Water Quality Projects
Data Analysis

Final Report to:

Florida Department of Environmental Regulation
Bureau of Watershed Restoration
Tallahassee, Florida

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Summary

This final report covers the work by Florida Gulf Coast University in reviewing and analyzing data associated with water quality projects focused on Best Management Practices conducted by Johnson Engineering, Inc. wit the cooperation of Bonita Bay Properties. We conducted a literature review focused on the analytical techniques used for examining stormwater issues. We reviewed the literature for analytical approaches and reviewed four data sets (Shadow Wood Preserve Pervious vs. Impervious Pavement Study, Shadow Wood Preserve Green Roof Study, The Brooks Deep and Shallow Wet Detention Ponds, and Bonita Bay Littoral Plantings) for opportunities for additional analysis. We concentrated our efforts on the richest data set, The Brooks Deep and Shallow Wet Detention Ponds. Our analysis indicated that there were clear differences between the 2004 and 2006 water quality conditions within and between ponds that could not be attributed to pond depth or aeration alone. Based on the limited samples and duration from aerated/non-aerated pond, it appears that aeration may help to stabilize overall water quality near the bottom where samples were collected. Future studies of the affect of aeration on ponds of varying depth should be designed to follow the dynamics over a longer period of time, and might more clearly detect differences with larger differences in pond depth. Future studies should also include an assessment of submerged aquatic vegetation coverage between and within ponds, and a detailed record of pond management practices.

Introduction

Bonita Bay Properties, (BBP) Johnson Engineering, Inc.(JEI) and the Florida Department of Environmental Protection (FDEP) began a unique collaboration to examine issues relative to Best Management Practices for stormwater treatment in South Florida. The FDEP funded several water quality projects, to be conducted by JEI on BBP land. In 2007, Florida Gulf Coast University (FGCU) was invited to participate in this collaboration. Our role has been to examine the data collected from these projects to determine if additional analyses might be warranted and to work with JE on possible future research initiatives.

The FGCU Scope of Work included: 1) a literature review of stormwater data management and analytical techniques directly related to the subject areas of treatment, 2) an initial review of four water quality studies; Shadow Wood Preserve Pervious vs. Impervious Pavement Study, Shadow Wood Preserve Green Roof Study, The Brooks Deep and Shallow Wet Detention Ponds, and Bonita Bay Littoral Plantings, 3) additional analyses of the project data sets as determined by the initial review, and 4) participation in coordination meetings with JEI.

Literature Review

We reviewed 69 journal papers or technical reports. The focus of our review was primarily to investigate alternative methods of analyzing stormwater or determining changes in water quality. The annotated bibliography for the peer-reviewed literature is included as Appendix A. The annotated bibliography for the technical reports is included as Appendix B. These versions of the annotations include some additional papers and annotations subsequent to the submission of the bibliographies as our Task I Interim Report submitted in November 2007. Electronic copies of the reviewed literature are included in the accompanying disk.

JEI (2005) conducted a literature review of current research on stormwater treatments BMPs . Their review focused on research projects. Our reviewed focused on analytical techniques. This review indicated a tendency to treat each pollutant of interest independently, with few studies attempting multivariate analyses. We feel that the simultaneous analysis of all water quality parameters allows us a clearer understanding to the detention pond system, where nutrient may transfer in form as the result of physical and biotic interactions. Furthermore, the multivariate approach to water quality analysis allows for some unique visual and graphical presentations of the data and more recently the introduction of global significance test (Clarke and Gorley 2006).

Deep/Shallow Aeration Study

The primary objective of this study was to evaluate differences in the water quality of wet detention ponds of various depths under aerated and non-aerated conditions (Johnson Eng. and CivaTerra 2007). A secondary objective was to determine if the presence or absence of aeration in the wet detention ponds impact stratification of the ponds. The study was made up of two phases lasting approximately three weeks each. Four ponds of various depths were selected from a wet detention system at The Brooks residential golf course community in Bonita Springs, Florida. Depths of the ponds range from 10-18 feet depending on the water levels. For the purpose of this study, ponds with depths greater than 12 feet were considered to be deep and ponds with depths less than 12 feet were considered shallow. The four ponds selected for this study are identified as follows: Lake 17 (deep), Lake 19 (shallow), Lake 20 (deep) and Lake 41 (deep). The ponds are interconnected with pipes to maintain similar water levels and are indirectly connected to a single outfall structure. Each of the ponds contains multiple aerators capable of aerating the pond volume over 24-48 hours. Dissolved oxygen data was not included in our analysis but was thoroughly discussed in a manuscript being submitted for presentation at a storm-water conference in August 2008 (Dennison et al. 2008) and is included in the Appendix of this report.

Analytical Approach

The initial approach was to evaluate the sonde/probe data and lab water quality data by simply charting the changes in parameter concentrations using features in the Excel ™ 2003 and 2007 software. This was useful for visualizing changes in field parameters (temperature, specific conductance, DO, pH, ORP, and turbidity) over time. It was also useful to graph concentration changes in the laboratory analyzed parameters from each of the grab sampling events. These

Excel charts reside in folders titled Sonde data charts and Grab data charts and are included in the Appendix of this report.

To examine the patterns of change in nutrient concentrations among lakes over time, we considered the ten laboratory- analyzed parameters (turbidity, pH, total Kjeldahl nitrogen, total nitrogen, nitrates and nitrites, ammonia nitrogen, ortho-phosphorus, total phosphorus, chlorophyll-a, and specific conductance) as a multivariate data set. To account for the variety of measurement scales across the measured parameters, we normalized the data. For each measured parameter, the mean is set at 0 and the standard deviation at 1. Each value is then adjusted to the equivalent value in a range of approximately -2 to 2. This normalizes the range of values for each parameter and assigns them equal value in the multivariate analysis (Clarke and Gorley, 2006). A resemblance matrix for these normalized values was then calculated using Euclidean distance, a quantification of the difference between two sample sites as a distance in multivariate space. Greater Euclidean distance translates to a lower similarity between the data sets of measured water quality parameters. Differences in Euclidean distance were applied to a hierarchical cluster analysis, multidimensional scaling (MDS), and principle components analysis (PCA). All multivariate analyses were performed using the PRIMER 6 software (Clarke and Gorley 2006).

<u>*Results*</u>

Aeration of the water column resulted in de-stratification and increased oxygen concentrations at depth (1 ft. above bottom) in both the 2004 and 2006 studies (Dennison et al. 2008). In the multivariate analysis, two outliers were identified including the Lake 19 sample collected on 21 October 2006 and Lake 17 sample, collected on 15 November 2004. The Lake 17 sample was collected during an aeration phase while Lake 19 was un-aerated during the entire experiment. Both samples were excluded from further analysis to avoid skewing the ordinations and clusters presented. Figure 1 is a hierarchical cluster analysis generated by comparing Euclidean distances among sampling events. PRIMER 6 offers permutation test for determining significant difference between groups, or clusters, of sampling events. For the analysis we set the significance level at $p < 0.05$ (95% confidence level). Significantly different groups are identified by black lines while groups shown in red cannot be separated. Figure 1 includes a horizontal line at the level of approximately 2.5 Euclidean distances, above which all branched clusters are significant, resulting in six major significantly different groups (and one minor below 2.5). The first branch divides the groups into sample years, with all 2004 samples more alike each other than similar to any sample from 2006. With the 2004 cluster there are three significant groups, separated largely my sampling date. Three of the four group members in the cluster to the left are from the November 15 sampling event, four of the five sample events in the middle cluster were from the December 6 sampling event, and the two in the right-most cluster for the 2004 data both were sampled on November 1. No clear pattern exists for lake depth or aeration. The 2006 similarly has three separate significant clusters, but divided by lake rather than time, and again independent of aeration. The left most cluster (of 2006 data) is all sampling events for Lake 20, the middle cluster shows all sampling events for Lake 41 which appears separate from but not significantly different from the cluster to the far right of the diagram with a mixture of sampling events from lakes 19 and 17.

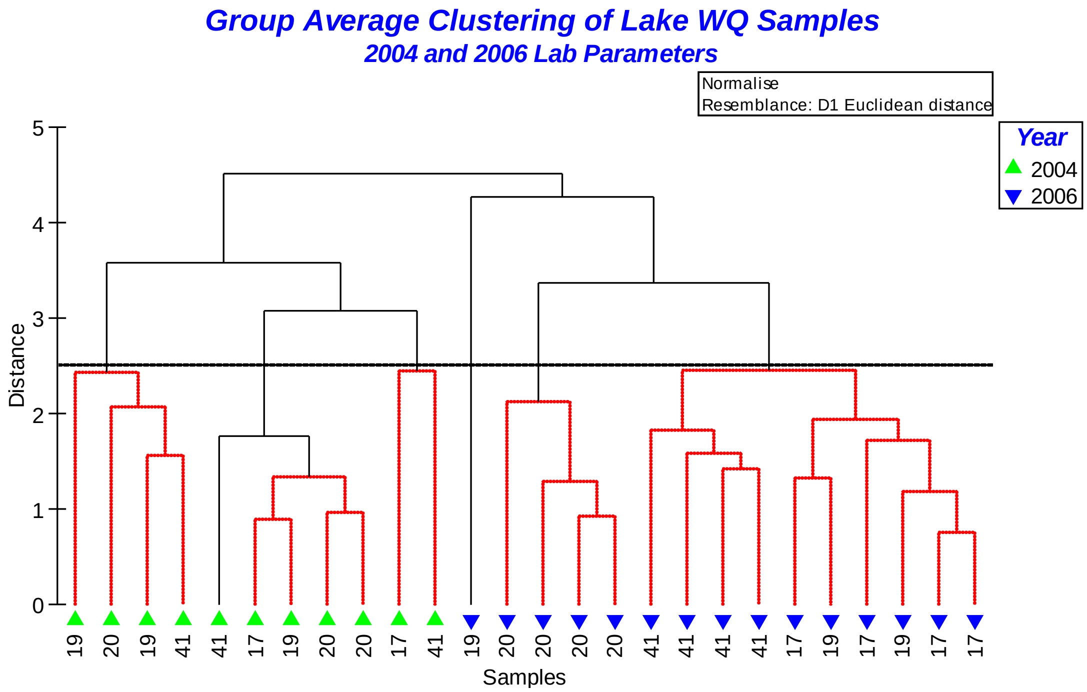


Figure 1. Hierarchical clustering of Lake samples using all lab parameters. The SIMPROF global significance test (Clarke and Gorley 2006) identified seven significantly different groups ($p<0.05$ = 95% confidence level) identified by black vertical lines. Groupings of lake samples in red are not significantly different. The horizontal slice inserted for emphasis at Euclidean distance 2.5 to illustrate six major significant groups to be used for overlay on MDS ordination.

Figures 2 and 3 are both multi-dimensional scaling (MDS) ordinations of the multivariate data set labeled by aerated/non-aerated and by sampling event respectively. Distance between sample events in this two-dimensional space indicates relative similarities between the samples – when simultaneously comparing all measured parameters. Proximity in the ordination space indicates short Euclidean distance and high similarity between measured parameters. More simply, plots that are close to one another have similar values in measured parameters. Figure 2 better illustrates the separation of lake samples in 2004 by sampling events, and in 2006 by lake, independent of aeration or depth.

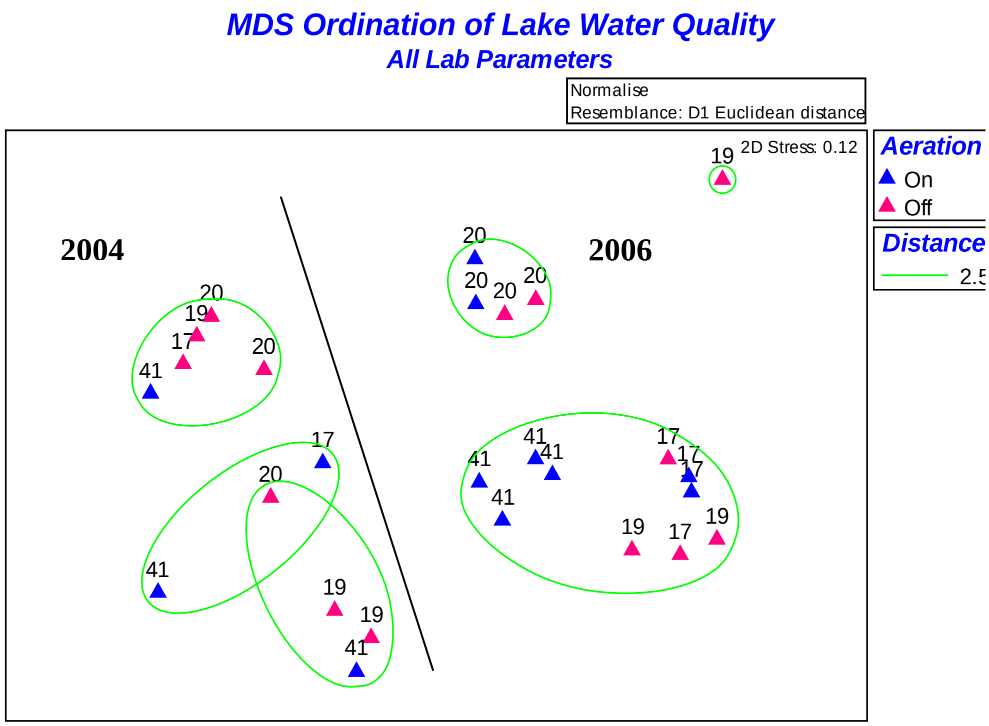


Figure 2. Non-metric multidimensional scaling (MDS) ordination of Lake samples using all lab parameters. Samples are labeled by Lake number and aeration status. Separation between study years is emphasized by line inserted over the plot and labels for 2004 and 2006. Note the six major groupings identified previously in the cluster diagram. Stress value of 0.12 corresponds to a good ordination with little prospect of a misleading interpretation.

In Figure 3, the same data is presented with the sampling events labeled sequentially from 1 through 7 to show the seasonal trend toward greater similarity in all lakes in December of 2004, and the consistent grouping by lake in 2006, with the exception of Lake 19, the non-aerated lake, which showed the greatest variability.

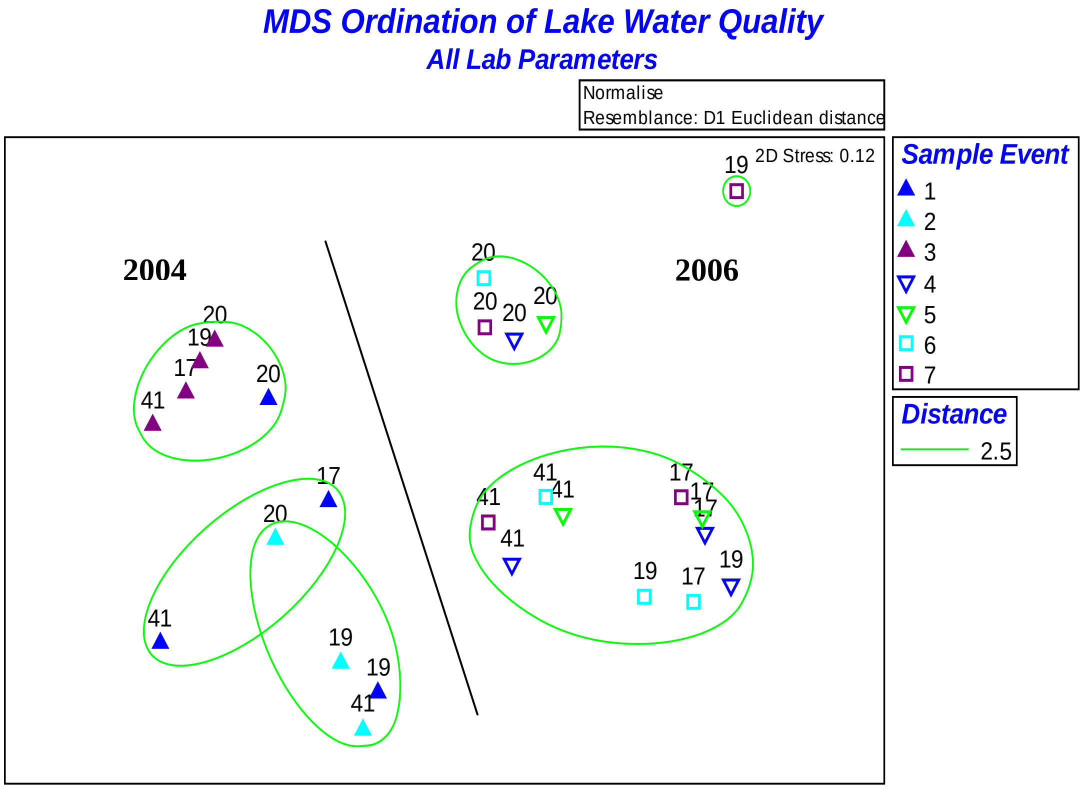


Figure 3. Non-metric multidimensional scaling (MDS) ordination of lake samples using all lab parameters. Samples are labeled by Lake number and sampling events (1-7) in 2004 and 2006 combined, listed in chronologic order. Separation between study years is emphasized by line inserted over the plot and labels for 2004 and 2006. Note the six major groupings identified previously in the cluster diagram Stress value of 0.12 corresponds to a good ordination with little prospect of a misleading interpretation.

Principal component analysis (PCA) allows an examination of which factors in the multivariate data set account for the greatest amount of the variance among the samples. In Figure 4 the overlay shows the importance of each parameter by the length of the vector and the direction indicates the axis of separation of sampling events. In the direction of the arrow, the parameter values increase. In the opposite direction the water quality measures decrease. Figure 4 shows the separation of the 2004 sampling events was largely explained by higher levels of chlorophyll-a and correspondingly higher turbidity. The sampling events in 2006 are separated vertically (along the second principle component axis) by higher levels of NOx to the top and higher levels of phosphorus toward the bottom.

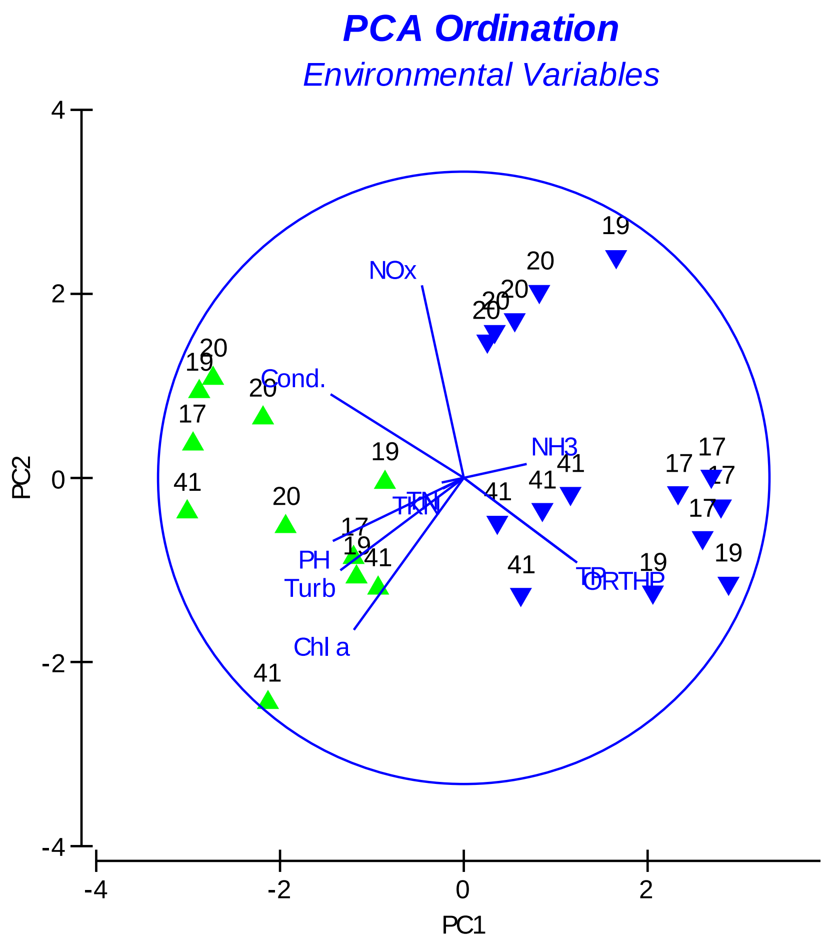


Figure 4. A 2-dimensional principle components analysis (PCA) ordination of Lake water quality labeled by year (2004 and 2006) with eigenvectors superimposed to illustrate the relative importance of each water quality parameter for PC1 and PC2. Note the separation between 2004 and 2006 samples in the ordination and parameter vector direction and length indicating relative importance of each parameter to PC1 and PC2.

Discussion

The multivariate analysis of laboratory parameters for samples collected from each wet detention pond indicates that there were clear differences between the 2004 and 2006 water quality conditions within and between ponds that could not be attributed to pond depth or aeration alone. In 2004, when low water levels limited the connection between ponds and water levels were receding at the end of the rainy season, the water quality of each pond (as represented by the ten laboratory parameters) appeared to follow a seasonal pattern. The differences between ponds diminished through each successive sampling period from November 1st to December 6th, 2004 such that by the end of the study there were no significant differences (cluster analysis, $p<0.05$) among the four wet detention ponds. Generally speaking, chlorophyll-a, turbidity, pH and specific conductance were higher in 2004 in all ponds than in 2006. This is likely a result of increased planktonic algae populations in 2004 relative to 2006, expressed as higher chlorophyll-a and turbidity values. In addition, the lack of flow between ponds, reduced rainfall (relative to the earlier seasonal sampling in 2006) and evaporation that increased specific conductance in all ponds in 2004.

The water quality data in 2006 that was collected during the rainy season between September 6th and October 16th, exhibited a completely different pattern than in the early dry season of 2004. Water quality was very similar within each wet detention ponds and did not appear to exhibit any temporal trends. Each pond seemed to have its' own identity, especially Lake 20 which separated out from all other lakes regardless of aeration or sampling event. Lake 41 samples clustered separately, but not significantly so. Lake 17 samples grouped loosely with Lake 19, but the greatest variability was observed in Lake 19 which happened to be the only pond that was not aerated at all during the entire study (2004 or 2006) and was also the shallowest pond in the study. Overall, NOX, NH3, TP and Ortho-P were higher in all lakes during the 2006 samples, than in 2004. This may be attributed to stormwater runoff carrying inorganic nutrients into the system. Interestingly, even though flow occurred in the pond system during part of the rainy season in 2006, each pond appeared to retain its own characteristics that separated it from the other lakes regardless of aeration. Based on the limited samples and duration from aerated/non-aerated pond, it appears that aeration may help to stabilize overall water quality near the bottom where samples were collected.

Future studies of the affect of aeration on ponds of varying depth should be designed to follow the dynamics over a longer period of time, and might more clearly detect differences with larger differences in pond depth. Future studies should also include an assessment of submerged aquatic vegetation coverage between and within ponds, and a detailed record of pond management practices.

Acknowledgements

This study could not have been accomplished without the unique research partnership between the Bonita Bay Group, the Florida Department of Environmental Protection, Lee County Community Development staff, Kim Fikoski of Bonita Bay Group, Florida Gulf Coast University's Inland Ecology Research Group, and Johnson Engineering Water Resources-Environmental Group. The authors would like to thank the Bonita Bay Group for their assistance and cooperation in the site selection of The Brooks development and allowing water quality monitoring of shallow and deep wet detention systems.

This project is a part of a group of Best Management Practice studies funded by the Florida Department of Environmental Protection.

Literature Cited

Carr, D.W. and Kehoe, M.J. 1997. Outfall Water Quality from Wet-Detention Systems. Southwest Florida Water Management District. Brooksville, FL.

Clarke, K.R. and R.N. Gorley. 2006. PRIMERv6: User Manual/Tutorial. PRIMER-E. Plymouth, UK.

Cunningham, J. 1993. Comparative Water Quality data of a Deep and a Shallow Wet-Detention Pond. Proceedings of the Third Biennial Stormwater Research Conference. Southwest Florida Water Management District. Brooksville, FL.

Dennison, T.J., M.L. Lohr, D.W. Ceilley, and E.M. Everham. 2008. Water quality evaluation of the impacts of aeration on deep and shallow wet detention ponds in Southwest Florida. Proceedings of StormCon**,** the North American Surface Water Quality Conference & Exposition, August 3–7, 2008, in Orlando, FL.

Johnson Engineering Inc. and CivaTerra Inc. 2007. The Brooks: Deep and Shallow Wet Detention Ponds Water Quality Monitoring Report. Florida Department of Environmental Protection Bureau of Watershed Management. Tallahassee, Florida. 21 pp.

Harper, H.H. 2005. Effects of Residence Time and Depth on Wet Detention System Performance. Proceedings Eight Biennial Stormwater Research and Wateshed Management Conference. Southwest Florida Water Management District. Brooksville, FL.

United States Environmental Protection Agency Office of Water. 1999. Storm Water Technology Fact Sheet: Wet Detention Ponds. EPA 832-F-99-048. United States Environmental Protection Agency. Washington, D.C.

APPENDIX A

Annotated Bibliography of Relevant Primary Literature

Peer-reviewed Publications

Barrett, M.E. (2005). Performance comparison of structural stormwater best management practices. Water Environment Research 77(1): 78-86.

The pollutant removal ability of a BMP has often been expressed as a percent reduction in concentration of load. This paper presents a methodology to eliminate some problems associated with this method so that BMPs in different watersheds can be compared. The methodology is based on a linear regression analysis carried out on concentrations rather than loads.

Berbee, R., G. Rijs, R. de Brouwer, L. van Velzen (1999). Characterization and Treatment of Runoff from Highways in the Netherlands Paved with Impervious and Pervious Asphalt. Water Environment Research 71(2) 183-190.

Impact of pervious surface on runoff water quality including: heavy metals, hydrocarbons, and suspended solids. The results are reported in pollutant removal efficiencies, and the study identifies the need for further long-term study of the effectiveness of pervious asphalt.

Carter, T., Rasmussen, T.C. (2006). Hydrologic behavior of vegetated roofs. Journal of the American Water Resources Association (42)5: 1261-1274.

In this study a green roof/black roof test plot was built at the University of Georgia and monitored for the green roofs effectiveness in reducing stormwater flows. Design, installation, and evaluation of this test plot were studied to determine the potential use of green roofs in reducing stormwater runoff in urban watersheds.

Clary, J., Urbonas, B., Jones, J., Strecker, E., Quigley, M., & O'Brien, J. (2002). Developing, evaluating and maintaining a standardized stormwater BMP effectiveness database. Water Science and Technology 45(7): 65-73.

There is a variety of information published on urban stormwater BMPs, but no centralized, easy to use, scientific tool to determine the appropriate BMP for a community's situation. The goal of this project is to gather design and performance information to improve BMP selection and design by communities to effectively address their stormwater issues.

DeNardo, J.C., Jarrett, A.R., Manbeck, H.B., Beattie, D.J., Berghage, R.D. (2005). Stormwater mitigation and surface temperature reduction by green roofs. American Society of Agricultural Engineers 48(4):1491-1496.

Green roofs have been in use in Europe for centuries. For green roofs to be more widely used in the US, more information on the benefits needs to be available. The goal of this report was to quantify the water retention and detention characteristics of green roofed buildings and to determine if they caused changes in surface temperature compared to traditional roofs.

Despotovic, J., Petrovic, J., & Jacimovic, N. (2002). Measurement, calibration of rainfall-runoff models and assessment of the return period of flooding events at

urban catchment Kumodraz in Belgrade. Water and Science Technology. 45(2):127-133.
This paper assesses design flows for 4 locations of a catchment based on results from calibrated models. Design peak flows are estimated using 1) design storms and 2) statistically derived design flows and volumes from a series of simulated runoff hydrographs.

France, R.L. (Ed). (2002). Handbook of water sensitive planning and design. Boca Raton, FL: Lewis Publishers, A CRC Press Company.
The author designed this book to introduce new interpretations to water management that engage a broad audience. Part I addresses site specific water sensitive design and Part II addresses issues relating to the water sensitive planning of riparian buffers and watersheds.

Griffin Jr., D.M., Grizzard, T.J., Randall, C.W., Helsel, D.R., & Hartigan, J.P. (1980). Analysis of non-point pollution export from small catchments. WPCF 52(4): 780-790.
Water pollution programs have long focused on point source pollution. This paper address non-point source pollution. The authors tried to establish the importance of land use characteristics and to address the first flush phenomenon. Finally the authors present an approach for the analysis of stormwater runoff data.

Graczyk, D. J., Walker, J. A., Horwatich, J. A., & Bannerman, R. T. (2003) Effects of best-management practices in the Black Earth Creek priority watershed, Wisconsin, 1984-1998 (USGS, Water-Resources Investigations Report 03-4163).
This report summarizes the results of a study on effectiveness of watershed-management practices for controlling nonpoint-source contamination in the Brewery and Garfoot Creek watersheds. In Wisconsin. Concentrations of phosphorus, nitrogen, and suspended sediment at base flow before BMP installation (pre-BMP) are compared and contrasted to those for the period after BMP installation (post-BMP). In addition, pre-BMP storm loads are compared and contrasted to the storm loads post-BMP. Statistics include the Kendall test, Wilcoxon rank-sum test, and regression analysis.

Harrel, L. J. and Ranjithan, S. R. (2003). Detention pond design and land use planning for watershed management. Journal of Water Resources Planning and Management 129 (2): 98-106.
Wet detention ponds are commonly used for nonpoint source pollution management. Designs are typically created to meet target total suspended solids removal level. A better approach is to create designs that meet system wide targets for removal of TSS, nitrogen, and phosphorus. This paper presents a modeling approach using a genetic algorithm based search procedure.

Hossain, A.A., M. Alam, D.R. Yonge, and P. Dutta. (2005). Efficiency and flow regime of a highway stormwater detention pond in Washington, USA. Water, Air, and Soil Pollution. 164: 79-89.

The study focuses on the removal efficiency of a wet detention system on TSS and heavy metals. The efficiency was affected by sedimentation.

Mallin, M. A., Ensign, S. H., Wheeler, T. L., & Mayes, D. B. (2002). Surface water quality: pollutant removal efficacy of three wet detention ponds. Journal of Environmental Quality. 31(2) 654-660.
Wet detention ponds are used to reduce pollutant levels in urban and suburban water. They are primarily designed to reduce suspended sediments. In this paper three wet detention ponds were analyzed for pollutant removal performance. Mean and standard deviation were calculated for the inflow and outflow at each pond.

Peterson, T.J.R. (1997). FEM-modelling of open stormwater detention ponds. Nordic Hydrology 28(4/5):339-350.
This paper discusses an FEM-Modeling of a pilot scale open stormwater detention pond in Goteborg during a rain event. FIDAP User 1993, an FEM software package, was used to calculate the three dimensional velocity flow field.

Sullivan, M., Warwick, J. J., Tyler, S. W. (1996). Quantifying and delineating spatial variations of surface infiltration in a small watershed. Journal of Hydrology 181. pp. 149-168.
The focus of this project is to determine which data collection techniques are best suited for quantifying and delineating spatial variations in surface infiltration and for estimating infiltration parameters used in computer models for simulation of runoff quantity following summer rainstorm events from a small Watershed (Incline Creek watershed, Nevada) in the Lake Tahoe Basin.

VanWoert, N.D., Rowe, D.B., Andresen, J.A., Rugh, C.L., Fernandez, R.T., & Xiao, L. (2005). Journal of Environmental Quality 34: 1036-1044
In this paper, two studies were performed. The first used three different roof surface treatments and the second tested the influence of roof slope and media depth. Data were analyzed as mean percent retention per rain event using an ANOVA model with platform as a random effect and roof treatment and rainfall category as fixed effects. Significant differences between treatments were determined using multiple comparisons with Tukey-Kramer adjustments (PROCMIXED, SAS Version 8.02; SAS Institute, 2001).

Wang, G., Chen, S., Barber, M. E., & Yonge, D. R. (2004). Modeling flow and pollutant removal of wet detention pond treating stormwater runoff. Journal of Environmental Engineering. 130(11): 1315-1321
Wet ponds play important roles in urban storm water management. This paper presents a mathematical model of pollutant removal by wet ponds based on the mass balance principal and the release storage equation.

Wanielista, M.P. (1997). Hydrology: water quantity and quality control. 2nd Edition. New York: John Wiley & Sons.
The book was developed to aid in the understanding of water control problems emphasizing measurement and interpretation of hydrologic cycle data and control of runoff quality and quantity.

Xue, R.Z. & Zhang, J.J. (1995). Modeling of a small watershed in Lake Okeechobee drainage basin. Journal of Water Resources Planning and Management, ASCE. (WRE #331).
The objective of this study was to develop a catchment scale model to assess urban and agricultural stormwater management alternatives.

Zhen, J., Shoemaker, L., Riverson, J., Alvi, K., & Cheng, J. (2006). Journal of Environmental Science and Health Part A, 41:1391-1403.
This project includes software development that used GIS technology, integrates BMP processes models, and applies system optimization techniques.

APPENDIX B

Annotated Bibliography of Relevant Technical Reports

Theses and Technical Reports

American Society of Civil Engineers (ASCE). (2002). Urban stormwater BMP performance monitoring, a guidance manual for meeting the national stormwater BMP database requirements. (EPA document No. EPA-821-B-02-001). Washington DC: GeoSyntec Consultants.

This manual recommends a set of protocols and standards for collecting, storing, analyzing, and reporting BMP data. It includes a lot of statistics, modeling methods, and analytical methods.

Bahk, B. & Kehoe, M. (1997). A survey of outflow water quality from detention ponds in agriculture. Brooksville, FL: Southwest Florida Water Management District.

This survey assessed the discharge water quality from detention ponds at six sites. Goals of the survey were 1) document the water quality from District permitted agricultural discharges 2) determine compliance of discharge with state standards 3) compare data to other literature values for treated and untreated agricultural discharges. This report provides an overview of the water quality from treated agricultural discharges. Quattro Pro version 6.0 was used for preliminary data analysis and SAS for Windows was used for correlation analysis.

Bateman, M., Livingston, E. H., & Cox, J. (1999). Overview of urban retrofit opportunities in Florida, national conference on retrofit opportunties for water resource protection in ruban environments, Proceedings Chicago, IL. February 9-12, 1998 (EPA/625/R-99/002).

This documents serves as a review of the framework implemented by the state to address stormwater problems associated with current land uses. It focuses on summarizing different types of retrofitting projects undertaken to reduce pollution from older stormwater discharges. BMP type and design, site characteristics, cost, and efficiency of pollutant removal are reviewed.

Camp, Dresser, and McKee. (1985). An assessment of stormwater management programs. (Final report to The Florida Department of Environmental Regulation). Maitland, FL.

The issue addressed by the authors in this study is whether the control of urban stormwater in the South Florida Water Management District should rely on 1) use of stormwater storage facilities that use filtration for treatment of runoff or 2) use of conventional detention basins that use physical or chemical treatment of runoff.

Camp, Dresser, and McKee. (April 1990). Nonpoint source evaluation, Six Mile Cypress watershed, Lee county, Florida. Prepared for Lee County Board of County Commissioners.

In this report, a nonpoint source pollution model is applied to study the area in order to evaluate land use scenarios and how those uses may impact the Six Mile Cypress watershed.

Carr, D. W. (1998). An assessment of an in-line alum injection facility used to treat stormwater runoff in Pinellas County, Florida. Brooksville, FL: Southwest Florida Water Management District.
Alum treatment is primarily used to remove phosphorus from stormwater. This study tried to determine the effectiveness of alum technology for an inline system.

Carr, D.W., & Kehoe, M. J., (1997). Outfall water quality from wet detention systems. Brooksville, FL: Southwest Florida Water Management District
This report sought to sought to compare the effluent water quality of permitted constructed wet detention ponds and natural wetland systems. Statistical analysis was performed with SAS version 6.08 and Quattro Pro version 6.02.

Carr, D. W. & Rushton, B. T. (1995). Integrating a native herbaceous wetland into stormwater management. Brooksville, FL: Southwest Florida Water Management District.
The goal of this report was to give insight into methods to improve SWFWMD's wetland stormwater management criteria and add to the statewide data base. Analysis were performed on water quality and hydrology, vegetation, and sediments. SAS (1990) was used for statistical analysis (PROC REG and UNIVARIATE procedures).

Center for Watershed Protection. (2007). National pollutant removal performance database. Version 3 Database
This represents an update of Version 2, which included 139 individual best management practice performance studies. This update adds 27 studies published through 2006. The database was statistically analyzed to determine the median and quartile removal values for each BMP group.

Conservancy, Inc. (1983). An assessment of stormwater volumes and impacts on water quality in Naples Bay, Collier County, Florida /prepared for the Southwest Florida Regional Planning Council by the Conservancy, Inc.
The objectives of this study were 1) to evaluate the physical, chemical and public health impacts on Naples Bay from stormwater runoff, 2) to estimate the total volume of stormwater entering the Bay, and 3) to evaluate engineering and water quality improvement recommendations from other studies and incorporate them into an updated plan to reduce environmental stress and pollution burdens in Naples Bay.

DB Environmental, Inc. (2005). Quantifying the effect of a vegetated littoral zone on wet detention pond pollutant load reduction. Final report to the Florida Department of Environmental Protection.
This study evaluated the potential of littoral zone vegetation to enhance contaminant removal performance of a wet detention pond. There were three objectives: 1) to determine if littoral zone vegetation enhanced reduction of
dissolved pollutants, and if vegetation type was important, 2) to determine if planting non-vegetated wet detention ponds with pickerelweed and cattail would enhance near-term pollutant reduction processes, and 3) to determine if herbicide

application to cattails diminished pollutant reduction processes. Results were evaluated primarily using graphical analyses. Calculations were done in Microsoft Excel.

Environmental Research & Design. (2003). Evaluation of alternative stormwater regulations for Southwest Florida. (Final report to the Water Enhancement & Restoration Coalition, Inc.) Orlando, FL.

Environmental Research & Design provides a summary of work they performed to evaluate and develop alternative stormwater treatment practices for Southwest Florida. The goal of these practices is to reduce loadings of stormwater pollutants, including nitrogen, total phosphorus, biochemical oxygen demand, and total suspended solids as constituents. Some statistics are included in the report (runoff calculations, loading volume, etc.)

Estevez, E.D. (2000). A review and application of literature concerning freshwater flow management in riverine estuaries : submitted to the South Florida Water Management District.

This literature review was requested by the South Florida Water Management District with the following goals: 1) to determine species that can be used as targets, indicators or criteria for minimum flow determinations in riverine estuaries; 2) to learn how the selection of living resource targets may be affected if working in rivers with long histories of extreme structural and hydrologic alteration; 3) to benefit from lessons learned by other Florida water management districts, other states, and other countries; and 4) to solicit an independent expert recommendation of approaches to develop flow management criteria, so as to improve water quality, increase habitat for key organisms, and sustain biodiversity.

Fitzpatrick, C. (1986). The use of buffer strips in controlling agricultural runoff. In Campbell, I. C. (Eds.). Stream protection: the management of rivers for instream uses (pp. 75-84.). East Caulfield, Australia: Water Studies Center Chisholm Institute of Technology.

This paper characterizes runoff in the Upper Yarra Valley of Victoria and assess the effects of maintaining buffer strips along streams. Statistical methods used were the Wilcoxon's Rank Sum test.

GeoSyntec Consultants & Urban Water Resources Research Council of ASCE. (2002). Urban stormwater bmp performance monitoring. (document # EPA-821-B-02-001). Washington DC: USEPA.

This manual provides a recommended set of protocols and standards for collecting, storing, analyzing, and reporting BMP monitoring data that will lead to better understanding of the function, efficiency, and design of urban stormwater BMPs. It provides insight into and guidance for strategies, approaches, and techniques that are appropriate and useful for monitoring BMPs. Historic and recommended modeling are discussed beginning in section 2.9.2.1.

Hand, J.; Col, J.; & Grimison, E. (1994). Southeast and South Florida district water quality assessment. #305b Technical appendix by the Bureau of Surface Water Management, Florida DEP.
This report is intended to inform the EPA and Florida residents about surface water quality conditions and trends within the state. It seeks to address the sources of pollution as well as trends in water quality. Assessment techniques include water quality indices, screening level exceedances, and statistical trend analysis.

Hardin, M. D. & Wanielista, M. (2007). Designing cisterns for green roofs in Florida. In: 9th Bienniel Conference on Stormwater Research and Watershed Management. May 2-3, 2007.
This paper focuses on the development of design equations for cistern size and the water quality benefits that result. An example problem is given.

Harper, H. H. & Baker, D. M. (2007). Evaluation of current stormwater design criteria within the state of Florida. Final Report, FDEP Contract No. SO108. Orlando, FL: Environmental Research and Design, Inc.
The purpose of this project is to evaluate current stormwater design criteria within the State of Florida and determine if these criteria meet the state treatment requirements. Data analysis and modeling is discussed in section 4.

Harper, H. H., Herr, J. L., Livingston, E. H. (1999). Performance evaluation of dry detention stormwater management systems, proceedings of the sixth biennial stormwater research and watershed management conference. pp. 162-178. Brooksville, FL. Southwest Florida Water Management District.
In this study field and laboratory investigations were conducted to evaluate the hydraulic and water quality characteristics of a dry detention pond system. There was no statistical analysis done other than mean calculations and no references were sited.

Heaney, James P. (1976). Storm water management model : level I, preliminary screening procedures. (EPA-600/2-76-275), Gainesville, FL: Department of Environmental Engineering Sciences, University of Florida.
This report develops a procedure to do a nationwide assessment of stormwater pollution control costs.

Henigar & Ray Engineering Associates, Inc. (1991). Stormwater management and treatment. Issue I in a Series of Papers for the SWIM Ordinance Model Project for the SFWMD. Crystal River, FL.
This is the first of seven papers written to provide background information to aid development of the SWIM Program. Quantity and quality of stormwater runoff is vitally important because research has shown that stormwater discharges are an important source of the pollution load entering Florida waters. BMP’s are discussed in Chapters 3 and 4, but with very little statistics.

Johnson Engineering, Inc. 2005. Literature Review of Stormwater Treatment Best Management Practices Research in Florida. Lee County Board of Commissioners. Fort Myers.
This report provides a review of research on stormwater BMPs. Conclusions include the relative paucity of research in southwest Florida and includes recommendations to focus on wet detention systems.

Karuna-Muni, A., Ottolini, R., & Livingston, E. (2007). Ten mile canal filter marsh project in Lee County. In: 9th Bienniel Conference on Stormwater Research and Watershed Management, May 2-3, 2007.
The Ten Mile Canal was built in the 1920's to control flooding in south Ft. Myers. In December 2005 a filter marsh was completed at the half way point. This paper is a report on the current status of the canal, including its operation, water quality monitoring and maintenance. There are no statistical analysis and no references.

Kehoe, M. J. (1993). Water quality survey of twenty-four stormwater wet-detention ponds. (Final report). Southwest Florida Water Management District. Brooksville, FL.
The Southwest Florida Water Management District conducts research to implement better stormwater regulations. This survey sought to 1) provide base-line water quality data in urban stormwater wet-detention ponds 2) document whether potential effluents from wet-detention ponds met state water quality standards, and 3) explore relationships between physical/chemical variables, water-level variables, and pond-dimension variables. Statistical analysis was done with SAS (1988) and Lotus 1-2-3 (1986).

Kehoe, M. J.; Dye, C. W.; & Rushton, B. T. (1994). A survey of the water-quality of wetlands-treatment stormwater ponds (Final Report). Southwest Florida Water Management District, Brooksville, FL.
The goals of this survey were to 1) document exceedence of state water quality standards from wetlands treatment systems, 2) to provide regional stormwater data and, 3) to explore relationships among survey variables. Lotus 1-2-3 (2.01 1986) was used for preliminary data analysis and SAS (6.03 1988) was used to perform more comprehensive analysis.

Kertesz, R.A. (2006). Methodologies to evaluate decentralized stormwater Best Management Practices in Gainesville, FL. MS Thesis. Gainesville.
This thesis examined BMPs, including Low Impact Development, at various spatial scales and included simulation studies.

Kollinger, R. J. (1999). Stormwater retrofit of the abandoned Jan-Phyl Wastewater Treatment Plant site, proceedings of the sixth biennial stormwater research and watershed management conference. pp. 238-247. Brooksville, FL: Southwest Florida Water Management District

This project was developed to solve a local flooding problem. It also included removal of wastewater sediments that had accumulated from the sewage treatment plant. There was no statistical analysis performed.

Kurz, R. C. Removal of microbial indicators from stormwater using sand filtration, wet detention, and alum treatment best management practices. Southwest Florida Water Management District, Brooksville, FL.
This study sought to determine the removal efficiencies for bacteria, viruses, and protozoa using three different stormwater treatment technologies: an above ground sand filter, a wet detention pond, and alum coagulation. Removal efficiencies were calculated and effluent concentrations were compared with Florida state standards. All comparisons were analyzed using NCSS software.

Livingston, E. H. & Crane-Amores, (2007) B. A review of urban stormwater retrofitting in Florida. In: 9th Bienniel Conference on Stormwater Research and Watershed Management. May 2-3, 2007.
This is a review of the framework implemented by the state to address stormwater problems of existing land uses. It summarizes several types of retrofitting projects undertaken to reduce pollution from older stormwater discharges. No statistical analysis is done.

Livingston, E. H. & McCarron, E. Stormwater management: a guide for Floridians. Tallahassee, FL: Florida Department of Environmental Regulation.
This book is a source of general information on urban stormwater management. It is to be used by local government as well as others interested in design and planning of stormwater management systems. It contains no statistical analysis.

Raulerson, G. E., Alderson, M., Cisar, J. L., & Snyder, G. H. (2002). Integration of the Florida Yards and Neighborhoods program into stormwater planning for nutrient removal, In: Seventh Biennial Stormwater Research and Watershed management Conference. pp. 204-212. Brooksville, FL: Southwest Florida Water Management District.
This project provides data to incorporate measurable benefits into state-wide stormwater permits (in lieu of costly retrofit projects), to continue to solidify the strong cooperation among Cooperative Extension Agents statewide, and to continue to forge strong multi-jurisdictional partnerships through the NEP process. No statistical analysis is done.

Rushton, B. (2002). Infiltration opportunities in parking lot designs reduce runoff and pollution, In: Seventh biennial Stormwater Research & Watershed Management Conference. pp. 146-155. Brooksville, FL: Southwest Florida Water Management District.
This study demonstrated how small alterations to parking lots can reduce runoff and pollutant loads. Little statistical analysis was performed and no sources were sited.

Rushton, B. T. (2001). Treatment of stormwater runoff from an agricultural basin by a wet-detention pond in Ruskin, FL. DEP contract number WM 539. Brooksville, FL: Southwest Florida Water Management District.
This study documents water quality treatment by a wet-detention pond and represents both wet and dry years. It also includes water quantity and quality interactions in the watershed. A great deal of statistical analysis was performed with SAS version 8.1.

Rushton, B. T. & Dye, C. W. (1993). An in-depth analysis of a wet detention stormwater system. Southwest Florida Water Management District. Brooksville, FL
The authors sought to determine the efficiency of a wet detention pond in reducing pollutants in stormwater runoff. They also looked at hydrologic responses to rainfall, groundwater-pond interactions, constituent input from rainfall, relationships between constituents and the dynamics of constituent concentrations over the hydrograph. SAS was used for statistical computations.

Rushton, B. T. & Hastings, R. (2001). Florida aquarium parking lot: a treatment train approach for stormwater management. Brooksville, FL: Southwest Florida Water Management District.
This study is designed to determine pollutant load reductions measured from three elements in a treatment train: different treatments in the parking lot, a planted strand with native wetland trees, and a small pond used for final treatment of runoff. All statistical analysis was performed with SAS version 8.1.

Rushton, B. T., Miller, C. Hull, C., & Cunningham, J. (1997). Three design alternatives for stormwater detention ponds. Brooksville, FL: Southwest Florida Water Management District.
Wet detention ponds are the most common stormwater management technique in Florida. In this study the effect of some rule modifications by the SWFWMD was tested by reshaping a wet detention pond to replicate three configurations representing different rule criteria. SAS 1990 was used for statistical analysis.

Schiffer, Donna M. (1989). Effects of three highway-runoff detention methods on water quality of the surficial aquifer system in central Florida. (Water-Resources Investigation Report 88-4170) Tallahasee, FL: USGS & FLDOT.
The purpose of this investigation was to evaluate the impact on the water quality of the surficial aquifer system near structures used for detention of highway runoff, define any spatial trends in water-quality detected during ground-water monitoring, and define the spatial distribution of constituent concentrations
in sediments. Statistical analysis included analysis of variance tests.

Shaw, L.Y., Zhen, J.X., & Zhai, S.Y. (2003). Development of a stormwater best management practice; placement strategy for the Virginia Department of Transportation (Report Number VTRC 04-CR9). Charlottesville, VA: Virginia Transportation Research Council

In this study the authors presented a method for determining the cost-effective placement and configuration of stormwater BMP's for the Virginia DOT. Several BMP placement strategies are compared.

South Florida Water Management District. An assessment of urban land use stormwater runoff quality relationships and treatment efficiencies of selected stormwater management systems.

This report assesses available published data for use as possible model input. It also provides a summary of land use related water quality information and treatment efficiencies.

Strassler, E., Pritts, J., Strellec, K. (1999). Preliminary data summary of urban storm water best management practices. (EPA -821-R-99-012). Washington, DC.

Information and data regarding BMP effectiveness in controlling and reducing pollutants in stormwater is summarized in this report. This includes what was known at the time about the costs and benefitsof BMP's.

United States Environmental Protection Agency (1996). Protecting natural wetlands: A guide to stormwater Best Management Practices. USEPA Office of Water. Washington, D.C.

A manual for planning and implementing stormwater BMPs. The decision-making process is reviewed. Several case studies are presented. BMPs are defined and described.

Upchurch, S. B., Janicki, A.; & Copeland, R. (2000). Designing monitoring programs to measure change and evaluate environmental management outcomes: a manual for designing monitoring plans as part of the integrated water resources monitoring program. Report to the Florida Department of Environmental Protection.

Chapters 4 - 8 discuss statistics. This report was developed as a tool to help the Florida DEP design monitoring projects implemented each year. Monitoring projects that fall short of their goals usually have poor designs to begin with. The authors of this document designed this document to help the DEP avoid this.

Wade, D.; Janicki, A.; & Beever, L. (2005). Surface water quality trends in the Charlotte Harbor watershed and management applications. Charlotte Harbor Watershed Summit. p. 47.

Charlotte Harbor National Estuary Program began data compilation for surface and ground water quality, hydrology, and rainfall to assess water quality status and trends. This presentation gives and overview of the results and how those results are being applied to management strategies.

Whalen, P.J. Cullum, M.J. (July 1988). As assessment of urban land use/stormwater runoff quality relationships and treatment efficiencies of selected stormwater management systems. Report to South Florida Water Management District.

Stormwater runoff quality for differing land uses throughout Florida are assessed. The results are compared to nationwide studies. Data on treatment efficiencies reported in the literature is evaluated.

Wanielista, M. & Chopra, M. (2007). Performance assessment of Portland Cement pervious pavement. Report 1 of 4: Hydraulic Performance Assessment of Pervious Concrete Pavements for Stormwater Management Credit. (FDOT project # BD521-02). Stormwater Management Academy, University of Central Florida, Orlando, FL.
Portland cement pervious concrete's ability to infiltrate water has encouraged its use for stormwater management. However for a number of reasons, it is not well supported. This study focuses on long term infiltration performances of pervious concrete parking lots and their stormwater management credit.

Wanielista, M. & Hardin, M. (2007). Stormwater effectiveness of an operating green roof stormwater treatment system and comparison to scaled down green roof stormwater treatment system chambers. (FDEP Project # WM 864). University of Central Florida, Stormwater Management Academy, Orlando, FL.
A full sized operating green roof stormwater treatment system was compared with scaled down green roof stormwater treatment system chambers. The study showed that the experimental chamber data can be used to predict full scale operation of an active green roof designed for Florida climate conditions. Comparisons and hypothesis tests were performed.

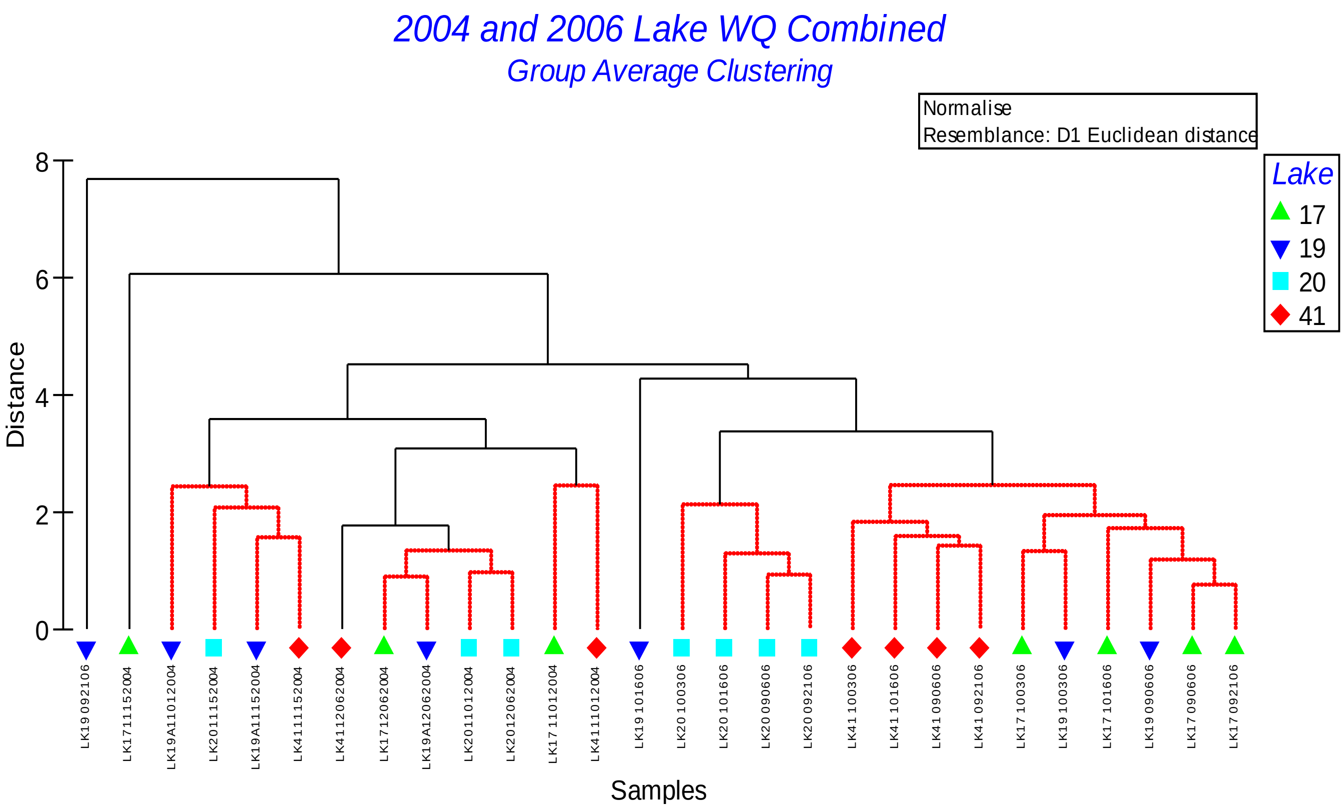
Wanielista, M., Hardin, M., & Kelly, J. (2007). The effectiveness of green roof stormwater treatment systems irrigated with recycled green roof filtrate to achieve pollutant removal with peak and volume reduction in Florida. (FDEP Project # WM 864). University of Central Florida, Stormwater Management Academy, Orlando, FL.
This study examines the effectiveness of a green roof irrigated with recycled green roof filtrate water. It documents the reduction of pollutants and water from the green roof as compared to a conventional roof. Hypothesis tests are done on ET, Filtrate Factors, and Nitrate Concentrations. A CSTORM model is developed using a mass balance approach to preserve a hydrologic balance.

Whalen, Paul J. (1988). An assessment of urban land use/stormwater runoff quality relationships and treatment efficiencies of selected stormwater management systems. For Water Quality Division, Resource Planning Department, South Florida Water Management District. West Palm Beach, FL.
This report assesses stormwater runoff quality throughout Florida for differing land uses. It compares the results to studies conducted across the United States. It also evaluates the data reported in the literature concerning the treatment efficiencies associated with various stormwater management systems.

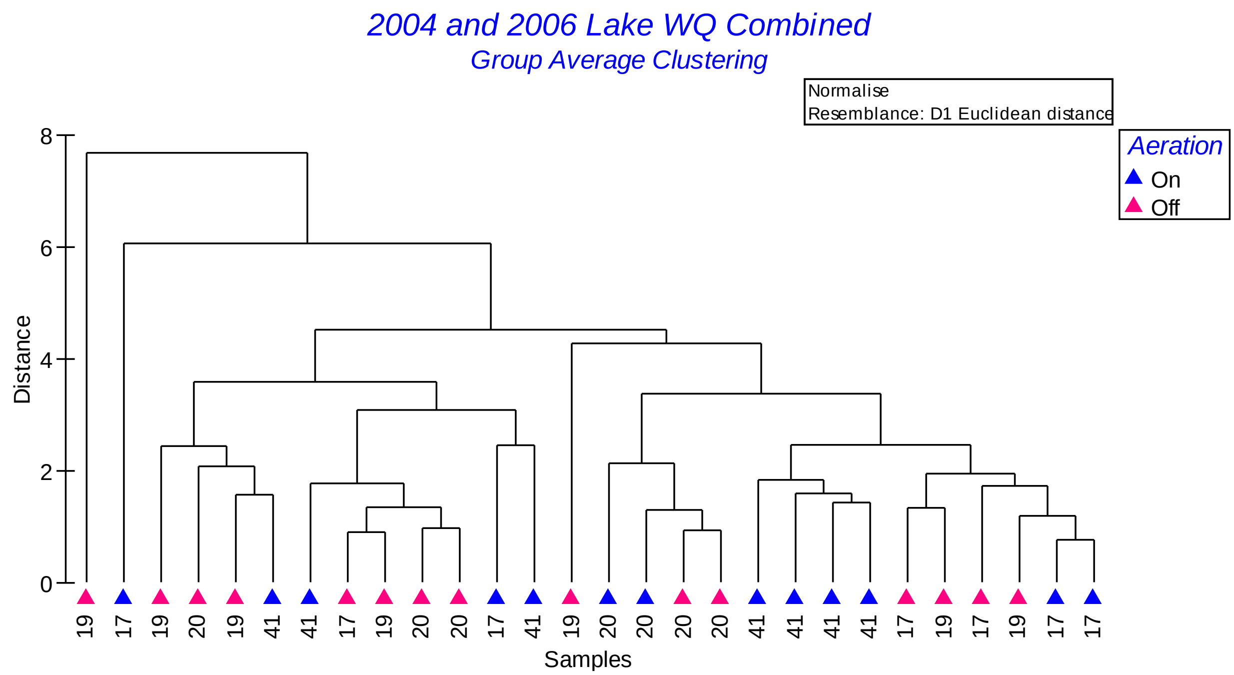
Yu., S.L., J.X. Zhen, and S.Y. Zhai.(2003) Development of a stormwater Best Management Practice placement strategy for the Virginia Department of Transportation. Virginia Transportation Research Council. Charlottesville, VA.
This report presents a modeling methodology for cost-effective application of stormwater BMPs. IT includes a watershed simulation model, a BMP model, and an optimization routine.

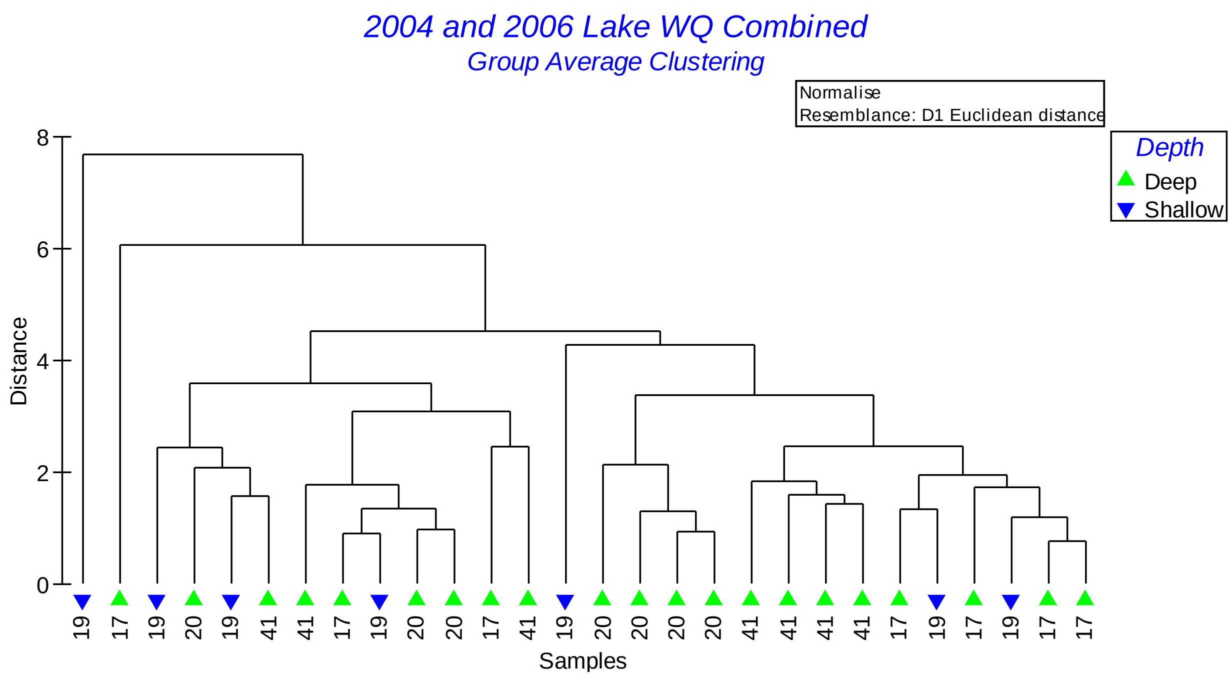
APPENDIX C

Multivariate Analysis:
Cluster Diagrams, MDS Plots, and PCA

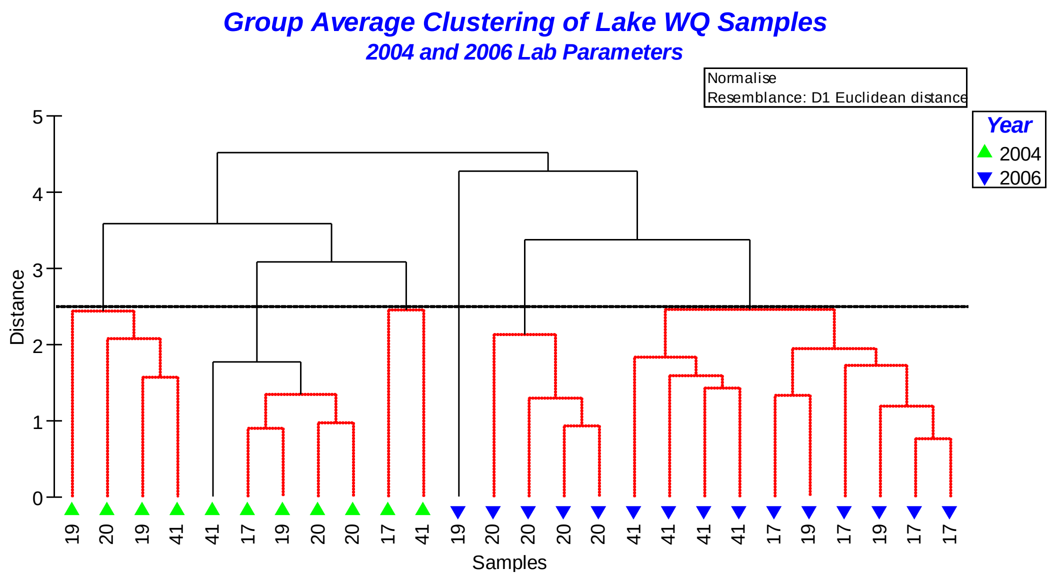


Hierarchical Clustering of Lake samples using all 10 laboratory parameters and all sampling events. Note two outliers to the left of the chart, Lake19 on 9/21/06 and Lake 17 on 11/15/04. These samples may have been contaminated were subsequently excluded from further multivariate analyses. For example, Lake 19 on 9/21/06 exhibited very high levels of ammonia (NH_3) and total phosphorus which may have been a localized event (bird feces or fertilizer) that did not persist.

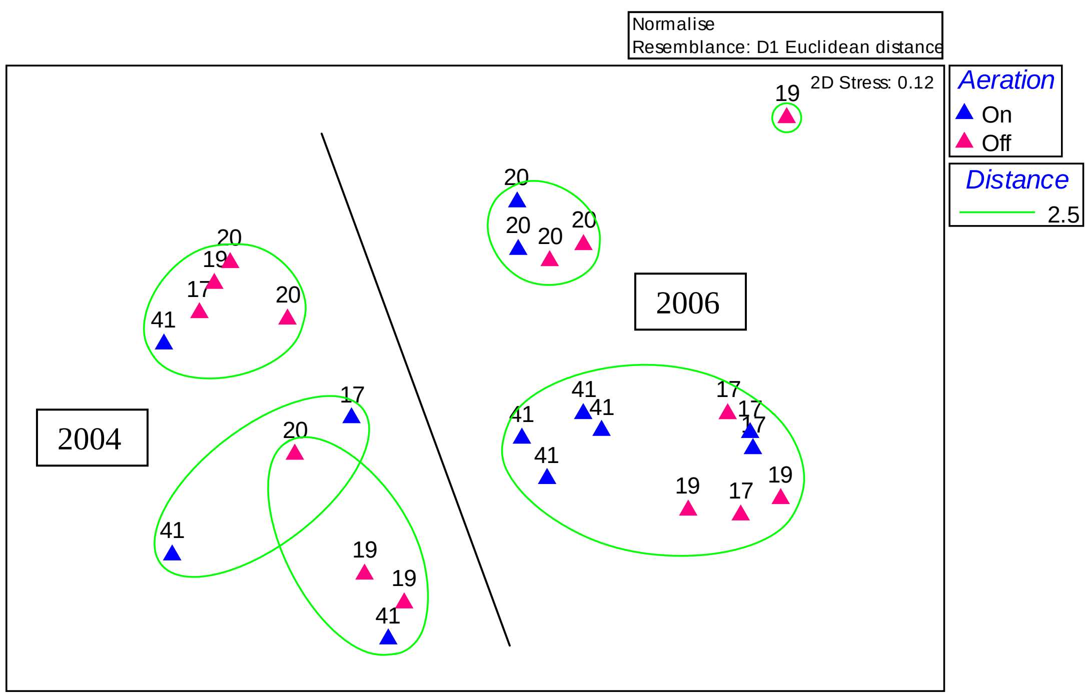




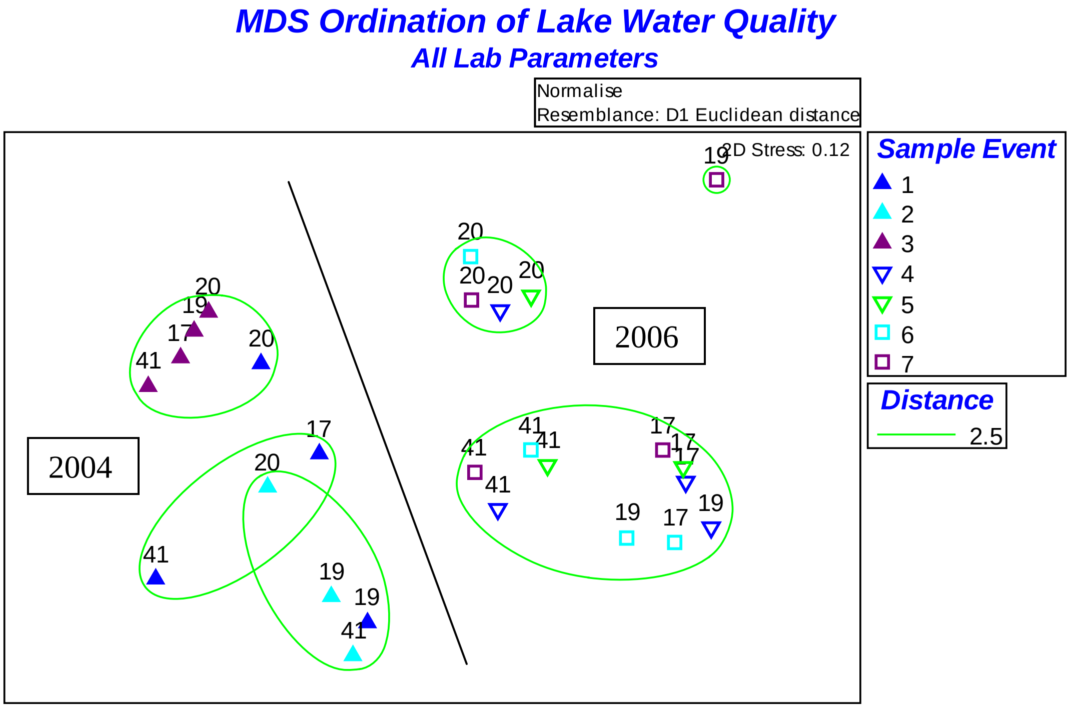
Hierarchical Clustering of Lake samples using all 10 laboratory parameters and all sampling events. Note two outliers to the left of the chart, Lake19 on 9/21/06 and Lake 17 on 11/15/04. Note that groupings of samples do not appear to be associated with aeration or pond depth.



Hierarchical Clustering of Lake samples using all 10 laboratory parameters and all sampling events. Outliers have been removed prior to creating the resemblance matrix of Euclidean distances and creation of the cluster diagram. Slice was added and distance 2.5 to illustrate 6 major groupings of the 7 significantly different groups (black lines). Note the large separation (distance 4.5) of samples by years 2004 and 2006.



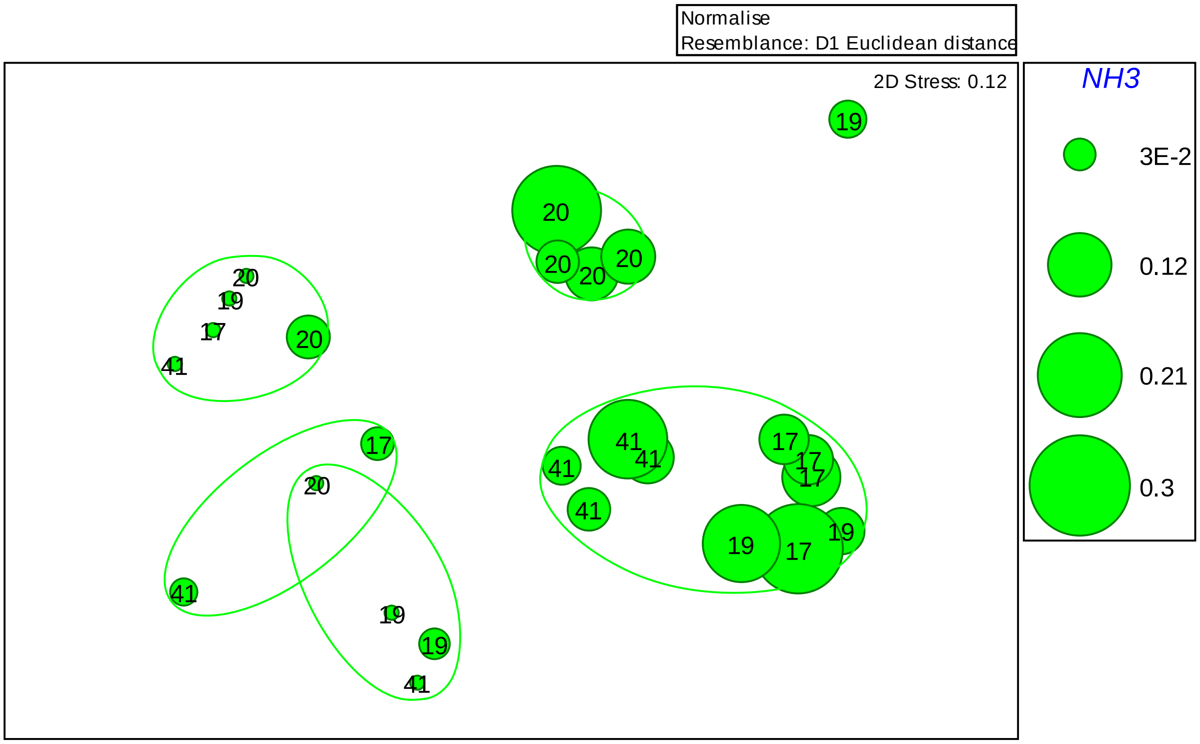
A multidimensional scaling (MDS) ordination of Lake samples illustrating the significant groupings ($p<0.05$), separation between sample years (2004 versus 2006 with line added for emphasis) lake number (17, 19, 20, and 41), and whether aeration was on or off.

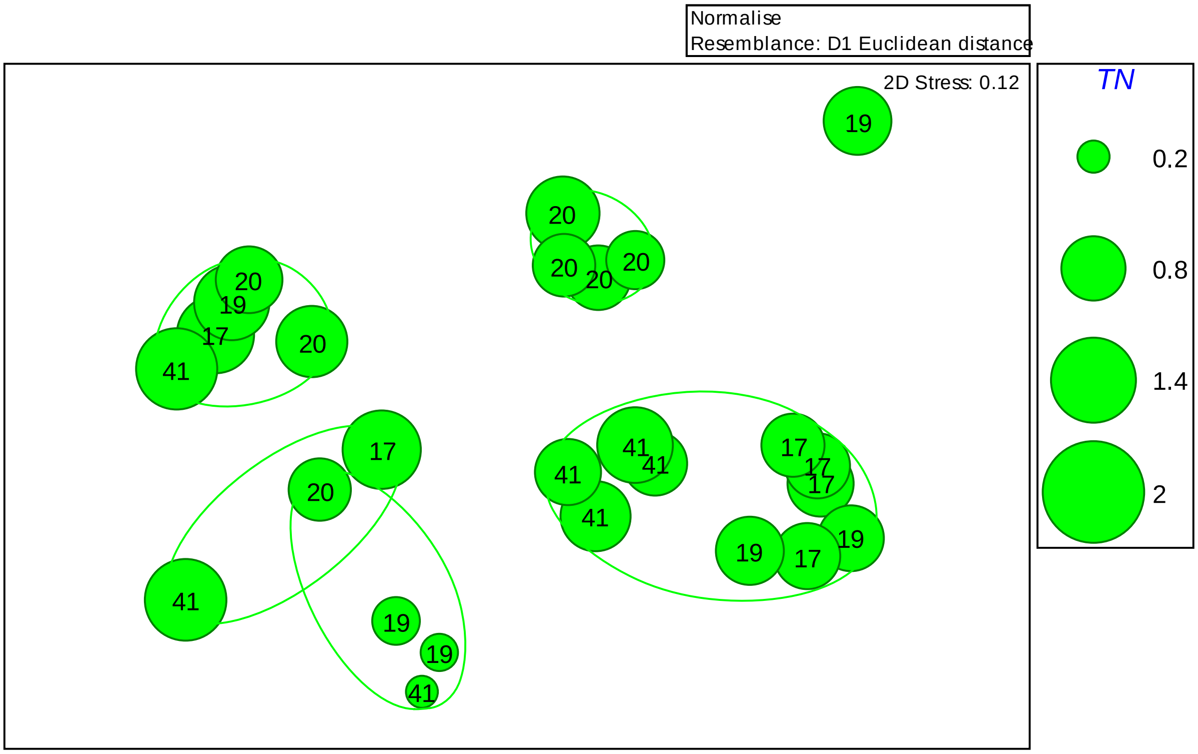


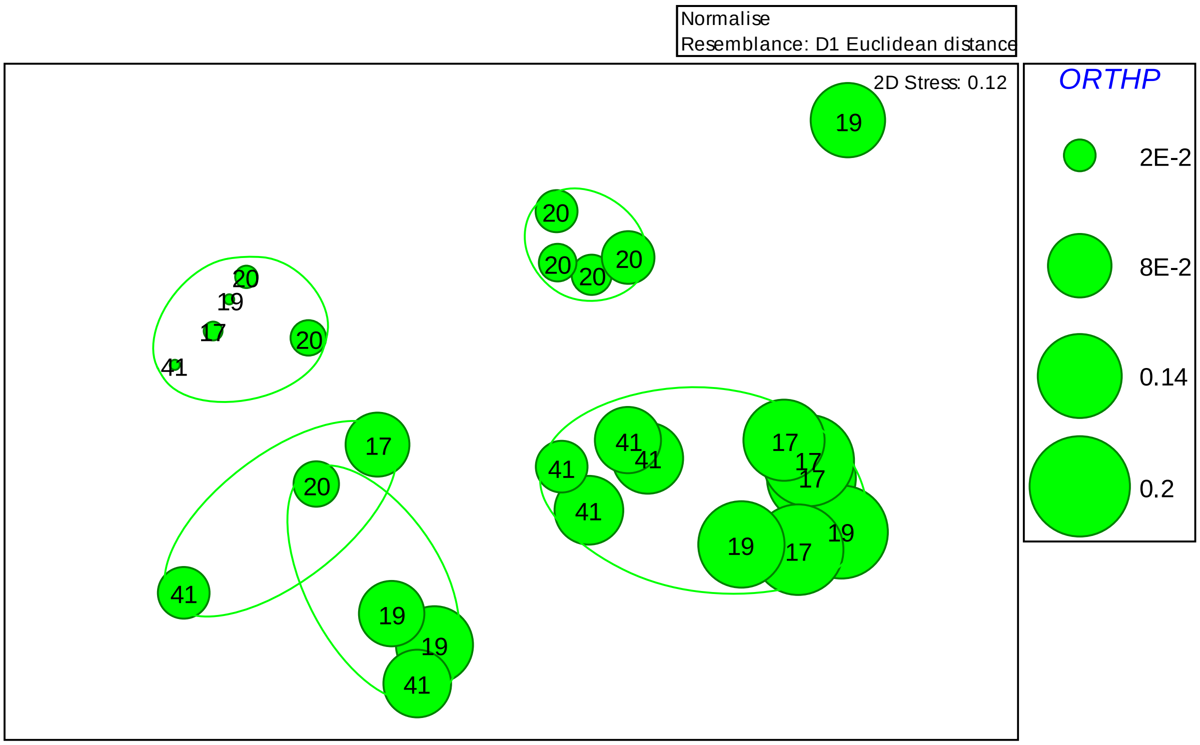
A multidimensional scaling (MDS) ordination of Lake samples illustrating the significant groupings ($p<0.05$), separation between sample years (2004 versus 2006 with line added for emphasis) lake number (17, 19, 20, and 41), and sampling event. Note how samples group by date (sample event) in 2004 and group by Lake number in 2006.

MDS Plots with Individual Parameters Overlayed:

The following 6 figures represent bubble overlays of concentration levels on the MDS plot which help illustrate the relative importance of selected water quality parameters in forming the ordination and separation between samples, lakes, and/or years.


Normalise
Resemblance: D1 Euclidean distance
2D Stress: 0.12
NH3
3E-2
0.12
0.21
0.3


Normalise
Resemblance: D1 Euclidean distance
2D Stress: 0.12
TN
0.2
0.8
1.4
2


Normalise
Resemblance: D1 Euclidean distance
2D Stress: 0.12
ORTHP
2E-2
8E-2
0.14
0.2
19
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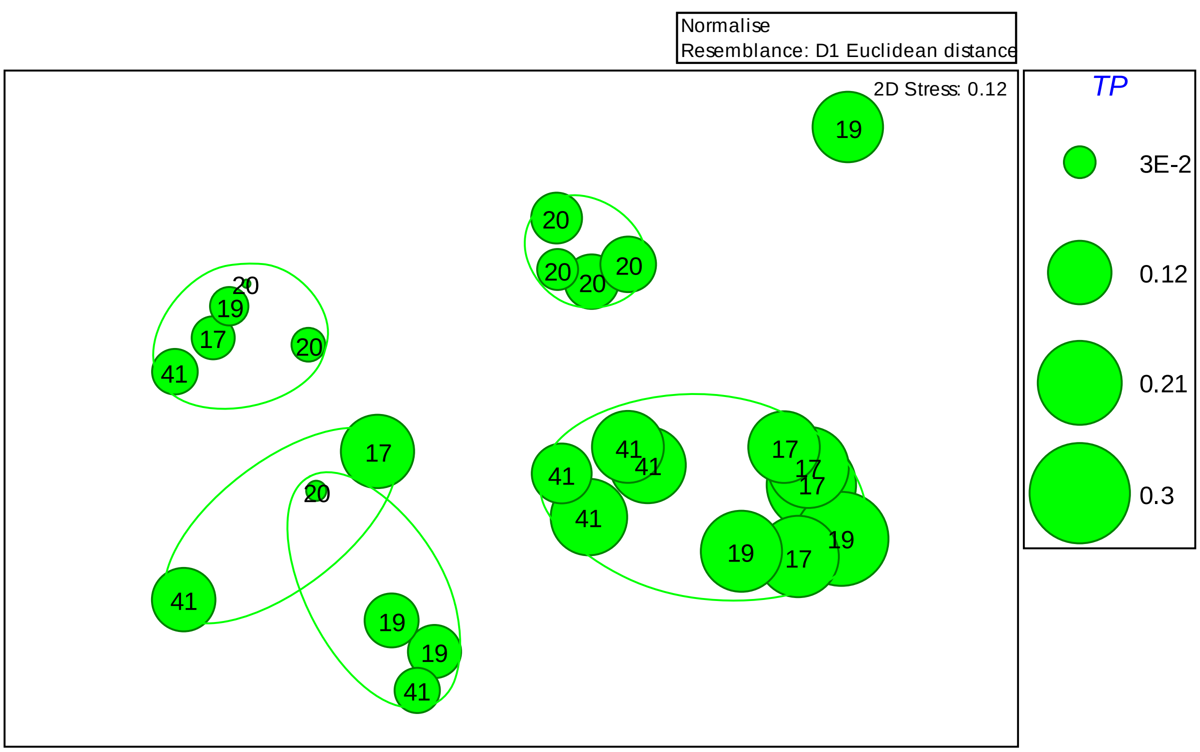
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Resemblance: D1 Euclidean distance
2D Stress: 0.12
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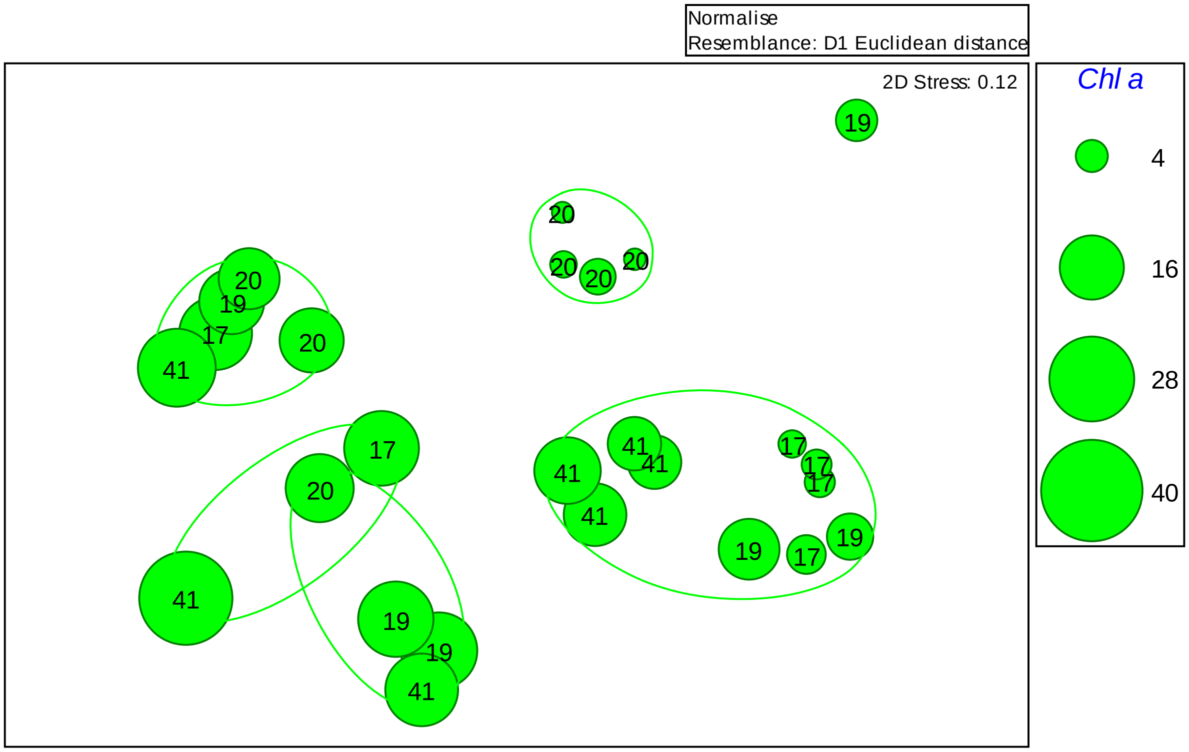
Normalise
Resemblance: D1 Euclidean distance
2D Stress: 0.12
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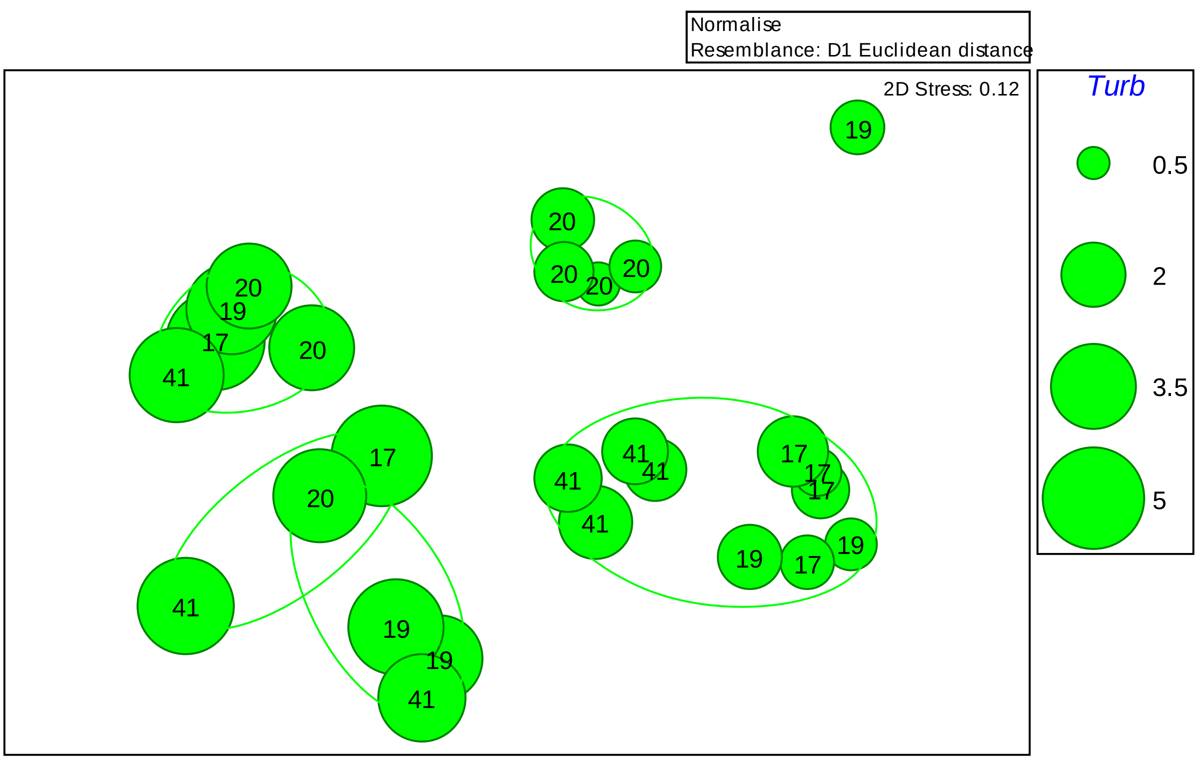
Normalise
Resemblance: D1 Euclidean distance
2D Stress: 0.12
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APPENDIX D

Dennison, T.J., M.L. Lohr, D.W. Ceilley, and E.M. Everham. 2008. Water quality evaluation of the impacts of aeration on deep and shallow wet detention ponds in Southwest Florida. Proceedings of StormCon**,** the North American Surface Water Quality Conference & Exposition, August 3–7, 2008, in Orlando, FL.

APPENDIX E

CD of Digital Files