2 and OD fall into this latter category

Table 8. Wilcoxon Signed-Rank “p” values comparing current velocity (cm/sec) at the five Sites with each other (n = 32). OD = old suburban development, UD = undeveloped shore, P1 = pseudomarina 1, P2 = pseudomarina 2, ND = new suburban development, and RM = real marina. FC vs. Cur. Data are Spearman correlation coefficients for FC MPN as a function of current speed at each site. Mean current velocity is given at the bottom of the table.

Land Use	**OD**	**UD**	**P1**	**P2**	**ND**	**RM**
UD	.034					
P1	.001	.005				
P2	<.001	0.003	.126			
ND	.001	.017	.407	.520		
RM	<.001	<.001	.019	.355	.247	
Mean (cm/s)	**4.7**	**6.5**	**8.1**	**9.9**	**9.2**	**10.3**

The multiple correlation analysis of environmental variables with each other yielded the expected strong positive and negative coefficients (Table 9). The strongest positive correlations were between pairs of surface and bottom environmental variables (temperature = 0.98, salinity = 0.79 and oxygen = 0.89). There were strong positive and negative correlations among temperature, turbidity, Secchi depth and dissolved oxygen that were related to the fact that estuarine waters are much clearer in the colder months due to reduced phytoplankton production (higher Secchi, lower turbidity) and because colder water holds more oxygen.

Table 9. Multiple correlation coefficients for environmental variables (Turb = turbidity, S Su. = surface salinity, s Btm = bottom salinity, T Su. = surface temperature, T Btm = bottom temperature, O Su. = surface oxygen, O Btm = bottom oxygen, Depth = water depth, Secchi = Secchi depth)for all samples together (ALL) and for each land use (OD = Old Development, UD = Undeveloped, P1 = Pseudo-marina 1, P2= Pseudomarina 2, ND = New Development, RM = Real Marina)

<u>All</u>

	Turb	*S Su.*	*S Btm*	*T Su*	*T Btm*	*O Su.*	*O Btm*	*Depth*	*Secchi*
Turb	1.00								
S Suf.	0.30	1.00							
S Btm.	0.19	0.79	1.00						
T Suf.	0.43	0.02	0.06	1.00					
T Btm.	0.44	0.04	0.03	0.98	1.00				
O Suf.	-0.35	-0.08	-0.09	-0.78	-0.79	1.00			
O Btm.	-0.34	-0.10	-0.22	-0.71	-0.68	0.89	1.00		
Depth	-0.05	0.03	0.08	-0.02	-0.01	0.04	-0.03	1.00	
Secchi	-0.39	0.16	0.08	-0.75	-0.74	0.63	0.63	0.23	1.00

<u>OD</u>

	Turb	*S Su.*	*S Btm*	*T Su*	*T Btm*	*O Su.*	*O Btm*	*Depth*	*Secchi*
Turb	1.00								
S Suf.	0.26	1.00							
S Btm.	0.21	0.97	1.00						
T Suf.	0.11	0.04	0.00	1.00					
T Btm.	0.12	0.05	0.01	1.00	1.00				
O Suf.	-0.05	-0.04	-0.01	-0.85	-0.85	1.00			
O Btm.	-0.06	-0.05	-0.04	-0.75	-0.76	0.94	1.00		
Depth	-0.21	-0.04	0.08	-0.07	-0.09	0.05	0.15	1.00	
Secchi	-0.29	0.08	0.12	-0.60	-0.61	0.57	0.64	0.60	1.00

<u>UD</u>

	Turb	*S Su.*	*S Btm*	*T Su*	*T Btm*	*O Su.*	*O Btm*	*Depth*	*Secchi*
Turb	1.00								
S Suf.	0.43	1.00							
S Btm.	0.30	0.86	1.00						
T Suf.	0.57	0.13	0.11	1.00					
T Btm.	0.57	0.00	0.04	0.95	1.00				
O Suf.	-0.58	-0.17	-0.19	-0.76	-0.80	1.00			
O Btm.	-0.57	-0.21	-0.30	-0.69	-0.70	0.91	1.00		
Depth	0.14	0.03	0.18	0.03	-0.03	0.00	-0.01	1.00	
Secchi	-0.51	0.23	0.16	-0.80	-0.82	0.68	0.69	0.06	1.00

<u>P1</u>

	Turb	*S Su.*	*S Btm*	*T Su*	*T Btm*	*O Su.*	*O Btm*	*Depth*	*Secchi*
Turb	1.00								
S Suf.	0.22	1.00							
S Btm.	0.16	0.91	1.00						

T Suf.	0.46	-0.06	-0.02	1.00					
T Btm.	0.45	-0.03	-0.01	1.00	1.00				
O Suf.	-0.39	0.01	0.03	-0.82	-0.84	1.00			
O Btm.	-0.38	0.01	-0.05	-0.74	-0.75	0.91	1.00		
Depth	0.21	0.12	0.26	-0.06	-0.09	0.01	-0.09	1.00	
Secchi	-0.36	0.29	0.24	-0.77	-0.77	0.78	0.73	0.11	1.00

P2

	Turb	*S Su.*	*S Btm*	*T Su*	*T Btm*	*O Su.*	*O Btm*	*Depth*	*Secchi*
Turb	1.00								
S Suf.	0.40	1.00							
S Btm.	0.29	0.79	1.00						
T Suf.	0.54	-0.08	0.00	1.00					
T Btm.	0.58	-0.03	0.01	0.99	1.00				
O Suf.	-0.49	0.05	0.02	-0.72	-0.75	1.00			
O Btm.	-0.51	0.03	-0.12	-0.71	-0.71	0.90	1.00		
Depth	0.11	0.10	0.24	0.08	0.10	-0.12	-0.10	1.00	
Secchi	-0.42	0.27	0.15	-0.80	-0.79	0.61	0.65	-0.13	1.00

ND

	Turb	*S Su.*	*S Btm*	*T Su*	*T Btm*	*O Su.*	*O Btm*	*Depth*	*Secchi*
Turb	1.00								
S Suf.	0.44	1.00							
S Btm.	0.24	0.79	1.00						
T Suf.	0.58	0.02	-0.02	1.00					
T Btm.	0.60	0.05	0.01	0.99	1.00				
O Suf.	-0.44	-0.21	-0.14	-0.78	-0.80	1.00			
O Btm.	-0.41	-0.24	-0.29	-0.70	-0.72	0.91	1.00		
Depth	-0.09	-0.08	0.18	-0.13	-0.10	0.04	0.04	1.00	
Secchi	-0.38	0.23	0.14	-0.81	-0.79	0.60	0.56	0.10	1.00

RM

	Turb	*S Su.*	*S Btm*	*T Su*	*T Btm*	*O Su.*	*O Btm*	*Depth*	*Secchi*
Turb	1.00								
S Suf.	0.26	1.00							
S Btm.	0.14	0.68	1.00						
T Suf.	0.50	-0.07	0.03	1.00					
T Btm.	0.53	0.05	-0.11	0.92	1.00				
O Suf.	-0.49	-0.01	-0.10	-0.72	-0.66	1.00			
O Btm.	-0.56	-0.10	-0.34	-0.68	-0.56	0.85	1.00		
Depth	0.11	0.30	-0.13	-0.24	0.08	0.20	0.25	1.00	
Secchi	-0.39	0.24	0.07	-0.80	-0.71	0.58	0.67	0.25	1.00

Discussion

Broad Creek was identified by the Shellfish Sanitation and Recreational Water Quality Section as an area with significant shellfish resources (oysters) that was experiencing increasing development pressures and increasing shellfish closures. The proliferation of numerous adjacent docking facilities, each having 10 or fewer boat slips, is of concern because of the possibility of cumulative impacts due to increasing FC counts. The marina siting rules do not usually allow a marina to be permitted in areas SA waters with significant shellfish resources because the presence of a marina (>10 slips) requires an automatic permanent closure buffer around the marina.

Table 10. Median fecal coliform MPN and percent of those > 43 for the five locations within each site type in Broad Creek estuary, Pamlico County, NC for 32 samples taken 4/2002 – 3/2003. OD = Old Development, UD = Undeveloped, P1 = Pseudo-marina 1, P2= Pseudomarina 2, ND = New Development, RM = Real Marina. "**Bold** *" indicates locations that would not meet the North Carolina SA (shellfishing) water quality standard.

	Median	**%>43**			**Median**	**%>43**			**Median**	**%>43**
OD1*	102	84		UD1	2.0	9		P11	4.5	13
OD2*	33	47		UD2	2.0	13		P12	4.5	13
OD3*	39	50		UD3	2.0	3		P13	6.4	6
OD4*	33	47		UD4	2.8	3		P14	4.5	6
OD5*	14	34		UD5	4.5	13		P15	4.5	13
	Median	**%>43**			**Median**	**%>43**			**Median**	**%>43**
P21	7.3	13		**ND1***	20	28		RM1	13	25
P22	4.5	0		ND2	7.8	16		RM2	7.8	16
P23	4.5	6		**ND3***	15	13		RM3	8.5	16
P24	4.5	6		ND4	13	19		RM4	2.0	34
P25	4.5	3		ND5	13	19		**RM5***	15	28

Based upon the results of this study Broad Creek still has relative clean waters compared to a number of more urbanized areas with denser development in North Carolina. The NC 15A NCAC 2B .0200 classification standards for FC in SA waters state that the fecal coliform counts shall not exceed a median of 14 colonies per 100 ml and that not more than 10% of the counts shall exceed 43 colonies per 100 ml. Using this standard (Table 10) we found, as expected, that all of the old development (OD) sites would be closed and that none of the undeveloped shoreline (UD) sites would be closed. Both the pseudomarina sites had MPN that fell below the closure standard even though they did have slightly elevated counts relative to the undeveloped shoreline. Even more interesting was the fact that only one of the real marina (RM) locations (RM5) would have required closure and this was located near the shore on the northeast side of the marina. This location is at the mouth of a small embayment, similar to the old development site, with a number of both older and newer homes along its bank. RM1 nearest the shore on the west side of the marina had mean MPN only 1.0 less that the standard. In addition RM1 had MPN's greater than 43 over 25% of the time. The most unexpected finding in this study was that the newly developed (ND) shoreline had the second highest mean FC MPN's (13), essentially the same as the real marina. Two ND locations exceeded the standard for closure. These data may be particularly significant in the ongoing discussions of the potential health risks to consuming oyster grown suspended from private docks close to shore (“oyster gardening”). Our samples were collected approximately 50 – 75 ft. off shore and FC counts would be expected to increase significantly closer to shore under the end of the docks.

The fecal coliform as a function of water level data suggest that significant sources of fecal coliform bacteria are appearing quickly in water along the relatively more developed shores, perhaps due to the greater surface runoff from lands that have been cleared, ditched, and shaped for drainage and have increased impervious surface. Another possibility is that increased concentrations of domestic pets and urban wildlife (e.g. raccoon, opossum) leave fecal material on the surface near the estuary where it washed quickly into surface waters. Correlations at the undeveloped and pseudomarina were very low and negative through the first 24 hours but became very high and positive on the second day following rainfall (0.94, 0.86, and 0.70 respectively). These data suggest that the sources of bacteria were remote to the site and probably carried into these areas by non-local runoff. For this study, we can conclude that, relative to rainfall, the pseudomarinas had patterns of change more similar to undeveloped shorelines and very different from both old and new development. The real marina bacterial counts had very low correlation with rainfall at any temporal scale. For the developed shorelines the subsurface transport of viable bacteria from septic systems into adjacent waters cannot be ruled out. However, given the soils of the area subsurface transport seems unlikely (Canter and Knox 1985).

The correlation of extreme weather events with elevated FC counts were noted on two occasions. On 9/3/2002, following over 6 inches of rainfall on 8/31 and 9/1, counts were extremely high at pseudomarina 1 and along the undeveloped shoreline thus reinforcing the strategy of SSRWQ’s policy of closing many areas conditionally approved following 1.5 inches of rain in 24 hours and then waiting several days before sampling the water to see if it can be reopened for shellfishing. On this same date, bottom oxygen was low and there was strong stratification of the water column. In the open waters the surface salinity was approximately 10 o/oo with the bottom salinity in the low 20’s.

A second extreme weather event occurred on the days preceding the 12/4/2002 sampling. The old development site had its greatest mean MPN (490) on this date coupled with a very high turbidity. In addition, water temperature was extremely low (7.5^{o}C) for this time of the year and salinities relatively high. The preceding few day had seen water rise significantly. Regional wind data indicate that a northeast storm passed trough over during the several days prior to 12/4. Since the old development site is sheltered from northeast winds it is most likely that the high bacteria counts were associated with water level rise flushing bacteria into the system.

In conclusion, Broad Creek’s increase in multiple adjacent docking sites did not severely impact water quality as measured by fecal coliform counts. Residential development, both old and new, had the highest bacterial counts. The chance of this being a source is greater in the old development due to the age of the systems. A more likely possibility is increased numbers of domestic pets and urban wildlife and improved surface runoff. The lack of impact by pseudomarina might be due to the low level of activity coupled with moderate rates of flushing.

Ott (1992) found similar results relative to intensity of use. In a comparison of two marinas in Carteret County he observed very low counts in a inland protected docking areas serving fairly an expensive suburban development and relatively high counts in the vicinity of a large active marina with a high tidal current flushing. It would appear that it is very difficult to predict fecal coliform impacts by cumulative number of docks and boat slips and that other criteria should be used in decisions to manage such development. The results of this study do suggest that consumption of raw shellfish from sites adjacent to both old and new suburban development may be a health concern.

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Appendix 1. Fecal coliform bacteria (FC) and *E. coli* (*E.c.*) most probably numbers (MPN) from sites samples on the dates listed in the Broad Creek estuary, Pamlico County, NC.

Date	4/4/02		4/8/02		5/2/02		5/6/02		5/23/02		5/28/02	
Site	FC MPN	*E.c.* MPN	FC MPN	*E.c.* MPN	FC MPN	*E.c.* MPN	FC MPN	*E.c.* MPN	FC MPN	*E.c.* MPN	FC MPN	*E.c.* MPN
OD1	920		49		49	49	540	540	170	170	23	23
OD2	220		17		49	49	33	33	23	23	33	33
OD3	49		13		7.8	7.8	17	17	17	17	27	27
OD4	49		22		33	33	49	49	4.5	2.0	79	79
OD5	220		7.8		11	11	79	27	7.8	7.8	33	33
UD1	6.8		4.0		2.0	2.0	1.8	1.8	2.0	2.0	2.0	2.0
UD2	17		<1.8		2.0	2.0	2.0	2.0	4.5	4.5	2.0	2.0
UD3	17		4.5		2.0	2.0	7.8	7.8	1.8	2.0	2.0	2.0
UD4	33		2.0		2.0	2.0	4.5	4.5	4.5	4.5	1.8	1.8
UD5	23		2.0		4.5	4.5	7.8	7.8	1.8	1.8	2.0	2.0
P11	11		4.5		4.5	2.0	2.0	2.0	2.0	2.0	4.5	2.0
P12	33		4.0		9.2	9.2	2.0	2.0	4.5	4.5	1.8	1.8
P13	33		6.8		13	4.5	4.5	4.5	11	11	4.5	2.0
P14	14		6.8		7.8	7.8	2.0	2.0	7.8	4.5	4.5	4.5
P15	49		4.0		2.0	2.0	2.0	2.0	2.0	2.0	4.5	4.5
P21	95		2.0		23	23	7.8	11	7.8	7.8	1.8	1.8
P22	13		<1.8		9.3	9.3	11	11	2.0	4.5	1.8	1.8
P23	13		2.0		4.5	4.5	6.8	6.8	7.8	7.8	2.0	2.0
P24	17		4.5		4.5	4.5	7.8	7.8	6.8	6.8	2.0	2.0
P25	33		9.3		13	13	7.8	7.8	7.8	7.8	4.5	2.0
ND1	170		4.5		17	17	49	33	4.5	4.5	2.0	2.0
ND2	350		4.5		13	13	17	17	7.8	7.8	4.5	4.5
ND3	240		6.8		4.5	4.5	22	22	1.8	1.8	2.0	2.0
ND4	79		<1.8		22	14	17	17	2.0	2.0	11	11
ND5	110		4.0		4.5	4.5	23	23	4.5	4.5	14	14
RM1	23		<1.8		4.5	4.5	4.5	2	7.8	7.8	49	49
RM2	17		4.5		4.5	4.5	7.8	7.8	7.8	7.8	13	13
RM3	79		2.0		7.8	7.80	11	6.8	17	17	7.8	7.8
RM4	110		4.5		11	11	70	46	11	11	17	17
RM5	130		.		2.0	2.0	23	23	17	17	79	79
	6/6/02		6/10/02		6/20/02		6/25/02		7/3/02		7/8/02	
OD1	240	240	79	79	350	350	46	46	49	33	33	33
OD2	4.5	4.5	33	33	240	240	49	49	17	17	49	49
OD3	33	33	17	17	540	350	70	70	79	79	33	33
OD4	13	13	13	13	540	540	33	33	49	49	23	23
OD5	4.5	4.5	4.5	4.5	350	350	11	6.8	2.0	2.0	11	11
UD1	<1.8	<1.8	2.0	2.0	11	11	2.0	2.0	1.8	1.8	2.0	2.0
UD2	4.5	2.0	<1.8	<1.8	17	17	1.8	1.8	1.8	1.8	2.0	2.0
UD3	<1.8	<1.8	<1.8	<1.8	33	33	1.8	1.8	1.8	1.8	1.8	1.8
UD4	2.0	<1.8	2.0	2.0	13	13	1.8	1.8	2.0	2.0	1.8	1.8
UD5	9.3	9.3	2.0	<1.8	23	23	7.8	7.8	1.8	1.8	1.8	1.8
P11	1.8	1.8	<1.8	<1.8	49	49	6.8	6.8	1.8	1.8	1.8	1.8
P12	2.0	2.0	4.0	4.0	23	23	7.8	7.8	4.5	1.8	1.8	1.8

	6/6/02		6/10/02		6/20/02		6/25/02		7/3/02		7/8/02	
P13	<1.8	<1.8	<1.8	<1.8	13	13	7.8	7.8	2.0	2.0	2.0	2.0
P14	<1.8	<1.8	1.8	1.8	4.5	4.5	23	23	2.0	1.8	2.0	2.0
P15	4.5	4.5	<1.8	<1.8	23	23	6.8	4.0	13	4.5	1.8	1.8
P21	1.8	1.8	4.5	4.5	11	11	7.8	7.8	1.8	1.8	1.8	1.8
P22	<1.8	<1.8	<1.8	<1.8	6.8	6.8	1.8	1.8	4.5	4.5	2.0	2.0
P23	<1.8	<1.8	4.5	2	22	22	4.5	4.5	4.5	4.5	2.0	1.8
P24	2.0	2.0	2.0	2.0	22	22	2.0	2.0	4.5	2.0	1.8	1.8
P25	7.8	<1.8	1.8	1.8	13	13	2.0	2.0	2.0	1.8	1.8	1.8
ND1	33	17	4.5	4.5	31	31	49	49	2.0	2.0	17	11
ND2	4.0	4.0	7.8	7.8	33	33	4.0	4.0	4.5	4.5	7.8	7.8
ND3	4.5	2.0	4.5	4.5	33	33	22	22	4.5	1.8	2.0	4.5
ND4	2.0	2.0	13	7.8	130	130	4.5	4.5	7.8	13	2.0	2.0
ND5	2.0	2.0	13	13	170	170	4.5	4.5	22	22	2.0	2.0
RM1	2.0	2.0	2.0	2.0	33	33	4.5	4.5	1.8	1.8	6.8	4.0
RM2	<1.8	<1.8	4.5	4.5	49	49	7.8	7.8	2.0	1.8	1.8	1.8
RM3	4.0	4.0	2.0	2.0	23	23	4.5	4.5	4.5	2.0	4.5	4.5
RM4	2.0	<1.8	2.0	2.0	33	33	4.5	4.5	2.0	2.0	23	23
RM5	2.0	<1.8	<1.8	<1.8	33	33	2.0	2.0	6.8	6.8	9	

	7/18/02		7/22/02		8/1/02		8/5/02		8/15/02		8/19/02	
OD1	79	79	79	79	49	49	170	170	95	64	110	170
OD2	22	22	>1600	>1600	17	17	49	49	49	33	22	22
OD3	23	23	79	49	49	49	33	33	79	79	49	49
OD4	6.8	6.8	240	130	22	22	33	33	17	23	46	46
OD5	11	11	350	350	23	23	23	23	<1.8	<1.8	6.8	6.8
UD1	2.0	<1.8	4.5	4.5	2.0	<1.8	2.0	2.0	<1.8	<1.8	<1.8	<1.8
UD2	<1.8	<1.8	4.0	4.0	2.0	2.0	<1.8	<1.8	<1.8	<1.8	2.0	2.0
UD3	2.0	2.0	4.5	2.0	2.0	2.0	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8
UD4	4.5	2.0	11	11	4.5	4.5	2.0	2.0	7.8	7.8	<1.8	<1.8
UD5	23	23	49	49	4.5	4.5	2.0	2.0	<1.8	<1.8	2.0	2.0
P11	1.8	<1.8	21	21	6.8	4.0	2.0	2.0	<1.8	<1.8	<1.8	<1.8
P12	2.0	2.0	4.5	4.5	7.8	7.8	4.5	2.0	<1.8	<1.8	2.0	2.0
P13	2.0	2.0	13	13	4.5	4.5	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8
P14	4.5	4.5	13	23	2.0	2.0	4.5	2.0	2.0	2.0	<1.8	<1.8
P15	<1.8	<1.8	17	22	4.5	<1.8	<1.8	<1.8	<1.8	<1.8	2.0	<1.8
P21	4.5	<1.8	23	23	4.5	2.0	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8
P22	2.0	2.0	4.5	2.0	2.0	2.0	4.5	2.0	<1.8	<1.8	<1.8	<1.8
P23	4.5	4.5	6.8	6.8	4.5	2.0	<1.8	<1.8	4.5	4.5	<1.8	<1.8
P24	1.8	1.8	130	130	2.0	2.0	2.0	2.0	1.8	1.8	<1.8	<1.8
P25	2.0	2.0	23	23	4.0	4.0	<1.8	<1.8	<1.8	<1.8	2.0	2.0
ND1	4.5	2.0	>1600	1600	23	23	4.5	2.0	13	13	<1.8	<1.8
ND2	7.8	2.0	13	23	7.8	4.5	4.5	4.5	2.0	2.0	2.0	<1.8
ND3	<1.8	<1.8	49	49	6.8	6.8	140	14	1.8	1.8	4.5	4.5
ND4	13	4.5	920	920	13	13	<1.8	<1.8	2.0	2.0	2.0	2.0
ND5	7.8	4.5	33	33	2.0	2.0	2.0	2.0	23	23	<1.8	<1.8
RM1	7.8	7.8	13	23	23	23	4.5	4.5	2.0	2.0	1.8	1.8

	7/18/02		7/22/02		8/1/02		8/5/02		8/15/02		8/19/02	
RM2	2.0	2.0	2	<1.8	4.5	4.0	<1.8	<1.8	2.0	2.0	6.8	4.0
RM3	4.5	4.5	11	7.8	2.0	2.0	<1.8	<1.8	<1.8	<1.8	2.0	2.0
RM4	7.8	4.5	33	6.8	33	33	4.5	4.5	130	130	<1.8	<1.8
RM5	2.0	2.0	920	920	17	17	13	4.5	12	12	<1.8	<1.8

Date	8/29/02		9/3/02		10/4/02		10/7/02		11/1/02		11/5/02	
OD1	3500	490	540	33	230	130	220	170	790	790	490	490
OD2	490	130	350	79	20	20	170	170	170	68	78	78
OD3	490	130	350	79	170	170	230	130	170	170	78	78
OD4	330	130	350	79	45	45	130	78	230	230	78	78
OD5	330	40	240	79	130	130	110	110	20	20	<18	<18
UD1	4	1.8	240	49	7.8	7.8	13	13	4.5	4.5	<1.8	<1.8
UD2	4	<1.8	240	49	<1.8	<1.8	13	17	7.8	7.8	2	<1.8
UD3	4	<1.8	240	130	7.8	4.5	11	11	11	11	<1.8	<1.8
UD4	11	11	170	49	11	7.8	4.5	4.5	13	23	<1.8	<1.8
UD5	17	17	130	49	4.5	4.5	14	22	7.8	7.8	1.8	<1.8
P11	11	11	130	46	4.5	4.5	27	27	17	17	4.5	4.5
P12	33	23	350	33	4.5	4.5	33	11	79	79	<1.8	<1.8
P13	6.8	6.8	70	70	4.5	4.5	6.1	6.1	17	17	7.8	7.8
P14	4.5	4.5	240	130	4.5	4.5	23	33	22	22	11	11
P15	4.5	4.5	350	110	7.8	7.8	49	49	13	2	7.8	4.5
P21	33	33	140	64	<1.8	<1.8	240	240	33	33	11	11
P22	7.8	7.8	33	49	2	2	33	33	26	26	7.8	7.8
P23	17	17	79	79	4.5	4.5	49	49	23	23	33	33
P24	23	23	79	49	2	2	33	33	33	33	7.8	7.8
P25	<1.8	1.8	31	31	2	<1.8	13	13	49	22	13	23
ND1	49	49	49	49	33	23	79	49	43	43	13	13
ND2	49	49	33	33	2	2	27	79	79	27	20	2
ND3	21	21	33	33	4	4	33	33	23	23	17	11
ND4	33	33	23	23	7.8	7.8	49	22	13	13	7.8	7.8
ND5	49	49	70	70	13	13	33	33	14	14	13	13
RM1	70	70	140	140	31	31	79	79	33	33	13	13
RM2	33	33	49	49	13	13	33	33	33	17	13	13
RM3	49	49	110	70	33	33	33	33	31	31	13	13
RM4	49	33	70	46	13	13	79	79	31	31	2	2
RM5	33	33	46	70	23	23	49	49	79	49	14	14

	12/4/02		12/10/02		1/10/03		1/13/03		2/6/03		2/10/03	
OD1	1300	1300	<18	<18	45	45	<18	<18	45	45	1100	1100
OD2	220	220	20	20	20	20	<18	<18	45	45	18	18
OD3	490	490	<18	<18	20	20	<18	<18	45	45	<18	<18
OD4	490	490	<18	<18	20	20	<18	<18	20	20	45	78
OD5	230	230	<18	<18	<18	<18	<18	<18	<18	<18	110	110
UD1	79	79	<1.8	<1.8	4.5	4.5	<1.8	<1.8	<1.8	<1.8	46	70
UD2	64	64	2.0	2.0	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8	79	79
UD3	23	23	<1.8	<1.8	2.0	2.0	<1.8	<1.8	<1.8	<1.8	2.0	2.0
UD4	23	23	2.0	2.0	<1.8	<1.8	<1.8	<1.8	1.8	1.8	<1.8	<1.8

UD5	70	70	2.0	2.0	<1.8	<1.8	2.0	2.0	<1.8	<1.8	4.0	2.0
P11	170	170	6.8	6.8	2.0	2.0	7.8	7.8	<1.8	<1.8	13	7.8
P12	46	46	4.5	2.0	13	13	2.0	2.0	2.0	2.0	33	33
P13	540	540	4.5	4.5	20	20	23	23	<1.8	<1.8	4.5	4.5
P14	22	22	2.0	2.0	4.5	4.5	2.0	2.0	<1.8	<1.8	2.0	2.0
P15	49	49	4.0	1.8	9.3	9.3	2.0	2.0	2.0	2.0	13	13
P21	49	49	4.5	4.5	7.8	7.8	6.8	6.8	<1.8	<1.8	13	13
P22	4.5	4.5	4.0	4.0	7.8	7.8	7.8	7.8	4.5	4.5	7.8	7.8
P23	11	11	4.0	4.0	13	13	2.0	<1.8	2.0	2.0	4.0	4.0
P24	17	17	2.0	2.0	4.5	4.5	11	11	<1.8	<1.8	14	14
P25	4.5	4.5	2.0	2.0	4.5	4.5	4.0	4.0	4.0	4.0	13	13
ND1	23	23	2.0	2.0	7.8	7.8	7.8	7.8	27	27	79	79
ND2	33	33	2.0	2.0	7.8	7.8	<1.8	<1.8	23	23	49	33
ND3	6.8	6.8	2.0	2.0	17	17	13	7.8	33	33	130	79
ND4	22	22	2.0	2.0	23	23	2.0	2.0	49	49	33	33
ND5	11	11	2.0	2.0	240	240	<1.8	<1.8	6.8	6.8	33	33
RM1	220	220	13	13	170	170	2.0	2.0	4.5	4.5	79	79
RM2	49	49	4.0	4.0	540	540	4.5	4.5	4.0	4.0	95	70
RM3	49	49	6.8	6.8	170	170	4.5	4.5	2.0	2.0	9.3	9.3
RM4	49	49	7.8	7.8	170	170	7.8	7.8	1.8	4.0	79	49
RM5	33	33	11	11	350	350	4.5	4.5	7.8	7.8	79	49

	2/27/03		3/3/03	
OD1	7.8	7.8	240	240
OD2	14	14	23	23
OD3	17	17	33	33
OD4	17	17	33	33
OD5	170	70	7.8	7.8
UD1	<1.8	<1.8	23	7.8
UD2	4.5	4.5	49	49
UD3	7.8	4.5	33	33
UD4	4.0	4.0	13	13
UD5	11	11	49	49
P11	4.5	4.5	46	46
P12	6.1	3.7	46	46
P13	17	17	23	23
P14	17	17	49	49
P15	4.0	4.0	33	33
P21	4.5	4.5	7.8	7.8
P22	7.8	7.8	17	17
P23	7.8	7.8	13	13
P24	11	11	23	33
P25	23	23	13	4.5

	2/27/03		3/3/03	
ND1	49	49	13	13
ND2	110	110	22	22
ND3	33	33	23	7.8
ND4	350	350	23	23
ND5	110	110	13	13
RM1	33	33	49	49
RM2	21	21	23	23
RM3	9.3	14	17	17
RM4	49	49	49	49
RM5	13	13	49	49

Appendix 2. Environmental Data from Broad Creek estuary, Pamlico County, NC. OD = Old Development, UD = Undeveloped, P1 = Pseudomarina 1, P2 = Pseudomarina 2, ND = New Development and RM = Real Marina. Turb = Turbidity, NTU = National Turbidity Units, S = Salinity, Surf. = Near Surface, Btm. = Near Bottom, o/oo = Parts Per Thousand, T = Temperature, C = Celsius, O = Dissolved Oxygen, D = Depth, Sec = Secchi Depth, M = Meters, Deg. = Compass Direction of Flow. Secchi Btm. = Secchi disc on the bottom.

Date	Sit	Turb	S	S	T	T	O	O	D	Sec	Flow	Flow
			Suf.	Btm.	Suf.	Btm.	Suf.	Btm.				
		NTU	o/oo	o/oo	C	C	mg/l	mg/l	M	M	cm/s	Deg.
4/4/02	OD	3.6	16.2	16.2	20.2	20.2	6.97	7.07	1.30	Btm	nd	nd
4/4/02	UD	3.8	16.1	16.1	19.7	19.7	7.25	7.31	1.69	1.45	nd	nd
4/4/02	P1	3.2	15.6	15.7	19.8	19.8	7.28	7.36	1.05	Btm	nd	nd
4/4/02	P2	3.0	15.7	15.7	19.9	19.9	6.87	6.84	1.90	1.10	nd	nd
4/4/02	ND	4.0	14.3	14.3	19.9	19.9	6.82	6.76	1.35	1.10	nd	nd
4/4/02	RM	3.1	15.3	15.4	19.8	19.8	6.71	6.90	2.00	1.30	nd	nd
4/8/02	OD	2.1	15.6	15.6	17.0	16.6	8.04	7.97	0.98	Btm	0.0	nd
4/8/02	UD	1.6	15.2	15.2	16.6	16.1	8.09	7.46	1.13	Btm	0.0	nd
4/8/02	P1	2.0	14.7	14.9	17.0	16.4	8.20	7.60	1.70	Btm	10.0	265
4/8/02	P2	4.5	14.6	14.6	18.5	17.0	7.90	7.47	1.50	1.48	6.7	120
4/8/02	ND	2.5	14.1	14.6	18.5	17.0	7.58	6.78	1.15	Btm	3.3	290
4/8/02	RM	3.5	14.7	15.1	17.8	16.9	7.89	7.08	1.70	1.38	10.0	350
5/2/02	OD	2.0	12.5	11.7	24.3	24.2	4.34	4.28	0.70	0.65	4.5	18
5/2/02	UD	3.5	3.5	11.2	10.5	23.7	7.33	7.18	1.41	1.00	4.5	331
5/2/02	P1	2.0	11	10.5	24.2	24.1	7.55	7.27	1.67	0.95	12.8	70
5/2/02	P2	5.5	10.8	10.3	25.3	24.3	7.57	7.16	1.70	1.00	11.2	343
5/2/02	ND	4.3	11	10.4	26.0	24.2	7.43	7.36	1.15	0.85	11.2	288
5/2/02	RM	5.5	11.2	11.1	25.0	24.5	7.26	7.22	1.85	1.00	10.8	172
5/6/02	OD	2.5	14.5	15.3	20.2	19.8	5.90	5.23	1.38	1.10	5.8	109
5/6/02	UD	3.0	15.5	16	20.1	20.1	7.60	7.54	1.60	1.45	11.7	31
5/6/02	P1	2.5	16.2	16.1	20.5	20.3	7.19	7.02	1.70	1.45	10.2	261
5/6/02	P2	0.7	15.6	15.6	20.6	20.3	7.10	6.84	1.70	1.55	15.5	105
5/6/02	ND	3.0	15.2	15.4	20.7	20.6	7.32	6.98	1.35	Btm	15.5	295
5/6/02	RM	2.1	15.2	15.3	20.8	20.4	7.40	7.30	2.10	1.60	14.1	215
5/23/02	OD	5.5	12.8	12.1	20.3	18.7	6.91	7.40	1.14	0.97	4.5	267
5/23/02	UD	4.0	10.7	9.9	18.7	18.8	8.13	8.40	1.69	1.10	14.1	260
5/23/02	P1	4.5	10.9	10.6	20.0	18.9	7.15	7.30	2.20	1.00	11.2	283
5/23/02	P2	5.0	10.7	10.6	19.8	19.2	6.53	6.33	1.79	1.00	4.5	217
5/23/02	ND	3.7	11.2	10.9	21.0	20.3	6.07	6.11	1.51	1.10	5.4	157
5/23/02	RM	5.6	13.2	12.7	20.0	19.1	6.33	6.37	2.15	1.05	11.2	273
5/28/02	OD	8.5	13.9	13.5	26.5	25.9	5.31	5.30	1.08	0.70	4.5	357
5/28/02	UD	7.5	11.4	11	25.6	25.6	7.10	7.00	1.69	0.80	2.8	150
5/28/02	P1	8.0	11.6	10.8	26.0	24.9	6.18	5.65	2.11	0.67	2.8	255
5/28/02	P2	6.5	11.5	10.5	26.5	25.7	3.75	3.61	1.70	0.70	10.2	326
5/28/02	ND	8.0	10.9	10.9	27.2	26.6	5.45	5.30	1.29	0.75	8.9	217
5/28/02	RM	4.1	11.1	26.5	25.3	6.4	5.80	1.99	0.80	0.80	10.2	309
6/6/02	OD	6.0	13.2	12.4	28.7	28.7	6.56	6.36	0.67	0.50	4.5	153
6/6/02	UD	5.5	10.9	10.7	28.4	27.5	7.01	6.16	1.45	0.70	10.2	34
6/6/02	P1	5.2	10.9	10.6	28.8	28.1	5.11	4.71	1.79	0.65	10.8	158
6/6/02	P2	7.1	11.6	11.3	28.9	27.2	6.63	3.53	1.73	0.45	22.4	252
6/6/02	ND	5.6	11.7	11.5	29.8	28.4	5.16	3.10	1.25	0.65	4.5	287
6/6/02	RM	4.0	11.7	11.6	29.3	28.6	7.55	7.39	1.95	0.80	7.8	265
6/10/02	OD	8.5	16	14.3	27.0	25.7	5.77	4.49	1.04	0.67	8.2	346
6/10/02	UD	6.0	13.5	13.1	26.6	25.0	7.41	6.56	1.67	0.75	8.2	166
6/10/02	P1	5.0	12.4	12.1	27.1	25.2	5.12	3.17	2.10	0.80	2.8	230
6/10/02	P2	6.3	12.6	12.2	27.5	25.6	7.70	7.30	1.69	0.70	10.2	109

6/10/02	ND	6.5	12.8	12.4	27.6	26.1	6.26	6.00	1.39	0.80	14.1	295
6/10/02	RM	5.8	11.9	11.8	26.9	25.9	6.81	6.58	2.00	0.80	10.8	268
6/20/02	OD	8.0	11	11.2	25.9	25.9	5.44	5.11	1.28	0.70	nd	nd
6/20/02	UD	7.2	11	11	25.4	25.4	4.82	4.66	1.85	0.60	nd	nd
6/20/02	P1	5.6	11	11.2	26.0	26.0	4.28	3.69	2.46	0.60	nd	nd
6/20/02	P2	7.2	10.8	11	26.0	26.0	3.57	2.12	2.10	0.58	nd	nd
6/20/02	ND	4.5	10.8	11.1	26.4	26.3	5.64	3.62	1.68	0.69	nd	nd
6/20/02	RM	5.5	10.9	11	26.1	26.0	4.72	3.87	2.28	0.63	nd	nd
6/25/02	OD	8.5	13.7	13.4	30.2	29.0	5.63	5.05	0.75	0.51	nd	nd
6/25/02	UD	5.0	12.5	12.4	29.3	27.1	6.13	5.46	1.40	0.53	nd	nd
6/25/02	P1	7.6	12.1	12	29.0	26.4	5.25	3.45	1.84	0.61	nd	nd
6/25/02	P2	7.6	11.9	12.1	29.6	26.9	5.30	3.33	1.64	0.53	nd	nd
6/25/02	ND	6.0	12.2	12.4	31.7	27.4	5.80	4.12	1.24	0.63	nd	nd
6/25/02	RM	8.7	11.8	11.8	30.4	27.7	4.23	2.33	1.91	0.61	nd	nd
7/3/02	OD	6.0	14.8	13.7	31.0	31.0	5.63	4.60	0.68	0.65	11.6	65
7/3/02	UD	7.4	13.5	12.7	30.7	29.5	6.99	5.78	1.30	0.71	10.2	100
7/3/02	P1	6.8	12.6	12	31.0	29.6	5.91	4.64	1.45	0.63	15.5	120
7/3/02	P2	7.0	13	12.6	31.2	29.3	5.06	3.20	1.62	0.54	10.2	55
7/3/02	ND	6.8	13.3	12.6	32.7	30.9	6.74	4.92	1.15	0.52	6.7	200
7/3/02	RM	6.5	13.5	12.8	31.5	30.5	5.35	2.94	1.96	0.70	14.1	215
7/8/02	OD	8.1	15.9	15.8	30.0	28.7	5.58	3.71	0.76	0.52	14.1	185
7/8/02	UD	5.4	15.2	15.1	29.8	29.2	6.13	5.10	1.38	0.82	4.5	260
7/8/02	P1	5.3	14.8	14.6	30.3	29.9	5.58	4.10	1.45	0.71	11.2	290
7/8/02	P2	8.0	14.4	14.6	31.2	30.0	4.25	3.10	1.98	0.70	4.5	217
7/8/02	ND	6.7	14.3	14.6	31.3	30.7	4.97	3.54	1.25	0.71	5.4	161
7/8/02	RM	9.3	14.7	14.4	30.6	29.9	6.68	4.14	1.94	0.75	11.2	217
7/18/02	OD	7.5	10.5	10.6	32.6	31.9	3.96	2.17	1.10	0.66	4.5	340
7/18/02	UD	5.3	11.5	11.7	32.2	31.9	3.51	3.00	1.70	0.71	2.8	330
7/18/02	P1	6.0	13.6	13.8	32.0	31.8	4.10	2.97	2.10	0.71	8.9	255
7/18/02	P2	8.1	14.2	14.4	31.8	31.0	3.10	2.99	2.00	0.65	2.8	225
7/18/02	ND	6.0	14.7	15	33.1	32.1	4.11	3.11	1.36	0.60	4.5	247
7/18/02	RM	6.9	14.9	15	32.3	31.1	6.40	3.46	2.00	0.58	10.2	301
7/22/02	OD	6.4	21.9	21.6	31.2	31.5	5.82	4.64	1.09	0.54	2.8	265
7/22/02	UD	9.5	22	22.1	30.5	30.6	4.60	2.17	1.71	0.58	2.8	320
7/22/02	P1	6.2	21.9	21.9	31.0	31.3	5.00	3.21	1.60	0.60	4.5	227
7/22/02	P2	10.6	21.6	21.6	31.0	31.5	5.32	4.61	1.89	0.54	14.1	170
7/22/02	ND	4.5	21.2	21.4	30.4	30.5	4.11	2.96	1.46	0.60	10.2	120
7/22/02	RM	7.5	21.4	21.5	30.5	30.8	3.17	2.85	2.00	0.65	10.2	290
8/1/02	OD	11.0	22.1	22.3	33.1	31.6	4.79	3.81	0.99	0.80	2.8	275
8/1/02	UD	8.2	21.9	22	31.9	30.9	4.38	4.13	1.69	0.89	4.5	300
8/1/02	P1	2.0	21.8	22.5	31.8	30.7	4.70	4.23	2.21	0.91	2.8	217
8/1/02	P2	8.1	21.2	21.6	32.4	30.9	6.73	2.86	1.89	0.68	11.2	180
8/1/02	ND	11.0	20.5	21.3	33.0	31.7	4.86	2.95	1.46	0.71	10.2	310
8/1/02	RM	6.6	21.3	22.6	32.5	30.4	6.91	2.37	2.05	0.67	11.2	310
8/5/02	OD	nd	22.7	22.9	31.6	29.7	4.92	4.02	1.00	0.58	8.9	265
8/5/02	UD	nd	22.8	22.8	30.2	29.9	5.38	4.95	1.76	0.71	14.1	315
8/5/02	P1	nd	22.3	22.3	30.3	30.2	5.22	4.75	2.14	0.73	14.1	227
8/5/02	P2	nd	22.3	22.2	30.5	30.2	5.42	4.57	1.89	0.68	15.5	160
8/5/02	ND	nd	21.8	20.1	31.3	30.6	5.23	4.99	1.54	0.63	10.2	120
8/5/02	RM	nd	22.1	22.3	30.4	30.0	4.90	4.41	2.20	0.75	15.5	290
8/15/02	OD	12.0	23.8	23.8	29.6	29.4	3.53	3.32	1.02	0.80	0.0	nd
8/15/02	UD	6.1	23.6	23.7	29.1	28.6	4.38	4.02	1.46	0.92	2.8	300
8/15/02	P1	7.5	23.4	23.4	28.9	29.0	4.31	4.03	1.98	0.96	2.8	217
8/15/02	P2	6.2	23.4	23.4	29.3	28.8	4.01	2.63	1.89	0.80	2.8	175
8/15/02	ND	7.8	23	23	29.9	29.7	4.43	3.10	1.26	0.80	4.5	120
8/15/02	RM	4.8	23.2	23.3	29.5	29.1	4.95	3.91	1.99	0.97	4.5	290

8/19/02	OD	6.5	24.2	24.2	31.9	31.1	4.04	3.96	0.90	0.61	0.0	nd
8/19/02	UD	6.2	23.9	24.2	31.7	29.4	5.99	3.39	1.64	0.82	2.8	320
8/19/02	P1	8.0	23.6	24	31.7	29.6	4.90	4.24	2.01	0.84	4.5	227
8/19/02	P2	8.2	23.6	23.7	31.7	29.8	4.84	3.48	1.92	0.71	8.9	170
8/19/02	ND	6.6	23.2	23.5	32.1	30.4	4.21	3.32	1.35	0.70	5.4	215
8/19/02	RM	6.0	23.5	23.9	32.2	29.8	5.13	3.37	2.01	0.84	2.8	320
8/29/02	OD	7.6	23.7	24	28.6	28.5	3.61	2.91	1.18	0.86	2.8	200
8/29/02	UD	9.7	23.7	23.7	28.2	28.0	4.50	4.28	1.70	1.00	2.4	317
8/29/02	P1	5.0	23.2	23.3	28.7	28.6	4.38	3.68	2.05	0.95	4.5	227
8/29/02	P2	11.0	22.4	22.9	28.7	28.4	4.57	3.20	1.95	0.90	10.2	170
8/29/02	ND	8.5	20.7	23.4	28.6	29.2	5.02	2.03	1.45	0.92	2.8	120
8/29/02	RM	7.1	22.7	24	28.8	29.0	4.75	2.31	2.18	1.00	14.1	295
9/3/02	OD	4.0	16.2	21	28.1	27.2	5.16	3.66	1.29	0.58	5.4	267
9/3/02	UD	3.1	9.6	21.3	29.7	27.6	5.92	2.92	1.95	0.60	8.9	317
9/3/02	P1	4.2	11.5	21.2	30.0	27.7	6.19	2.66	2.40	0.60	11.2	200
9/3/02	P2	4.3	8.6	24.3	31.2	27.3	5.20	1.78	1.92	0.56	6.7	225
9/3/02	ND	3.0	10.9	24.3	28.9	27.4	4.51	1.28	1.59	0.60	15.5	215
9/3/02	RM	4.6	11.1	24.2	30.5	27.3	5.57	1.90	2.21	0.54	10.2	287
10/4/02	OD	5.5	20.6	21.2	29.1	28.5	6.62	5.61	1.09	1.00	2.8	200
10/4/02	UD	5.5	19.1	21.7	28.0	27.2	6.95	6.57	1.70	1.05	2.8	320
10/4/02	P1	6.0	19.7	22.2	28.2	26.6	6.87	5.38	2.31	1.10	2.8	227
10/4/02	P2	7.0	18.9	19.3	28.4	28.0	6.25	5.10	1.91	1.05	5.4	170
10/4/02	ND	5.3	18.3	22.3	28.8	26.6	6.22	3.20	1.40	1.00	10.2	290
10/4/02	RM	8.5	19.6	22.2	28.0	26.6	6.49	4.60	2.10	1.00	6.7	355
10/7/02	OD	5.0	22.1	22.1	26.9	26.6	6.50	6.15	0.94	0.85	nd	nd
10/7/02	UD	7.5	21.8	21.8	27.1	27.0	7.21	6.98	1.60	1.02	nd	nd
10/7/02	P1	12.0	21.5	21.6	27.2	26.6	6.65	6.32	2.21	1.05	nd	nd
10/7/02	P2	13.0	21.4	21.4	26.9	26.6	6.44	5.81	1.87	1.00	nd	nd
10/7/02	ND	10.0	21	21.2	27.4	26.9	7.00	5.67	1.40	0.95	nd	nd
10/7/02	RM	6.6	21.3	21.6	27.1	26.4	6.66	4.51	2.20	0.90	nd	nd
11/1/02	OD	5.6	21.7	21.6	16.0	15.5	7.90	7.88	1.02	Btm	2.0	200
11/1/02	UD	6.5	21.8	21.8	16.0	15.6	7.17	7.03	1.60	Btm	2.0	320
11/1/02	P1	6.0	21.5	20.5	15.8	16.0	7.20	5.00	2.20	1.65	5.0	300
11/1/02	P2	9.0	20.4	20.1	16.1	15.8	6.60	4.81	1.80	1.60	5.0	200
11/1/02	ND	5.0	21	21.1	16.1	16.1	6.13	5.17	1.41	Btm	5.0	300
11/1/02	RM	9.0	21	24.5	16.2	16.1	5.99	5.00	2.17	1.58	8.0	320
11/5/02	OD	6.5	21.5	21.5	14.4	14.5	8.90	7.90	1.05	Btm	0.0	nd
11/5/02	UD	7.5	21.4	21.4	14.1	14.3	7.91	6.17	1.60	1.21	7.0	300
11/5/02	P1	6.0	21.5	21.7	14.3	14.2	7.80	6.93	2.17	1.31	2.0	300
11/5/02	P2	7.0	22	21.7	14.3	14.5	7.77	7.08	1.81	1.44	10.0	200
11/5/02	ND	7.7	21.6	21.7	14.1	14.4	7.91	7.15	1.43	1.30	5.0	300
11/5/02	RM	6.0	21.9	21.7	14.2	14.3	8.15	6.15	2.20	1.31	10.0	320
12/4/02	OD	25.0	20	20.2	7.3	7.7	10.4	10.1	0.81	Btm	2.8	200
12/4/02	UD	3.0	20.5	20.7	7.4	8.0	9.77	nd	1.50	1.00	5.4	310
12/4/02	P1	3.2	20.6	20.6	7.4	7.9	9.01	8.45	2.00	1.05	2.8	227
12/4/02	P2	4.2	20.6	20.5	7.4	7.9	8.65	8.01	1.70	1.10	6.7	175
12/4/02	ND	2.8	20.3	20.7	7.4	7.6	9.05	7.76	1.31	1.55	6.7	280
12/4/02	RM	3.3	20.5	20.6	7.5	7.5	10.1	8.16	2.01	1.27	5.4	350
12/10/02	OD	5.0	17.1	17.6	8.7	9.0	7.16	5.08	1.01	Btm	2.8	215
12/10/02	UD	7.0	17.3	17.6	8.6	9.0	9.44	6.74	1.67	1.31	5.4	315
12/10/02	P1	4.5	17.5	17.6	8.8	9.1	8.60	5.13	2.16	1.40	10.2	200
12/10/02	P2	6.0	17.4	17.7	8.7	9.2	8.65	6.48	1.91	1.36	10.2	235
12/10/02	ND	3.5	17.6	17.6	8.7	9.0	7.65	6.91	1.51	1.20	6.7	270
12/10/02	RM	5.5	17.7	17.8	9.0	9.1	9.01	4.84	2.37	1.20	6.7	315
1/10/03	OD	3.4	18.9	19.1	10.2	9.6	10.00	10.38	1.08	Btm	12.7	340

1/10/03	UD	2.0	18.9	18.9	9.2	9.1	11.2	11.0	1.71	Btm	10.2	109
1/10/03	P1	5.1	18.7	18.8	9.3	9.2	11.6	11.1	2.20	2.05	12.2	126
1/10/03	P2	4.2	18.4	18.7	9.7	9.0	10.1	9.07	1.87	1.75	12.2	350
1/10/03	ND	4.7	16.6	17.3	10.2	9.9	10.8	9.03	1.41	Btm	22.4	348
1/10/03	RM	5.0	18.6	18.7	9.5	9.3	11.4	11.0	2.40	1.71	17.0	315
1/13/03	OD	3.2	18.6	18.8	7.2	7.3	7.18	4.17	0.66	Btm	2.8	270
1/13/03	UD	3.1	18.6	18.9	7.2	7.4	6.17	4.00	1.40	Btm	2.8	315
1/13/03	P1	2.8	18.7	18.9	7.3	7.4	7.87	5.96	1.91	1.40	5.8	200
1/13/03	P2	5.5	18.7	18.9	7.0	7.4	6.50	4.10	1.54	1.36	12.2	200
1/13/03	ND	4.0	18.6	18.9	7.2	7.4	7.00	3.90	1.04	Btm	22.4	290
1/13/03	RM	5.2	18.9	19.1	7.5	7.7	6.87	4.75	2.03	1.41	12.2	328
2/6/03	OD	1.6	17.2	17.1	9.0	9.1	nd	nd	0.95	Btm	14.6	46
2/6/03	UD	1.9	17	17	7.6	7.6	nd	nd	1.50	Btm	6.3	333
2/6/03	P1	2.5	17.2	17.1	8.9	8.7	nd	nd	2.06	1.31	10.8	218
2/6/03	P1	2.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2/6/03	P2	3.0	17	17	8.9	8.9	nd	nd	1.69	1.48	8.5	90
2/6/03	ND	3.0	15.6	16.8	8.8	9.7	nd	nd	1.25	Btm	8.1	35
2/6/03	RM	2.5	16.9	17	8.8	8.8	nd	nd	2.01	1.61	7.2	34
2/10/03	OD	1.5	16.2	16.8	8.2	9.0	10.5	10.8	1.00	Btm	2.0	185
2/10/03	UD	1.7	16.1	16.4	8.3	8.0	10.8	10.9	1.61	Btm	8.9	203
2/10/03	P1	2.4	16.1	16.4	8.5	8.3	11.0	11.2	1.90	1.36	3.2	235
2/10/03	P2	2.0	15.6	15.9	9.0	8.9	10.*	10.4	2.00	1.10	15.6	270
2/10/03	ND	2.3	8.8	16.6	8.5	9.3	11.6	10.9	1.48	0.93	10.2	29
2/10/03	RM	2.0	15.4	16.9	8.7	8.4	11.4	11.0	2.05	1.05	10.4	103
2/27/03	OD	3.5	14.4	14.5	10.2	10.2	9.22	8.89	1.05	Btm	0.0	nd
2/27/03	UD	2.5	14.5	14.5	10.0	9.9	9.25	9.03	1.81	Btm	14.1	262
2/27/03	P1	4.0	14	14.4	10.5	10.7	5.84	5.70	1.91	1.20	14.1	65
2/27/03	P2	3.2	13.7	13.8	10.5	10.6	6.03	5.35	2.02	1.41	6.3	72
2/27/03	ND	3.6	12.5	13.9	10.3	11.2	6.53	4.68	1.56	1.38	10.0	37
2/27/03	RM	3.2	13.8	14.2	10.5	10.9	5.95	5.32	2.20	1.34	6.3	178
3/3/03	OD	3.0	14.7	16.4	13.0	10.8	9.28	10.4	1.43	Btm	4.5	288
3/3/03	UD	3.6	12.6	16.1	11.8	10.1	9.92	9.74	1.76	1.12	10.0	258
3/3/03	P1	3.0	13.7	16.6	12.1	9.7	9.68	9.10	2.13	1.61	16.9	275
3/3/03	P2	4.2	12.7	16.2	12.4	10.3	9.92	8.59	2.04	1.16	16.5	239
3/3/03	ND	4.0	13.4	16	12.5	10.8	9.10	9.51	1.60	0.94	14.1	305
3/3/03	RM	4.0	14.1	16.6	12.2	9.9	9.96	9.36	2.17	1.53	18.4	266

Appendix 3. Rainfall at Bayboro, North Carolina recorded by NOAA-NCDC

3/3/02	1.53	7/22/02	0.12	11/11/02	0.34
3/4/02	0.03	7/23/02	0.03	11/13/02	0.54
3/13/02	2.45	7/25/02	0.21	11/14/02	0.05
3/14/02	0.05	7/26/02	0.55	11/16/02	0.95
3/17/02	0.10	7/27/02	2.15	11/17/02	0.57
3/18/02	0.03	7/28/02	0.03	11/18/02	0.10
3/20/02	0.26	8/1/02	0.21	11/21/02	0.02
3/21/02	0.73	8/4/02	0.03	12/5/02	0.87
3/26/02	0.10	8/15/02	0.14	12/10/02	0.25
3/27/02	0.31	8/16/02	0.05	12/11/02	0.42
3/30/02	0.03	8/18/02	0.02	12/13/02	0.40
4/1/02	1.27	8/25/02	0.93	12/14/02	0.05
4/4/02	0.05	8/26/02	0.95	12/20/02	0.20
4/10/02	0.05	8/27/02	0.21	12/24/02	0.38
4/15/02	0.05	8/28/02	1.37	12/25/02	0.05
4/16/02	0.61	8/29/02	0.70	12/31/02	0.06
4/20/02	0.35	8/30/02	0.28	1/1/03	1.03
4/25/02	0.09	8/31/02	1.53	1/2/03	0.02
4/26/02	0.03	9/1/02	4.53	1/3/03	0.10
4/27/02	0.06	9/2/02	0.02	1/17/03	0.27
5/4/02	0.85	9/8/02	0.01	1/22/03	0.03
5/10/02	0.10	9/10/02	1.63	1/30/03	0.20
5/14/02	0.14	9/11/02	0.48	1/31/03	0.45
5/19/02	0.88	9/15/02	0.22	2/1/03	0.05
5/30/02	0.42	9/16/02	1.73	2/4/03	0.10
6/7/02	0.09	9/23/02	2.00	2/7/03	0.78
6/15/02	1.70	9/24/02	0.10	2/10/03	0.58
6/17/02	0.11	9/26/02	2.15	2/16/03	1.21
6/18/02	0.61	10/12/02	0.56	2/17/03	0.72
6/19/02	0.22	10/15/02	0.43	2/18/03	0.03
6/20/02	0.41	10/16/02	0.73	2/23/03	0.50
6/22/02	1.26	10/21/02	0.10	2/26/03	0.06
6/23/02	0.10	10/24/02	0.08	2/27/03	0.35
6/26/02	0.06	10/25/02	0.05	2/28/03	0.71
6/27/02	1.92	10/27/02	0.05	3/1/03	0.05
6/28/02	1.00	10/29/02	0.40	3/2/03	0.10
7/6/02	0.48	10/30/02	0.30	3/5/03	0.38
7/10/02	1.42	11/1/02	0.01	3/6/03	0.07
7/11/02	0.01	11/4/02	0.06	3/7/03	0.37
7/14/02	0.60	11/6/02	1.92	3/11/03	0.33
7/15/02	0.06	11/10/02	0.28	3/12/03	0.25
7/19/02	1.55			3/14/03	0.05
7/21/02	1.25			3/16/03	1.05