Fecal coliform bacterial concentrations, Little Wicomico River, Virginia

The concentrations of fecal coliform bacteria are monitored throughout tidewater Virginia by the Shellfish Sanitation Division of the Virginia Department of Health (VDH) in order to ensure that harvested shellfish are safe for human consumption. The source of the bacteria is uncertain. Wildlife such as raccoons and birds, and anthropogenic sources from septic systems, pets, livestock and the land application of sewage sludge or poultry litter could all contribute. Few studies in the Chesapeake Bay watershed have attempted to identify the source(s) of bacteria using reliable modern biochemical techniques. One study (Simmons, Herbein and James, 1995, Managing Nonpoint Fecal Coliform Sources of Tidal Inlets, Universities Council on Water Resources. Water Resour. Update 100: 64-74) identified raccoons as the primary source of contamination. When the numbers of raccoons were reduced, the contamination was also reduced.

During the 1980's the entire mainstream of the Little Wicomico River was unrestricted for the harvesting of shellfish, and only a few small arms of the river were restricted. Beginning in 1991 the mainstream west of station 15 (Fig. 1) was restricted, as well as more small arms of the river. Throughout the 1990's the restricted areas remained similar although there was less restriction for several years, with the boundary in the mainstream as far west as station 17 in 1997. Between 2000 and 2010 the restricted area in the mainstream expanded, reaching as far east as station 12 in 2005. The boundary returned to between station 14 and 15 by 2009 and remains there today (2011). Between 1990 and 2000 Northumberland County experienced a growth spurt of 1735 citizens, compared to 696 in the previous decade and only 71 between the 2000 and 2010 census. Thus changes in the volume of restricted water as measured by the location of the boundary in the mainstream of the river do not reflect changes in population.

Several lines of evidence suggest that contamination from wildlife dominates anthropogenic contributions. Wildlife are obviously very much more abundant than people or their pets in a 192 square mile county with 12,000 residents, where about 90% of the land is forested, farmed or wetland. It is always true, without exception, that fecal coliform bacterial concentrations increase, and salinity and pH decrease, toward the headwaters of tidal creeks and rivers and their arms. Rarely excepted, there are fewer houses toward the headwaters of the water bodies than near their mouths, largely because of shallower water depth and the distance to open water for view and recreation. Runoff is certainly a major vector of bacterial contamination, and lower salinity and pH are less lethal to bacteria than is true of higher salinity and pH closer to the mouths of the water bodies (Rozen and Belkin, 2001, Survival of enteric bacteria in seawater, FEMS Microbiology Reviews 25: 513-529). There are very few livestock any longer in the Little Wicomico watershed because of environmental regulations and because of a decline in agricultural acreage in an area where waterfront property values are high. Data for fecal coliform concentrations in ponds and runoff are not abundant, but those that do exist are commonly relatively high.

Shallow groundwater is extensively used locally as a domestic water supply but there is no evidence that groundwater discharge constitutes a vector of contamination unless it is associated with improperly functioning septic systems. Bacterial contamination of domestic water supplies can always be traced to construction and maintenance of the water well itself.

High bacterial concentrations are most commonly observed between April and November and lower bacterial concentrations occur between December and March, especially in February. Elevated temperatures are known to favor the persistence of fecal coliform bacteria in the water (Anderson, Rhodes and Kator, 1983, Applied and Environmental Microbiology 45: 1877-1883). Horned pondweed blooms typically begin in late April or early May and are gone by early June. Blooms can be so dense as to seriously impede boat traffic and those three months are commonly associated with high bacterial concentrations, possibly because of the availabilty of substrate for colony growth. Bacterial concentrations are also commonly high in September, when named storms are most likely. Seasonal wildlife migration or behavior patterns also may play a role in the introduction of animal fecal matter into receiving waters. Phytoplankton blooms in small estuaries can stimulate populations of predatory protozoans and zooplankton which remove bacteria in the water column through feeding. High bacterial concentrations in isolated samples might be due to flocks of birds on the water just prior to sampling or because of boats stirring up bottom sediment, but these two explanations can only apply to isolated “spikes” in the data from one or a very few stations.

A complete daily rainfall record is available from my pier (37 54.196N, 76 17.570, Fig. 1) beginning in 1999. The number of inches of rainfall was determined by the volume of water collected in a calibrated glass cylinder, and recorded each morning. The rainfall was attributed to the previous date. There are currently 23 stations in the Little Wicomico River where samples are collected monthly and analyzed for fecal coliform bacteria by VDH and where complete bacterial and rainfall records exist. Those data were used in this analysis.

Rainfall measurements were added to a spreadsheet of the bacterial concentration data provided by the Division of Shellfish Sanitation between January 1, 1999, and September 10, 2009. The bacterial concentrations were summed for all 23 stations for each of the 117 dates sampled and the data were sorted according to decreasing total bacterial concentration. The highest value observed was 9349 and the lowest 23, or a value of 1 entered for all 23 stations.

Inspection of the ranked data indicates that when elevated concentrations of bacteria were recorded, many stations were affected. Figure 2 is a scatter plot of the sum of the eight stations with the highest bacterial concentrations (in descending order, 16, 17, 13.5Y, 15, 9W, 14, 7.4 and 13.5Z), all located at the headwaters of the river or small arms of the river, versus the sum of the other 15 stations. The two sums are well correlated (correlation coefficient = 0.85, r^2 = 0.72), suggesting that the cause of bacterial contamination operates river-wide. Figure 3 is a scatter plot of the sum of the total bacteria for all 23 stations versus the number of stations that exceeded 14 MPN, the cut-off for shellfish harvesting restriction. Clearly, increased bacterial concentrations are not caused by a few stations, but many stations are always involved. These observations support the contention that the vector(s) of contamination operate(s) river-wide. Aside from runoff, windy events that might stir up anoxic bottom sediment, known to harbor fecal coliform bacteria (Gerba and McLeod, 1976, Applied and Environmental Microbiology 32: 114-120), are the only other physical variable likely to operate river-wide. This explanation is a doubtful generalization because a dry Nor'easter on 3/22/07 failed to result in high bacterial concentrations and because the numerous small arms of the river are not all oriented similarly and therefore they do not all have the same fetch.

Table 1 shows some of the data with sample dates sorted according to decreasing total concentration of bacteria (total column). All 26 sample dates with concentrations of bacteria above the average of 620 are shown. Rainfall for the 14 days prior to sampling is shown in columns 1 through 14. All except 3 of those 26 dates experienced more than one inch of rain within the previous two weeks. But it is also true that of the remaining 91 dates with total bacterial concentrations lower than the average of 620, 68 had rainfall in excess of one inch within the previous two weeks. All dates when 4 or more inches of rain fell in the two weeks prior to sampling are shown in Table 1.

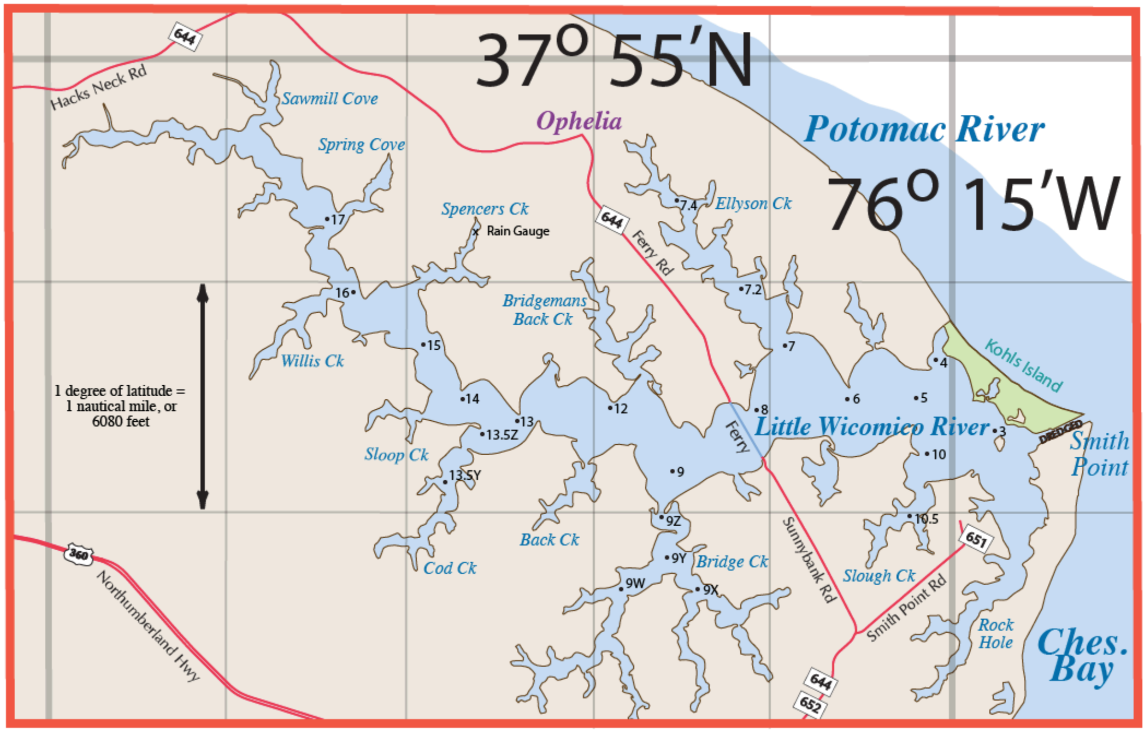
The amount of rain immediately prior to sampling is probably insufficient to predict runoff. Rather, it is variation in the recent history of rainfall that is important. Localized cloudbursts might affect the rainfall monitoring station, but not the entire river. A very important variable is the degree of ground saturation and duration of surface flow, which determines how much rain infiltrates into the soil and how much runs off. Rozen and Belkin assert that "… previous growth history also has a major influence on subsequent survival ….." of bacteria in seawater. Fecal material that remains moist because of relatively frequent rain as opposed to being desiccated during drought likely results in increased viability on being transported into the water. It is possible, but unlikely, that sample contamination or systematic laboratory error could affect suites of samples collected the same day.

On the date when bacteria were highest, 10/29/03, 2 inches of rain fell the previous day. Hurricane Isabel passed through the area on 09/17/03 and 6.7 inches of rain fell between the passage of Isabel and the sample date. It is likely that soils were relatively saturated after Isabel, so runoff shortly before sampling was favored over infiltration. The date with the fifth highest bacterial concentration experienced no rain for a week prior to sampling, but in the previous week 9.2 inches of rain fell, associated with hurricane Ernesto on 9/01/06. It is clear that heavy rainfall events at much as several weeks prior to sampling can be responsible for bacterial contamination. Anomalously strong storms may also play a role. Anderson et al. confirmed the persistence of fecal coliform bacteria in seawater for several weeks.

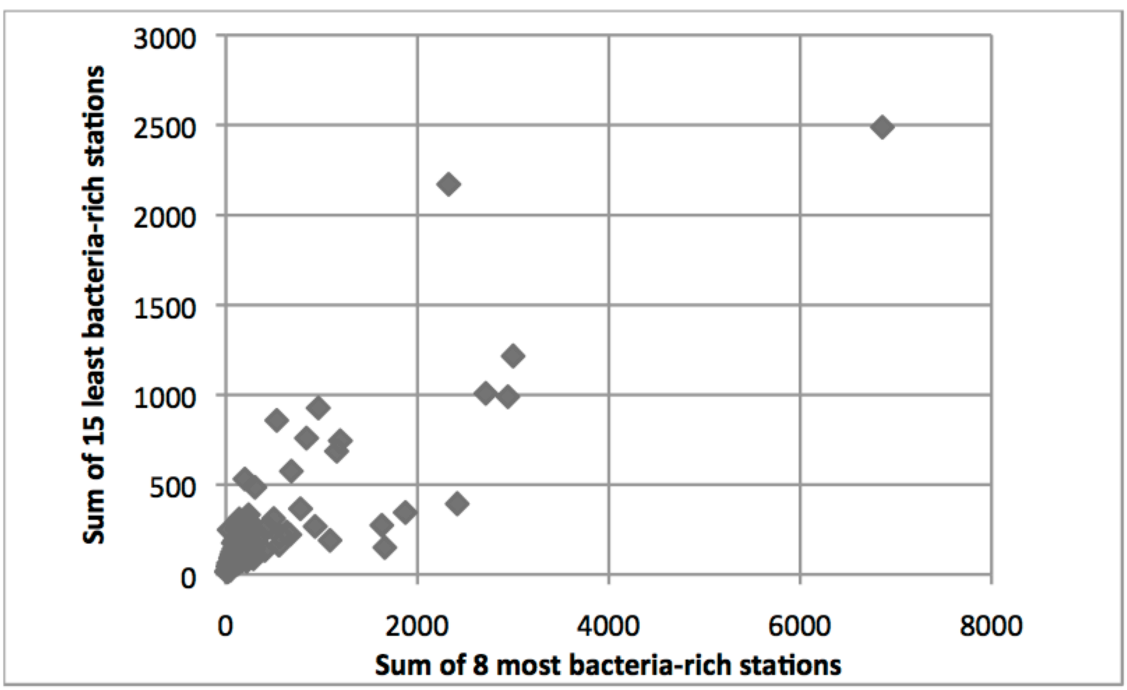
Dates having moderate bacterial concentrations associated with little rainfall are not uncommon. As an example, there was 0.5” of rain on Oct. 6, 2001, and 0.4” on Oct 14. No additional rain fell until Dec. 8, after samples that ranked 44th highest in total bacteria (292) were taken on Dec. 7 (data included in Table 1). Those samples, where 8 of the 23 stations exceeded the 14 MPN cut-off for restricted water, are difficult to explain.

Conversely, dates with low bacterial concentrations associated with appreciable rainfall are not uncommon and are also unsatisfactorily explained. For example, 3.2 inches of rain fell in the two weeks prior to the samples collected on August 5, 2008 (ranked 113th), and 1.7” of that rain fell 8 days before the samples were taken. Yet only four of the stations sampled had more then 1 MPN, which is the minimum entered for all samples, and none exceeded the 14 MPN cut-off for restricted water. This date, other dates when no rainfall was recorded for two weeks prior to sampling, and the lowest ranked two samples (116 and 117), are also shown in Table 1.

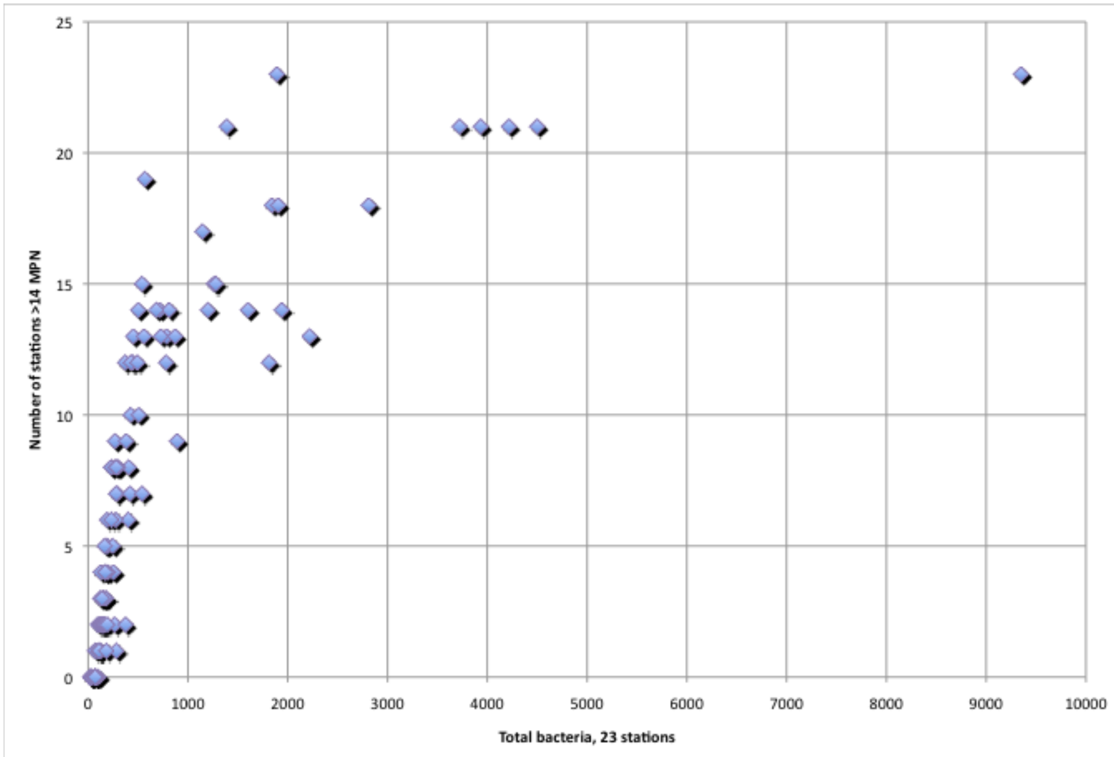
In conclusion, it is likely that the most important vector of contamination that operates river-wide is runoff. Rainfall, especially heavy rainfall, accounts for most of the observations. Yet heavy rainfall events do not always cause high levels of bacterial contamination and high levels of bacterial contamination are not always associated with recent rainfall. Other variables such as water temperature, ground saturation, duration of runoff, wildlife behavior, the availability of substrate for bacterial growth, patterns of predatory protozoan abundance and other biological factors such as “blooms” associated with seasonal biological progression could all exert river-wide controls on the observed concentrations of fecal coliform bacteria. The data (date, recorded bacterial concentrations for 23 stations, total of the 23 stations and recorded rainfall for 14 days prior to sampling) are available in an Excel spreadsheet from the author at JandL@nnwifi.com.


37° 55′N
76° 15′W
Potomac River
Ophelia
Hacks Neck Rd
Sawmill Cove
Spring Cove
Spencers Ck
Rain Gauge
Ellyson Ck
Ferry Rd
Bridgemans Back Ck
Willis Ck
1 degree of latitude = 1 nautical mile, or 6080 feet
Kohls Island
Little Wicomico River
Smith Point
Sloop Ck
Back Ck
Cod Ck
Bridge Ck
Sunnybank Rd
Slough Ck
Smith Point Rd
Rock Hole
Ches. Bay
Northumberland Hwy
Ferry
DREDGED

(Fig. 1)


Sum of 15 least bacteria-rich stations
Sum of 8 most bacteria-rich stations
0
500
1000
1500
2000
2500
3000
2000
4000
6000
8000

(Fig. 2)



25
20
15
10
5
0
Number of stations >14 MPN
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Total bacteria, 23 stations

(Fig. 3)

total	comments	date	rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14
9349	Isabel 9/17	10/29/03	1	2.0	0.4										0.1		
4500		6/28/06	2	1.0	1.6		0.1	1.0									1.2
4217		11/15/04	3			2.3	0.3							1.3			
3935	Nor'easter 5/24	6/8/05	4			0.8		0.1	1.4			0.2					0.2
3723	Ernesto 9/01	9/12/06	5								0.7	0.2		6.7	0.9	0.7	
2812	Horned pondweed	6/6/00	6	0.8							0.5	0.2			0.1		
2219	Nor'easter 10/06	10/18/06	7	0.4										4.5			
1940		7/8/04	8	0.1		0.1	0.3		0.3			0.3				1.4	
1904		7/6/00	9		2.6	0.6				0.1	0.6	0.7					
1891	Nor'easter 5/10	5/12/08	10	1.6	0.1	0.5	2.1										1.3
1842		1/8/07	11			0.8				0.8	0.1					0.1	0.7
1812		11/8/06	12	1.0											1.2		
1602	Horned pondweed	4/13/04	13	1.4	0.1	0.4								0.2	0.5	0.8	0.1
1388		11/12/03	14						2.7	0.7							
1278		3/19/02	15	0.1	1.1				0.2								
1261	Charlie 8/14, Francis 9/07	9/13/04	16					0.4	0.9								0.7
1200		12/16/05	17	1.2							0.9			1.5		0.1	
1145	Jeanne 09/28	10/26/04	18		0.1				0.1	1.1				0.2	0.1	0.4	
890		9/29/05	19						0.1			1.4			0.1		
872		9/26/01	20	0.1	1.3			2.0									
811		6/1/04	21	0.1	1.2			0.2	0.1	0.2						0.2	
787	Nor'easter 8/06	8/11/04	22						1.2		0.6	0.8	1.0				0.2
781		9/9/03	23					0.5	1.7	0.6			0.8			0.1	
729	Horned pondweed	5/26/04	24	0.2						0.2			0.2				
718		4/28/05	25	0.2				0.2		0.1							
683	Lots horned pondweed	5/7/03	26		0.1									0.2	0.3		
502	Horned pondweed	6/4/03	31	0.2			0.5		0.4		0.1			1.6	0.3	0.4	1.6
494	Nor'easter 09/05	9/6/00	32			0.3	0.5		0.6	0.5		0.2	1.3				
452	Wilma 10/24	11/7/05	33													0.1	1.2
447	Dead zone in river	8/5/03	34	0.3			1.2		0.8	0.1	2.7						0.8
406	Hanna 09/05	9/10/08	38	1.1			2.0	0.5							0.1	1.0	
292		12/7/01	44														
282	Horned pondweed	5/7/01	47											0.1	0.3		
267	one station high - 150	11/20/01	52														
193	Irene 10/17	11/2/99	59													1.2	
170	Dennis 8/30, Floyd 9/15	10/4/99	71					0.5								0.9	
165	13.2" within 30 days	8/8/00	73		0.1		0.3	0.2		0.9	0.2	0.7		1.3		1.0	1.1
152		11/6/07	76	0.1									0.1	3.2	1.0	1.8	
133	Nor'easter 10/16	10/24/02	83				0.2				1.5					1.4	1.2
117		3/6/03	89	0.5	0.7		0.9		0.8	0.4					0.3	0.5	
112		11/7/00	90														
94	Nor'easter 3/08	3/10/05	97		1.3			0.1					0.7			0.1	
67		3/9/06	108														
28		8/5/08	113			0.2				0.3	1.7				0.9	0.1	
23		3/5/09	116				1.0	0.3							0.1		0.2
23		3/3/08	117										0.3		0.1		

(Table 1)