Rivanna River Watershed Health: A Yearlong Evaluation of Ecological Indicators for Environmental Analysis

St. Anne's-Belfield School Environmental Statistics Class of 2013-14

Abstract:
This paper addresses the health of the Rivanna River watershed as evaluated through close analysis of environmental indicators. The Rivanna River watershed, a major part of Virginia's ecology, encompasses the Piedmont region of Virginia and empties into the James River. Data in ten indicators collected from twenty-five randomly selected rivers was compared to established environmental standards. Two methods, both focusing on the importance of individual rivers within the watershed, led to the conclusion that the Rivanna River watershed is unhealthy.

Introduction:
What is the health of the Rivanna River watershed? The Rivanna watershed contains most of the freshwater environments in central Virginia, thus supporting almost all of the aquatic life in the area. Metropolitan areas and industrial development pose a grave threat to the watershed, as runoff from roads introduces harmful chemicals into the rivers. Nitrates, ammonia, and pH, along with other indicators that were tested, can rise or fall to levels detrimental to aquatic life due to pollutants from roads and highways. Natural elements, such as steep banks, can lead to erosion, which also has a negative impact on the health of the river. The following indicators were tested: nitrates, ammonia, pH, dissolved oxygen (DO), biological oxygen demand (BOD), turbidity, phosphates, temperature, conductivity and E Coli. Benthic specimens were also counted and identified, and the data was collated to determine the overall health of the watershed.

Methods:
Data Collection: Data was collected from twenty-five randomly selected rivers between orders 1 and 5 (five from each order). Vernier probes and chemical kits were used to test the indicators. Three samples were collected for nitrates, ammonia, pH, DO, BOD, and turbidity, either across the width of the river, or, in the case of narrow rivers, up the river against the flow of the water. Probes were left in the water until the readings began to settle. Benthic data was also collected, using a net and two-minute agitation samples to collect a goal minimum sample of 200 organisms. These readings were recorded on data sheets and entered into Fathom, split both into individual river files as well as a master data file.

Group A: Group A first compiled the data points from the ten indicators, collected from twenty-five different rivers, into one collection. A box-and-whisker plot was then used to determine outliers in the collected data of individual indicators. These outliers were tallied and then discarded. Additionally, any impossible readings, most notably negative turbidity readings, were discarded. At this point, one indicator, E Coli prevalence, was discarded because of a lack of data and inconsistent rating systems. "Healthy" standards for each indicator were then researched. For the purposes of this study, the cutoff for "healthy" was considered the point at which the level of the indicator would no longer pose a risk to aquatic life. At this point, temperature was discarded as an indicator, as the time span of the study was too long to use temperature as a relative indicator. Curves were then created to rate each data point when compared to the established "healthy" standard. A scale of 0 to 100 was used (with 0 being the furthest possible from the "healthy" standard, 100 being the closest, and 50 being the cutoff for "healthy" and "unhealthy" data), and the curves were formed to fit each standard for each indicator.

Three general forms of curve were used to translate physical data into a score on the 0-100 scale, depending on the type of health standard. In each situation, curves were chosen so that the optimum indicator level corresponded to a score of 100, indicator levels at the edges of healthy ranges corresponded to a score of 50, and the behavior of the curve at the theoretical extremes of indicator readings (indicator readings of 0 or indefinitely large readings, for example) were roughly consistent with the health of a river with such indicator levels. Curves were chosen with simplicity in mind.

For indicators where a complete absence was optimum (nitrate, BOD, ammonia, turbidity), an exponential curve was used with the following form:

$$100 \cdot 2^{-\left(\frac{\text{Indicator}}{\text{Edge of healthy range}}\right)}$$

For indicators where neither a complete absence nor an indefinitely large presence was healthy (conductivity, pH), the assumption was made that the center of the healthy range was optimum, and a normal curve was used with the following form:

$$100 \cdot 2^{-\left(\frac{\text{Indicator} - \text{Middle of healthy range}}{\text{Half the width of healthy range}}\right)^2}$$

For DO, the only indicator for which an absence was unhealthy and any practical abundance was healthy, a logistic curve of the following form was used, with "Score of 90" indicating the value at which the indicator is considered to have a score of 90:

$$\frac{100 + \dfrac{100}{9^{\left(\frac{\text{Edge of healthy range}}{\text{Score of 90} - \text{Edge of healthy range}}\right)}}}{1 + 9^{-\left(\frac{\text{Indicator} - \text{Edge of healthy range}}{\text{Score of 90} - \text{Edge of healthy range}}\right)}} - \frac{100}{9^{\left(\frac{\text{Edge of healthy range}}{\text{Score of 90} - \text{Edge of healthy range}}\right)}}$$

Due to the fact that the healthy range of phosphate was so near to zero, a continuous piecewise combination of a normal curve and exponential curve, both of the forms above, was used, with the switch occurring at the edge of the healthy range.

Health scores were synthesized in two different ways. Given a chart of the data points with each row corresponding to a river and each column corresponding to an indicator (as in the charts below), data points were synthesized vertically using an arithmetic mean and horizontally using a type of weighted geometric mean, specifically a simple geometric mean of a standard weighted geometric mean and a geometric mean for which the weighting also depends on the magnitude of the score:

$$\left(\left(\left(\prod_{n=1}^{m}\left(s_n^{\frac{w_n}{s_n}}\right)\right)^{\frac{1}{\sum_{n=1}^{m}\left(\frac{w_n}{s_n}\right)}}\right)\cdot\left(\left(\prod_{n=1}^{m}\left(s_n^{w_n}\right)\right)^{\frac{1}{\sum_{n=1}^{m}w_n}}\right)\right)^{\frac{1}{2}}$$

These two types of synthesis were used in different orders in the final analysis of the data. This method was used so that considerably more emphasis would be placed on the indicators that were unhealthy than on those that were healthy, as a river with any one majorly unhealthy indicator would not be considered healthy, even if the other indicators were fine.

The final conclusion was confirmed by the benthic data, which was collected using the "Save Our Streams Benthic Index" with a few modifications. Hellgrammites and true flies, which were not included in the index, were incorporated into the "tolerant" count to accurately represent all of the benthic data collected. This resulted in slightly different results than those of Group B. The final benthic score was a 7.5, landing below the "grey rank" (8) on the scale of 0-12. This benthic reading served to affirm the final conclusion drawn from the data analysis.

Group B: Group B answered the essential question using deductive reasoning. Each river was subjectively classified as either existing in a stressed or unstressed environment. This procedure originated from a conversation with Virginia Department of Environmental Equality employee and statistician, Jason Hill. Agricultural fields, roads, highways, parking lots, and steep banks conducive to erosion were all concluded to be "stressors", or factors that would negatively impact the health of a river. Additional natural elements impacting the health of the river were also taken into account, such as the composition of the riverbed and the agricultural practice that surrounded the river. Rivers that were largely free of stressors were classified as unstressed. All the data for each of the indicators was formally collected and recorded. Box and whisker plots were used to compare the stressed and unstressed values of each indicator, as well as eliminate outliers. Matched-pair tests were used to confirm the differences in the specific measurements between stressed and unstressed rivers. Benthic data was also collected, and each river was given a numerical score based on the "Save our Streams Benthic Index." This index gave each river a score, ranging from 0-12, with 9 or above indicating a healthy water environment, and 7 or below indicating an unhealthy one. Nitrates, benthic, and DO were determined to be good indicators of river health, based on their significant difference in stressed and unstressed values. A single average for each indicator was calculated and formatted to a 0-7 scale created by the Virginia Department of Environmental Quality for determining the health of a river. A score of 0-3.5 showed the river was unhealthy, greater than 3.5 and less than 4.5 showed the river was fairly healthy, and 4.6-6.5 showed the river was in good health.

Charts:

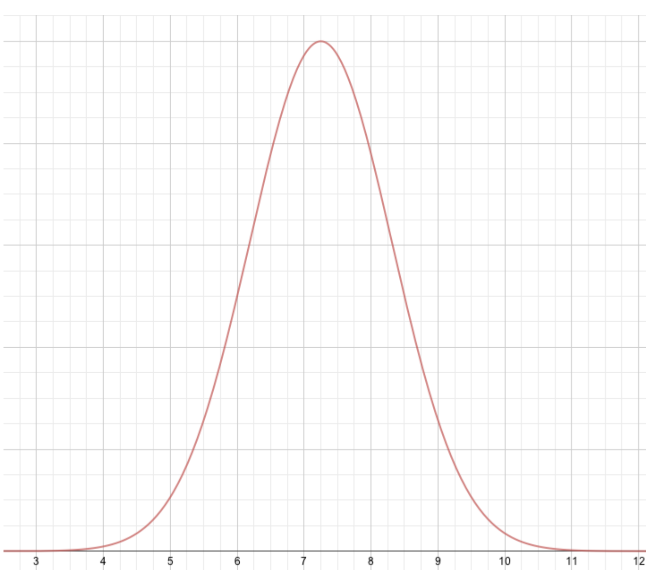
Site locations:

Site_Number	Order	River	Description	Longitude	Lattitude	Test_Date
1	1	Rocky Creek	Route 325	78° 35'56.21" W	38° 8'30.22" N	11/07/2013
2	1	Powell Creek	Proffit	78° 26'59.89" W	38° 6'2.04" N	11/15/2013
3	1	Jacobs Run	Mallek Farm	78° 28'9.40" W	38° 10'6.81" N	12/12/2013
4	1	Jacks Branch	Cloverfield	78° 20'7.02" W	38° 2'42.78" N	12/18/2013
5	1	Doyles River	CCC Road	78° 41'0.60" W	38° 10'34.97" N	02/06/2014
6	2	Long Island Creek	Route 601	78° 13'47.46" W	37° 50'40.80" N	12/05/2013
7	2	Ballinger Creek	Route 631	78° 14'4.82" W	37° 56'4.04" N	12/05/2013
8	2	Ivy Creek	Dick Woods Road	78° 36'32.15" W	38° 1'56.79" N	11/30/2013
9	2	Broad Axe	Broad Axe Road	78° 39'25.37" W	38° 1'51.04" N	12/12/2013
10	2	Daniels Branch	Route 22 / Route 231	78° 17'52.57" W	38° 4'15.84" N	02/06/2014
11	3	Oliver Creek	Route 600	78° 17'13.66" W	37° 57'18.57" N	12/05/2013
12	3	Mechunk River	Clarks Tract Road	78° 18'58.39" W	38° 1'11.76" N	12/18/2013
13	3	Mechunk River	Campbell (Route 600)	78° 18'17.27" W	38° 2'1.47" N	01/09/2014
14	3	Buck Mountain Creek	Davis Shop Road	78° 33'53.67" W	38° 12'31.79" N	01/29/2014
15	3	Swift Run	Route 633	78° 27'49.87" W	38° 15'3.31" N	01/30/2014
16	4	Rivanna	Route 250	78° 18'43.81" W	37° 59'1.91" N	12/05/2013
17	4	Mormans	Millington Road	78° 36'45.11" W	38° 7'19.95" N	11/08/2013
18	4	Moores	Raymond Road	78° 29'33.43" W	38° 0'56.21" N	11/14/2013
19	4	Mechums	Garth Road	78° 35'35.25" W	38° 6'8.88" N	11/14/2013
20	4	Ivy Creek	Old Garth Road	78° 31'53.85" W	38° 4'28.55" N	11/30/2013
21	5	Rivanna	Palmyra (Route 15)	78° 15'58.44" W	37° 51'20.79" N	12/05/2013
22	5	Rivanna	Route 615	78° 13'30.00" W	37° 49'42.45" N	12/05/2013
23	5	Rivanna	Darden Towe	78° 27'6.50" W	38° 2'44.45" N	11/21/2013
24	5	Rivanna	Crafton (Route 600)	78° 17'52.76" W	37° 55'3.81" N	12/18/2013
25	5	Rivanna	Lake Monticello Road, Hopi Way	78° 20'7.06" W	37° 56'32.52" N	12/18/2013

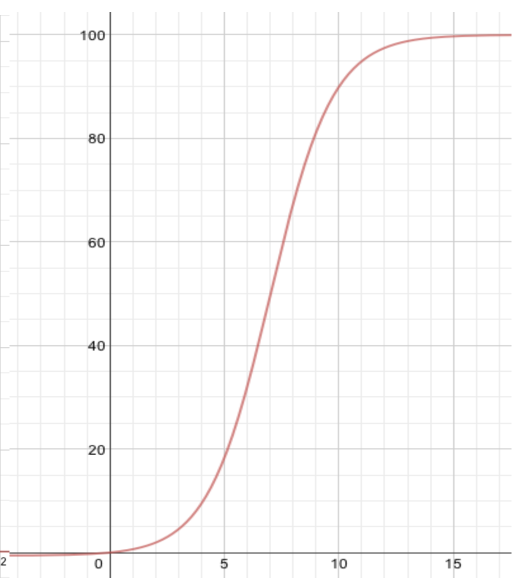
Group A

Charts of curves used to convert indicator levels to health scores:

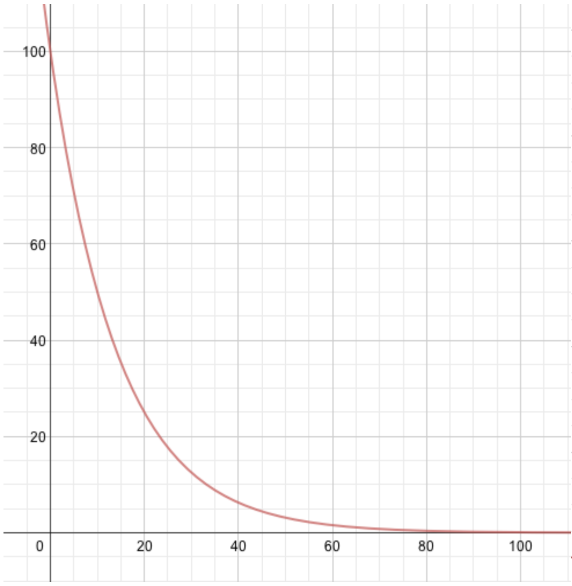
Score by pH
(no units)



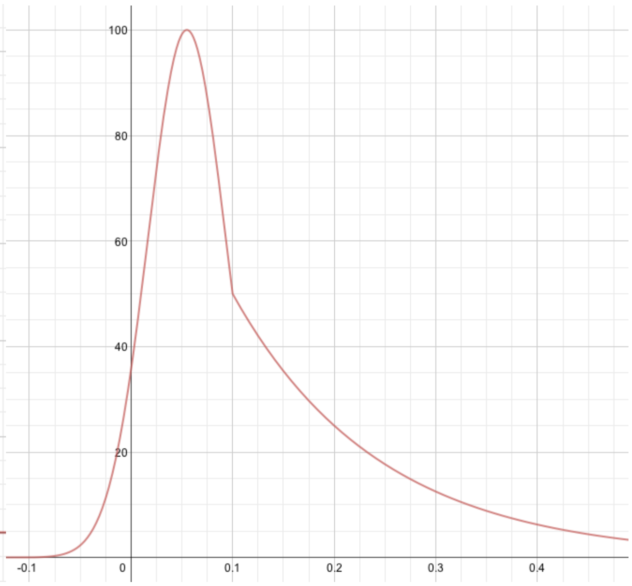
Score by DO
(*Mg/L*: Milligrams Per Liter)



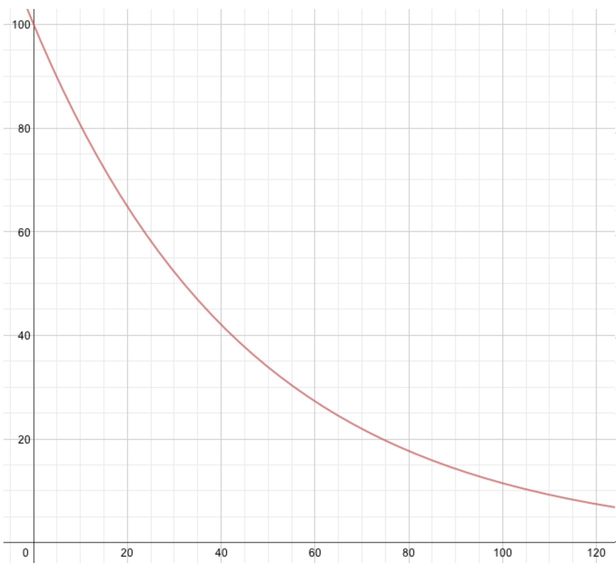
Score by Nitrate
(*Mg/L*: Milligrams Per Liter)



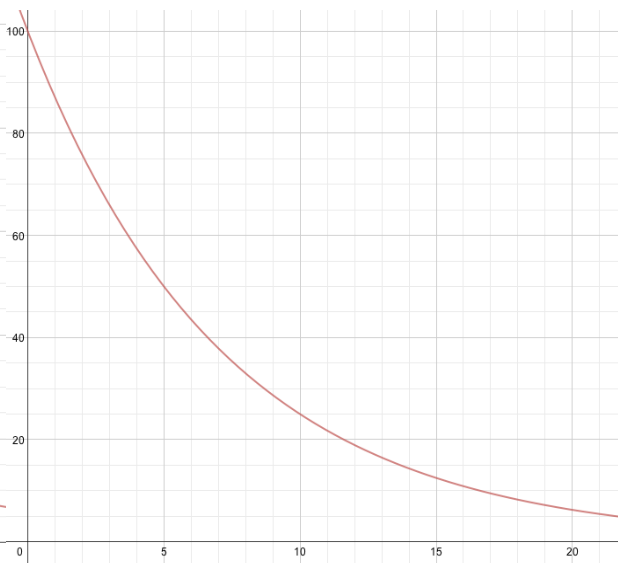
Score by Phosphate
(*Mg/L*: Milligrams Per Liter)



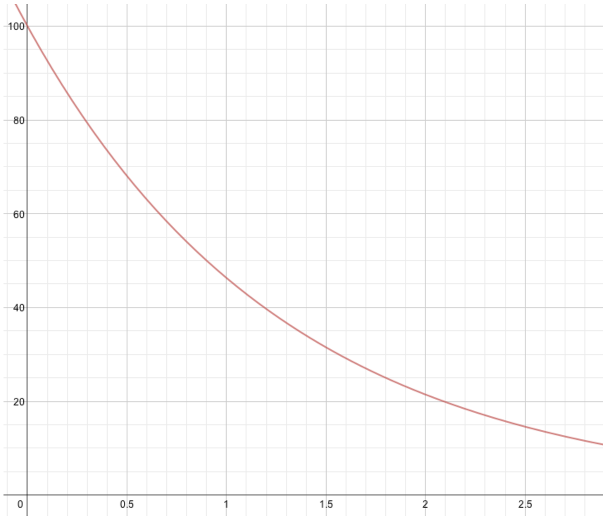
Score by Turbidity
(*NTU*: Nephelometric Turbidity Units)



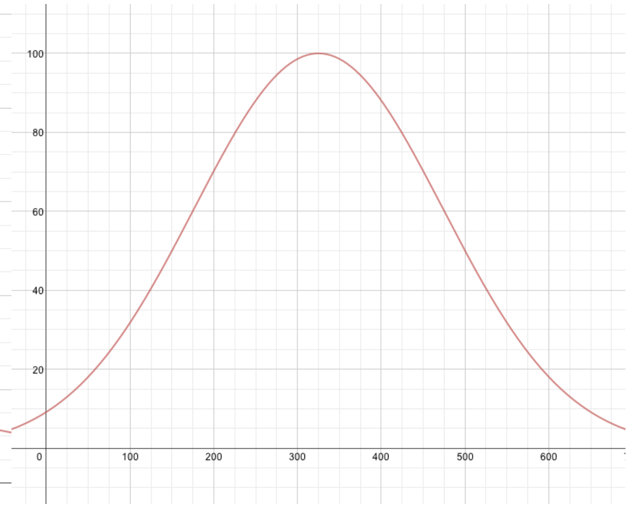
Score by BOD
(*Mg/L*: Milligrams Per Liter)



Score by Ammonia
(Mg/L: Milligrams Per Liter)



Score by Conductivity
($\mu S/cm$:microsiemens per centimeter)



Average indicator reading for each indicator for each river, rivers numbered 1-25:

Raw data:

Site_Number	Nitrate	Ammonia	PH	Conductivity	Turbidity	DO	BOD	Temperature	Phosphate	EColi	Benthic
	mg/L	mg/L		muS_per_cm	NTU	mg/L	mg/L	Celsius	absorbance	colonies	
1	0.5133 mg/L	0.1567 mg/L	9.323	42.21 muS_per_cm	30.9733 NTU	7.4667 mg/L	0.8 mg/L	12.53 C	0.114 absorbance	0 colonies	8
2	10.3667 mg/L	23.7333 mg/L	8.5	106.5 muS_per_cm		6.3 mg/L		7.2 C	0.71 absorbance		8
3	2.16667 mg/L	0.933333 mg/L	9.13333	39 muS_per_cm	11.3537 NTU	6.6 mg/L	-0.63333 mg/L	6.4 C	0.47 absorbance	2 colonies	9
4	2.1 mg/L	0.045 mg/L	8.81667	57.61 muS_per_cm	128.333 NTU	7.93333 mg/L	0.8 mg/L	5.8 C	0.318 absorbance	6 colonies	9
5	0.1945 mg/L	0.103 mg/L	6.48333	35.53 muS_per_cm	45.6667 NTU	8.2333 mg/L	1.36667 mg/L	6.6 C	0.119 absorbance	1 colonies	9
6	1.61233 mg/L	1.01 mg/L	8.07	67.5 muS_per_cm	-1.52 NTU	8.36667 mg/L	1.4 mg/L	8 C	0 absorbance	15 colonies	8
7	2.128 mg/L	0.770333 mg/L	7.61	56.9 muS_per_cm	53 NTU	7.2333 mg/L	1.23333 mg/L	10.3 C	0.369 absorbance	25 colonies	9
8		2.96667 mg/L	8.84333	51.6 muS_per_cm	1.22333 NTU	10.0667 mg/L	3.86667 mg/L	12.3 C			8
9	3.5 mg/L	1.084 mg/L	8.071	95.39 muS_per_cm	64.6667 NTU	13.9333 mg/L	6.33333 mg/L	5 C	0 absorbance	1 colonies	8
10	0.22333 mg/L	0.0553 mg/L	6.34667	63.4 muS_per_cm	1.12267 NTU	6.93333 mg/L	0.066667 mg/L	5.4 C	0.246 absorbance		8
11	2.526 mg/L	1.16767 mg/L	7.58	71.44 muS_per_cm	11.3333 NTU	7.36667 mg/L	1.16667 mg/L	9.9 C	0 absorbance	8000 col...	8
12	195 mg/L	0.143333 mg/L	8.28	80.9 muS_per_cm	82.1 NTU	8.8 mg/L	0.633333 mg/L	5 C	0.133 absorbance	0 colonies	8
13	1.8 mg/L	0.037 mg/L	8.32333	69 muS_per_cm	149.667 NTU	9.36667 mg/L	1.86667 mg/L	2.5 C	2.73 absorbance	4 colonies	8
14	0.002333 mg/L	0.143 mg/L	8.5	44.18 muS_per_cm	21.5 NTU	7.16667 mg/L	-0.666667 mg/L	0.9 C	0.214 absorbance		7
15	9.065 mg/L	1.132 mg/L	8.26	46.18 muS_per_cm	1.53033 NTU	6.56667 mg/L	-0.9 mg/L	0.5 C	0.142 absorbance	1 colonies	8
16	2.546 mg/L	1.9 mg/L	7.93333	78.36 muS_per_cm	40.3333 NTU	7.36667 mg/L	0.4 mg/L	10.4 C	0 absorbance	12 colonies	
17	0.548333 mg/L	1.67333 mg/L	8.48333	45 muS_per_cm	5.07167 NTU	7.86667 mg/L	0.966667 mg/L	12.26 C	0.137 absorbance	0 colonies	11
18	5.66667 mg/L	5.53333 mg/L	8.21667	128.1 muS_per_cm	23.3114 NTU	12.6 mg/L	5.56667 mg/L	5.7 C	0 absorbance	0 colonies	6
19	2.25667 mg/L	0.255667 mg/L	9.27667	75.96 muS_per_cm	41.7457 NTU	7.63333 mg/L	0.3 mg/L	5.5 C		0 colonies	8
20	2.06467 mg/L	0.112667 mg/L	7.82	81.88 muS_per_cm	9.65067 NTU	10 mg/L	3.63333 mg/L	11.9 C			8
21	3.07733 mg/L	0.815 mg/L	8.00667	90.27 muS_per_cm	43.95 NTU	8.16667 mg/L	1.8 mg/L	8.3 C	0 absorbance	20 colonies	8
22	3.89233 mg/L	1.95733 mg/L	7.98333	102.51 muS_per_cm	3.574 NTU	8.16667 mg/L	1.6 mg/L	8.5 C	0.425 absorbance	10 colonies	10
23	1.54433 mg/L	0.221667 mg/L	8.68667	73.59 muS_per_cm	99.726 NTU	8.89 mg/L	1.57 mg/L	7.4 C	0.002 absorbance		8
24	6.17267 mg/L	5.79033 mg/L	8.7	85 muS_per_cm	4.42567 NTU	9.13333 mg/L	1.53333 mg/L	4.8 C	0.4 absorbance	4 colonies	6
25	16.613 mg/L	0.268333 mg/L	7.98667	85 muS_per_cm	14.9437 NTU	9.56667 mg/L	3.26667 mg/L	4.2 C	0.147 absorbance	6 colonies	

Data without outliers and impossible data points (“clean data”):

Site_Number	Nitrate	Ammonia	PH	Conductivity	Turbidity	DO	BOD	Temperature	EColi	Phosphate	Benthic
1	0.5133	0.1567	9.323	42.21	30.9733	7.4667	0.8	12.53	0	0.114	8
2			8.5	106.5		6.3		7.2		0.71	8
3	2.16667	0.933333	9.13333	39	11.3537	6.6		6.4	2	0.47	9
4	2.1	0.045	8.81667	57.61		7.93333	0.8	5.8	6	0.318	9
5	0.1945	0.103		35.53	45.6667	8.2333	1.36667	6.6	1	0.119	9
6	1.61233	1.01	8.07	67.5		8.36667	1.4	8	15	0	8
7	2.128	0.770333	7.61	56.9	53	7.2333	1.23333	10.3	25	0.369	9
8		2.96667	8.84333	51.6	1.22333	10.0667		12.3			8
9	3.5	1.084	8.071	95.39	64.6667			5	1	0	8
10	0.22333	0.0553		63.4	1.12267	6.93333	0.066667	5.4		0.246	8
11	2.526	1.16767	7.58	71.44	11.3333	7.36667	1.16667	9.9	8000	0	8
12		0.143333	8.28	80.9	82.1	8.8	0.633333	5	0	0.133	8
13	1.8	0.037	8.32333	69		9.36667	1.86667	2.5	4		8
14	0.002333	0.143	8.5	44.18	21.5	7.16667		0.9		0.214	7
15	9.065	1.132	8.26	46.18	1.53033	6.56667		0.5	1	0.142	8
16	2.546	1.9	7.93333	78.36	40.3333	7.36667	0.4	10.4	12	0	
17	0.548333	1.67333	8.48333	45	5.07167	7.86667	0.966667	12.26	0	0.137	11
18	5.66667		8.21667	128.1	23.3114			5.7	0	0	6
19	2.25667	0.255667	9.27667	75.96	41.7457	7.63333	0.3	5.5	0		8
20	2.06467	0.112667	7.82	81.88	9.65067	10	3.63333	11.9			8
21	3.07733	0.815	8.00667	90.27	43.95	8.16667	1.8	8.3	20	0	8
22	3.89233	1.95733	7.98333	102.51	3.574	8.16667	1.6	8.5	10	0.425	10
23	1.54433	0.221667	8.68667	73.59	99.726	8.89	1.57	7.4		0.002	8
24	6.17267		8.7	85	4.42567	9.13333	1.53333	4.8	4	0.4	6
25		0.268333	7.98667	85	14.9437	9.56667	3.26667	4.2	6	0.147	

Health scores for each indicator used in analysis for each river, excluding benthic (derived using the “clean data” above and the translation curves above):

Site_Number	Nitrate	Ammonia	PH	Conductivity	Turbidity	DO	BOD	Phosphate	Standard_Weight	Subjective_Weight
1	97	89	15	16	51	92	90	45.0	40	34
2			50	34		84		0.7	4	5
3	86	49	21	16	78	86		4.0	18	17
4	86	97	34	20		94	90	11.0	36	33
5	99	92		15	37	95	83	44.0	50	42
6	89	46	74	22		96	82	36.0	55	49
7	86	55	94	20	32	91	84	8.0	32	30
8		10	32	18	97	99			28	24
9	78	43	74	30	25			36.0	42	46
10	98	96		21	98	89	99	18.0	48	41
11	84	41	95	23	78	92	85	36.0	57	50
12		90	62	26	17	97	92	40.0	47	51
13	88	97	60	23		98	77		64	55
14	100	90	50	17	63	91		23.0	45	40
15	53	42	64	17	97	86		37.0	47	40
16	84	23	81	25	42	92	95	36.0	49	45
17	96	28	51	17	90	94	87	39.0	48	40
18	68		66	42	60			36.0	52	51
19	86	82	16	25	40	93	96		43	38
20	87	92	87	26	81	99	60		68	61
21	81	53	78	29	39	95	78	36.0	56	54
22	76	22	79	33	93	95	80	5.0	24	23
23	90	84	40	24	12	97	80	38.0	41	48
24	65		39	27	91	98	81	6.0	26	24
25		81	79	27	72	98	64	36.0	59	53

Group B

Group B classified each river into stressed and unstressed. The stressed rivers were located in areas such as farmlands, recreation fields, parks, and roads. Sites that were not surrounded by farmlands, recreation fields, parks, and roads were classified as unstressed rivers. We expected the stressed rivers to have higher averages than the unstressed rivers.

Data from stressed sites:

Site_Number	Nitrate	Ammonia	PH	Conductivity	Turbidity	DO	Temperature	Phosphate	Benthic
23	1.5	0.22	8.7	73.6	99.7	8.89	7.4	0.0	8.0
20	2.1	2.06	7.8	81.9	9.7	10.00	11.9	0.0	8.0
2	10.4	23.73	8.5	106.5	17.7	6.30	7.2	0.7	8.0
9	3.5	1.08	8.1	95.4	64.7	13.90	5.0	0.0	8.0
18	5.7	5.53	8.2	128.1	77.7	12.60	5.7	0.0	6.0
4	2.1	0.04	8.8	57.6	128.3	7.90	5.8	0.3	9.0
24	6.2	5.79	8.7	85.0	4.4	9.10	4.8	0.4	6.0
25	16.6	0.82	8.0	85.0	14.9	9.56	4.2	0.1	
10	0.2	0.06	6.3	63.4	2.2	6.93	5.4	0.2	8.0
14	0.0	0.14	8.5	44.2	21.5	7.17	1.0	0.2	7.0
Average (all)	5.1	3.90	8.2	82.1	44.1	10.20	5.8	0.2	7.6
Average (clean)	6.3	1.80							

The turbidity reading from site 2 was originally negative. Compensating for issues relating to the turbidity probe yielded the number shown. The ammonia reading from site 2 and the nitrate readings from sites 4 and 10 are outliers and were ignored in the calculation of Average (clean), which was used in the evaluation of the health of the watershed.

Data from unstressed sites:

River	Nitrate	Ammonia	PH	Conductivity	Turbidity	DO	Temperature	Phosphate	Benthic
8		2.96	8.8	51.6	2.6	10.10	12.3		8.0
13	1.8	0.04	8.8	69.0	149.7	9.36	2.5	2.7	8.0
21	3.1	0.82	8	90.3	44.0	8.17	8.3	0.0	8.0
17	0.5	1.67	8.483	45.0	5.1	7.86	12.3	0.1	11.0
19	2.3	5.53	9.27	128.1	41.7		5.5	0.0	8.0
22	3.9	1.96	7.983	102.5	3.6	8.16	8.5	0.4	10.0
16	2.5	1.90	7.93	78.4	41.6	7.37	10.4	0.0	
1	0.5	0.16	9.32	42.2	30.8	7.47	13.7	0.1	8.0
6	1.6	1.01	8.07	67.5	55.4	8.36	8.0	0.0	8.0
11	2.6	1.17	7.58	71.4	11.3	7.36	9.9	0.0	8.0
12		0.14	8.28	80.9	82.1	8.80	5.0	0.1	8.0
7	2.1	0.77	7.61	56.9	53.0	7.20	10.3	0.4	9.0
3	2.2	0.93	9.13	39.0	11.4	6.60	6.4	0.5	9.0
15	9.1	1.13	8.26	46.2	1.5	6.57	0.5	0.1	8.0
5	1.8	0.10	6.483	35.5	45.7	8.23	6.6	0.1	9.0
Average (all)	2.6	1.35	8.269	67.0	38.6	7.97	8.0	0.3	8.6
Average (clean)	2.1								

The turbidity reading from sites 6, 8, and 16 were originally negative. Compensating for issues relating to the turbidity probe yielded the number shown. The nitrate reading from site 15 was an outlier and was ignored in the calculation of Average (clean), which was used in the evaluation of the health of the watershed.

Original DEQ rating scale before ranges were modified by Group B:

			Water Qu	
Temperature	Rank S		Temperat	
< 20.00	7	>	-10.00	7
>= 20.00, but <2	6	>	20.00	6
>= 25.00, but <2	5	>	25.00	5
>= 27.50, but <3	4	>	27.50	4
>= 30.00, but <3	3	>	30.00	3
>= 32.50, but<3	2	>	32.50	2
>= 35.00	1	>	35.00	1

			Water Quality	
Minimum Rank Sc	Evaluat		Min. Rank Sc	Evaluation
> 1, but < 2	Dead	>	1	Dead
> 2, but < 3	Awful	>	2	Awful
> 3, but < 4	Poor	>	3	Poor
> 4, but < 5	Fair	>	4	Fair
> 5, but < 6	Good	>	5	Good
> 6, but < 7	Excelle	>	6	Excellent
>= 7	Pristine	>	7	Pristine

Dissolved Oxyg	Rank S		Dissolved	
< 3.0	1	>	0.0	1
>= 3.0, but < 4.	2	>	3.0	2
>= 4.5, but < 6.	3	>	4.5	3
>= 6.0, but < 7.	4	>	6.0	4
>= 7.5, but < 9.	5	>	7.5	5
>= 9.0, but < 10	6	>	9.0	6
>= 10.0	7	>	10.0	7

Conductivity	Rank S		Conductivity	
< 100	7	>	0	7
>= 100, but < 175	6	>	100	6
>= 175, but < 250	5	>	175	5
>= 250, but < 500	4	>	250	4
>= 500, but < 100	3	>	500	3
>= 1000, but < 30	2	>	1000	2
>= 3000	1	>	3000	1

Path = . . . / AW

pH (Units)	Rank S		pH (Units	
< 4.00	1	>	1.00	1
>= 4.00, but < 4	2	>	4.00	2
>= 4.65, but < 5	3	>	4.65	3
>= 5.35, but < 6	4	>	5.35	4
>= 6.00, but < 6	5	>	6.00	5
>= 6.35, but < 7	6	>	6.35	6
>= 7.00, but < 8	7	>	7.00	7
>= 8.00, but < 8	6	>	8.00	6
>= 8.65, but < 9	5	>	8.65	5
>= 9.00, but < 9	4	>	9.00	4
>= 9.65, but < 1	3	>	9.65	3
>= 10.35, but <	2	>	10.35	2
>= 11.00	1	>	11.00	1

% DO Saturation	Rank S		% Do Saturati	
< 50	1	>	0%	1
>= 50, but < 60	2	>	50%	2
>= 60, but < 70	3	>	60%	3
>= 70, but < 80	4	>	70%	4
>= 80, but < 90	5	>	80%	5
>= 90, but < 95	6	>	90%	6
>= 95, but < 105	7	>	95%	7
>= 105, but < 110	6	>	105%	6
>= 110, but < 120	5	>	110%	5
>= 120, but < 130	4	>	120%	4
>= 130, but < 140	3	>	130%	3
>= 140, but < 150	2	>	140%	2
>= 150	1	>	150%	1

			Water Quality	
Rank Sc Avg. - R	Evaluat		Avg. Rank Sc	Evaluation
< 1.5	Dead	>	0	Dead
1.5, but < 2.5	Awful	>	1.5	Awful
2.5, but < 3.5	Poor	>	2.5	Poor
3.5, but < 4.5	Fair	>	3.5	Fair
4.5, but < 5.5	Good	>	4.5	Good
5.5, but < 6.5	Excelle	>	5.5	Excellent
>= 6.5	Pristine	>	6.5	Pristine

Discussion/Results:

Group A: Group A found four numerical answers as a result of two different methods (orders of synthesis) of data compilation and two different weighting systems. One method, “Geo-Arith,” compiled data first into individual scores for each river, based on the scores for each of eight indicators for the river. The scores for the rivers were then combined into one final number. The second method, “Arith-Geo,” compiled each of an individual indicator’s scores into one overall indicator score before combining all the indicators into one final numerical answer. The first method, which focuses more heavily on the health of individual rivers, not individual indicators, was judged to fit more closely the goal of the original question, which asked for the health of the watershed as a compilation of individual rivers. Two more numerical answers were obtained through the same methods of combination but a different weighting system. The first weighting system used researched and established weightings to compile the data; the other system took into account the perceived reliability and importance of the indicators to incorporate probable error into the weighting system. In this manner, four numbers were found as the results of various combinations of the two methods and two weighting systems. The two “Geo-Arith” scores (43 and 40) were lower, while the two “Arith-Geo” scores (53 and 48) were higher. The weighting system that incorporated perceived reliability yielded the lower score for each group (40 for “Geo-Arith” and 48 for “Arith-Geo”). As the “Geo-Arith” method approached the data compilation from a river-by-river basis, which took into account the need to evaluate rivers as individual bodies, it should have considerably greater weight. Additionally, the weighting system that incorporated equipment reliability is considered more significant, as it takes into account the experience of data collection and the individual issues with the probes. It follows that the score of 40 should be weighted most heavily and the score of 53 should be weighted least heavily. Even without this weighting, however, the arithmetic mean of the final scores was still 46, below the “healthy” cutoff at 50, and three of the four final scores were below that cutoff. The collection of final scores through a variety of methods demonstrates a general range of potential final scores, and thus provides some context for the final conclusion of an “unhealthy” Rivanna River watershed. This outcome should be carefully considered in light of its impact on the ecology of the Rivanna River watershed area and surrounding locations. Wildlife diversity can be negatively impacted, as well as the quality of drinking water and the overall health of the adjacent environments, posing a fairly significant health risk to those who utilize the watershed in any capacity.

Group B: Group B calculated an overall score of 3.425 on a modified version of DEQ’s standardized scale, indicating that the Rivanna watershed was slightly unhealthy. This score was found using the Virginia Department of Environmental Quality Indices for determining the impact of each indicator on the river, as well as overall health of the river. This one numerical answer was the summation of three numbers related to the three selected indicators. The summation was placed on a scale provided by the DEQ that stemmed from scales for each indicator examined (with emphasis on as many indicators as were selected.) Group B found that, when examining nitrate, benthic and DO indicators with the outlier-reducing method chosen, the nitrate average for the watershed suggested a significantly poor level of health, while DO and benthic both suggested a borderline average level of river health. When ranked in the indicator scale, (after making adjustments to ensure that an unhealthy increase in one indicator--i.e., nitrate--did not negatively the average when increases in other indicators--benthic and DO--were generally positive signs) the watershed as a whole was categorized as neutral health with a significant tendency towards poor health. For example, weighting nitrate as a indicator that was, say, 1.5 times more important than the other two considered, would have yielded an overall numerical answer that would have been much farther within the range of poor health. Perhaps the primary concern of Group B's method was taking advantage of the subjectivity of the classification. Part of creating a statistical method that reflected the unique geographical area was creating a focus on the watershed environment through observation of the physical surroundings—rural lands, agricultural use (extrapolation), highly concentrated urban areas, animal populations, bank composition, river floor composition—and evaluating the site upon arrival to determine its categorization as stressed or unstressed.