Challenging assumptions: Analysis of physical contributions to water quality in stormwater retention ponds

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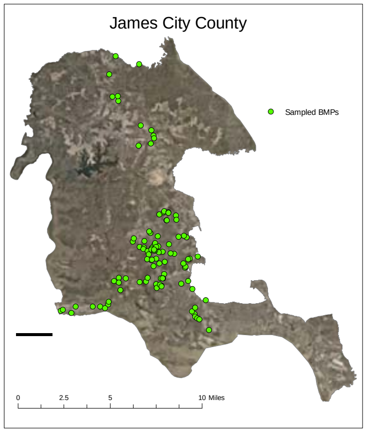
Introduction

State and county governments have come to rely on stormwater best management practices, or BMPs, to control excess water drainage from urban and suburban development. The most common BMP is the wet retention pond. In addition to functioning as a preventative flood measure, ponds are also relied upon as putative processing systems to reduce the flow of pollutants directed downstream from development. This "water quality enhancement" function is largely based on the assumption that greater retention time leads to better water quality. No research to date has documented which, if any, physical parameters of a pond affect the quality water of water released. Small, in-depth case studies of a limited number of ponds have indicated that an abundance of aquatic plant life may enhance pollutant removal. However, more comprehensive studies have not been undertaken to determine if this relationship holds true in other ponds as well. To address this information gap, we measured water quality and researched construction parameters in 96 stormwater retention ponds in James City County, VA, intending to discover which parameters were most strongly correlated with water quality in wet retention ponds.



Methods

We sampled 96 of approximately 500 James City County stormwater BMPs (stormwater retention ponds labeled with a JCC county code), located in ArcGIS using a BMP shapefile provided by the James City County GIS Division. Water samples were collected near the pond's outlet structure in the morning, during non-storm events. On-site tests were completed for oxygen content, percent saturation, conductivity, and temperature using YSI meters. Water clarity was measured using a secchi tube. We also noted whether each pond was dyed, on a golf course, or possessed a fountain. A photograph was taken at each pond for use in a later vegetation ranking. Waters samples were then brought back to the lab and tested for pH, total suspended sediment (TSS), fecal coliform bacteria, Total Phosphorus, Dissolved Phosphorus, Nitrate + Nitrite, and Ammonium.

In ArcGIS, perimeter and surface area were calculated for each pond using a water shapefile downloaded from the James City County GIS website. Additional physical data describing volume, age, BMP points, drainage area, impervious area, pool elevation, and JCC rating were collected from the JCC stormwater division offices' database or by studying pond engineering files. To account for variation in shape between different ponds, a perimeter to area ratio was also calculated.

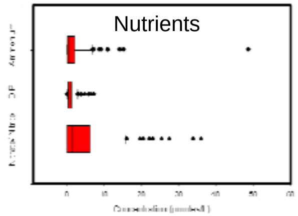
The data for each of these variables were input into SPSS software and factor analyses were performed on water quality and physical data separately. The factor analyses generated a number of principal components describing the main sources of variation for these two sets of data. For each pond, eigenvalues were generated for each principal component. We then plotted each principal component value for the pond physical data as the independent variable against each principal component value for the pond water quality data as the dependent variable. Significant correlations between pond physical structure and water quality were identified at the P<0.05 level.

Results

In general, both the water quality and the physical data were clustered tightly around the median. In most variables, there were several outliers far greater than the median, skewing the data positively and pulling up the means. Descriptive statistics for some of the variables in our dataset are shown to the left. A plot of our nutrient measures is on the right.

Water Quality Data	Mean	Median	Minimum	Maximum
Temperature C	26.7	26.9	22.6	31.1
Conductivity µS	133.6	114.8	12.2	406.2
Oxygen mg/L	7.9	7.9	1.2	13.7
Oxygen Saturation %	98.7	99.2	13.9	174.9
pH	6.7	6.6	4.9	8.9
Fecal Coliform Bacteria #/100mL	251.6	66.0	0.0	2805.0
Secchi cm	64.3	59.5	0.0	120.0
Total Suspended Sediment mg/L	37.3	10.6	0.5	2247.6
Total Phosphorus µM	3.7	1.0	0.1	208.2
Dissolved Phosphorus µM	1.1	0.5	0.0	7.4
Nitrate/Nitrite µM	7.6	1.5	0.0	160.6
Ammonium µM	4.0	0.6	0.0	85.0

Physical Data	Mean	Median	Minimum	Maximum
Age months	195	198	20	811
Perimeter ft	1756	932	142	14645
Area ft^2	117085	34552	1215	1410454
Vegetation Rating	3	3	1	5
Drain Area acres	111	33	1	3960
Impervious Area acres	27	7	0	990
Pool Elevation ft	45	46	2	90
JCC Rating	3	3	1	5
Volume ft^3	1332838	120000	1668	31111560
BMP Points	8	9	4	11



Laboratory tests for dissolved nutrient content of water exiting ponds in James City County, VA. For each nutrient tested, a fairly narrow concentration range was observed, with some outliers (extreme outliers not shown). Of the tested ammonium concentrations, 50% ranged from 0.7 – 2.2 µM. Dissolved inorganic phosphate (DIP) had a range of 0.5- 1.2 µM and nitrate/nitrite ranged from 1.5- 7.1 µM.

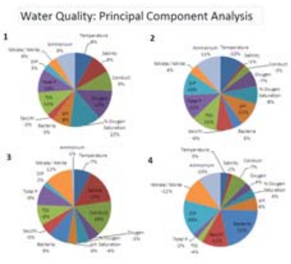
In SPSS statistical software, factor analyses of water quality and physical data for each pond yielded four and five principal components of variation, respectively, for each data set.

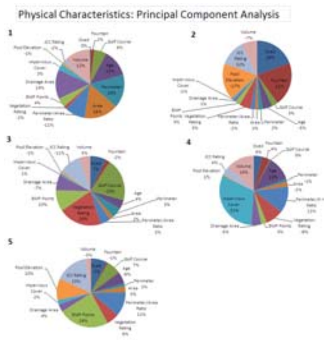
For water quality, the principal components of variation included:
1) oxygen content 25.7%
2) TSS/ total P/ ammonium 22.1%
3) Conductivity 15.7%
4) Bacteria 8.8%

These four principal components account for a total of 72.3% of total observed variation.

For pond physical data, the principle components of variation included:
1) perimeter/ area 30.2%
2) dyed/ fountain 17.2%
3) vegetation rating 14.0%
4) impervious surface 8.7%
5) BMP Points 7.4%

These components accounted for 77.5% of the variation.





The above pie charts illustrate the factor score coefficients of each variable for the principal components. Each component was described by 1-3 water quality or physical characteristics variables, based on the relative sizes of the coefficients.

Linear regressions were then generated using these components, plotting each dependent water quality component, in turn, against the five principal components of physical variation. From this analysis, no correlations between variables were statistically significant (P<0.05).

Results Part 2: Ford's Colony

The unexpected absence of statistically significant correlations between water quality and physical characteristics led us to examine a smaller subset of our collected data. This was done to determine whether or not other variables unaccounted for might play a role in water quality. Accounting for 32% of our total dataset, 31 ponds were sampled from Ford's Colony, a large property in James City County featuring a golf course and residential neighborhoods.

Pulling out a subset of data from the Ford's Colony neighborhood, the data clustered more tightly. Almost all variables had smaller maxima; further, the means tended to be closer to the medians, indicating that the data set was less skewed. These descriptive numbers suggest that by looking at ponds in this neighborhood only, we are able to eliminate some of the more extreme outliers and hopefully control for confounding variables.

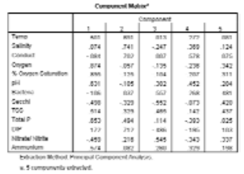
Ford's Colony Water Quality Data	Mean	Median	Minimum	Maximum
Temperature C	27.0	27.3	24.7	29.2
Conductivity µS	128.0	118.6	42.4	273.4
Oxygen mg/L	8.2	8.2	4.5	12.8
Oxygen Saturation %	102.5	100.8	54.9	165.5
pH	6.8	6.7	6.0	8.2
Fecal Coliform Bacteria #/10	109.6	66.0	0.0	561.0
Secchi cm	69.8	68.0	15.0	120.0
Total Suspended Sediment r	11.6	7.4	0.8	50.0
Total Phosphorus µM	1.4	1.0	0.2	4.3
Dissolved Phosphorus µM	0.8	0.5	0.0	2.9
Nitrate/Nitrite µM	3.6	0.7	0.0	25.5
Ammonium µM	1.8	0.5	0.0	15.3

Ford's Colony Physical Data	Mean	Median	Minimum	Maximum
Age months	227	253	84	306
Perimeter ft	1697	1351	401	8294
Area ft^2	96605	57460	8234	750605
Vegetation Rating	3	2	1	5
Drain Area acres	78	43	2	488
Impervious Area acres	26	13	0	241
Pool Elevation ft	43	46	23	60
JCC Rating	3	4	2	4
Volume ft^3	1198524	676000	29000	8188000
BMP Points	7	6	5	10

Factor analyses and linear regressions were run on the data for these ponds.

Five principal components accounted for 80.1% of the variation in water quality:
1) oxygen content 28.8%
2) conductivity/ DIP 19.9%
3) nitrates/ bacteria/ (negative) Secchi 12.5%
4) conductivity 10.5%
5) bacteria/ secchi/(negative)TSS 8.34%

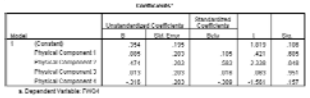
Four principal components accounted for 73.5% of the variation in physical traits.
1) perimeter/ area/ drainage area/ volume 37.5%
2) vegetation rating 13.0%
3) impervious surface area 12.6%
4) perimeter to area ratio 10.4%



When linear regressions were run comparing the eigenvalues for each water component against the independent, physical components, two correlations were determined significant (P<0.05).

Physical Component 2 and water quality component 4 were correlated with P= 0.048, indicating that more lush and diverse vegetation yields a higher conductivity coefficient.

Plotted against water quality component 2, physical component 4 has a P value of 0.010, indicating a positive correlation between perimeter to area ratio and conductivity and DIP.



Conclusion

As determined by our collected data, overall physical characteristics of a pond are not reliable predictors for water quality. We found no significant correlations between physical pond factors and water quality in our large sample. In our subsample of the Ford's Colony neighborhood, we were able to identify a positive correlation between perimeter to area ratio and conductivity and DIP. We also found that a large amount of diverse vegetation is associated with higher conductivity. These correlations indicate that some water quality components can be predicted by physical parameters. More information on surrounding watershed land use (beyond impervious cover) would likely improve correlations.

Of particular concern for this study was the presence of "outliers" for water quality, i.e., a significant fraction of ponds was underperforming with respect to nutrient concentrations and other metrics. Because the contributions of pollutants downstream from these ponds could be substantial, ongoing work should determine what other characteristics of these ponds make them outliers with respect to water quality, and, more importantly, whether those characteristics can be corrected.

Acknowledgments

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