# DEVELOPMENT AND USE OF WATER QUALITY INDICES (WQI) TO ASSESS THE IMPACT OF BMP IMPLEMENTATION ON WATER QUALITY IN THE COOL RUN TRIBUTARY OF THE WHITE CLAY CREEK WATERSHED

by

Alison Kiliszek

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Bioresources Engineering

Spring 2010

# DEVELOPMENT AND USE OF WATER QUALITY INDICES (WQI) TO ASSESS THE IMPACT OF BMP IMPLEMENTATION ON WATER QUALITY IN THE COOL RUN TRIBUTARY OF THE WHITE CLAY CREEK WATERSHED

by

Alison Kiliszek

Approved: __________________________________________
Anastasia E. M. Chirnside, Ph.D.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: __________________________________________
William Ritter, Ph.D.
Chair of the Department of Bioresources Engineering

Approved: __________________________________________
Robin Morgan, Ph.D.
Dean of the College of Agricultural and Natural Resources

Approved: __________________________________________
Debra Hess Norris, M.S.
Vice Provost for Academic and International Programs

ACKNOWLEDGMENTS

This research report was prepared by Alison Kiliszek to fulfill the requirements by the University of Delaware for a degree of Master in Bioresources Engineering. Many thanks go to Dr. Anastasia Chirnside for being my academic advisor and always providing me with words of encouragement and support. I also wish to thank Soraya Azahari, Nicole Dobbs, Drew Erensel, Miles Fisher, Kaitlin Green, Ryan Minor, Lauren Popyack, and Nicole Scarborough for helping in the sample collection and analysis. Special thanks to my family and friends who supported and encouraged me throughout the years.

Anastasia Chirnside thought of the concept of a Water Quality Index (WQI) for the UD Experimental Watershed to aid the college in determining the effects of the implemented Best Management Practices (BMPs). She started to research previously created WQIs as a staring point to the project that has evolved into a working model for the future. We hope the University of Delaware continues to monitor the Cool Run stream to provide an on-campus education and research site that will show faculty, staff, and students the effects and importance of BMPs.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| BF | Base flow |
| BMP | Best Management Practice |
| BMPs | Best Management Practices |
| BOD | Biochemical Oxygen Demand |
| BREGSWQL | Bioresources Engineering Soil and Water Quality Laboratory |
| CANR | College of Agriculture and Natural Resources |
| CFU | Colony Forming Units |
| Chl a | Chlorophyll a |
| CWA | Clean Water Act |
| DNREC | Department of Natural Resources and Environmental Control |
| DO | Dissolved Oxygen |
| DWCPHH | Delaware Water Quality Criteria for the Protection of Human Health |
| DWQCPAL | Delaware Water Quality Criteria for the Protection of Aquatic Life |
| DWQS | Delaware Water Quality Standards |
| HDPE | High Density Polyethylene |
| IDEQ | Idaho Division of Environment Quality |
| KWQI | Kiliszek Water Quality Index |
| KWQIs | Kiliszek Water Quality Indices |
| MCL | Max contaminant level |
| NREC | Newark Research and Education Center |
| NRECF | Newark Research and Education Center Farm |
| NSF | National Sanitation Foundation |
| NSFWQI | National Sanitation Foundation Water Quality Index |
| ORP | Oxidation/Reduction Potential |

| | |
|---|---|
| OWQI | Oregon Water Quality Index |
| RCWP | Rural Clean Water Program |
| SCA | Standards and Criteria Approach |
| SF | Storm flow |
| T | Temperature |
| TD/TDS | Total Dissolved Solids |
| TMDL(s) | Total Maximum Daily Load(s) |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| TS/TSS | Total Suspended Solids |
| UD | University of Delaware |
| UDAESF | University of Delaware Agricultural Experimental Station Farm |
| UDEW | University of Delaware Experimental Watershed |
| UDSTL | University of Delaware Soils Testing Laboratory |
| UDWRA | University of Delaware Water Resources Agency |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| VBA | Visual Basic for Applications |
| WAR(s) | Water Assessment Report(s) |
| WCC | White Clay Creek |
| WQI | Water Quality Index |
| WQIs | Water Quality Indices |

# ABSTRACT

The purpose of this project was to develop Water Quality Indices (WQI) that could be utilized to describe the water quality in the Cool Run tributary and to evaluate the impact of BMP implementation within the University of Delaware Agricultural Experimental Station Farm (UDAESFF) on water quality. A variety of water quality parameters have been measured at eight sites within the UDAESF over the past three years. Based on this data there has been a positive impact on the water quality as Cool Run exits the UDAESF and continues through residential areas. Many sections of the stream within the UDAESF are still impaired from previous farm management practices. New management practices have been implemented during the study period these include a manure collection system and a constructed wetland. Older management practices have been in place since before 2001, these practices include riparian buffer zones, prevention of livestock from entering the stream and the addition of a weir. A working model was developed to allow the WQI to be used for the evaluation of up to eight different parameters sets or to be used to create a spatial distribution of the WQI values as the stream flows through the UDAESF. The model was used for the evaluation and rating of the individual sites and the Best Management Practices (BMPs) that are in place. Evaluations were completed using the effects on streams associated with the individual BMPs and parameters that related general stream health. Future researchers will be able to use and update the Kiliszek Water Quality Index (KWQI) with the current Delaware water quality standards and criteria to monitor the quality of water within the Cool Run Stream.

# Chapter 1

# WATER QUALITY INDICES: ASSESSING STREAM HEALTH

## Introduction

Watershed assessment is a process for evaluating the health of a watershed. The process includes steps for identifying issues, examining the history of the watershed, describing its features and evaluating various resources within the watershed (Watershed Professionals Network, 1999). An assessment can help identify potential problems that need further investigation. Watershed assessments use aspects of water quality and fish habitat as indicators of watershed health. It can help determine how natural processes, human activities, and land management practices influence these resources.

The National Clean Water Act (CWA) of 1972 was created as an effort to repair and maintain the chemical, physical and biological characteristics of the nation's water bodies. Each State was required under the CWA to set water quality standards that would protect human health and also enhance the quality of water within that State. Standards and regulations were to be approved by the United States Environmental Protection Agency (USEPA) before a state could implement them. Delaware created water quality standards and criteria based on the following water body usages: Public Water Supply, Industrial Water Supply, Primary Contact (swimming), Secondary Contact Recreation (wading), Fish Aquatic Life and Wildlife, Cold Water Fisheries, Agricultural Water Supply, Waters of Exceptional Recreational of Ecological Significance, and Harvestable Shellfish Waters. The CWA requires a public review every three years to reevaluate the water quality standards used by each state; this is called the Triennial Review. Based on the findings in the Triennial Review water quality standards and criteria will remain the same or be amended (DNREC, 2004).

In addition to the public review every three years, Watershed Assessment Reports (WARs) (known as 305(b) Reports) are submitted to the USEPA every two years. The WARs summarizes the water quality assessments, initiatives and concerns and waters needing Total Maximum Daily Loads (TMDLs) for the state. Data used for creating this report comes from monitoring related to the TMDLs, general assessment, toxics in the biota, toxics in sediment and biological assessment. If the monitoring data used to create the WARs indicates that a water body does not meet the standards then that water body is added to the impaired waterways list (known as 303(d)). A TMDL is then determined so that a limit is set for the amount of pollution that is discharged to that particular waterway, this can include anything that impairs the natural health. The purpose of the TMDL is to limit the amount of new pollution added to the waterway so that the water quality standards can be achieved (DNREC, 2008).

Watershed assessment results in the production of vast quantities of water quality monitoring data describing many different parameters. For example, in this research project, a minimum of 20 paramerters per site were monitored on a monthly basis resulting in more than 4,320 quality variables. This monitoring can detect water quality criteria violations for individual constituents but fails to give a clear, condensed description of the actual stream health. This collection of data does not allow for a single composite site evaluation that can depict temporal and spatial variations of water quality. Neither can it prioritize different sampling sites according to their level of contamination due to variability in land use and environmental factors that can influence the type and extent of contamination (House, 1990; Kaurish and Younos, 2007; Maret *et al*., 2008 and Pesce and Wunderlin, 2000).

Researchers and regulators developed mathematically derived Water Quality Indices (WQIs) that reduce the massive amounts of data on a variety of physical, chemical and microbiological parameters to a single, unit-less, numeric score. Policy makers often use WQIs as tools to help monitor and review the results of water quality monitoring programs. Researchers may utilize WQIs to study trends in environmental quality, and to evaluate the impacts of reguatory policies on enviromental management (Swamee and Tyagi, 2007).The use of a WQI can describe the water quality conditions at a particular time and location and can act as an indicator of an ecosystem's health overtime. Water Quality Indices allow for a summation of parameter effects on the overall changes in stream water quality. The use of an index can translate water quality monitoring data into a form that the public and policy makers can easily interpret and utilize (House, 1990; and Pesce and Wunderlin, 2000). Indices facilitate quantification, simplification, and communication of complex data allowing for an effective way to convey environmental information (Swamee and Tygai, 2007).

Since the summer of 2006, the surface water quality of the Cool Run Stream within the University of Delaware Experimental Watershed (UDEW) has been monitored for nutrients, metals, and bacteria. The monitoring sites are located in the Newark Research and Education Center Farm (NRECF). The goals of this monitoring project are to assess the changes in water quality after the implementation of conservation practices within the sub-watershed and to compare surface water quality of the tributaries draining institutional and residential land use areas to those draining agricultural land use areas (McDermott and Sims, 2005). The monitoring has resulted in massive data sets collected from 6 different sites containing values for 20 different water quality parameters per site.

The Cool Run Wetland Restoration Project, a collaboration between Delaware Department of Natural Resources and Environmental Control (DNREC) and the University of Delaware (UD), has led to the development of a rain garden located in the tributary headwaters, to the creation of a wetland located in unproductive pasture and crop land, to the partial restoration of a stream running through the agricultural lands and to the installation of fencing around streams running through agricultural pastures. Implementation of a nutrient management plan has resulted in reductions in fertilizer application on the NRECF. Installation of a new dairy waste management system in 2008 has led to the improvement in manure storage and land application practices (McDermott and Sims, 2007; Sims and McDermott, 2008). Evaluation of the monitoring data can lead to an assessment of the impacts these Best Management Practices (BMPs) have on the surface water quality within the Cool Run watershed. By installing and maintaining these BMPs, the collaborators of the Wetland Restoration Project expect to see an increase in overall stream health within the sub-watershed over time (Maret *et al.*, 2008). Ultimately, the objective of this research is to assess the impact of these BMPs on the health of the Cool Run watershed through the development and use of WQIs.

## **Objectives**

In general, the first objective of this reseach is to develop WQIs for the Cool Run watershed based on previously collected water quality data. The second objective is to utilized the developed WQIs to assess the impact of BMPs on watershed health.

Objective 1: To acccomplish Objective 1, the following tasks will be performed.

Task A: Research previously developed WQIs in order to define the following: 1) what water quality standards and/or criteria were used for WQI development, 2) what water quality prameters were utilized in the development of the WQIs and 3) for what purpose were the WQIs utilized.

Task B: Adapt the WQIs so that they help define stream health based on the state of Delaware's and/or the United States Environmental Protection Agency's (USEPA) criteria for surface water quality. Develop additional WQIs that will contain any additional parameters previously measured for Cool Run but not included in the researched indices. .

Task C: Convert each water quality parameter into a corresponding subindex value. Determine additional equation constants that may be required to develop subindices for measured parameters.

Task D: Aggregation of subindices into a single WQI value for various scenarios.

Task E: Develop a user-friendly computational interface tool for calculating the WQIs.

Objective 2: The second objective is to utilize the developed WQIs to assess the current and future impact of BMPs on watershed health. To achieve the second objective, the following tasks will be performed.

Task A: Determine parameter sets that are the most vital for calculating a WQI that best describes stream health based on the desired criteria. Parameter sets selected will be determined by the type of BMP under assessment and the potential water use of the stream.

Task B: Evaluate BMPs over time using WQIs based on measured water quality data. The developed WQIs will also be used to compare and contrast stream health as it flows through and then exits the NRECF.

## Literature Review

There are many smaller components that must be considered when making a watershed assessment. The first component of an assessment is to identify issues that are in the watershed, for example, high nutrient levels within streams. The next step is to develop a watershed description that includes historical conditions and channel habitat type classification. The third component is to characterize the watershed using a combination of hydrology and water use, riparian/wetlands, sediment sources, channel modification, water quality, and fish and fish habitat assessments. The final steps are to complete the watershed condition analysis and then create a monitoring plan based on the condition analysis (Watershed Professionals Network, 1999).

The use of WQIs in the analysis of watershed condition is similar to the use of the Dow Jones Index in the stock market business. While the use of each index is quite different, the concept behind both are the same; *i.e.*, compile many variables into a single number that can be used to track changes over time (Carruthers and Wazniak, 2004). Two main types of indices are "absolute subindices" and "relative subindices". Absolute indices are independent of quality standards while Relative indices depend on the quality standards being used. A relative subindex will be used in this research, it allows for the injection of "scientific evidence" into the laws and regulations that are created by policy makes as part of the monitoring plan (Gupta *et al.*, 2003).

One of the first water quality indices was used in 1970 when the National Sanitation Foundation (NSF) developed a WQI that demonstrated the tendency for the occurrence of eutrophication in streams and lakes. Nine parameters were selected by a team of scientists and used to develop a water quality score that ranged from 0 to 100. The parameters utilized were temperature (T), dissolved oxygen (DO), pH, biochemical oxygen demand (BOD), nitrate-nitrogen, total phosphorous (TP), total solids (TS), fecal coliform and turbidity. These parameters were chosen to reflect water quality in terms of potential water uses (House, 1990 and Kaurish and Younos, 2007).

In 1979, Oregon developed a WQI (OWQI) that was used to help assess water quality for general recreational uses including fishing and swimming (Cude, 2001). In 1995, modifications were made to the OWQI to reflect advances in the knowledge of water quality and in the design of water quality indices. The index was developed using the nine previously mentioned parameters as well as % DO saturation. The index has been used to report water quality status to state legislators and to other water resources policy makers (Cude, 2001).

The state of Maryland developed a WQI that combined the status of four water quality indicators [chlorophyll *a* (Chl *a*), total nitrogen (TN), TP and DO] into a single indicator. Three year median values of these parameters were compared to criteria based on ecosystem function, such as maintaining fisheries (DO threshold), or maintaining submerged aquatic grasses (Chl a, TN and TP threshold) (Carruthers and Wazniak, 2004).

A common question that will occur when using indices is the relationship between the indices and water quality standards and criteria. For example when an index value is given a rating of "Poor," what does "Poor" mean? Does a rating of "Poor" mean that the water body is in terrible condition with many major problems or that it simply does not meet the water quality standards? For this project, WQIs were developed in relationship to the state of Delaware's Water Quality Standards (DWQS; DNREC, 2004). For water quality parameters that do not have regulated standards listed in the DWQS, the ratings were based on criteria provided by the USEPA (USEPA, 2000). Therefore, the term "Poor" used in this work describes any water quality variable that does not meet the required standards or criteria.

There are four stages used in the development of a WQI. The first step is the selection of parameters which are chosen to reflect water quality in terms of a range of potential uses or in terms of environmental stresses, such as heavy metals, pesticides and organic compounds that are potentially harmful to both humans and aquatic life. Many states have defined standards for particular parameters based on the potential use of the water body (Ott, 1978) as well as the effect on downstream reaches (Watershed Professionals Network, 1999). Potential use categories in Delaware include drinking water, industrial processes, irrigation, maintenance of a suitable fishery and/or wildlife habitat, recreation (boating, swimming) and aesthetics (Ott, 1978). Usage categories are more easily defined than the parameters that are meant to illustrate the quality of water because they fall under a category of “fuzzy logic” (Varadharajan *et al.*, 2009). Fuzzy logic can be described as all the uncertainties with human thinking, reasoning, and perception and as a method to solve the incompatibility of observations, and uncertainty, among other things that arose with the use of a WQI. In turn, policy and law makers can use a WQI not as an absolute measure of degree of pollution or the actual water quality but as a tool for evaluating an approximation or general health of a stream (Varadharajan *et al.*, 2009). Due to this, there is no set parameter combination that is absolute; being able to choose from a series of parameters creates a more adaptable WQI.

The second step in WQI development is normalization of the parameters to the same scale. Step two involves the conversion of parameter concentration into a corresponding subindex value using an equal and dimensionless numeric scale. The third step is the development of parameter weighting. The purpose of parameter weighting is to place a greater emphasis on particular parameters that are considered more or less important depending on what the WQI is being used for (House, 1990). The parameters that are considered most important and have the greatest weight in the overall WQI value in this research are parameters with the lowest subindex values (Swamee and Tayagi, 2007). Finally, an appropriate aggregation function is selected in order to compile the subindices into a single index (House, 1990).

Three generic subindex equations are used to relate concentrations of the various water quality variables to their respective index scores. After the subindices are calculated the individual scores are mathematically aggregated into a single number for the WQI value.  An improved method of aggregation developed by Swamee and Tyagi (2007) will be used to calculate the WQI for the Cool Run watershed.  The improved method was developed to reduce and/or eliminate the problems caused from eclipsing and ambiguity which are known problems with past subindex aggregations.  A quantitative value is calculated using one of three subindex equations.  These values are then used to calculate the total WQI value.  This final value is related back to a qualitative rating scale.  Eclipsing occurs when the importance of a parameter or value is diminished or under estimated.  For example, if there are 5 ‘excellent’ ratings and 1 ‘poor’ for the subindices, then the final index should be able to reflect the poor rating included in the subindices and not be hidden by the higher ratings of the subindices calculated for the  other pollutant variables.  Ambiguity occurs when the sum of subindices exaggerates the severity of the overall pollution status.  As more pollutant variables are aggregated into the total sum, the value of the final index becomes greater, indicating poor overall quality.  The improved method for aggregation of the subindices will provide flexibility when additional parameters are desired for calculating the WQI.

In 2001, the University of Delaware Experimental Watershed (UDEW) was developed as a research and educational tool for watershed study (Campagnini and Kauffman, 2001).  After 2000, BMPs that were implemented on the NRECF located within the UDEW include the installation of fencing for cattle exclusion from the stream, the reconstruction of riparian buffer zones, the installation of a manure handling system, and the construction of a wetland.  Upstream in the headwaters of Cool Run, a rain garden and the Harrington stormwater wetland were installed to increase pervious surface area for better stormwater management. Some natural pond areas have also occurred throughout the farm within the stream corridor.

The impact of implemented BMPs may not be able to be immediately observed or measured quantitatively until some time has passed. In a study done by the Idaho Division of Environment Quality (IDEQ) and the U.S. Geological Survey (USGS) as part of the Rural Clean Water Program (RCWP), a more in depth approach at the long-term responses to BMPs was researched over a series of 10 years (Maret *et al*., 2008). Changes in water quality of Rock Creek, Idaho were assessed utilizing monitoring data from 1981 to 2005. BMPs were implemented prior to the study in attempts to reduce the negative impacts of approximately 75% of the western irrigated cropland on water quality in Rock Creek. Reduction in total solids (TS) and total phosphorus (TP) loads to the creek were seen over the 25 years. The authors concluded that over time BMPs are effective in reducing stressors that are introduced into the environment. Long term studies provided verification that assessment of BMPs after short time spans such as a few years may not provide accurate evaluations of the change in water quality. For example, Maret *et al* (2008) found that the lowest recorded concentrations of TP, TS and nitrate-nitrite nitrogen occurred during the low flow conditions occurring from 2001 to 2004.

Agricultural environments where animals are allowed to defecate directly into the stream tend to have greater concentrations of nutrients and bacteria than in nonagricultural surface waters. These areas should not be overlooked as significant sources of non point source pollution especially when they are at or near their total livestock capacity (Line *et al.*,2000). The higher source of cattle traffic on the area will result in lower vegetation and ultimately higher runoff and erosion rates. The increase in nutrient loading is also caused by the common practice of pasture land being located in wetter areas closer to streams and on sloped land that is unsuitable for cropland (Line *et al.*, 2000). The installation of fencing around the Cool Run as it moves through pasture land can reduce the amount of animal waste directly entering the stream. Line *et al.* (2000) found that after conducting their livestock fencing study over a 137 week (2.6 year) period, there were significant reductions in nitrate-nitrite, total kjeldahl nitrogen (TKN), total phosphorus (TP), total suspended solids (TSS), and total solids (TS) coming from the pasture land. The nonpoint source reductions were 32.6, 78.5, 75.6, 82.3, and 81.7% respectively. Reductions in TKN, TP, TSS, and TS were associated with a decrease in erosion from the cattle not walking in or around the stream banks (Line *et al*, 2000). The concept of lag time between fencing installation and noticeable improvements were not exclusively discussed in Line *et al.* (2000). Meals *et al.* (2010) researched the lag time from different BMPs using parameters such as sediment, nitrate, total nitrogen, phosphorus, and bacteria. They concluded that for livestock exclusion in particular, a response lag time of at least one year was to be expected. Parameters that would be most affected include phosphorus, nitrogen, and bacteria (Meals *et al.*, 2010).

Frequent land application of manure increases the growing concern with nutrient buildup in the soils and the potential for increased leaching into nearby water bodies (Powell *et al.*, 2005). Installation of manure collection systems allows for the collection, treatment and management of agricultural animal wastes. The collection of manure and manure-laden runoff helps to prevent nutrients, bacteria and other organic pollutants from entering surface and ground water (McDermott, 2008). Other concerns with constant land applications that have arisen are the effects on area air quality, land acidification, and the severe impairment of surface water resources. Research indicated that farms of all sizes can have an affect on the surrounding land and not just the larger farms (Powell *et al.*, 2005). The use of manure collection systems provide farmers with better management options for land application of the animal wastes. Meyer *et al.* (1997) discussed that manure should be applied to crops as needed for plant growth and at the appropriate time of the year resulting in minimum environmental impact. Manure application management should reduce pollutant loads to both surface and ground water. The use of nutrient management practices such as manure collection and storage will have one of the longest lag times until significant changes can be documented. The response time varies from a minimum of 4 years and up to 50 years depending on the scale that is being monitored. For smaller areas, the response time is estimated to be 4-30 years, while larger watersheds are estimated to be 15-50 years (Meals *et al.*, 2010)

Riparian buffer zones serve as an interface between terrestrial uplands and fresh water systems. They act as a conduit, transformer, and barrier for nutrients and other possible pollutants (Tabacchi *et al*., 2000; Vidon *et al*., 2008). The erosion that occurs along the stream banks can be minimized in most cases by the stabilization that the roots of plants, shrubs, and trees provide within the buffer zone. These plants also provide an environment for nutrient uptake and sedimentation to occur as stormwater travels toward the stream. Riparian vegetation helps dissipate energy of floods, support perennial flows and moderate stream temperature (Coles-Ritchie *et al*., 2007). Buffer zones also help to promote the general health of the stream by providing wildlife with shade and a habitat to reside in (Todd, 2008). Although the effects that riparian zones have on streams vary temporally and spatially, these buffer zones have excellent nitrate removal potential. Vidon *et al*. (2008) found that riparian buffer zones removed more than 90% of the nitrate-nitrogen within the stormwater before discharging into the stream. The estimated lag time response for a riparian buffer zone is approximately 10 years (Meals *et al.*, 2010).

Historically wetlands have been considered nuisances of little importance that have slowed transportation and economic growth. Within the past 20 years there has been a shift on the importance of wetlands and the functions that they serve in an environment. Some of the ecological functions that are associated with wetlands include flood control, water purification, and wildlife habitats (Meindl, 2005). Wetlands also function as a site for the storage of sedimentation on both short and long term scales. Studies in California show that 14-58% of solids from upstream areas were removed from the system by wetland sedimentation. The actual amount of sedimentation that can occur is site specific (Phillips, 1990). In a 2 year study, Reinhardt *et al* (2006) measured a nitrogen removal efficiency of approximately 27% in a wetland. The study showed that 94% of the nitrogen was removed by denitrification while 6% accumulated in the sediments. A study conducted in central Illinois found that wetlands were most efficient at removing nitrogen in the form of nitrate. Average removal rates were reported to be about 37% in 1997 with the higher removals in wetlands with longer retention times (Kovacic *et al*, 2000). Phosphorus removal in wetlands is mostly from the sedimentation of suspended solids in the system (Reinhardt *et al*, 2006). Removal rates from central Illinois wetlands for phosphorus were estimated to be only 2%; significantly lower than the nitrogen removal rates (Kovacic *et al*, 2000).

Ponds and detention basins have been used for pollutant reduction and to mitigate stormwater impacts on the surrounding areas. Pollutants that have been documented to be reduced within ponds and detention basins are BOD (by microbial degradation), nitrogen, phosphorus, and sediments (Corbitt, 1990). The BOD in water will best be reduced in a multi cell system; however, retention time in the pond will also affect the BOD reduction (Bryant, 1987). Nitrogen and phosphorus removals have been estimated to be 76% and 52%, respectively. In a study conducted with a simulated agricultural runoff, an average of 94% of the sediment within the basin was removed before the water was discharged from the system based on a three day retention time. The longer the retention time in the pond the greater the decrease in the sediment, phosphorus and nitrogen found in the effluent (Edwards *et al*, 1999). Ponds and detention basins are used to control stormwater by providing storage during surge events. They are designed to help control the peak flow of water within the stream, based on the pre-development flow as a reference. Unfortunately, studies have shown that this practice may not help control water flow on a watershed basis for extremely large or frequent storm events (Emerson *et al*, 2005).

The impact of BMPs on a water body can not be assessed unless there is monitoring done after BMP installation to document changes in water quality. In Delaware, the WARs document the states' water quality assessment findings every three years. Using this and other water quality assessments, new and old concerns can be addressed by adjusting TMDLs, changing previously used initiatives and by creating new plans for water body protection and rehabilitation (DNREC, 2004). Another use for the evaluation of the impacts of BMPs is their ability for improving nearby water body conditions to remove them from the impaired waterways list (known as 303(d)) (Watershed Professionals Network, 1999). If BMPs are not functioning as expected after the estimated lag times then a reevaluation of that BMP should be conducted and other water improvement techniques should be considered.

# Chapter 2

# METHODS

## Characterization of Monitoring Program

The water quality data used in the development of the WQIs were collected from 8 sampling sites located on the Cool Run tributary that runs through the NRECF. Both physical and chemical parameters were monitored at each of the designated sites. Grab samples were collected in double acid-washed high density polyethylene (HDPE) bottles. Separate sterilized HDPE bottles were used for *Enterococcus* analysis. Separate 500 mL bottles containing 2 mL of 1:1 $HNO_3$ (v/v) (as a preservative) were utilized for Total Metal analysis. Samples were stored on ice in coolers until delivered to the associated testing labs. Samples were then stored at 4°C until the time of analysis.

The physical stream measurements that were taken during each sampling event included surface velocity, average stream depth and stream width. Stream flow was calculated from the physical measurements.

Field measurements of temperature, DO, total dissolved solids (TDS), conductivity and oxidation reduction potential (ORP) were taken on site using an YSI Multiparameter Meter Model 556. The field probe was calibrated before each use. Table 2.1 lists the chemical parameters that were analyzed in the water samples. Sample analysis was performed by the DNREC laboratory, the University of Delaware Soils Testing Laboratory (UDSTL) and the University of Delaware Bioresources Engineering Soil and Water Quality Laboratory (BREGSWQL). Comparative analyses were performed during the first month of sampling to ensure consistency of reported values. The analytical methods used are summarized in Table 2.2.

There were two types of samples collected during this project representing base flow (BF) and storm flow (SF) conditions. The BF samples were collected on a monthly basis from Sites 1 through 6. Storm flow samples were collected from Sites 7 & 8 during storm events. Later, after wetland installation was completed, SF samples were collected from the constructed wetland. During one sample date in 2007 and one in 2008, SF samples were collected from all 8 sites. Table 2.3 and Table 2.4 lists the type of sample, sample date and the corresponding laboratory that performed the analyses.

## Site Description

The Cool Run Tributary of the White Clay Creek Watershed lies within the Delaware River Basin. The Delaware River Basin covers 13,539 square miles and is fed by 216 tributaries draining parts of New York, Pennsylvania, New Jersey and Delaware (Figure 2.1). The White Clay Creek (WCC) is a sub-watershed of the Christina River Basin, which is a sub-basin of the Delaware River Basin. In October 2000, congress approved the addition of a section of the lower Delaware River and the White Clay Creek to the National Wild and Scenic Rivers System. The White Clay Creek Wild and Scenic Rivers System Act designated the entire watershed, approximately 190 miles of segments and tributaries, as components of the national system (Delaware River Basin Commission, 2009). The creek flows from southeastern Pennsylvania to northwestern Delaware, through the UD campus and eventually joins the Christina River, a tributary to the Delaware River (Figure 2.2).

**Table 2.1 Chemical Parameters Monitored.** This table shows the parameters measured within the UDAESF and the units that were used for calculations in this research.

| Parameter | Unit of Measurement |
|---|---|
| Ammonia-Nitrogen ($NH_3$-N) | mg/L |
| Arsenic (As) | mg/L |
| Biochemical Oxygen Demand ($BOD_5$) | mg/L |
| Boron (B) | mg/L |
| Cadmium (Cd) | mg/L |
| Chlorophyll a | mg/L |
| Conductivity | mS/cm |
| Copper (Cu) | mg/L |
| Dissolved Oxygen (DO) | ppm, % DO |
| *Enterococcus* | CFU/100 mL |
| Lead (Pb) | mg/L |
| Nickel (Ni) | mg/L |
| Nitrate-Nitrogen ($NO_3$-N) | mg/L |
| Ortho-Phosphorus (OP) | mg/L |
| pH | Standard pH Unit |
| Temperature | ℃ |
| Total Dissolved Solids (TDS) | mg/L |
| Total Kjeldahl Nitrogen (TKN) | mg/L |
| Total Phosphorus (TP) | mg/L |
| Total Suspended Solids (TSS) | mg/L |
| Zinc | mg/L |

**Table 2.2 Analytical Methods.** The table illustrates methods used by the BREGSWQL and DE DNREC for determining the quality variable values**.**

| Bioresources Engineering Soil & Water Quality Laboratory | | | |
|---|---|---|---|
| **Parameters** | **Method*** | **Comments** | **MDL** |
| $NH_3$-N, $NO_3$-$NO_2$-N | SMWW4500 $NH_3$ B,C; $NO_3$ D | Distillation, acid titration | $NH_3$ 0.129 mg $l^{-1}$ $NO_3/NO_2$ 0.118 mg $l^{-1}$ |
| TKN | SMWW4500C | Acid digestion, distillation & acid titration | 0.087 mg $l^{-1}$ |
| Phosphorous Ortho and Total | SMWW 4500E SMWW 4500B | Colorimetric- ascorbic acid; alkaline persulfate digestion-TP | OP = 0.012 mg $l^{-1}$ TP = 0.029 mg $l^{-1}$ |
| Chlorophyll a /Pheophytin a | SMWW 10200H | | 3.13 ug/L |
| Enterococcus | SMWW 9222D | We usually run fecal coliforms using the membrane filter technique | 1 cfu/100 mL for both methods |
| Conductivity/ Dissolved Oxygen/Salinity/p H | SMWW2510A 2520A | ISE/pH meter or YSI Field Probe | Cond-1 uS/cm DO- 0.2 mgL Salinity-0.10ppt pH-0.2pH units |
| BOD/DO | SMWW 5210B Winkler titration | BOD-5 –Winkler DO - Winkler or YSI Field probe | BOD -2.4 mg/L DO - 0.2 mg/l |
| TDS/TSS VDS/VSS | SMWW2540 B,C,D,E | | 0.33 mg $l^{-1}$ |
| **DE DNREC – Environmental Laboratory Section** | | | |
| **Parameters** | **Method** | **Comments** | **MDL** |
| $NH_3$-N, $NO_3$-$NO_2$-N | $NH_3$-EPA 350.1 $NO_2/NO_3$-EPA 353.2 | Semiautomated colorimetry | NH3-0.004 mg/L NO2/NO3-0.002 mg/L |
| TN | SM 4500-NC | Alkaline Persulfate digestion | 0.040 mg/L |
| Phosphorous Ortho and Total | EPA 365.1 | Colorimetric- ascorbic acid; alkaline persulfate digestion-TP | OP-0.001 mg/L TP-0.002 mg/L |
| Chlorophyll | EPA 445.0 | Fluorometry (pheophytin a not performed) | 0.02 ug/L |
| Enterococcus | SM 9230C or Enterolert | MF for SM9230C & IDEXX for Enterolert | 1 cfu/100 mL for both methods |
| Conductivity/ Dissolved Oxygen/Salinity/p H | Cond-EPA 120.1 DO-EPA 360.1 Salinity-SM2520B pH-EPA 150.1 | YSI Field Probe | Cond-1 uS/cm DO- 0.2 mgL Salinity-0.10ppt pH-0.2pH units |
| BOD/DO | SM 5210B DO-360.2 or Field Parameter | BOD-5 or 20 day DO-Winkler or YSI Field probe | BOD -2.4 mg/L DO-0.2 mg/L |
| TSS/TDS | TDS-EPA 160.1 TSS-EPA 160.2 VSS-EPA 160.4 | | 2 mg/L |

Clesceri, L. S., Greenberg, A. E., Trussell, R. R. (Eds), 1989. Standard Methods for the Examination of Water and Wastewater. 17th ed., American Public Health Association, American Water Works Association and Water Pollution Control Federation, Washington, D.C., pp.4-75-4-81

**Table 2.3 Base Flow Summary.** This table lists the days where base flow analysis was preformed, on which sites the analysis was preformed and which laboratory preformed the analysis.

| Date Sampled | Sites Sampled | Performed Analysis | Date Sampled | Sites Sampled | Performed Analysis |
|---|---|---|---|---|---|
| 7/6/2006 | BF 1-6 | | 3/12/2008 | BF 1-6 | UD |
| 8/2/2006 | BF 1-6 | DNREC | 4/7/2008 | BF 1-6 | DNREC |
| 9/7/2006 | BF 1-6 | UD | 5/5/2008 | BF 1-6 | DNREC |
| 10/3/2006 | BF 1-6 | DNREC | 6/11/2008 | BF 1-6 | UD |
| 10/31/2006 | BF 1-6 | DNREC | 7/1/2008 | BF 1-6 | DNREC |
| 12/7/2006 | BF 1-6 | UD | 8/5/2008 | BF 1-6 | DNREC |
| 1/9/2007 | BF 1-6 | DNREC | 10/1/2008 | BF 1-6 | UD |
| 2/6/2007 | BF 1-6 | DNREC | 10/7/2008 | BF 1-6 | DNREC |
| 3/14/2007 | BF 1-6 | UD | 11/3/2008 | BF 1-6 | DNREC |
| 4/11/2007 | BF 1-6 | DNREC | 12/8/2008 | BF 1-6 | UD |
| 5/2/2007 | BF 1-6 | DNREC | 1/6/2009 | BF 1-6 | DNREC |
| 6/6/2007 | BF 1 - 6, 8 | UD | 2/3/2009 | BF 1-6 | DNREC |
| 7/9/2007 | BF 1-6 | DNREC | 3/9/2009 | BF 1-6 | UD |
| 8/6/2007 | BF 1-6 | DNREC | 4/1/2009 | Aprl 1-6 ? | DNREC |
| 9/20/2007 | BF 1-6 | UD | 5/6/2009 | BF 1-6 | DNREC |
| 10/9/2007 | BF 1-6 | DNREC | 6/30/2009 | BF 1-6 | UD |
| 11/6/2007 | BF 1-6 | DNREC | 7/7/2009 | BF 1-6 | DNREC |
| 12/12/2007 | BF 1-6 | UD | 8/4/2009 | BF 1-6 | DNREC |
| 1/7/2008 | BF 1-6 | DNREC | 10/13/2009 | BF 1-6 | DNREC |
| 2/6/2008 | BF 1-6 | DNREC | | | |

**Table 2.4 Storm Flow Summary.** This table lists the days where storm flow analysis was preformed and on which sites the analysis was preformed.

| Date Sampled | Sites Sampled | Performed Analysis | Date Sampled | Sites Sampled | Performed Analysis |
|---|---|---|---|---|---|
| 6/4/2007 | SF 1-6, 8 | UD | 11/15/2007 | SF 7 & 8 | UD |
| 6/20/2007 | SF 7 & 8 | UD | 2/1/2008 | SF 7 & 8 | UD |
| 6/29/2007 | SF 7 & 8 | UD | 6/5/2008 | SF 7 & 8 | UD |
| 7/11/2007 | SF 7 & 8 | UD | 7/14/2008 | SF 7 & 8 | UD |
| 7/30/2007 | SF 7 & 8 | UD | 7/24/2008 | SF 1-8 | UD |
| 8/21/2007 | SF 7 & 8 | UD | 11/14/2008 | SF 7, 8, Wetland | UD |
| 10/19/2007 | SF 7 & 8 | UD | 12/12/2008 | SF 7, 8, Wetland | UD |
| 10/24/2007 | SF 7 & 8 | UD | 4/15/2009 | SF 7, 8, Wetland | UD |
| 10/26/2007 | SF 7 & 8 | UD | | | |

The UDEW lies within the White Clay Creek watershed and contains both Piedmont and Coastal Plain physiographic provinces (Figures 2.2 and 2.3). Due to its location within the physiographic fall line, the WCC watershed is divided into two sub-watersheds. The Piedmont sub-watershed contains three WCC tributaries; the Lost Stream, Fairfield Run and Blue Hen Creek. The Coastal Plain sub-watershed contains part of Cool Run and four of its unnamed tributaries (Campagnini and Kauffman, 2001).

The Cool Run begins as a small ephemeral stream flowing through the residential part of campus north of the Amtrak railroad tracks. It then passes under the railroad tracks and flows onto the Newark Research and Education Center Farm (NRECF). Three strahler (Strahler, 1964) first-order tributaries of Cool Run flowing from west to east converge into the second-order Cool Run main channel on the farm at a pond/wetland area containing a stormwater weir. The Cool Run main channel travels 2.5 miles across the farm until finally discharging into the WCC ($4^{th}$ order stream). The major sources of pollution in this watershed are stormwater runoff from north of the Amtrak railroad tracks, agricultural fertilizers, and animal waste.

The portion of the Cool Run that was monitored for this research lies within the NRECF. A bird's eye view of the entire study site is shown in Figures 2.4 and 2.5 depicting the western and eastern sections, respectively. The major land uses contained within the Cool Run study site include industrial, institutional, residential, agricultural and urban residential. The locations of the sampling stations, the Cool Run stream path and installed BMPs within the study area are depicted in Figures 2.6, 2.7 and 2.8.

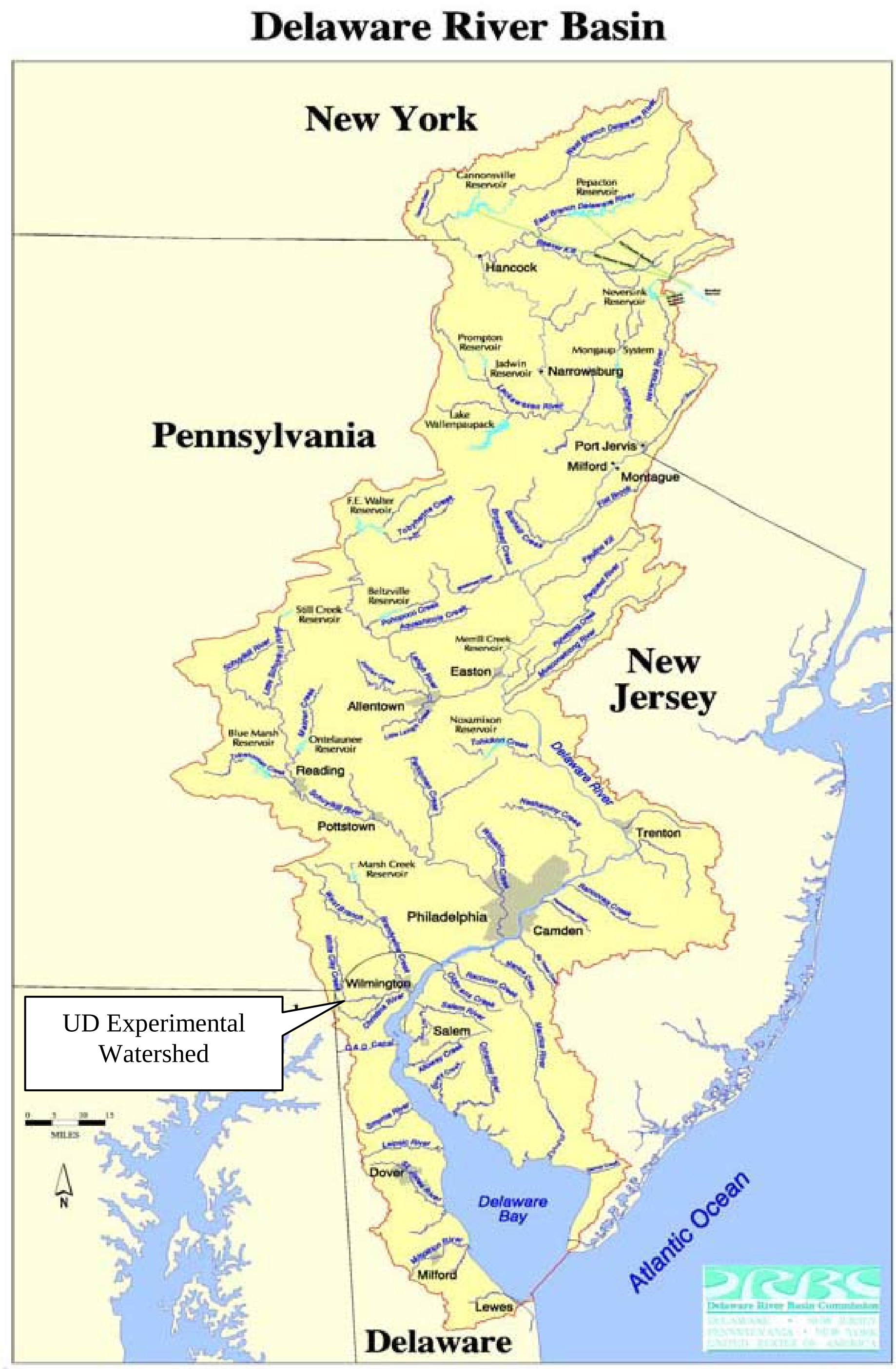



**Figure 2.1** **Delaware River Basin.** This figure shows the location of the UD Experimental Watershed withing the Delaware River Basin. (Image: Campagnini and Kauffman, 2001)

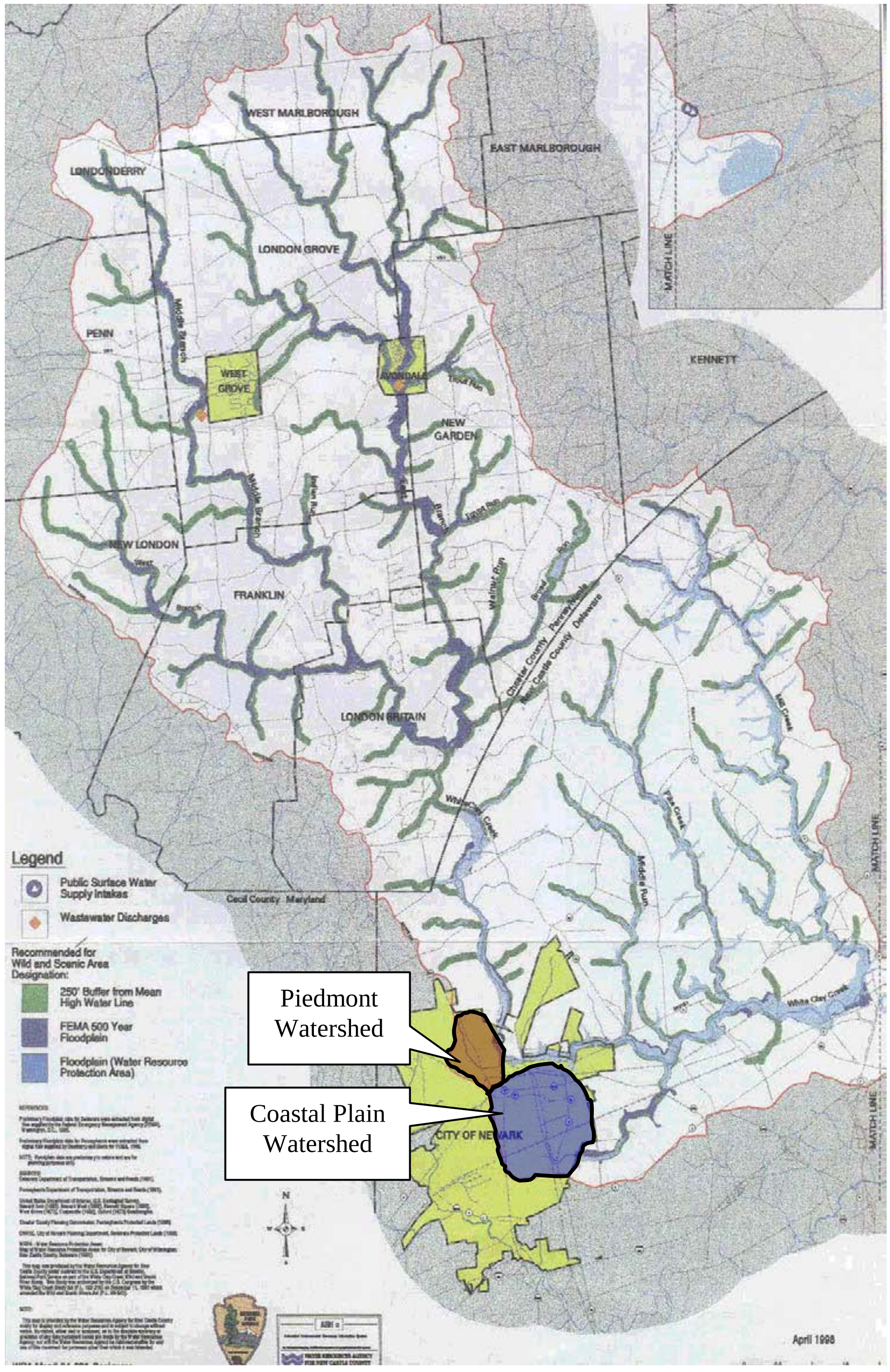



**Figure 2.2** **White Clay Creek Watershed.** This figure shows the locations of the City of Newark and the Piedmont and Coastal Plain Sub-Watersheds. (Image: Campagnini and Kauffman, 2001).

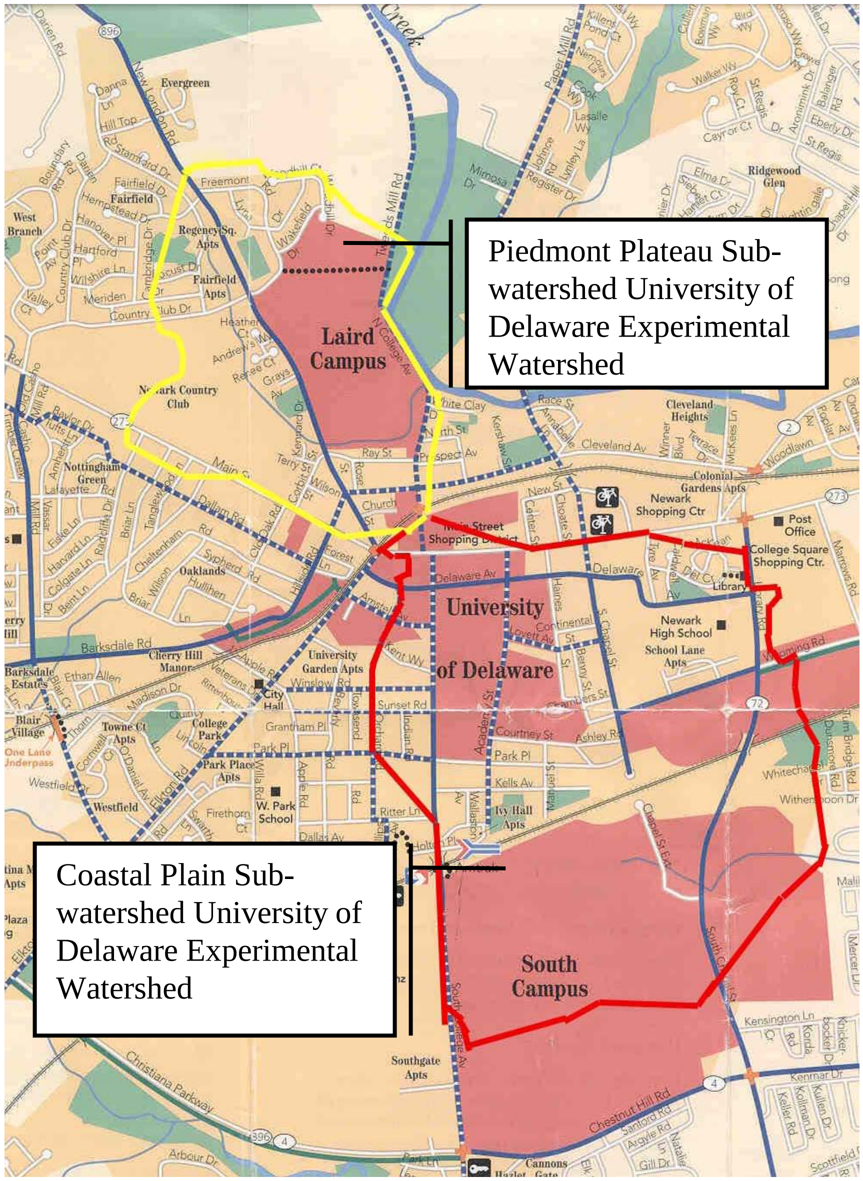



**Figure 2.3 The University of Delaware Experimental Watershed.** This figure outlines the Piedmont Plateau (yellow outline) and Coastal Plain (red outline) Sub-watersheds within the UD Experimental Watershed. (Image: Campagnini and Kauffman, 2006).

**Figure 2.4 Newark Research and Education Center of the University of Delaware College of Agriculture and Natural Resources –** West side of UDAESF. (Image: Alison Kiliszek and bing.com.)

**Figure 2.5 Newark Research and Education Center of the University of Delaware College of Agriculture and Natural Resources –** East side of UDAESF. (Image: Alison Kiliszek and bing.com)

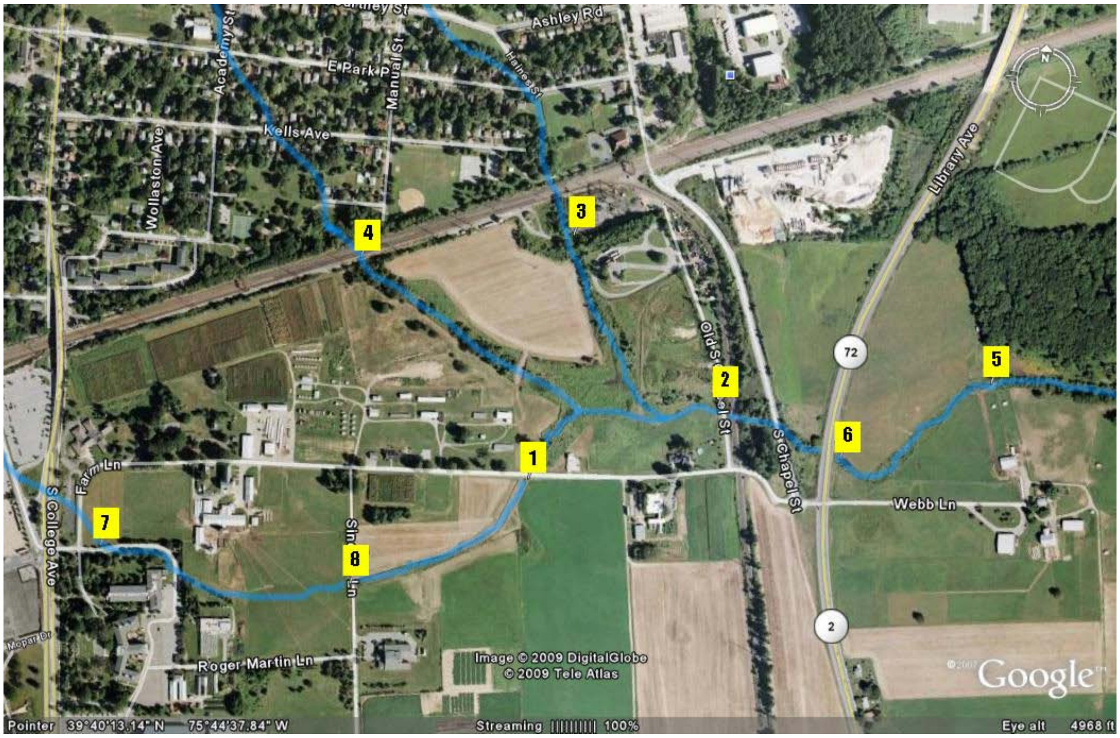



**Figure 2.6 Sample Site Location in the UD Experimental Watershed.** This figure is an aerial view of the entire UD Experimental Watershed showing the location of the stream as well as the locations of the different sampling sites. (Image: Alison Kiliszek and Google Earth)

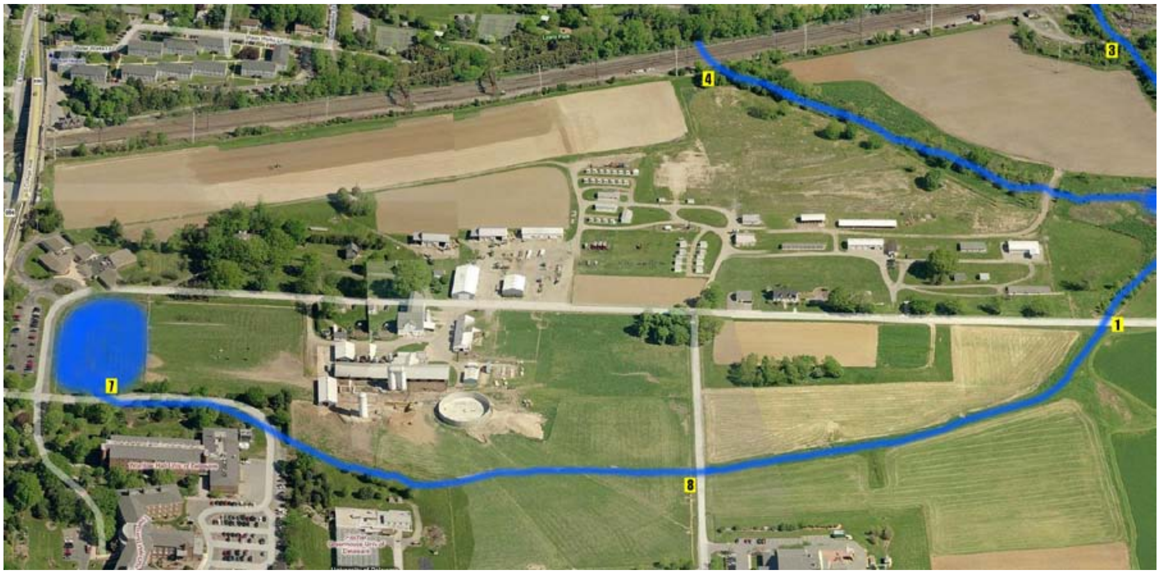


**Figure 2.7 Sample Site Locations in UD Experimental Watershed –** West side of NRECF created by Alison Kiliszek using maps from bing.com.

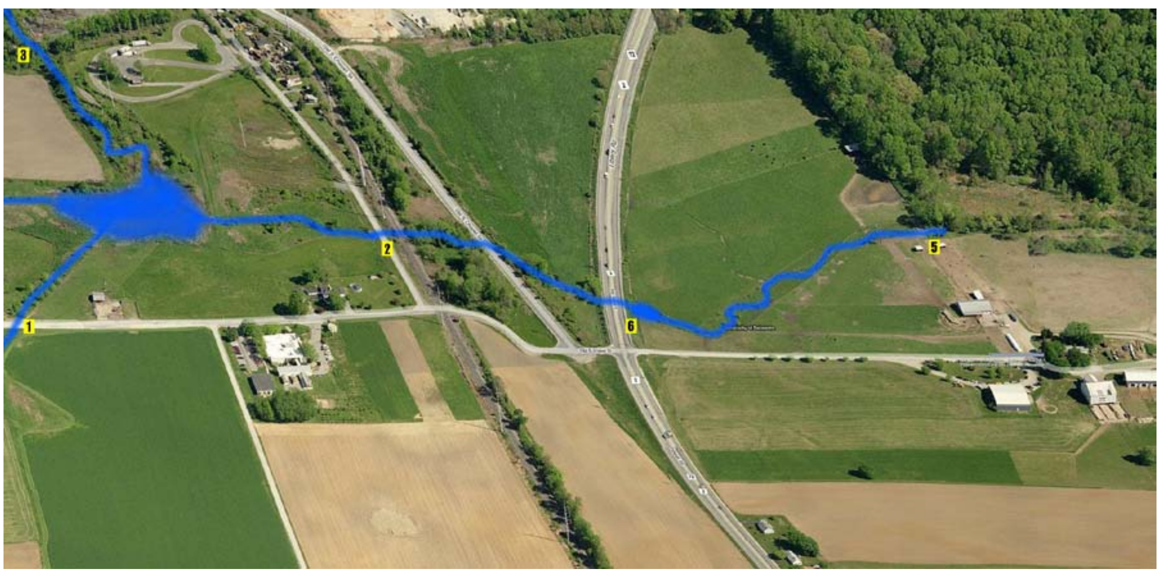


**Figure 2.8 Sample Site Locations in UD Experimental Watershed –** East side of NRECF created by Alison Kiliszek using maps from bing.com

**Sampling Site 1**

Site 1 is located on one of the Cool Run tributaries that travels through agricultural land containing dairy pastures and cropland. Site 1 is situated down stream from Sites 7 and 8 (Figure 2.7). The source of the water entering the site is from a combination of storm drains and underground streams (discussed in more detail in later sections). After passing though Site 8, the tributary is uncapped and travels through cropland to the Site 1 monitoring location (Figure 2.9). A riparian buffer strip lines the sides of the waterway as it flows between Sites 8 and 1.

**Figure 2.9 UDAESF Site 1 –** This site is located along Farm Lane on the NRECF, the picture is taken from the south side of Farm Lane looking north.

**Sampling Site 2**

Site 2 is located downstream after the convergence of the 3 first-order tributaries. Figures 2.7 and 2.8 show the 2 tributaries flowing north to south (Sites 3 and 4) converge with the stream flowing from the southwest (Site 1) forming a stormwater runoff basin/wetland. The stream flows from the basin, passes through a weir forming a second-order main channel. The monitoring station is located approximately 143 yards below the weir (Figures 2.8). The grass outcrop located between the second and third culvert has developed over the past three years (Figure 2.10). Agricultural and industrial land uses will have an impact on water quality found at Site 2. A comparison of the water quality found at the three tributaries (Sites 1, 3, 4) to that found at Site 2 can provide an evaluation of the pollutant removal efficiency of the wetlands, basin and riparian zones that the three branches travel through.

**Figure 2.10** **UDAESF Site 2 –** This site is located along Old South Chapel Street near the intersection with Farm Lane. The three culverts run under Old South Chapel Street.

**Sampling Site 3**

Site 3 is located on the south side of an old industrial area next to a power sub-station (Figure 2.7). The stream starts underground in a residential area, flows through an old industrial area and then moves uncapped but guided by a concrete trench through the railroad underpass culvert. The monitoring station is located at the south end of the culvert (Figure 2.11). The stream water quality found at Site 3 is influenced by industrial and residential land uses.

**Figure 2.11** **UDAESF Site 3 –** This site is located near the power transfer station where one of the Cool Run tributaries crosses under the Amtrak access road. The view is looking through the culvert under the road from the north side of the access road toward the south side.

**Sampling Site 4**

Site 4 is located due west of Site 3 on the south side of the railroad tracks (Figure 2.7). Head waters of this tributary begin on the UD main campus and flow through a rain garden constructed near the Ocean Engineering Laboratory and the Harrington stormwater wetland. The tributary travels through a highly dense residential area before flowing through the railroad track underpass culvert. Samples are collected at the south end of the culvert (Figure 2.12). The stream water quality found at Site 4 is influenced by institutional and residential land uses.

**Figure 2.12 UDAESF Site 4 –** This site is located next to the Amtrak tracks as Cool Run tributary enters UD property. The view of the site was taken looking north from the south side of the tracks; the culvert runs the width of the tracks.

**Sampling Site 5**

As seen in Figure 2.8, Site 5 is located on the Cool Run main channel immediately before the stream exits the NRECF. Water flows from Site 6 through a series of seasonally rotated grazing areas for a herd of beef cattle before reaching the sampling station. The section of the stream that flows through these grazing areas has previously been restored with a riparian buffer zone and exclusion fencing. Water quality at Site 5 is influenced primarily by agricultural land uses (Figure 2.13). A comparison of the water quality found at Sites 5 to that found at Site 6 can provide an evaluation of the pollutant removal efficiency of the installed BMPs that the main channel travels through. The comparison can also provide an evaluation of the impact that newly initiated agricultural management practices have on water quality.

**Figure 2.13 UDAESF Site 5 –** This site is located at the east end of the cattle pasture on the Webb Farm.

**Sampling Site 6**

Site 6 is located at the east end of the culvert that runs under Route 72. At Site 6, the Cool Run main channel flows into a detention pond that formed naturally at the mouth of the culvert (Figure 2.8). Surface water at Site 6 flows from Site 2, passing through a wooded area and a drainage area receiving surface water from the Newark Concrete facility before flowing under the highway through a 12 in culvert and into the pond (Figure 2.14). Water quality at Site 6 is influenced by agricultural and industrial land uses.

**Figure 2.14 UDAESF Site 6 –**This site is located on the east side of Route 72 near the entrance to the Webb Farm. The culvert is located in the upper left hand part of the photo grown over with vegetation.

**Sampling Site 7**

Site 7 is in a stormwater grate located within a constructed wetland (Figure 2.7). This site was added during the second year of the study in order to monitor stormwater flows. During storm events, water drains from residential areas north of the railroad tracks and from the old Newark Delaware Chrysler Assembly Plant located west of Site 7. The land surrounding the grate was previously used as a dairy pasture. Due to poor drainage conditions, the pasture was converted to a wetland and fallow pasture (Figure 2.15). Water quality of the storm samples collected from the grate is influenced by agricultural, industrial, residential and institutional land uses.

**Figure 2.15 UDAESF Site 7 –** This site is located near the intersection of Farm Lane and Mopar Drive in the constructed wetland near one of the entrances to the walking path through the wetland.

**Sampling Site 8**

Site 8 is in a stormwater grate located adjacent to a dairy pasture ( Figure 2.7). Stormwater that flows into the grate contains runoff from the adjacent field as well as underground stormwater drains (Figure 2.16). This site is important for monitoring the quality of stormwater runoff due to the grates' close vicinity to the open stream and dairy pastures. An analysis of the water quality found at Sites 8 over time may provide an evaluation of the impact that the manure collection system has on the reduction of nutrient and bacterial concentrations.

**Figure 2.16 UDAESF Site 8 –** Located near the Allen Biotechnology Lab on the UDAESF and adjacent to the dairy cattle pastures.

## **Characterization of Best Management Practices**

Many BMPs have been installed on the NRECF in order to improve the management of stormwater runoff. These BMPs include constructed wetlands, a stormwater detention pond, a manure collection system, livestock exclusion fencing, riparian buffer zones (natural and restored), and a weir to control water movement from the stormwater detention basin. Figures 2.17 and 2.18 show maps of the NRECF indicating the locations of the BMPs relative to the monitoring sites and the Cool Run. Table 2.5 lists the different BMPs installed on the NRECF, their locations, and installation dates. Information in the table was acquired through personal communication with the College's facilities manager, Jenny McDermott.

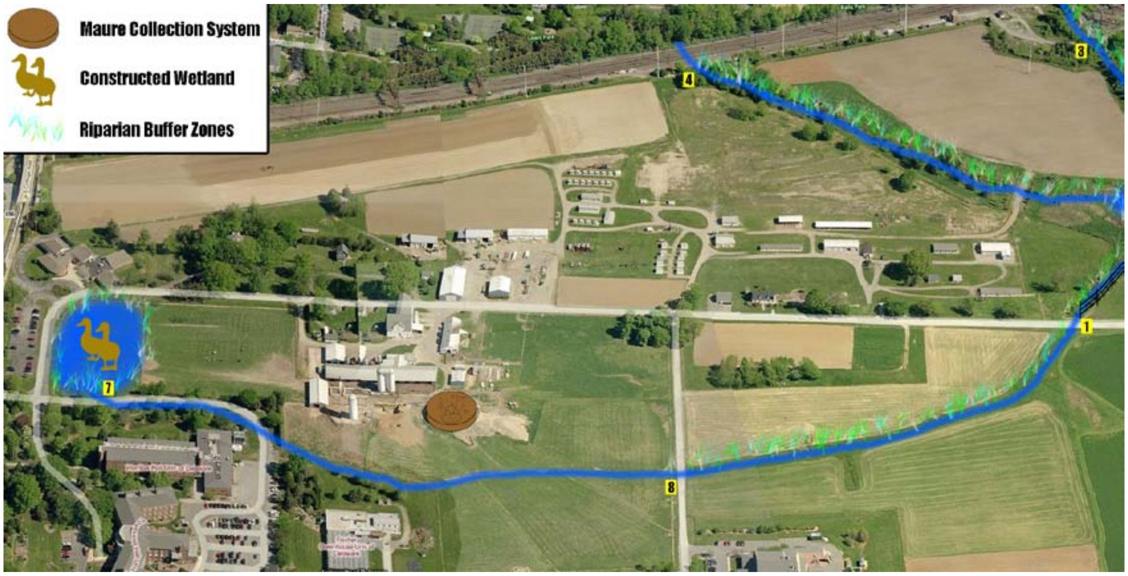



**Figure 2.17 BMP Locations on the Newark Research and Education Farm -** West side of farm containing sites 1, 3, 4, 7, and 8. (Image: Alison Kiliszek and bing.com)

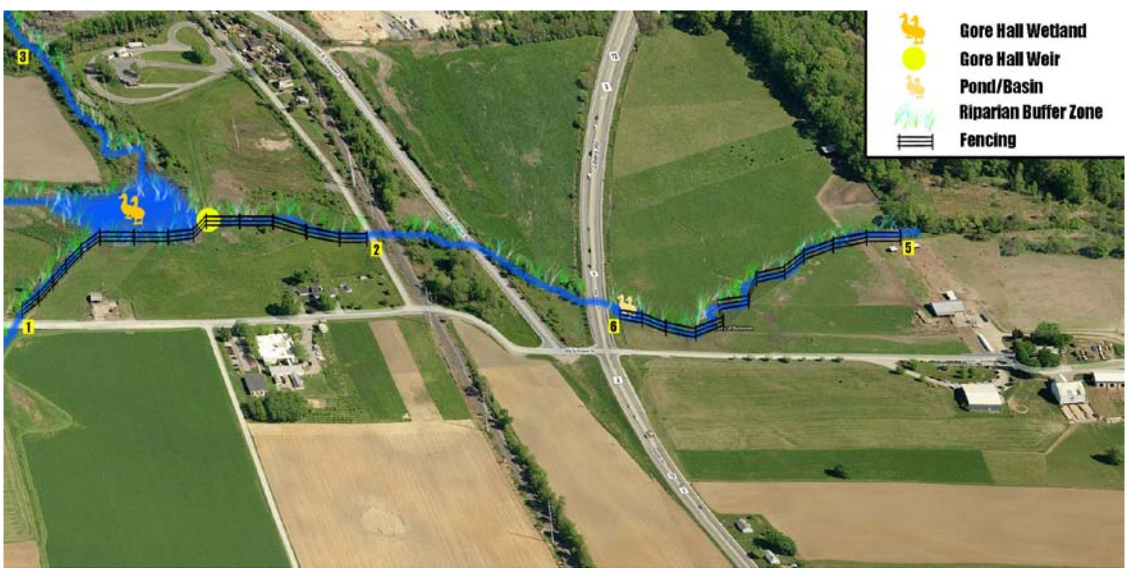



**Figure 2.18 BMP Locations on the Newark Research and Education Farm –** East side of farm containing sites 1, 2, 3, 5, and 6. (Image: Alison Kiliszek and bing.com)

**Table 2.5** **BMP Summary.** The table summarizes the location and construction times for the different BMPs that are within the UDAESF.

| BMP Summary | | | |
|---|---|---|---|
| **BMP** | **Location** | **Construction Start Date** | **Construction End Date** |
| Constructed Wetlands | Front Pasture | September 8, 2008 | October 14, 2008 |
| Gore Hall Wetlands | Directly Upstream of Gore Hall Weir | Occurred Naturally | Occurred Naturally |
| Fencing of Stream | Within cow pasture land | Before 2002 | Before 2002 |
| Gore Hall Weir | Upstream of Site 2 | In 1997 | In 1998 |
| Manure Collection | Dairy Pasture | April 2007 | October 2007 |
| Riparian Buffer Zone | Site 7 & Wetland | September 8, 2008 | October 14, 2008 |
| Riparian Buffer Zone | Site 8 to Gore Hall Wetland | Occurred Naturally | Occurred Naturally |
| Riparian Buffer Zone | Sites 3 & 4 to Gore Hall Wetland | Occurred Naturally | Occurred Naturally |
| Riparian Buffer Zone | Near Weir, Site 2, ending Site 6 | Occurred Naturally | Occurred Naturally |
| Riparian Buffer Zone | Sites 6 to 5 | Occurred Naturally | Occurred Naturally |
| Ponding Area | Site 6 | Occurred Naturally | Occurred Naturally |

## Constructed Wetlands

The constructed wetlands are located in the front pasture of the dairy cow area adjacent to the Girl Scouts of the Chesapeake Bay Headquarters building. Its design intentions were to replace unproductive and poor performing pastureland with a more functional ecological system. The area was previously used as a grazing pasture for the dairy cows until approximately 2005. After years of use by the dairy herd, the underlying compacted clay layer was formed causing reduced water infiltration with subsequent ponding and increased stormwater runoff.

The construction of the wetland came in a few different stages. The first stage of construction included the excavation and installation of a raised outlet pipe which connects directly into the storm drain at Site 7. This step was completed between September 8, 2008 and September 17, 2008. The second stage of the construction was the initial planting of trees, shrubs, and plants within the wetland, which took place on October 14, 2008. One year later, the third stage of construction was completed by volunteers who participated in a second planting of trees, shrubs, and plants in late October 2009 (McDermott, 2009, personal communication). Site 7 is located at the southern edge of this wetland (Figure 2.17).

Once the wetland has stabilized, it should provide an area for stormwater runoff to be held until it can evaporate, be recharged into groundwater, or slowly leave the area over time preventing flood surges downstream. The wetland also provides a natural filtration system for sediments and a location for nutrient removal. If functioning correctly, the wetland has the potential to reduce nutrient and suspended solids concentrations within the stormwater as it moves through the wetland and into the stormwater drain outlet. Figure 2.19 shows a picture of the wetland taken in December 2009.

**Figure 2.19 Constructed Wetland –** This BMP is located at the intersection of Farm Lane and Mopar Drive. This picture shows one of the large ponded areas.

**Gore Hall Wetlands Floodplain and Weir**

All three tributaries of Cool Run converge and form one 2nd order stream in an area described as a wetland and/or ponded area (Figure 2.18). Before 1997, this area was a naturally occurring wetland. In 1997, during the construction of Gore Hall, located on the headwaters of the Cool Run, the convergence area wetland was retrofitted and expanded into a stormwater detention basin in order to mitigate the loss of pervious surface area upstream (Figure 2.20). This area is used for water storage during storm events to reduce surface runoff and act as a sedimentation basin. A weir was installed on the downstream side of the basin to prevent flooding and to control the movement of water through the basin. However, due to poor construction and maintenance, the weir did not direct the flow of the moving water causing sediment deposition that filled in the natural stream channel. In 2009, the weir was repaired allowing the detention basin to function properly and redirecting stream flow through the natural channel (Figures 2.18 and 2.21). After passing through the weir the Cool Run flows towards Site 2.

**Figure 2.20 Gore Hall Wetland –** This BMP is located directly upstream of the Gore Hall Weir. The photo was taken looking west standing at the location of the Gore Hall Weir.

**Figure 2.21 Gore Hall Weir –** This BMP is located at the exit of the Gore Hall Wetland and upstream of Site 2. The photo shows the east (downstream) side of the weir.

**Livestock Exclusion - Fencing of Streams**

Exclusion fencing was installed prior to 2002 by the New Castle County Conservation District along the Cool Run Stream (Figure 2.18; McDermott, 2009). One section of fencing runs along the Cool Run between Sites 1 and 2 with sections adjacent to the Gore Hall Wetland basin and weir. A second section of fence runs along both sides of the Cool Run between Sites 5 and 6 dividing the pasture into two sections (Figure 2.18 and 2.22). The fence keeps the animals 2 or more feet away from the stream edge. One cattle crossing consisting of a concrete pad overlying the stream is located at Site 5.

**Figure 2.22 Fencing of Streams –** This BMP shows a portion of the exclusion fencing that is located along the stream throughout of the farm. This photo in particular is of a section downstream of Site 6.

**Manure Collection System**

Construction of the dairy manure collection system started in April 2007 and was completed in October 2007. The system was operational by December 2007.

The collection apparatus removes urine and manure wastes from the impervious surfaces of the milking house and feeding barn floors. The wastes are stored in a holding tank where separation of the solids and liquids occur (Figure 2.17 and 2.23).

All the concrete surfaces in the surrounding area were redone so that the runoff water is collected and added to the collection tank. With the installation of a new gutter system, rain water from the building roofs is collected and redirected to the fields for infiltration bypassing any contact with the manure laden surfaces (McDermott (personal communication), 2009). The most important benefit of the manure collection system is that the NRECF farmers no longer apply manure to the fields every other day year round. Implementation of manure management BMPs on the farm will help reduce the pollutant loads in the surface runoff and leachate entering the streams from the fields.

**Figure 2.23 Manure Collection System –** This BMP is located within the dairy cow facility.

**Riparian Buffer Zones**

The riparian buffer zones are located on the NRECF along the Cool Run main stream and its tributaries as well as around both wetland areas (Figures 2.17 and 2.18). To better describe the individual sections of the buffer zones they have been divided into five sections. The first section of buffer zone is located around the constructed wetland located near Site 7. The walking path through the wetland is lined with grasses and bushes. The outside edge of the wetland is also surrounded by grasses and bushes as well as trees. The trees and bushes have only been planted for about a year and are still small in size. As they mature they will provide and help to maintain a more productive buffer zone.

The second section of riparian buffer zone occurs after the stream re-surfaces near Site 8. Between Site 8 and Site 1, it consists of wild grasses and weeds spreading a few feet on either side of the stream channel running through the fields. This section has been mowed occasionally in the past but for the most part is left alone to grow naturally. Unfortunately, because this section is not maintained the grasses have started to fill in the stream channel, collect sediment, and block water from flowing freely through this section of the farm (Figure 2.24). This is one reason that there is little or no recorded flow occurring at this site. Poor maintenance of the buffer zone also occurs along the stream after it passes under the road at Site 1and flows toward the Gore Hall Wetland area. This section of stream is surrounded on both sides by a cattle pasture that drains into the stream. This dense buffer zone will be able to provide a sediment deposition area and nutrient removal before the runoff from the pasture actually enters a part of the stream that is flowing freely

**Figure 2.24 Poorly Maintained Riparian Buffer Zone –** This BMP is located throughout the entire site, this was taking looking upstream from Site 1.

The third section of the riparian buffer zone runs along both of the Cool Run tributaries flowing from north of the farm. The first tributary flows from Site 4 to the Gore Hall Wetland area while the second tributary flows from Site 3 to the Gore Hall Wetland area. These are well established, naturally occurring buffers complete with trees, grasses and dense underbrush in areas. The riparian buffer zone continues around the edge of the Gore Hall Wetland.

The fourth section of the riparian buffer zone runs along the Cool Run as it travels from the convergence area through Site 2 and continues to Site 6. There is a grassy riparian buffer zone with a few scattered trees throughout the section that is between the Gore Hall Weir and Site 2. After crossing under the access road and the railroad tracks at Site 2, the Cool Run travels through a densely wooded area, crosses under Old South Chapel Street through three large culverts and then flows through a grassy buffer zone before moving through the culvert at Rt. 72.

The final section of the riparian buffer zone runs along the Cool Run within the fenced area as it travels between Site 6 and Site 5.

**Figure 2.25 Adequately Maintained Riparian Buffer Zone –** This BMP is located throughout the entire site, this was taking looking upstream from Site 5.

Although there is highly dense vegetation lining the banks, the stream flows freely through the riparian zone (Figure 2.25). There are scattered small trees and bushes that are mixed in with the grass. The size of the buffer zone varies along this entire section. From observations after storm events, the fences have been placed outside the flood zone for normal rain events.

**Small Pond**

There is a naturally occurring stormwater pond located at Site 6 (Figure 2.18). The pond is fed by two culverts that cross under Route 72. The main stream flows through a 12 inch diameter culvert while a secondary branch of the Cool Run and excess storm runoff flow through the larger 5 foot diameter culvert. The pond has been estimated to be around 3 feet in depth (Figure 2.26). Over the last three years, we have observed the far side of the pond slowly eroding away reducing the size of the riparian buffer zone surrounding the entire pond.

**Figure 2.26 Small Pond –** This BMP is located at Site 6, the image was taken looking toward the downstream reach at Site 6.

A history of agronomic management practices was developed and depicted through a timeline that indicates implementation and construction time of the different BMPs as well as sample type and sample dates (Figure 2.27). Although the sample dates are not specially listed on the timeline the two types of samples are indicated by two different symbols listed in the key.

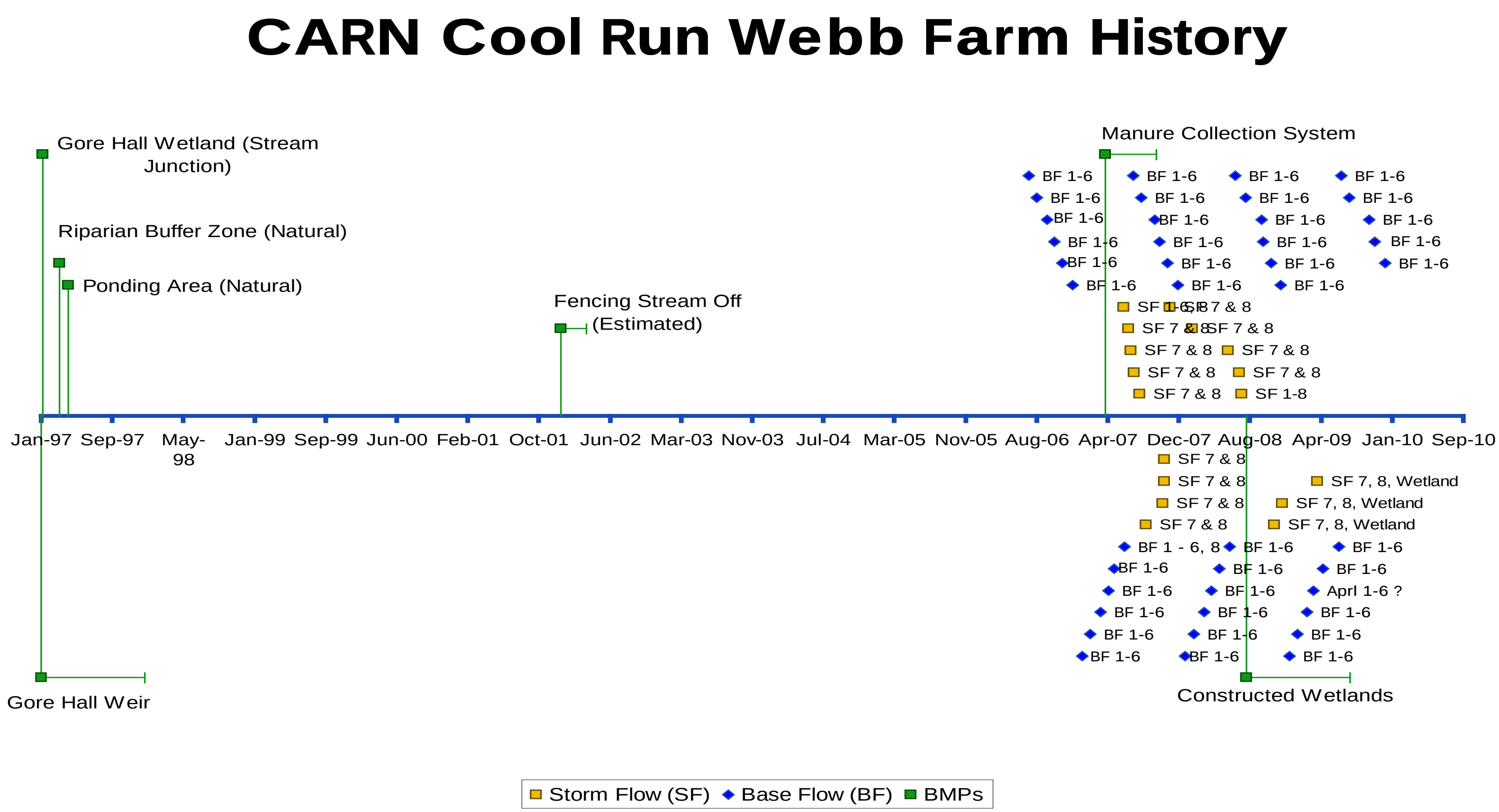



**Figure 2.27 CARN Cool Run NRECF History.** This is a timeline showing BMP installation and sampling dates.

**Delaware Standards, Delaware Criteria and EPA Water Quality Criteria**

In this research work, WQIs were developed using several different assessment scenarios, which utilized different combinations of the monitored water quality parameters. In order to develop the subindices for each of these water quality parameters, concentration values for the regulated standard and/or criteria for each of the parameters were needed. These values were taken from the State of Delaware Surface Water Quality Standards (DNREC, 2004). For water quality parameters not listed by the State of Delaware, standard values were taken from USEPA listings (USEPA, 2000). As mentioned before, the standard values are set in order to protect surface water quality in relation to the designated use of the water body under evaluation. All assessment scenarios were related only to fresh water bodies. A summary of the general water quality standards for fresh water from the DWQS are listed in Table 2.6. These criteria relate to any designated use.

**Table 2.6 General Delaware Fresh Water Quality Standards.** These standards are listed in Delaware Surface Water Quality Standards for general fresh water.

| PARAMETER | WQ STANDARD |
|---|---|
| Temperature | No greater than 27.7-30°C (unless naturally occurring) |
| Dissolved Oxygen | Daily Average ≥ 5.5 mg/L<br>Instantaneous > 4.0 mg/L |
| pH | 6.5 – 8.5 |
| Total Suspended Solids | 20 mg/L |
| Turbidity | > 10 FTU or NTU |
| Coliforms (*Enterococcus*) | Single Sample 925/100mL<br>Geometric Mean 500/100mL<br>{Secondary Contact} |

The criteria that will be used for *Enterococcus* is based on the designated water use of "secondary contact recreation fresh water." This contact is defined as a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of water (examples include but are not limited to wading, boating and fishing) (DNREC, 2004).

Delaware also has criteria that are specifically related to the protection of aquatic life in fresh water. Table 2.7 summarizes those values for acute and chronic exposure limits. Criteria for certain water quality parameters are related to pH or water hardness of the sample. The values of these related parameters used in the establishment of the criteria concentrations are given in Table 2.7. A pH of 7.0 and a Hardness of 100 mg/L $CaCO_3$ were used in calculating the values in Table 2.7 if a formula required either of the values.

The state of Delaware does not specifically state criteria for nitrate in the protection of aquatic life section, however there is a maximum contaminant level (MCL) that was specified in the section regarding Human Health Protection. Table 2.8 shows the standard limits of nitrate-nitrogen and fluoride for fish and water ingestion for systemic toxicants listed in the DWQS document.

**Table 2.7 Delaware Water Quality Criteria for Aquatic Life Protection.** These criteria are listed in Delaware Surface Water Quality Standards under the section for the protection of aquatic life.

| PARAMETER | ACUTE (mg/L) | CHRONIC (mg/L) |
|---|---|---|
| Aluminum (pH 6.5 – 9.0) | 0.750 | 0.087 |
| Ammonia (pH 7.0) | 24.10 | 5.97 |
| Arsenic (III) | 0.340 | 0.150 |
| Cadmium (hardness = 100 mg/L) | 0.0025 | 0.00025 |
| Chromium (III) (hardness = 100mg/L) | 0.5698 | 0.0741 |
| Chromium (VI) | 0.016 | 0.011 |
| Copper (hardness = 100 mg/L) | 0.0134 | 0.000001 |
| Cyanide | 0.022 | 0.0052 |
| Iron | - | 1.000 |
| Lead (hardness = 100 mg/L) | 0.06458 | 0.06391 |
| Mercury | 0.0014 | 0.00077 |
| Nickel (hardness = 100 mg/L) | 0.468 | 0.052 |
| Selenium | 0.020 | 0.0050 |
| Zinc (hardness = 100 mg/L) | 0.117 | 0.118 |

**Table 2.8 Delaware Water Quality Criteria for Human Health Protection.** These criteria are listed in the Delaware Surface Water Quality Standards for the protection of human health.

| PARAMETER | WQ STANDARD |
|---|---|
| Fluoride | 4 mg/L (MCL) |
| Nitrate | 10 mg/L (MCL) |

The EPA criteria for the protection of aquatic life will be used for parameters that are not specified in the Delaware criteria. The nutrient criteria that are classified by ecoregion are listed in Table 2.9. Ecoregion XIV: Eastern Coastal Plain was used to gather the nutrient standards. Total nitrogen and total phosphorus were taken from the 2008 Delaware Combined Watershed Assessment Report (known as 305(b)); the high ranges were selected as the maximum values these were 3 and 0.2 mg/L respectively.

**Table 2.9 EPA Ecoregional Nutrient Water Quality Criteria.** These criteria were based off of values recommended by the USEPA for nutrients.

| PARAMETER | EPA STANDARD (μg/L) |
|---|---|
| Chlorophyll a | 3.75 |
| Total Nitrogen | 3,000 |
| Total Phosphorus | 200 |

In 1986, the EPA issued the ‘Quality Criteria for Water 1986’, commonly known as ‘The Gold Book (EPA 1986).’ This reference was used to determine any criteria that were not specified in the current Delaware and EPA standards and criteria. The values that were taken from the Gold book are listed in Table 2.10.

**Table 2.10 EPA "Gold Book" Criteria.** These criteria are based off of values that were from the USEPA Quality Criteria for Water from 1986.

| PARAMETER | EPA STANDARD (mg/L) |
|---|---|
| Boron* | 0.75 |
| Manganese† | 0.50 |
| Dissolved Solids | 250 |

*Boron that is naturally occurring in the environment should have no effect on aquatic life. This value is based on long-term irrigation on sensitive crops
†Manganese limit for domestic water

No information was found for BOD limits for the Delmarva area. Criteria for this parameter based on wastewater discharge from The Kansas Department of Health and Environment Region 7 4B Rationale is shown is Table 2.11 (US EPA, 2008). The values in the table vary by the time of year to help prevent impairment to the stream from high BOD peaks. The value that will be used in this analysis will set the upper limit for the BOD concentration at 5 mg/L. This value was chosen fairly low in comparison to the discharge values (Table 2.11) to try to insure that there would be a high dilution factor that would prevent impairment.

**Table 2.11 EPA Region 7 4B <u>Rationale.</u>**

| TIME PERIOD | EPA CRITERIA |
|---|---|
| September –May | 45 mg/L (wkly avg) |
| September – May | 30 mg/L (mthly avg) |
| June – August | 40 mg/L (wkly avg) |
| June – August | 25 mg/L (mthly avg) |

Conductivity is not a regulated parameter by Delaware or the EPA, however, there are optimal ranges described in the USEPA (2006) manual. Water that has conductivity concentrations out of the ranges listed in Table 2.12 could be impaired for sustaining certain fish and macro invertebrate species.

**Table 2.12 EPA Volunteer Stream Monitoring Manual.** The criteria for the conductivity was taken from a Volunteer Stream Monitoring Manual that the USEPA published in 2006.

| WATER TYPE | EPA STANDARD |
|---|---|
| US Rivers | 50 – 1500 μmhos/cm |
| Inland Fresh Water | 150 – 500 μmhos/cm |

All the water quality variables that are listed above will be available for use in the developed model (Objective 2) in order to make the model more diverse and applicable for many uses. Specific assessments done for this project using the model may not include all the previously listed quality standards.

## Calculation of Subindices

The method in Swamee and Tyagi (2007) states the first step in developing a WQI is the selection of the parameters that are of most concern. The next step is to make a set of subindices creating an equal and dimensionless numeric scale. Finally the subindices are combined to create an overall index value. The KWQI subindex calculations will use the following equations defined in Swamee and Tyagi (2000). The WQIs developed for this research were calculated utilizing the 22 parameters that have been monitored in the Cool Run Stream since 2006. In addition, several different water quality parameters utilized by Swamee and Tyagi (2000, 2007) in the calculation of water quality subindices will also be available for use in assessment scenarios. The equation constants determined by Swamee and Tyagi (2000, 2007) for calculation of subindicies for individual parameters will be adapted to meet the water quality standards defined previously. Any additional constants needed for subindex development will be calculated based on researched methodologies.

**Uniformly Decreasing Subindices**

The uniformly decreasing subindices equation is used to calculate the subindex of water quality parameters for which the quality rating monotonically decreases as the concentration of the quality variable increases. Equation 2.1 will be used to calculate the sub index value for ammonia-nitrogen, $BOD_5$, coliforms, total nitrogen, nitrate-nitrogen, total phosphorus, and turbidity.

$$s = \left(1 + \frac{q}{q_c}\right)^{-m} \tag{2.1}$$

The individual sub index value is $\boldsymbol{s}$, $\boldsymbol{q_c}$ is a characteristic value of q to each parameter, $\boldsymbol{q}$ is a water quality variable concentration inputted by the user, and $\boldsymbol{m}$ is a positive number constant specific to each parameter.

To relate the sub index to the DWQSs and the USEPA Standards the constants m and $\boldsymbol{q_c}$ for each of the water quality variables were recalculated. When plotted the values form a negative exponential as expected from the equation. To calculate these constants, the sub index value s that would indicate a “Poor” quality was set equal to a WQI value of 0.25. Therefore, any quality variable that exceeds the standard will receive a rating of “Poor”. The values for $\mathbf{q_c}$ and **m** were determined using Microsoft Excel Solver by setting the difference between the calculated sub index and the desired outcome to zero.

**Nonuniformly Decreasing Subindices**

The nonuniformly decreasing subindex equation is used on water quality parameters where the relationship between the rating and the concentration are not linear. The nonuniformly decreasing subindex accounts for the variability in the rate at which the quality variables changes with increased concentrations, constants are based on a threshold concentration. Equation 2.2 will be used to calculate the subindex for arsenic, chlorophyll a, boron, chromium, cadmium, copper, lead, nickel, and zinc. Additional water quality parameters that are nonuniformly decreasing include: aluminum, iron, mercury, selenium, cyanide, and manganese.

$$s = \frac{1 + \left(\frac{q}{q_T}\right)^4}{1 + 3\left(\frac{q}{q_T}\right)^4 + 3\left(\frac{q}{q_T}\right)^4} \tag{2.2}$$

The individual sub index value is ***s***, $\boldsymbol{q_T}$ is the threshold concentration for the specific parameter, and ***q*** is the water quality variable concentration inputted by the user.

To relate the sub index to the DWQSs and the USEPA Standards the constants for each of the quality variables were recalculated. When plotted the values form a negative S-curve. The constant $\boldsymbol{q_T}$ for each of the parameters was calculated based on conditions to make the threshold limit subindex value 0.25. Therefore, any quality variable that exceeds the threshold will receive a rating of “Poor”. The value for $\mathbf{q_T}$ was determined using Microsoft Excel Solver by setting the difference between the calculated sub index and the desired outcome to zero.

**Unimodal Subindices**

The unimodal subindices equation is used for parameters that have optimum values within a water system, the optimum value is considered the point where s = 1. Equation 2.3 will be used to calculate the subindex for conductivity, dissolved oxygen, pH, temperature, total dissolved solids and total suspended solids. The constants for fluoride were calculated for use in the program but were not utilized in assessments for this project.

$$s = \frac{pr + (n+p)(1-r)\left(\frac{q}{q_*}\right)^{n}}{p + n(1-r)\left(\frac{q}{q_T}\right)^{n+p}} \qquad (2.3)$$

The individual sub index value is ***s***, ***p*** and ***n*** are parameter specific constants, $\boldsymbol{q_*}$ is the optimum value for the specific parameter, ***q*** is the water quality variable concentration inputted by the user, and ***r*** is the subindex value when q = 0.

To relate the sub index to the DWQSs and the USEPA Standards the constants ***r***, ***p*** and ***n*** for each of the water quality variables were recalculated. When plotted the values of s versus concentration form a Bell curve. Constants will be calculated by a two different methods in this section based on the parameter. The first method is to use the sum of the difference of the desired and calculated WQI subindex value. This method is used for parameters that have optimum ranges such as pH and conductivity. The other method is to run a series of trials until the concentration values fit the desired WQI concentration plot.

**Overall Water Quality Index**

The various subindices will be combined to form a single index value by the method described in Swamee and Tyagi (2000, 2007). This method is summarized below.

The final water quality index is based on Equation 2.4 where ***I*** is the total WQI value, ***N*** is the number of subindices, $s_i$ is the individual subindex value, and ***k*** is a positive constant independent of varying N and $s_i$ values.

$$I = \left(1 - N + \sum_{i=1}^{N} s_i^{-1/k}\right)^{-k} \tag{2.4}$$

Due to the nature of the value of k, the equation becomes rigid and creates an ambiguity problem with the increasing number of subindices. Swamee and Tyagi (2007) determined that in order to resolve this problem and make the index flexible to varying N, k must be a function of N.

To solve for k, the following conditions were applied: For $s_i = 0.5$, i = 1, 2, 3, …, N; I = 0.25. The reduction of Equation 2.4 using the above conditions is shown in Equation 2.5.

$$2^{2/k} - N2^{1/k} + N - 1 = 0 \tag{2.5}$$

Solving Equation 2.5 for the value of k, Swamee and Tyagi (2007) determined Equation 2.6.

$$k = \frac{1}{\log_2(N-1)} \tag{2.6}$$

By substitution of Equation 2.6 into Equation 2.4 the final overall WQI will be calculated using Equation 2.7.

$$I = \left[1 - N + \sum_{i=1}^{N} s_i^{-\log_2(N-1)}\right]^{-1/\log_2(N-1)} \quad (2.7)$$

## Model Development

### WQI Calculation

The final task for Objective 1 includes the development of a model interface that will be used for determining the sub indices and overall WQI value. The model will be set up based on the following criteria. Concentration data inputted into the model can be based on a single measurement, yearly averages, monthly averages, and overall averages for the study period or any desired condition.

1) The model will use Microsoft Excel as the user interface; it will be constructed by using a mixture of cell references and programming in Visual Basic for Applications (VBA).
2) The input parameters will be limited to a pre determined list of parameters each containing a unique set of constants. The user will be able to choose any combination of the parameters that are provided, or choose from pre programmed parameter sets.
    a) The 1st option given to the user will be for determining the WQI for a single site with one unique set of data.
    b) The 2nd option will allow the input of two sets of data for a side-by-side comparison. The second purpose is to allow a site to be compared over time by inputting data from two different sampling days. This can also be used to rate a BMP based on data collect before and after the BMP.
    c) The 3rd option will be to calculate an estimated WQI trend for the Cool Run Stream running through the entire farm. This will use data from

any combination of Sites 1 to 8. Limitations include the assumption that between sampling points there is an equal gradient between the WQI values. To use this plot a flow value must be entered for Sites 1, 3 and 4 on the input screen if values are desired for Site 2.

3) The outputted data will include the following:
   a) For the 1st and 2nd options:
      i) A list of each parameter that shows the individual WQI sub index value and the rating associated with that value.
      ii) A plot of each parameter's sub index value with the value indicated on the plot.
      iii) An overall WQI value and the rating associated with it.
      iv) A table summarizing the number of parameters that received each rating.
      v) A plot of the distribution of received ratings.
   b) For the 2nd option only:
      i) The percent change between the two values will be calculated.
      ii) The percent change for each subindex will also be plotted.
   c) For 3rd option only
      i) For each site slot used for data the overall WQI value will be given and the rating that is associated to that value.
      ii) A spatial 3D plot of the farm will be constructed based on the calculated WQI values. The plot is based on inputting the calculated WQI values into the site locations and then interpolating the parts of the stream between sites. For simplification of

calculations this assumes an even distribution based on the estimated pixel parcels between sites. The values are only meant to simulate the values in the stream and to show basic trends that occur within the NRECF.

## Model Validation

The first tests will use Cool Run water quality monitoring data collected and reported in Harrell (2001). The data will be used as a basis for water quality before the installation of BMPs in the watershed. Five of the sites that were used in Harrell (2002) are close to or the same as the ones that have been used in this study. The data will also be used to test and calibrate the parameters to be used in the final model.

The second part of the test will include selecting multiple parameter sets based on common indicators used to determine water quality based on water use requirements. As previously stated, the water uses requirements will be based on quality variables determined by DNREC and the USEPA. From this, tests will be run to show the effect of different parameters on the overall WQI. This will also be used in the attempt to determine a minimum, optimum and maximum number of parameters that should be used.

## Assessment of BMP Efficiency

The final objective of determining the effects of the BMPs will be achieved by using the model to make comparisons. Comparisons will include point to point comparisons over time, trends at individual sites, and an estimation of trends for the farm over time as well as changes in water quality after installation of the BMPs. The following steps will be taken to accomplish the assessments.

1) Since data from Sites 2, 3, and 4 are available for a base line of water quality before the BMPs were implemented, the WQI values will be used to make point to point comparisons between 2001 and the data collected in 2009.
2) Site 2 is fed from Sites 1, 3, and 4, speculations and comparisons will be made to relate what happens to water quality as the Cool Run flows through the farm to Site 2.
3) Sites 2 and 6 are located closest together. A comparison of the WQI values and trends between these sites in relationship to land use could show how land use influences water quality over short distances.
4) The comparison between Sites 5 and 6 will assess the effect of riparian buffer zones and exclusion fencing on water quality.
5) Site 8 primarily measures the quality of stormwater runoff from a nearby pasture area. The water quality data from this site can be evaluated over time to show how the runoff water quality has changed over time during storm events after the installation of the manure collection system.
6) An overall comparison of water quality at all monitoring sites will be made based on the calculated WQIs. The same parameter sets will be used to evaluate each of the sites on the same level for each of the years to determine trends in the WQI ratings.
7) The final analysis will be done using parameter sets that relate to the removal capabilities of the individual BMPs installed near the different monitoring sites. Once the parameter set is chosen, it will be used for that site in all the

analysis.  This will be done to provide an assessment of the efficiency of the BMPs on water quality improvement and to draw conclusions of how the sites have been affected over the years.

# Chapter 3

## RESULTS AND DISCUSSION

Annual water quality data from the Cool Run monitoring program indicates that several of the Cool Run tributaries have elevated levels of nutrients, bacteria and suspended solids (Tables 3.1, 3.2 and 3.3). In general, metal concentrations were below Delaware's water quality criteria. However, copper concentrations exceeded the criteria limits. The highest concentrations of copper were found at Site 3 where the tributary flows through an old industrial area. Water quality values for Site 1 showed the greatest impairment with the highest ammonia nitrogen (0.92- 2.10 mg $l^{-1}$) and total phosphorus concentrations (1.46-2.02 mg $l^{-1}$) and the lowest flow volumes.

The annual water quality data was used in the calculation of the Kiliszek WQI (KWQI). Subsequently, the calculated KWQIs were used to evaluate the general health of the Cool Run and its tributaries located on the NRECF. The KWQIs were also used in the model comparisons of water quality at the monitoring sites and in the assessments and evaluations of the installed BMPs.

**Table 3.1 Average Annual Concentrations of Monitored Water Quality Parameters- 2006**

| 2006 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Ammonia-N (NH4-N) (mg/L) | 2.10 | 0.39 | 0.11 | 0.06 | 0.16 | 0.24 | | |
| Nitrates (NO3-N) (mg/L) | 0.93 | 3.22 | 4.29 | 3.25 | 3.15 | 2.91 | | |
| Total Nitrogen (mg/L) | 5.20 | 4.12 | 4.62 | 3.66 | 3.82 | 3.86 | | |
| Total Phosphorus (mg/L) | 2.02 | 0.22 | 0.51 | 0.06 | 0.16 | 0.20 | | |
| Arsenic(III) (mg/L) | 0.0222 | 0.0085 | 0.0015 | 0.0110 | 0.0045 | 0.0110 | | |
| Boron (mg/L) | 0.0535 | 0.0393 | 0.0295 | 0.0875 | 0.0370 | 0.0450 | | |
| Cadmium (mg/L) | 0.0008 | 0.0008 | 0.0001 | 0.0008 | 0.0005 | 0.0005 | | |
| Chromium (III) (mg/L) | 0.0012 | 0.0013 | 0.0010 | 0.0000 | 0.0000 | 0.0000 | | |
| Copper (mg/L) | 0.0111 | 0.0240 | 0.0368 | 0.0131 | 0.0207 | 0.0198 | | |
| Lead (mg/L) | 0.0049 | 0.0103 | 0.0086 | 0.0148 | 0.0103 | 0.0135 | | |
| Nickel (mg/L) | 0.0270 | 0.0225 | 0.0240 | 0.0220 | 0.0240 | 0.0240 | | |
| Zinc (mg/L) | 0.0309 | 0.0499 | 0.0699 | 0.0564 | 0.0458 | 0.0716 | | |
| BOD5 (mg/L) | 5.04 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | | |
| DO (mg/L) | 3.11 | 7.23 | 8.87 | 6.82 | 9.10 | 7.96 | | |
| Temperature (°C) | 16.66 | 18.32 | 19.39 | 18.23 | 19.25 | 18.43 | | |
| pH | 6.80 | 6.74 | 6.93 | 6.64 | 6.99 | 6.93 | | |
| Conductivity (mS/cm) | 0.431 | 0.910 | 1.370 | 1.650 | 0.952 | 1.774 | | |
| Turbidity (mg/L) | 11.25 | 13.50 | 9.00 | 3.00 | 12.25 | 9.75 | | |
| Chlorophyll a (mg/L) | 0.0120 | 0.0051 | 0.0010 | 0.0037 | 0.0054 | 0.0072 | | |
| Coliform bacteria (1 sample) | 10439 | 10077 | 10450 | 4144 | 9772 | 1908 | | |
| Total Dissolved Soilds (mg/L) | 113 | 160 | 183 | 188 | 171 | 176 | | |
| Total Suspended Solids (mg/L) | 33 | 15 | 6 | 13 | 9 | 20 | | |
| Flow ($m^3/s$) | 0.0069 | 0.2383 | 0.0312 | 0.0287 | 0.0628 | 0.1668 | | |

**Table 3.2 Average Annual Concentrations of Monitored Water Quality Parameters- 2007**

| 2007 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Ammonia-N (NH4-N) (mg/L) | 1.79 | 0.57 | 0.24 | 0.23 | 0.40 | 0.72 | 0.53 | 3.70 |
| Nitrates (NO3-N) (mg/L) | 3.55 | 3.81 | 3.81 | 3.47 | 3.69 | 3.59 | 1.06 | 1.41 |
| Total Nitrogen (mg/L) | 7.06 | 5.29 | 4.56 | 4.10 | 4.67 | 4.69 | 3.27 | 4.43 |
| Total Phosphorus (mg/L) | 1.46 | 0.18 | 0.27 | 0.07 | 0.18 | 0.17 | 0.30 | 2.83 |
| Arsenic(III) (mg/L) | 0.0093 | 0.0158 | 0.0108 | 0.0078 | 0.0073 | 0.0090 | 0.0077 | 0.0087 |
| Boron (mg/L) | 0.0463 | 0.0713 | 0.0563 | 0.1010 | 0.0713 | 0.0585 | 0.0302 | 0.0484 |
| Cadmium (mg/L) | 0.0015 | 0.0018 | 0.0021 | 0.0014 | 0.0015 | 0.0015 | 0.0057 | 0.0007 |
| Chromium (III) (mg/L) | 0.0123 | 0.0083 | 0.0058 | 0.0048 | 0.0043 | 0.0143 | 0.0145 | 0.0082 |
| Copper (mg/L) | 0.0142 | 0.0389 | 0.4015 | 0.0173 | 0.0246 | 0.0521 | 0.0330 | 0.0193 |
| Lead (mg/L) | 0.0083 | 0.0131 | 0.0081 | 0.0052 | 0.0052 | 0.0227 | 0.0087 | 0.0059 |
| Nickel (mg/L) | 0.0350 | 0.0574 | 0.1035 | 0.0483 | 0.0468 | 0.1933 | 0.0288 | 0.0138 |
| Zinc (mg/L) | 0.0587 | 0.0698 | 0.0961 | 0.0527 | 0.0468 | 0.1202 | 0.3807 | 0.1383 |
| BOD5 (mg/L) | 2.40 | 4.98 | 3.59 | 5.23 | 3.62 | 3.47 | 0.00 | 0.00 |
| DO (mg/L) | 3.00 | 6.99 | 8.26 | 6.86 | 8.18 | 8.41 | 4.82 | 2.51 |
| Temperature (°C) | 12.09 | 14.70 | 16.98 | 14.55 | 14.36 | 14.12 | 18.62 | 19.42 |
| pH | 6.30 | 6.44 | 6.80 | 6.60 | 6.71 | 6.65 | 5.76 | 6.62 |
| Conductivity (mS/cm) | 0.506 | 0.705 | 1.325 | 0.754 | 0.722 | 0.752 | 0.677 | 1.008 |
| Turbidity (mg/L) | 29.63 | 20.25 | 10.25 | 3.88 | 7.63 | 17.13 | 0.00 | 0.00 |
| Chlorophyll a (mg/L) | 0.0421 | 0.0089 | 0.0027 | 0.0026 | 0.0058 | 0.0101 | 0.0048 | 0.0049 |
| Coliform bacteria (1 sample) | 1872 | 5438 | 1510 | 7938 | 4201 | 3899 | 54767 | 1191660 |
| Total Dissolved Soilds (mg/L) | 396 | 559 | 1000 | 585 | 550 | 577 | 499 | 721 |
| Total Suspended Solids (mg/L) | 64 | 30 | 6 | 6 | 29 | 22 | 113 | 49 |
| Flow ($m^3/s$) | 0.0001 | 0.2279 | 0.0648 | 0.0047 | 0.0437 | 0.2790 | 0.0000 | 0.0000 |

**Table 3.3 Average Annual Concentrations of Monitored Water Quality Parameters- 2008**

| **2008** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Ammonia-N (NH4-N) (mg/L) | 0.92 | 0.73 | 0.06 | 0.12 | 0.31 | 0.54 | 0.29 | 1.12 |
| Nitrates (NO3-N) (mg/L) | 1.87 | 3.02 | 3.92 | 3.26 | 3.05 | 2.53 | 1.39 | 4.41 |
| Total Nitrogen (mg/L) | 5.47 | 4.41 | 4.44 | 3.79 | 3.95 | 3.72 | 2.98 | 8.42 |
| Total Phosphorus (mg/L) | 1.93 | 0.11 | 0.21 | 0.38 | 0.08 | 0.12 | 0.62 | 1.63 |
| Arsenic(III) (mg/L) | 0.0059 | 0.0104 | 0.0163 | 0.0125 | 0.0163 | 0.0089 | 0.0051 | 0.0140 |
| Boron (mg/L) | 0.1168 | 0.0958 | 0.0760 | 0.1253 | 0.1680 | 0.1000 | 0.0170 | 0.0356 |
| Cadmium (mg/L) | 0.0016 | 0.0010 | 0.0009 | 0.0018 | 0.0013 | 0.0010 | 0.0007 | 0.0000 |
| Chromium (III) (mg/L) | 0.0063 | 0.0022 | 0.0022 | 0.0112 | 0.0015 | 0.0023 | 0.0158 | 0.0024 |
| Copper (mg/L) | 0.0161 | 0.0196 | 0.0359 | 0.0129 | 0.0174 | 0.0121 | 0.0127 | 0.0132 |
| Lead (mg/L) | 0.0060 | 0.0073 | 0.0069 | 0.0039 | 0.0055 | 0.0052 | 0.0482 | 0.0008 |
| Nickel (mg/L) | 0.0400 | 0.0213 | 0.0198 | 0.0228 | 0.0188 | 0.0224 | 0.0739 | 0.0272 |
| Zinc (mg/L) | 0.0510 | 0.0832 | 0.1200 | 0.0565 | 0.0489 | 0.0736 | 0.0768 | 0.0778 |
| BOD5 (mg/L) | 4.57 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 0.00 | 0.00 |
| DO (mg/L) | 1.58 | 4.48 | 5.59 | 5.05 | 6.05 | 6.23 | 4.78 | 4.60 |
| Temperature (°C) | 11.23 | 12.20 | 13.94 | 12.94 | 12.21 | 12.19 | 10.86 | 13.54 |
| pH | 6.13 | 6.39 | 6.61 | 6.50 | 6.74 | 6.63 | 6.20 | 6.49 |
| Conductivity (mS/cm) | 0.693 | 0.892 | 0.924 | 1.052 | 0.833 | 0.804 | 0.594 | 0.645 |
| Turbidity (mg/L) | 14.63 | 10.38 | 6.00 | 2.25 | 5.75 | 7.88 | 0.00 | 0.00 |
| Chlorophyll a (mg/L) | 0.0274 | 0.0052 | 0.0024 | 0.0055 | 0.0056 | 0.0131 | 0.0069 | 0.0126 |
| Coliform bacteria (1 sample) | 2075 | 1439 | 853 | 1259 | 1318 | 1749 | 13846 | 596740 |
| Total Dissolved Soilds (mg/L) | 623 | 781 | 791 | 895 | 739 | 689 | 236 | 272 |
| Total Suspended Solids (mg/L) | 66 | 20 | 15 | 5 | 7 | 15 | 46 | 71 |
| Flow (m3/s) | 0.0001 | 0.1508 | 0.0228 | 0.0168 | 0.0432 | 0.2185 | 0.0000 | 0.0000 |

**Table 3.4 Average Annual Concentrations of Monitored Water Quality Parameters- 2009**

| 2009 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Ammonia-N (NH4-N) (mg/L) | 0.92 | 0.73 | 0.06 | 0.12 | 0.31 | 0.54 | 0.03 | 0.00 |
| Nitrates (NO3-N) (mg/L) | 2.59 | 3.20 | 3.42 | 3.54 | 3.11 | 3.15 | 0.00 | 0.50 |
| Total Nitrogen (mg/L) | 8.09 | 4.92 | 4.01 | 4.07 | 4.06 | 4.18 | 0.99 | 203.00 |
| Total Phosphorus (mg/L) | 1.48 | 0.16 | 0.18 | 0.03 | 0.12 | 0.12 | 0.16 | 0.99 |
| Arsenic(III) (mg/L) | 0.0110 | 0.0060 | 0.0110 | 0.0085 | 0.0035 | 0.0075 | 0.0010 | 0.0000 |
| Boron (mg/L) | 0.0325 | 0.0445 | 0.0495 | 0.0680 | 0.0525 | 0.0375 | 0.0270 | 0.0350 |
| Cadmium (mg/L) | 0.0005 | 0.0010 | 0.0010 | 0.0005 | 0.0005 | 0.0005 | 0.0010 | 0.0010 |
| Chromium (III) (mg/L) | 0.0185 | 0.0020 | 0.0065 | 0.0050 | 0.0020 | 0.0030 | 0.0100 | 0.0260 |
| Copper (mg/L) | 0.0192 | 0.0169 | 0.0281 | 0.0152 | 0.0105 | 0.0110 | 0.0230 | 0.0210 |
| Lead (mg/L) | 0.0049 | 0.0013 | 0.0060 | 0.0066 | 0.0015 | 0.0028 | 0.0140 | 0.0060 |
| Nickel (mg/L) | 0.0345 | 0.0180 | 0.0220 | 0.0190 | 0.0155 | 0.0155 | 0.0320 | 0.0180 |
| Zinc (mg/L) | 0.0456 | 0.0447 | 0.0828 | 0.0633 | 0.0364 | 0.0462 | 0.1030 | 0.0400 |
| BOD5 (mg/L) | 4.67 | 2.76 | 2.53 | 2.40 | 2.81 | 2.40 | 0.00 | 0.00 |
| DO (mg/L) | 2.14 | 6.94 | 8.65 | 7.45 | 8.80 | 8.36 | 3.80 | 3.22 |
| Temperature (°C) | 13.89 | 16.09 | 16.17 | 15.83 | 14.46 | 13.97 | 10.65 | 10.38 |
| pH | 6.73 | 6.83 | 7.04 | 6.86 | 6.90 | 6.96 | 6.60 | 6.24 |
| Conductivity (mS/cm) | 0.582 | 0.783 | 0.969 | 0.905 | 0.763 | 0.799 | 0.355 | 0.397 |
| Turbidity (mg/L) | 41.25 | 57.00 | 5.75 | 1.50 | 10.00 | 43.00 | 0.00 | 0.00 |
| Chlorophyll a (mg/L) | 0.0154 | 0.0095 | 0.0070 | 0.0024 | 0.0073 | 0.0146 | 0.0227 | 0.0086 |
| Coliforms (1 sample) | 8066 | 819 | 838 | 1503 | 1023 | 1245 | 3000 | 3600 |
| Total Dissolved Soilds (mg/L) | 498 | 627 | 760 | 741 | 634 | 682 | 160 | 194 |
| Total Suspended Solids (mg/L) | 31 | 26 | 26 | 7 | 10 | 15 | 0 | 2 |
| Flow ($m^3/s$) | 0.0001 | 0.1464 | 0.0276 | 0.0126 | 0.0585 | 0.1816 | 0.0000 | 0.0000 |

The methodology used in the work for the KWQI development was based on a modification of the National Sanitation Foundation's Water Quality Index [NSFWQI] (Syamee and Tyagi, 2000, 2007). The NSFWQI used curves to relate concentration of various water quality parameters to subindices. The subindices were then aggregated into a single water quality index. The subindices equations were developed using a consensus of national criteria, state standards and information developed from the literature (Swamee and Tyagi, 2000). For this work, the three generic subindex equations developed by Swamee and Tyagi were modified using the State of Delaware water quality standards. For water quality parameters not addressed in the State of Delaware's regulations, standard values were based on USEPA eco-region XIV criteria. This modification resulted in the alteration of the equation constants as outlined below.

## **Determination of Subindex Equation Constants**

The modifications that were made to the subindex equations constants were made using Microsoft Excel Solver. The solver function was set to make the difference between the desired sub-WQI value and the calculated sub-WQI to be zero. The desired sub-WQI value associated with the calculated sub-WQI was different for each water quality parameter and was based on the standards or criteria that were set by the state for the designated water use. Before adapting the constants to meet the standards and criteria for the Cool Run watershed, the unmodified equations from Swamee and Tayagi (2000 & 2007) were run through the solver function using water quality values used in their research. Agreement between the constant values derived through the solver to those provided by Swamee and Tyagi (2000) verified the accuracy of the modification method. After verification was achieved for the 3 subindice equations, the solver was used to determine the modified constants required for every water quality parameter as described below.

The uniformly decreasing subindex was determined by setting the desired sub-WQI value to 0.25. In this subindex, parameters with concentrations greater than the allowable limit received a rating of poor. An initial number similar to the value of the provided sub-WQI constant was used as a starting point for the solver.

The nonuniformly decreasing subindex constants are determined based on the threshold concentration of each parameter. Similar to the uniformly decreasing subindex values, the desired calculated sub-WQI value was set to 0.25. Any value that is greater than the threshold limit would receive a rating of poor. The initial number that was used in the solver function was the threshold concentration of the parameter or a value very similar to it.

The unimodal subindices constants were determined using two different methods of calculation. Both methods were dependant on the individual parameter and the acceptable range for the parameter. When solving for the constants for pH, temperature, and TSS the desired sub-WQI values were set to be 0.51. Initially all the parameter constants were calculated based on a sub-WQI value of 0.25. When these parameters were being tested in the initial stages of model development, the sub-WQI vs. Concentration curves (discussed in following sections) did not make sense. The natural average pH value from the monitoring data was on the lower boundary of the acceptable pH range listed in the Delaware standards. Many of the documents reporting standards and criteria for water quality parameters state that there are optimum levels for some parameters but that naturally occurring concentrations may not fall within the provided range. The criteria values for temperature and TSS behaved similarly to those for pH. These curves were also adjusted to fit naturally occurring regional values. The sub-WQI for conductivity, TDS and fluoride were all calculated based on the criteria limits set equal to a sub-WQI value of 0.25.

Many of the parameters have acute and chronic exposure limits described in the water quality criteria by Delaware and the USEPA. To make the KWQI program more diverse, the sub-WQI constants for acute and chronic limits were calculated and will be able to be used in the KWQI program.

## Comparison of Determined Constants

The modified and unmodified values for $q_T$ used in the nonuniformal subindex equation are listed in Table 3.5. The water quality parameters that were used in the Swamee and Tyagi (2000 & 2007) sub-index equations had only a single criteria value for calculations. The KWQI divided the exposure limits into acute and chronic values to make the model useful for estimating long term effects on the stream water quality. There is much variability between the modified and unmodified constant values. This variability can be attributed to the difference in state regulations and criteria values. Some states break down every water quality parameter into individual water uses while others may only separate them into fresh or marine water categories. It was not stated what water use or if the limits were for chronic or acute exposure in the criteria values used by Swamee and Tyagi (2000 & 2007). Also, regulation standards and criteria values vary spatially and temporally. Constant values calculated for water quality parameters not addressed by Swamee and Tyagi are also included in Table 3.5.

**Table 3.5 Nonuniformal Subindex $q_T$ Constants –** Includes values from Swamee and Tyagi (2000 & 2007) and calculated constants

| **Nonuniformal Subindex $q_T$ Constants** | | | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **S&T*** | **Acute** | **Chronic** |
| **Aluminum** | **mg/L** | **0.20** | **0.72** | **0.08** |
| **Arsenic** | **mg/L** | **0.05** | **0.33** | **0.14** |
| **Boron** | **mg/L** | **-** | **-** | **0.72** |
| **Cadmium** | **mg/L** | **0.0005** | **0.0024** | **0.0002** |
| **Chlorophyll a** | **mg/L** | **-** | **0.0036** | **-** |
| **Chromium** | **mg/L** | **0.050** | **-** | **-** |
| **Chromium (III)** | **mg/L** | **-** | **0.547** | **0.071** |
| **Chromium (VI)** | **mg/L** | **-** | **0.015** | **0.011** |
| **Copper** | **mg/L** | **0.050** | **0.013** | **0.009** |
| **Cyanide** | **mg/L** | **0.050** | **0.024** | **0.005** |
| **Iron** | **mg/L** | **0.10** | **0.96** | **-** |
| **Lead** | **mg/L** | **0.05** | **0.06** | **0.06** |
| **Manganese** | **mg/L** | **0.05** | **-** | **0.05** |
| **Mercury** | **mg/L** | **0.001** | **0.001** | **0.001** |
| **Nickel** | **mg/L** | **-** | **0.449** | **0.050** |
| **Selenium** | **mg/L** | **0.010** | **0.019** | **0.005** |
| **Zinc** | **mg/L** | **5.000** | **0.112** | **0.113** |

*** S&T are values from Swamee and Taygi (2000 & 2007)**

The modified and unmodified values of the different constants used in the uniform subindex equation are listed in Table 3.6. The constants were calculated for five water quality parameters: $BOD_5$, coliform bacteria, nitrogen, phosphorus and turbidity. The $BOD_5$ constants taken from Swamee and Tyagi (2000 & 2007) did not state whether they were for a monthly or weekly average. The criteria values used to calculate the modified equation constants were divided into acceptable values for the time of year and for weekly or monthly averages. The modified and unmodified constants for $BOD_5$ are similar with little variation among the separate criteria values.

**Table 3.6 Uniform Subindex Constants** - Includes values from Swamee and Tyagi (2000 & 2007) and calculated constants

| Uniform Subindex Constants | | | |
|---|---|---|---|
| **Parameter** | **Unit** | **m** | **qc** |
| **$BOD_5$*** | **mg/L** | **3.0** | **20.0** |
| **$BOD_5$** | **mg/L** | **1.2** | **20.1** |
| | | | |
| **Coliforms*** | **MPN/100mL** | **0.30** | **4.00** |
| **Coliforms (geometric mean)** | **MPN/100mL** | **0.29** | **4.00** |
| **Coliforms (single sample)** | **MPN/100mL** | **0.27** | **5.00** |
| | | | |
| **Nitrates ($NO_3$-N)*** | **mg/L** | **3.0** | **40.0** |
| **Nitrate ($NO_3$-N)** | **mg/L** | **6.2** | **39.8** |
| **Total N** | **mg/L** | **6.2** | **19.9** |
| **Ammonia (NH4-N) (acute)** | **mg/L** | **6.4** | **99.0** |
| **Ammonia (NH4-N) (chronic)** | **mg/L** | **23.1** | **96.9** |
| | | | |
| **Phosphates*** | **mg/L** | **1.0** | **0.67** |
| **Total P** | **mg/L** | **612.3** | **88.2** |
| | | | |
| **Turbidity*** | **JTU** | **1.5** | **50.0** |
| **Turbidity** | **JTU** | **6.2** | **39.8** |

***Values are from Swamee and Taygi (2000 & 2007)**

The modified and unmodified values for sub-index constants for coliform bacteria were similar, which indicates similar criteria standards were used in the calculations. Swamee and Tyagi (2000 & 2007) only calculated the values for the sub-index constants for nitrate. Sub-index constant values were calculated for ammonia nitrogen and total nitrogen in order to include these water quality parameters in the assessment model. Values for sub-index constants for acute and chronic exposure limits were calculated for ammonia nitrogen. There were no criteria for phosphate regulation in the Delaware standards so a comparison between modified and unmodified values could not be made. However, the criteria for total phosphorus, found within USEPA documents, were used to calculate the values of the sub-index constants. The modified and unmodified values for the turbidity sub-index constants were quite different indicating large differences between the states' regulations and criteria.

The values of the modified and unmodified constants that are to be used with the unimodal subindex equation are listed in Table 3.7. Conductivity was the only parameter that was not utilized by Swamee and Tyagi (2000 & 2007), so no comparison could be made between values. Comparison between the modified and unmodified values of the sub-index constant for DO was difficult to make because of the difference in criteria units (units of proportion *vs*. mg $l^{-1}$). The modified and unmodified values of the sub-index DO constant s for q* are very different, however, the values for the sub-index constants n, p, and r are similar. Although fluoride is not used in this project the values for the sub-index constants for the parameter were determined for use in the KWQI if desired. The modified and unmodified values of the sub-index pH constants were identical for q* but fairly different for the other constants. This was the direct result of not using just the optimum criteria value for pH. Instead, the solver set the range of optimum values so that anything out of range would receive a rating of fair or lower. Swamee and Tyagi (2000 & 2007) used the total of the suspended and dissolved solids for calculations of the sub-index constants. However, the state of Delaware has water quality criteria set for each individual parameter. For this reason the, TDS and the TSS were utilized as separate parameters in the KWQI. Therefore, no comparisons could be made. The modified and unmodified values of the sub-index constant for temperature were expected to be different because of the variance in optimum temperatures for different ecoregions.

**Table 3.7 Unimodal Subindex Constants** - Includes values from Swamee and Tyagi (2000 & 2007) and calculated constants

| Unimodal Subindex Constants | | | | | |
|---|---|---|---|---|---|
| **Parameter** | **Unit** | **q*** | **n** | **p** | **r** |
| **Conductivity** | **mS/cm** | **0.36** | **0.89** | **1.79** | **0.02** |
| | | | | | |
| **Dissolved Oxygen*** | **proportion** | **1.0** | **3.0** | **1.0** | **0.0** |
| **DO (daily average)** | **mg/L** | **9.6** | **4.2** | **2.4** | **0.0** |
| **DO (instantaneous)** | **mg/L** | **8.3** | **3.4** | **1.6** | **0.0** |
| | | | | | |
| **Fluoride*** | **mg/L** | **1.0** | **4.0** | **4.0** | **0.0** |
| **Fluoride** | **mg/L** | **2.4** | **4.0** | **4.0** | **0.0** |
| | | | | | |
| **pH*** | **-** | **7.0** | **4.0** | **6.0** | **0.0** |
| **pH** | **-** | **7.3** | **9.1** | **10.2** | **0.0** |
| | | | | | |
| **Total Solids (TDS+TSS)*** | **mg/L** | **75.0** | **1.0** | **1.0** | **0.8** |
| **TDS** | **mg/L** | **5.0** | **1.0** | **1.1** | **0.8** |
| **TSS** | **mg/L** | **30.0** | **0.9** | **1.1** | **0.8** |
| | | | | | |
| **Temperature*** | **°C** | **20.0** | **0.5** | **7.0** | **0.0** |
| **Temperature** | **°C** | **20.1** | **1.8** | **4.8** | **0.4** |

*** Values are from Swamee and Taygi (2000 & 2007)**

## Comparison of the Sub-KWQI to Water Quality Parameter Concentration

The sub-KWQI values were plotted against the water quality parameter concentrations in order to demonstrate the relationship among the sub-KWQI, the associated concentration and the rating scores. The plots include four additional horizontal lines that mark the division of the five different ratings (Poor, Fair, Average, Good and Excellent) that a water quality parameter sub-index can represent. Any calculated index values that are below the red line will receive a rating of “Poor”. Values that fall between the red and orange lines will have a rating of “Fair”. Values that occur between the orange and yellow lines receive a rating of “Average”. A rating of “Good” is received when the calculated value is located between the yellow and green line. Any value that is above the green line will receive an “Excellent” rating.

The uniform subindex equation creates an exponentially decreasing plot where the sub-index increases with decreasing concentration. The relationship between concentration and sub-indices for ammonia nitrogen is shown in Figure 3.1. The difference in the concentration values that exceeds the state criteria between the acute and chronic exposure for ammonia nitrogen increases significantly as the rating decreases from excellent to poor. The difference between the acute concentration and chronic concentration for an excellent rating is approximately 1.6 mg $l^{-1}$ while the difference for a poor rating is 18.00 mg $l^{-1}$. Therefore, the sub-KWQI will vary greatly and be dependent on the type of exposure under evaluation. The sub-indice values for the acute exposure limit are used for calculations in the model assessments because we were evaluating changes in water quality over short periods of time.

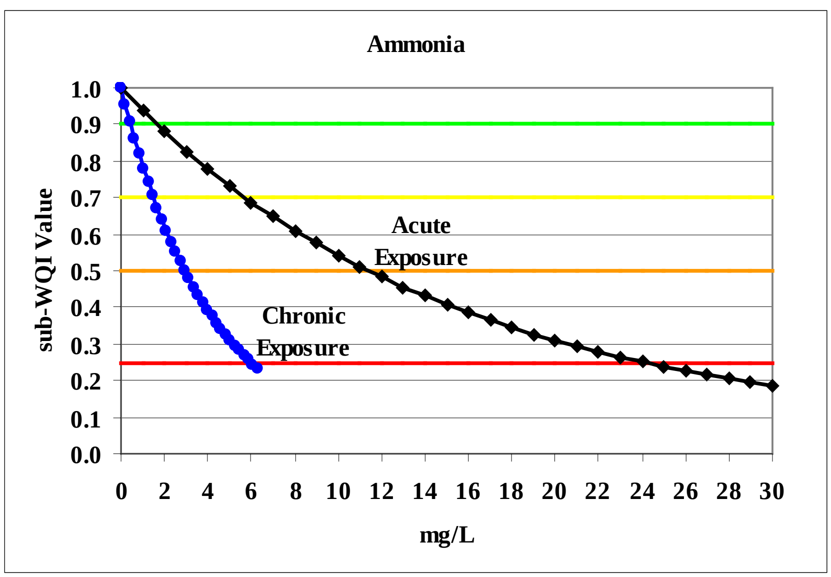



**Figure 3.1 Uniform Sub-KWQI *Versus* Concentration Curve -** Ammonia

Unlike the ammonia sub-indices, the relationship between concentration and the sub-KWQI for $BOD_5$ is similar regardless of whether monthly or weekly averages are used (Figure 3.2). Criteria concentrations for weekly averages are allowed to be higher assuming that averages for the month are within the tolerable ranges. The differences in the concentration values that exceeds the state criteria between the weekly average and the monthly average for $BOD_5$ are similar for both the September to May and the June to August time periods. The difference between the weekly average and the monthly average values for an average rating is approximately 5 mg $l^{-1}$ while the difference for a poor rating is 16.00 mg $l^{-1}$ for both time periods. When using the sub-KWQI in model assessments for yearly averages, it is best to use the September to May values.

The relationship between the sub-KWQI and coliform concentration is shown in Figure 3.3. This concentration criteria used to create the curves assumes that at times a single sample measurement may be higher than expected but that an average of several measurements will fall below the occasional peak values. Therefore, the concentrations receiving poor ratings are 925 and 500 CFU per 100 ml for single sample and geometric mean sample, respectively, whereas the concentrations receiving average ratings are 80 and 50 CFU per 100 ml, respectively.

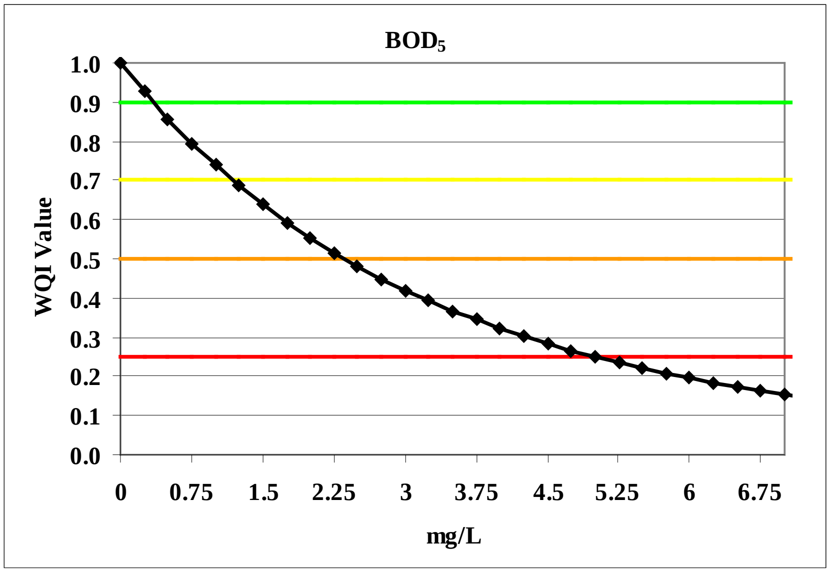



**Figure 3.2 Uniform Sub-KWQI *Versus* Concentration Curves –** BOD

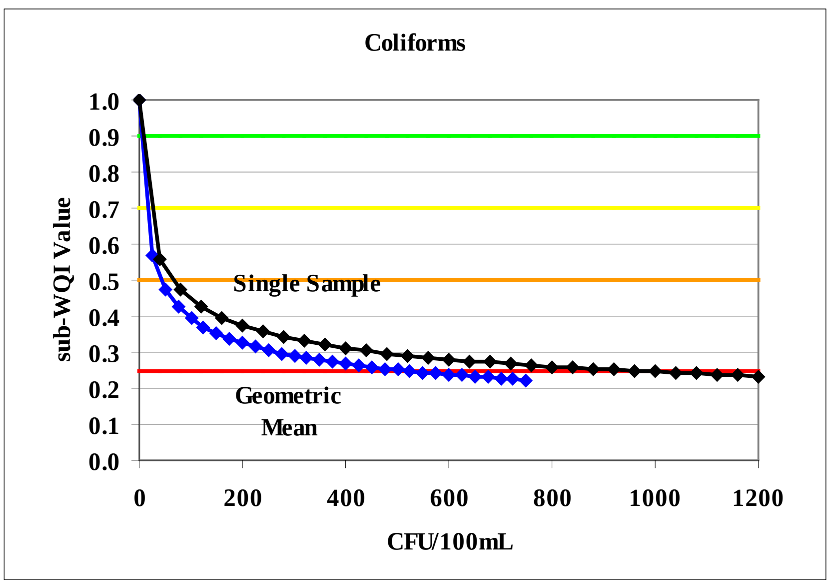



**Figure 3.3 Uniform Sub-KWQI *Versus* Concentration Curves –** Coliform

The regulations and criteria for turbidity, nitrate, total nitrogen and total phosphorus only state that there is a maximum value that should not be exceeded. Concentration measurements that were greater than the criteria would result in a poor rating for water quality. Figures 3.4 and 3.5 illustrate the relationship between the sub-KWQI value and the parameter concentration for turbidity and nitrate-nitrogen. A water body receiving a rating of excellent will have concentrations equal to or less than 0.5 JTU and 0.8 mg $l^{-1}$ for turbidity and nitrate nitrogen, respectively. Figures 3.6 and 3.7 illustrate the relationship between the sub-KWQI value and the parameter concentration for total nitrogen (TN) and total phosphorus (TP). A water body receiving a rating of excellent will have concentrations equal to or less than 1.25 and 0.0036 mg $l^{-1}$ for TN and TP, respectively. The rating falls below average when concentrations reach 15.0 and 0.027 mg $l^{-1}$ for TN and TP, respectively.

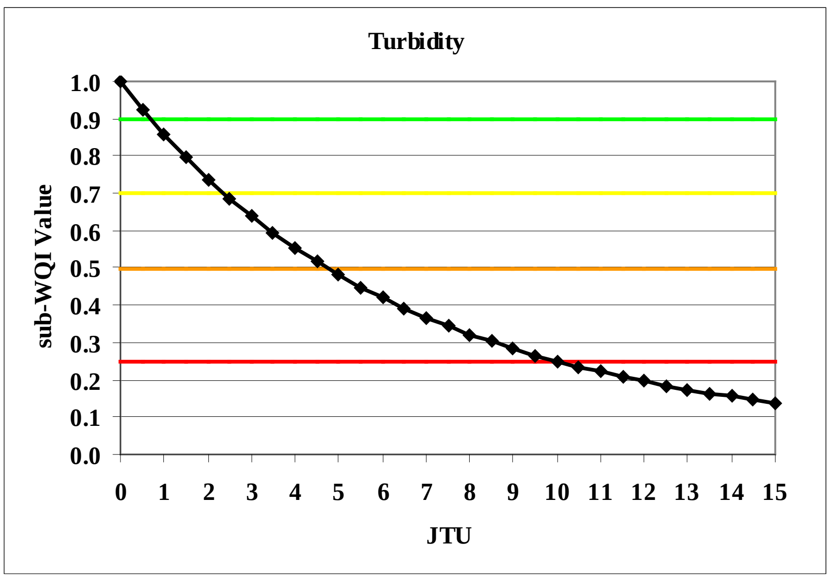



**Figure 3.4 Uniform Sub-KWQI *Versus* Concentration Curves - Turbidity**

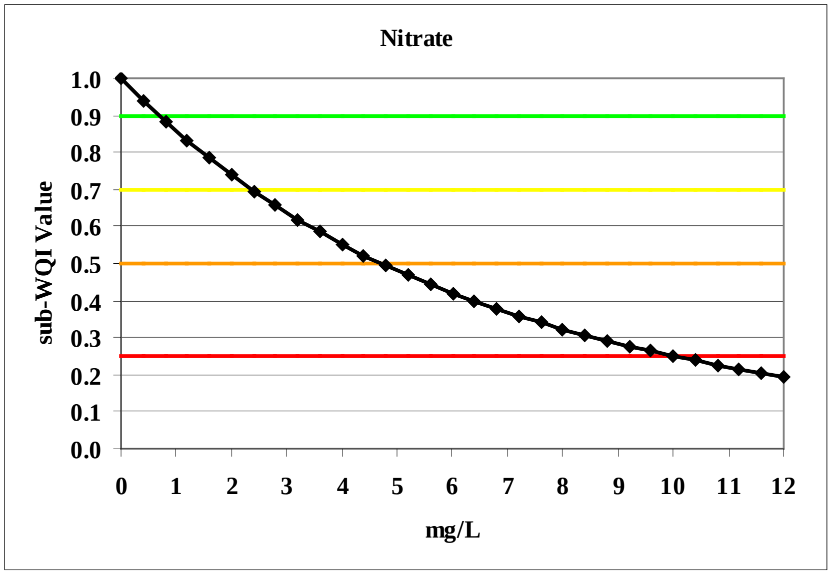



**Figure 3.5 Uniform Sub-KWQI *Versus* Concentration Curves –** Nitrate

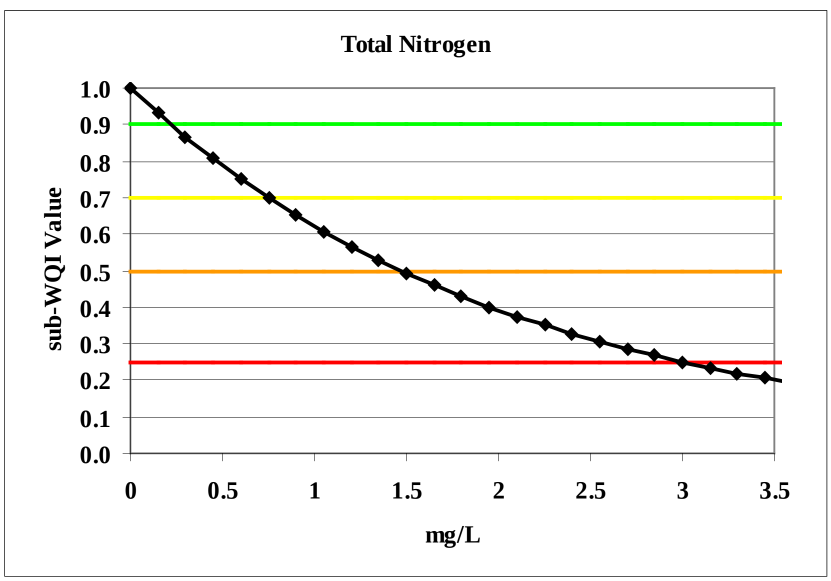



**Figure 3.6 Uniform Sub-KWQI *Versus* Concentration Curves –** Total Nitrogen

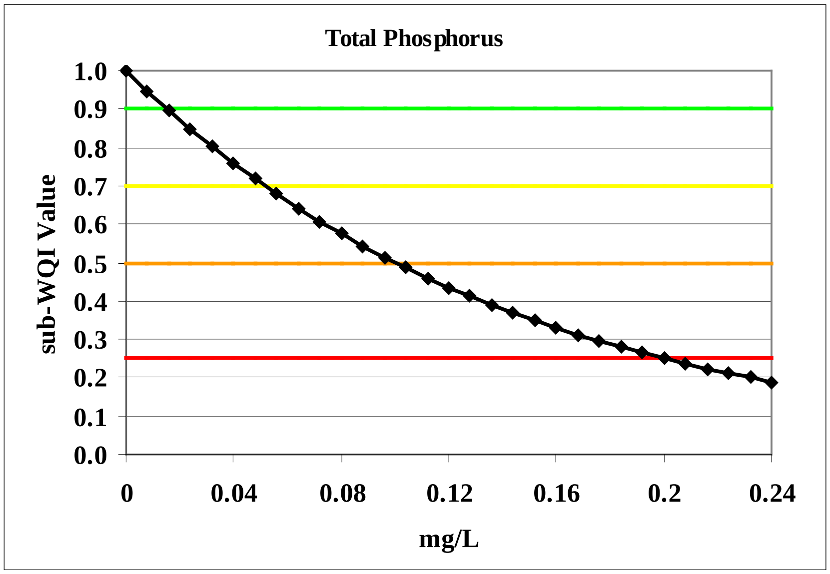



**Figure 3.7 Uniform Sub-KWQI *Versus* Concentration Curves –** Total Phosphorus

The relationship between the nonuniformal subindex values and concentration for aluminum and cadmium behaves quite differently for the acute and chronic exposures (Figures 3.8 and 3.9). The steeper slope of the chronic exposure curve indicates a greater change in the sub-KWQI value for smaller changes in concentration. For ratings ranging between excellent and poor, the concentrations range from 0.039 to 0.087 and from 0.338 to 0.754 mg $l^{-1}$ for chronic and acute aluminum exposures, respectively. Similarly, for ratings ranging between excellent and poor, the concentrations range from 0.00011 to 0.00024 and from 0.0011 to 0.0025 mg $l^{-1}$ for chronic and acute cadmium exposures, respectively. The rating concentrations for acute exposure measurements are 10 times higher than the rating concentrations for chronic exposure measurement. The relationship between the nonuniformal subindex value and concentration for chromium (III) and cyanide are shown in Figures 3.10 and 3.11. The relationship behaves quite differently for the acute and chronic exposures. For ratings ranging between excellent and poor, the concentrations range from 0.035 to 0.0725 and from 0.260 to 0.560 mg $l^{-1}$ for chronic and acute chromium (III) exposures, respectively. Similarly, for ratings ranging between excellent and poor, the concentrations range from 0.0024 to 0.0052 and from 0.011 to 0.025 mg $l^{-1}$ for chronic and acute cyanide exposures, respectively. The relationship between the nonuniformal subindex value and concentration for nickel and selenium are shown in Figures 3.12 and 3.13. As for the other parameters discussed above, the relationship behaves quite differently for the acute and chronic exposures. For ratings ranging between excellent and poor, the concentrations range from 0.024 to 0.052 and from 0.220 to 0.460 mg $l^{-1}$ for chronic and acute nickel exposures, respectively. Similarly, for ratings ranging between excellent and poor, the concentrations range from 0.0022 to 0.0050 and from 0.009 to 0.0203 mg $l^{-1}$ for chronic and acute selenium exposures, respectively. Both the acute and chronic exposure parameters will be able to be utilized in the KWQI model to calculate the overall KWQI.

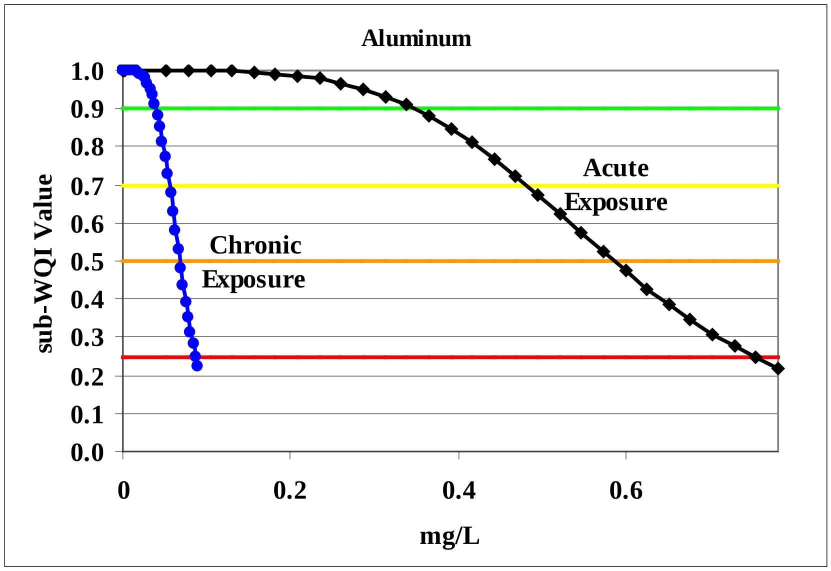



**Figure 3.8 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Aluminum

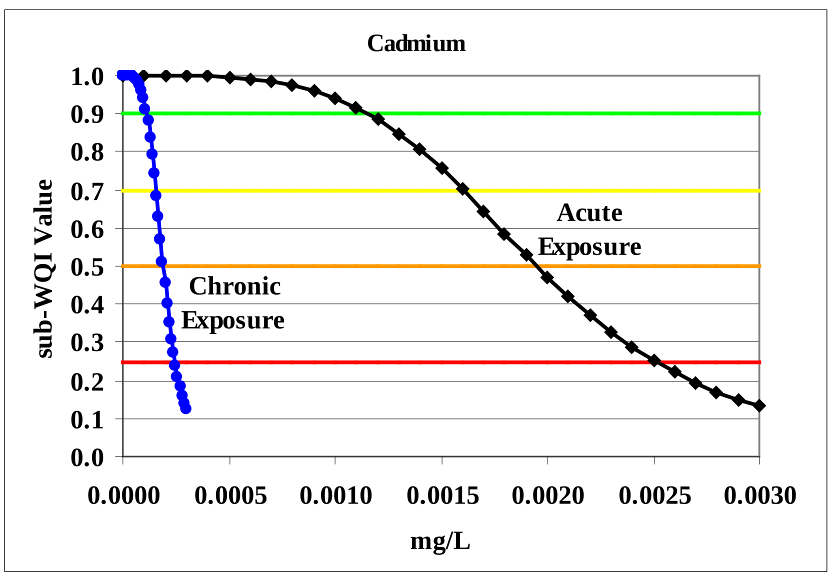



**Figure 3.9 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Cadmium

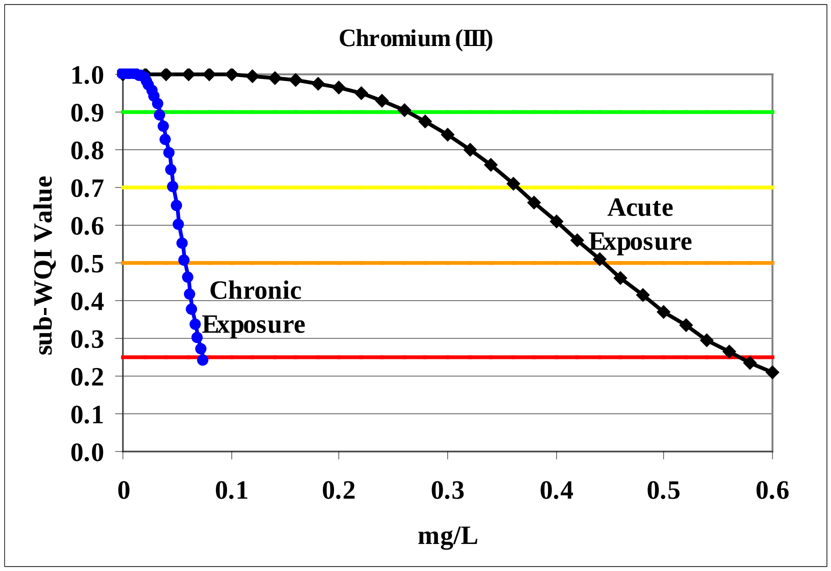



**Figure 3.10 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Chromium (III)

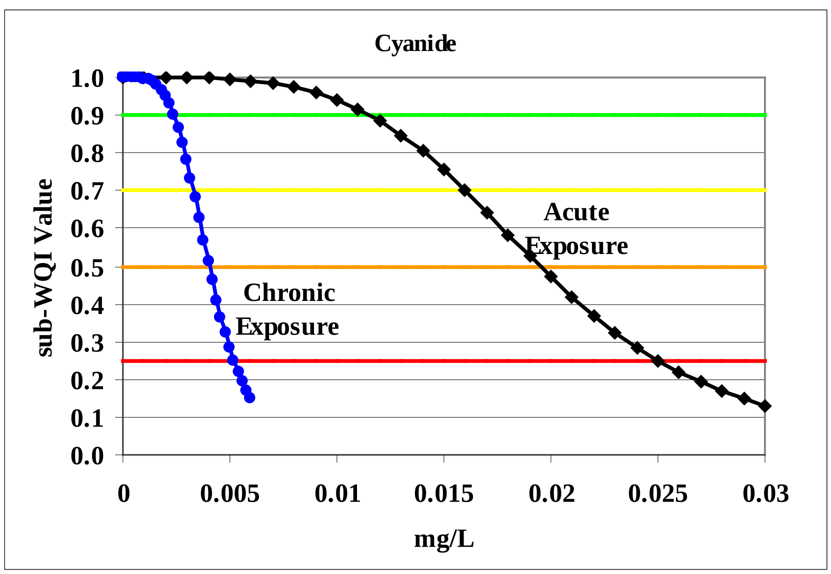



**Figure 3.11 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Cyanide

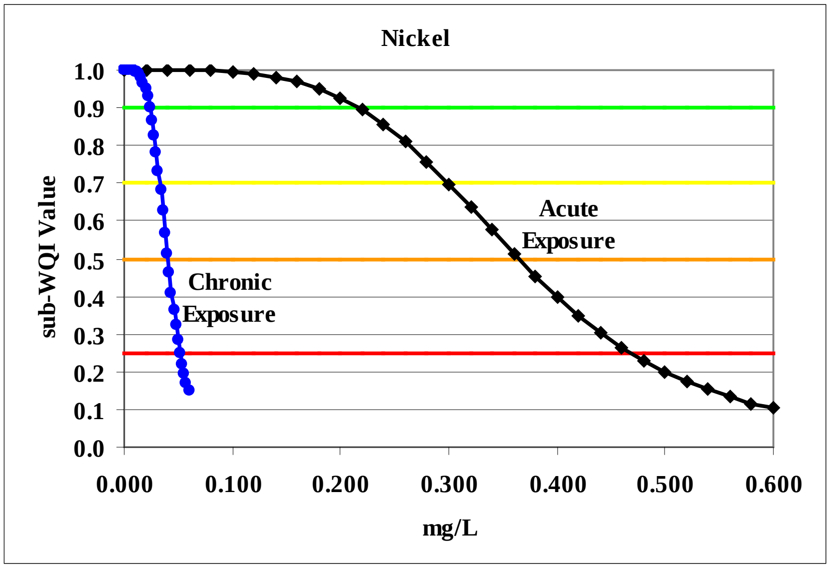



**Figure 3.12 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Nickel

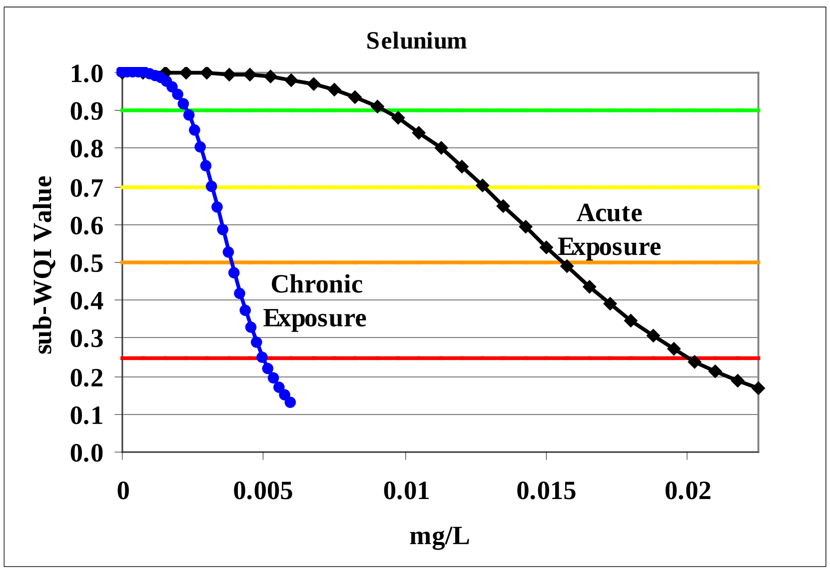



**Figure 3.13 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Selenium

The relationship between the nonuniformal subindex value and concentration for arsenic (III) and mercury are shown in Figures 3.14 and 3.15. The relationship for the chronic exposure criteria behaved differently than that of the previous set of parameters (nonuniformal) in that the sub-KWQI decreases at a slower rate as concentration increases resulting in a smaller difference between the acute concentration and the chronic concentration for a particular sub-index value. For example, a sub-KWQI of 0.70 (GOOD/AVERAGE) is received while the difference between the chronic and acute concentration is 0.00144 and 0.00042 mg $l^{-1}$ for cadmium and mercury respectively. The difference between the acute and chronic concentration for a particular sub-index value is reduced even more for chromium (VI) and copper (Figures 3.16 and 3.17). For example, a sub-KWQI of 0.70 (GOOD/AVERAGE), is received but difference between the chronic and acute concentration is 0.0096 and 0.00274 mg $l^{-1}$ for selenium and copper, respectively.

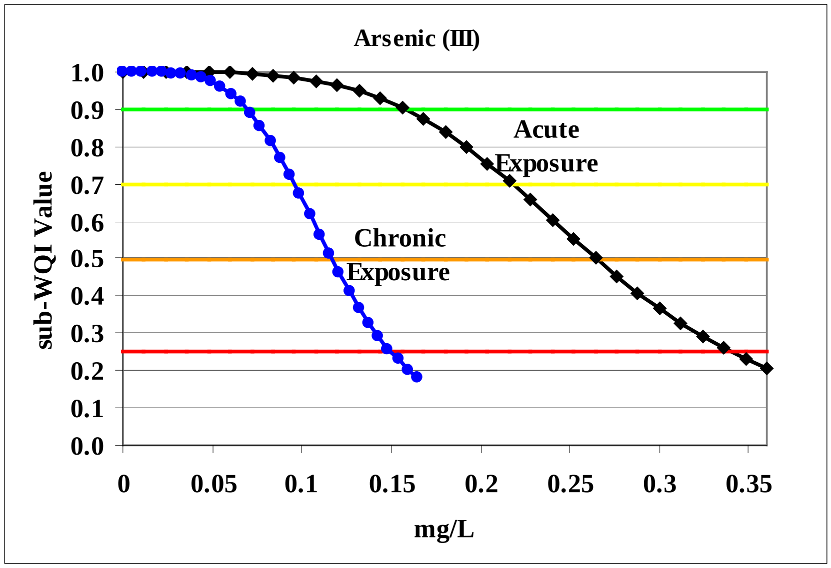



**Figure 3.14 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Arsenic (III)

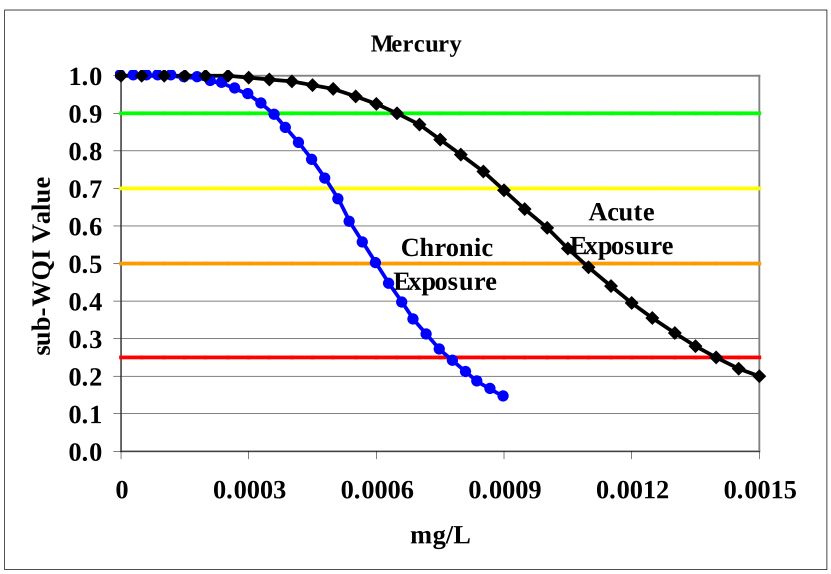



**Figure 3.15 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Mercury

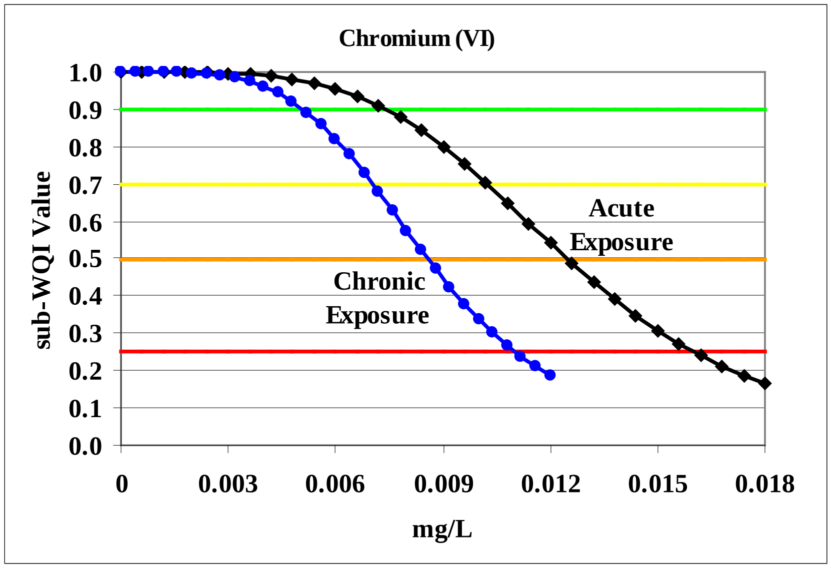



**Figure 3.16 Nonuniform Sub-KWQI *Versus* Concentration curves –** Chromium

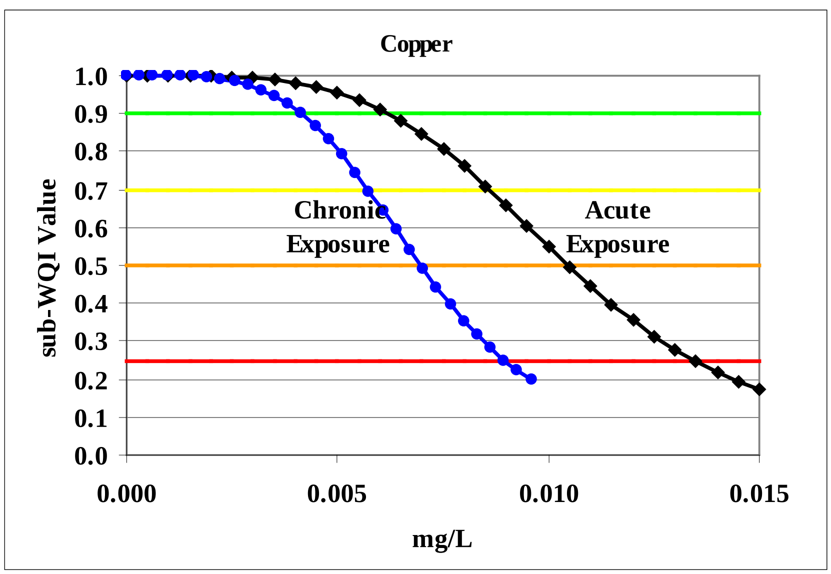



**Figure 3.17 Nonuniform Sub-KWQI *Versus* Concentration curves –** Copper

The relationship between the nonuniformal sub-KWQI and concentration for zinc and lead are shown in Figures 3.18 and 3.19. The curves for the chronic and acute exposure limits were relatively the same because the criteria concentrations for acute and chronic exposures were almost equal; 0.117 *vs.* 0.118 and 0.06458 *vs.* 06391 mg $l^{-1}$ for zinc and lead, respectively.

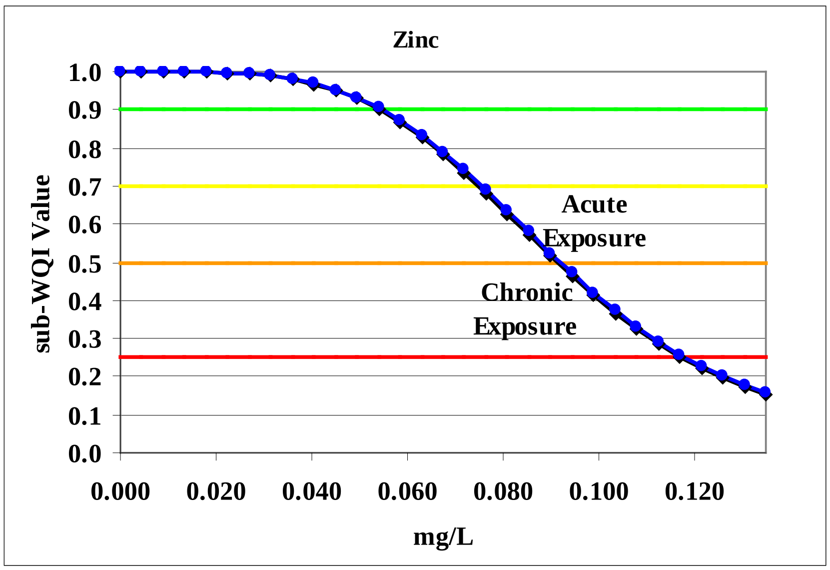



**Figure 3.18 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Zinc Lead

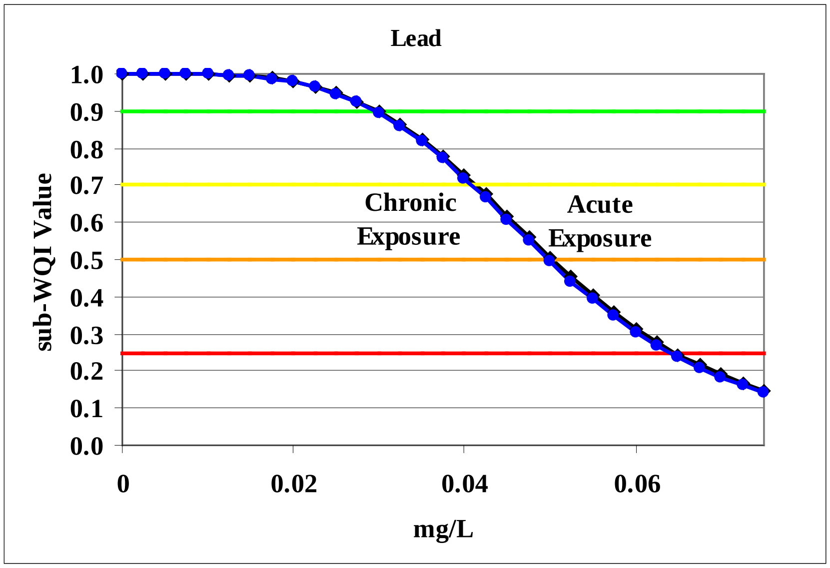



**Figure 3.19 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Lead

The relationship between the nonuniformal sub-KWQI and concentration for manganese and iron are shown in Figures 3.20 and 3.21. For a GOOD water quality rating, the concentration must be below 0.0234 and 0.455 mg $l^{-1}$ for manganese and iron, respectively. Manganese concentrations that fall between 0.0396 and 0.0486 mg $l^{-1}$ will result in a FAIR water quality rating while iron concentrations between 0.63 and 0.77 mg $l^{-1}$ will have a FAIR rating.

The relationship between the nonuniformal sub-KWQI and concentration for chlorophyll *a* and boron are shown in Figures 3.22 and 3.23. For an EXCELLENT water quality rating, the concentration must be below 0.00169 and 0.336 mg $l^{-1}$ for chlorophyll *a* and boron, respectively. Chlorophyll *a* concentrations that fall between 0.00234 and 0.00286 mg $l^{-1}$ will result in an AVERAGE water quality rating while boron concentrations between 0.476 and 0.588 mg $l^{-1}$ will have an AVERAGE rating.

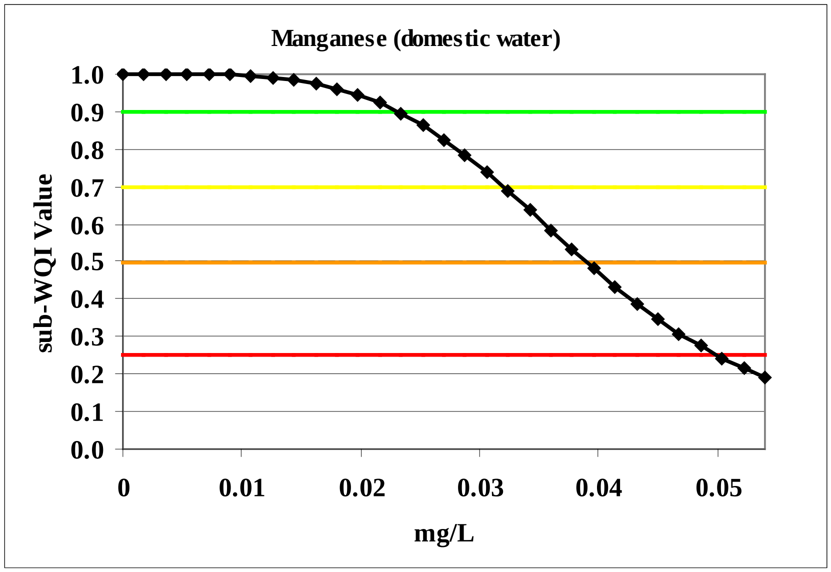



**Figure 3.20 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Manganese

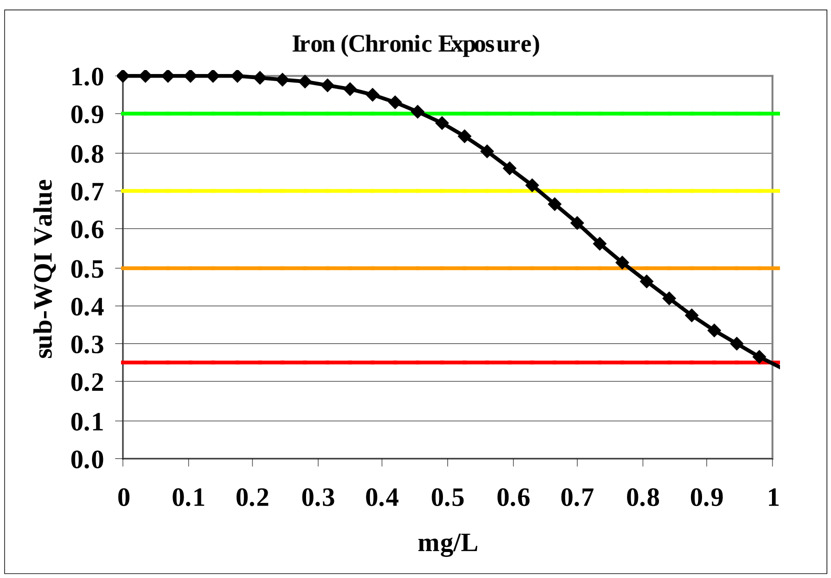



**Figure 3.21 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Iron

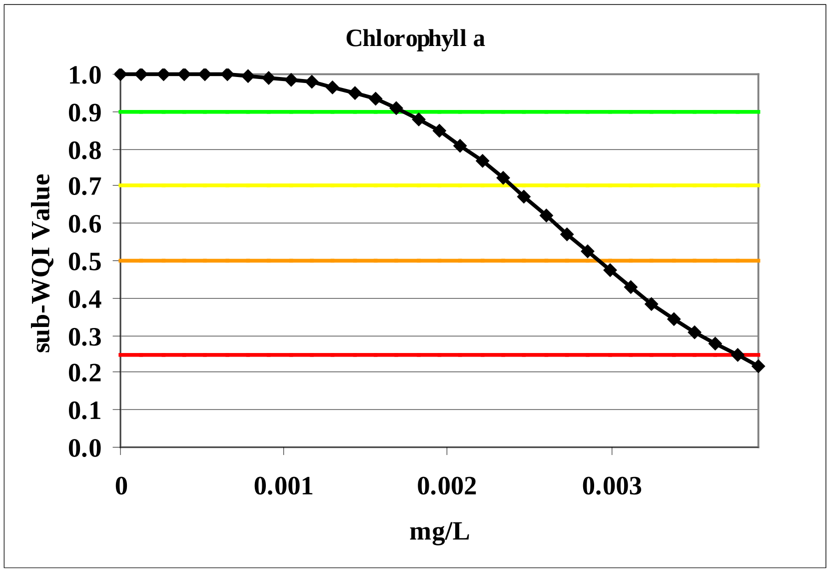



**Figure 3.22 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Chlorophyll *a*

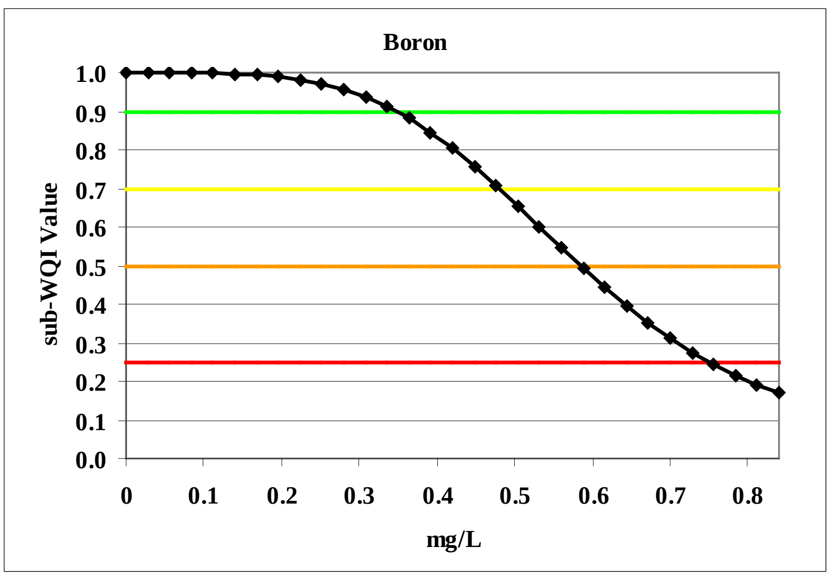



**Figure 3.23 Nonuniform Sub-KWQI *Versus* Concentration Curves –** Boron

The final subindex, classified as unimodal, is based on the parameters having an optimum value or range. The relationship between the unimodal sub-KWQI and concentration for a single grab sample measurement and a daily average measurement for dissolved oxygen is shown in Figure 3.24. The sub-KWQI values decrease after reaching a concentration of 8.5 and 9.5 mg $l^{-1}$ for a single (instantaneous/grab) sample measurement and a daily average measurement, respectively. Before reaching the optimum DO concentration, the sub-KWQI increases at a slightly faster rate with increasing concentration for the grab sample curve. However, for DO concentrations above the optimum value, the grab sample sub-KWQI decreases at a slower rate than the daily average sub-KWQI. Grab sample DO concentrations between 7.0 and 10.0 mg $l^{-1}$ will have a water quality rating of EXCELLENT while daily average DO concentrations between 8.5 and 11 mg $l^{-1}$ will receive an EXCELLENT. The DO curve starts to decrease after the optimum ranges however, this can be explained. The natural upper level of solubility in water is around 15 mg/L however this can be increases in particular cases. The additional aeration could be the result from biological processes by autotrophic organisms (algae) through photosynthesis. High levels of naturally occurring DO should be investigated to determine if the water body has been taken over by too much plant biota (Biswas, 1997).

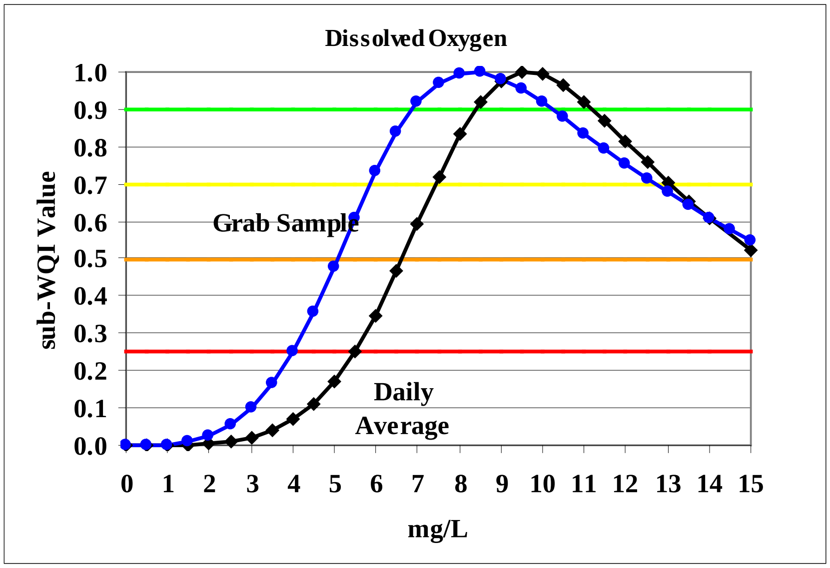



**Figure 3.24 Unimodal Sub-KWQI *Versus* Concentration Curve** - Dissolved Oxygen

The relationship between the unimodal sub-KWQI and concentration for conductivity and pH are shown in Figures 3.25 and 3.26. Conductivity sub-KWQI values increase to 1.00 for concentrations between 0 and 0.35 mS/cm, and decrease at a slower rate for concentrations greater than 0.35 mS/cm. Changes in sub-KWQI values for pH occur between the range of 4 and 11.5, reaching the maximum sub-KWQI value (1.0) at pH 7.0. A rating of POOR is received for pH values below 5.8 or above 9.0

The relationship between the unimodal sub-KWQI and concentration for temperature and fluoride are shown in Figures 3.27 and 3.28. The sub-KWQI value for temperature increases at a slower rate for temperatures between 0° C and 20° C. Temperatures above 20° C decrease in sub-KWQI values. Fluoride concentrations that fall between 2.4 and 2.8 mg $l^{-1}$ will result in an EXCELLENT rating while concentrations below 1.43 and above 4.0 mg $l^{-1}$ will have a POOR rating.

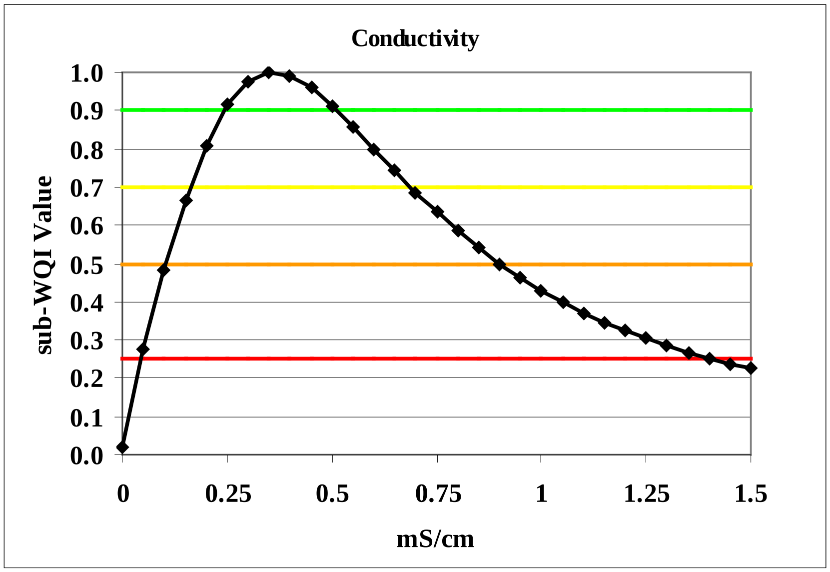



**Figure 3.25 Unimodal sub-KWQI *Versus* Concentration Curves –** Conductivity

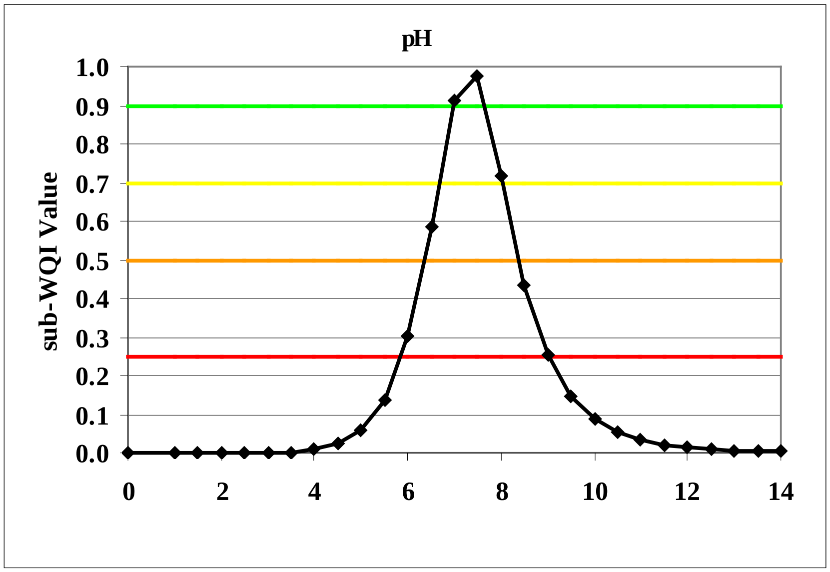



**Figure 3.26 Unimodal sub-KWQI *Versus* Concentration Curves –** pH

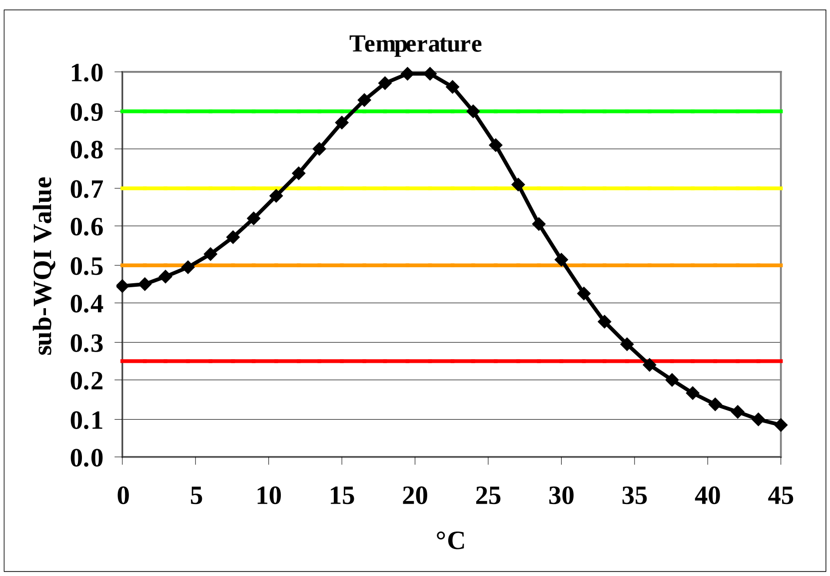



**Figure 3.27 Unimodal Sub-KWQI *Versus* Concentration Curves –** Temperature

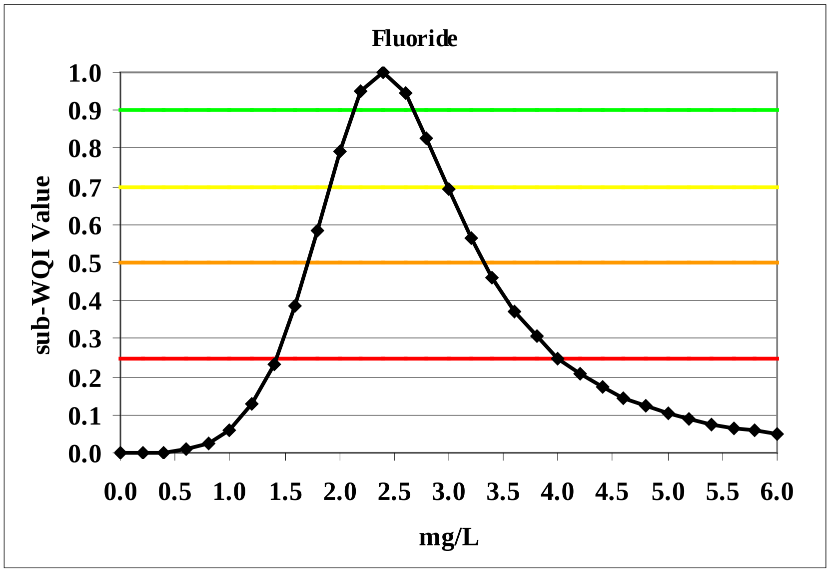



**Figure 3.28 Unimodal Sub-KWQI *Versus* Concentration Curves –** Fluoride

The relationship between the unimodal sub-KWQI and concentration for Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) are shown in Figures 3.29 and 3.30. The sub-KWQI value for TDS and TSS concentrations of 0 mg $l^{-1}$ is 0.76. Even though these water quality parameters fall under the unimodal sub-index definition, the Delaware standards are based on a maximum concentration rather than a range of acceptable concentrations. A POOR water quality rating occurs for TDS concentrations above 39 mg $l^{-1}$ and for TSS concentrations above 250 mg $l^{-1}$.

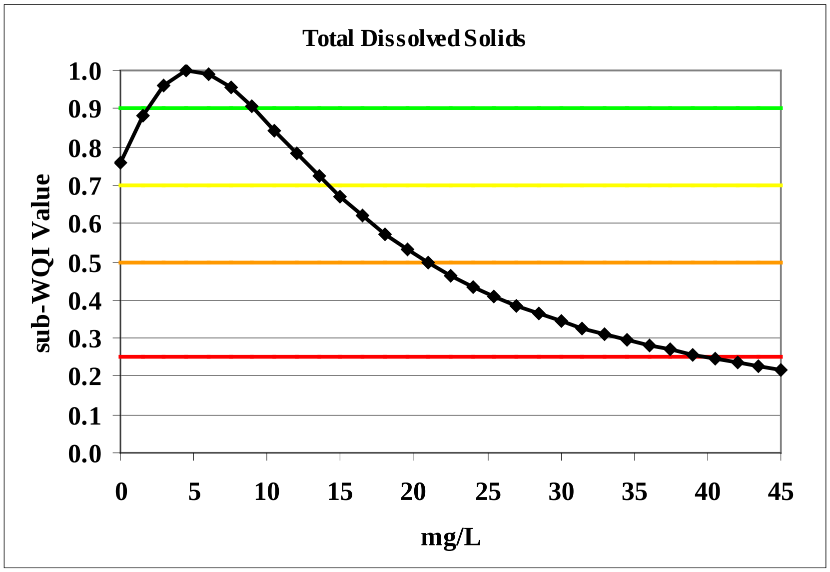



**Figure 3.29 Unimodal Sub-KWQI *Versus* Concentration Curves –** Total Dissolved Solids

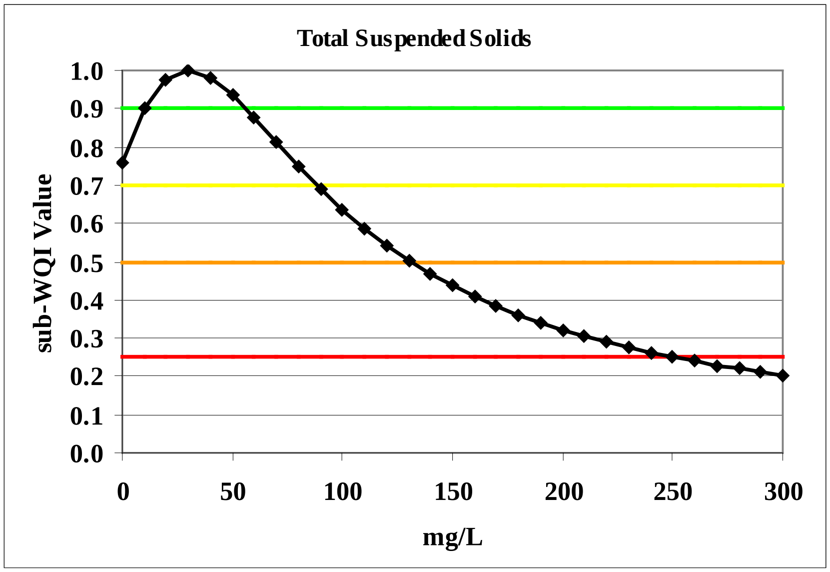



**Figure 3.30 Unimodal Sub-KWQI *Versus* Concentration Curves** – Total Suspended Solids

## Model Development

A computer model was developed to perform the aggregation function that computes the final, single, water quality index (KWQI) from the calculated sub-water quality indices of individual water quality parameters. The KWQI can be calculated by aggregating any number of different water quality parameters. The selection of which water quality parameters to use to calculate the final index is usually based on the type of water body under assessment, the intended water use, and the purpose of the assessment. The model was created with a user friendly interface that would allow for a variety of water quality parameters and parameter sets to be used for KWQI aggregation.. This would allow the model to calculate a KWQI that could be used in the future for the evaluation of the water quality of the Cool Run on the Newark Research and Education Center Farm and for the assessment of the impacts that the installed BMPs have on water quality in the Cool Run tributary. Because the model was developed using Delaware's water quality criteria, it could be used to assess any surface water in the state. A brief overview describing the model functions and application will be discussed. This will be followed by a breakdown of the individual options that are available in the three parts of the model. It will conclude with a simple example that will walk through one of the three options that are available in the model.

**Model Overview**

The function of the model is to take many different parameter sub-indices and create a single water quality index value that can determine the health of a stream or the performance of a BMP. As stated in Chapter 1, having large amounts of data and no basis to evaluate the data can cause a problem for environmentalists and policy makers. The model is meant to help make sense of collected water data and to put it into a presentable manner that can be use to describe processes in simplistic terms. For instance, the model has been made with three main options. The first option will provide an index value (KWQI) for a single set of parameters. The second option will provide a way to directly compare two sets of data. For example, the model could make a comparison of two different sample dates or a comparison of two points along the same stream. The third option will allow a person to assess up to 8 different sets of data at one time. These data sets can include monitoring data from single sampling dates, monthly averages, yearly averages, or any other statistical evaluations (median values for example).

When using the navigation buttons to switch between input pages, a serious of options will be presented to guide the user through the KWQI. For example, when clicking the navigation buttons, a window will pop up that will ask the user to select from the following list of options: "continue to the page'', "create your own data set", or "use one of the predefined parameter sets". There are five groups of predefined parameter sets that are broken down into the following categories: Water Quality Standards and Criteria Sets, Manure Collection System Sets, Riparian Buffer Zone Sets, Wetland Sets and Ponds/Basins Sets. Within each of these set categories, there are 2-3 different options that are preprogrammed into the model. To make it easier on the user, the list of water quality parameters that are used to calculate the KWQI of each set is listed with the set name. The model also allows you to go back to look at all the options before closing out the box by clicking the "Continue to Input Page" button. When any of the preprogrammed parameter sets are chosen, there is always the option of changing any of the parameters in the set. The purpose of the predefined parameter sets it is to allow users with limited knowledge of the subject to use this model for assessment of the impacts of particular BMPs with the Cool Run tributary.

There are reset options built into the program to make clearing sheets easier for the user. There are four options that are given when the "Reset Options" button is clicked on the input or output pages. The first option is to clear only the values that were entered on the input page. This is mainly for when the user runs the same water quality parameters over and over again but changes the concentration of the quality variables being entered into the model. The second option is to allow the user to erase the values that are on the output page only. This is intended to be used between runs to make sure that all the calculations are done correctly. It will also provide an easy way to clear all the output from a specific run if a change in parameters is desired. The third option clears the concentration of the quality values from the input page and also clears the data that was outputted. This is mainly for situations when the user is running many assessments and wants to make sure that all the values are calculated correctly. The final option is to reset both the input and output pages. The end result for this option is that the outputted data is cleared, the quality variables are erased and all the parameter choices are cleared.

There are many applications where this model can be used. The main intention for the development of the model was to create a way to evaluate the changes that occur, if any, in the stream water quality in an agricultural setting where BMPs are being implemented. The model can also be used to evaluate the health of any flowing freshwater body, such as larger streams or rivers. This model can be applied to almost any water body, even those outside of Delaware, as long as the criteria for the parameters are adjusted for the area under study.

## Model Options

The options that are available for use in the KWQI model are listed in Table 3.8. Option 1 (Single Site) refers to sections of the model used with a single set of data for a range of parameters. Option 2 (Side-by-Side) refers to sections of the model used to compute up to two sets of data for a range of parameters. Option 3 (Spatial Estimation) refers to sections of the model where up to eight sets of data can be done in a single run.

**Table 3.8 Table of Options built into Model.** This table shows the three main options that are built into the model and the different sub-options that are automatically part of the model.

| | **Option 1** | **Option 2** | **Option 3** |
|---|---|---|---|
| Number of Data Sets Available to be Run at One Time | 1 | 1-2 | 1-8 |
| ALL Parameters Available for Use | ✓ | ✓ | ✓ |
| Chart Counting the Number per Rating | ✓ | ✓ | ✓ |
| Navigation Button to Side-by-Side Input | ✓ | ✓ | ✓ |
| Navigation Button to Side-by-side Output | ✓ | ✓ | ✓ |
| Navigation Button to Single Input | ✓ | ✓ | ✓ |
| Navigation Button to Single Output | ✓ | ✓ | ✓ |
| Navigation Button to Spatial Estimation Input | ✓ | ✓ | ✓ |
| Navigation Button to Spatial Estimation Output | ✓ | ✓ | ✓ |
| Navigation to Main Page | ✓ | ✓ | ✓ |
| Output of Each Individual Subindex | ✓ | ✓ | ✓ |
| Plot of Distribution of Rating | ✓ | ✓ | ✓ |
| Plot of Each Value from Subindices | ✓ | ✓ | ✓ |
| RESET: Only Values on Input Page | ✓ | ✓ | ✓ |
| RESET: Only Values on Output Page | ✓ | ✓ | ✓ |
| RESET: Values & Parameters on Input & Output Page | ✓ | ✓ | ✓ |
| RESET: Values on Input & Output Page | ✓ | ✓ | ✓ |
| Use of Preprogrammed Parameter Sets | ✓ | ✓ | ✓ |
| WQI & WQ Subindex Grading Scale | ✓ | ✓ | ✓ |
| Calculated % Difference Between Two Data Sets | | ✓ | |
| Plot of Calcualted % Difference | | ✓ | |
| Spatial Distribution of Sites Option | | | ✓ |

## Model Example

This example is included in the report to show how the model works and what can be expected from using the model. Figure 3.31 is a print screen of the opening statement of the model. As shown in the figure, it provides the name of the model and what the model was designed to do. It also includes a statement telling the user to choose one of the three options that will be given soon that best fits what the desired outcome from using the model is.

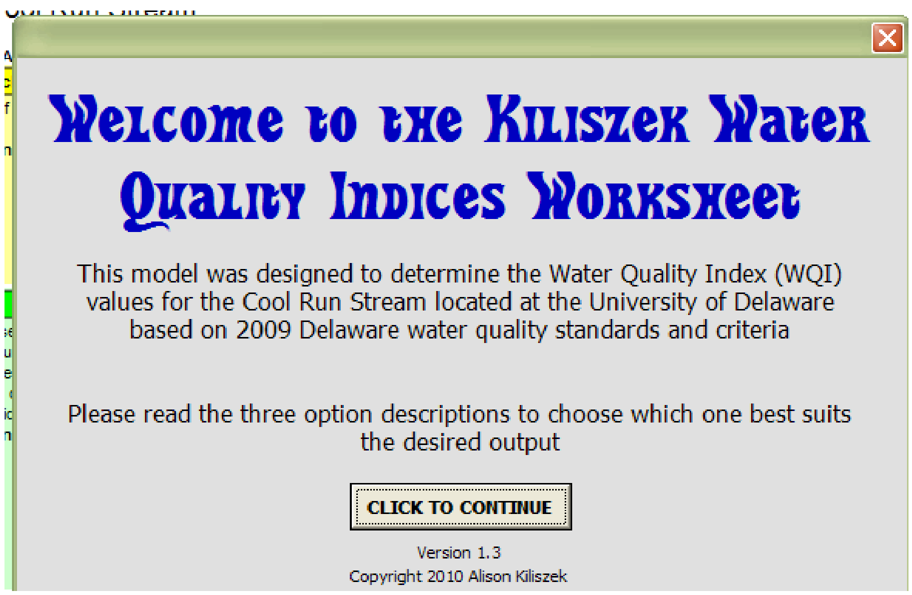



**Figure 3.31 KWQI Model - Opening Screen of Kiliszek WQI Worksheet.** This is a screen shot of the opening screen providing some background information on the KWQI and instructing the user to read the options list to make best use of the options available.

After clicking the continue button, the user will then see the print screen that is in Figure 3.32. To help the user navigate to the part of the model that is most useful to them, each option is described in detail. The description for each option includes what types of data sets were intended to be used to calculate the final index. The content of the output page that is automatically generated with each run of the model is given in list form.

Created by Alison Kiliszek

***Option 1 : Single Site Evaluation***

Click to use Option 1: Single Site Evaluation

This option should be chosen when the evaluation of a single site from a specific sample collection date is desired.

**Included in the Output:**

List of each paramter used in calculations
List of each parameter with the Subindex Value
List of each parameter with the Subindex Rating
Table of Subindex Rating Distribution
Table of WQI Scale Values
Table of WQI Rating
Plot of Subindex Value
Plot of Subindex Rating Distribution
Total WQI value
Total WQI rating
Total Number of Parameters Used

***Option 2 : Side-by-Side Evaluation***

Click to use Option 2: Side-by-Side

This option should be used for the following two cases:

*Case One* : This option should be chosen when an upstream site is to be compared to a downstream site using the same parameter set; the percent difference compares the individual parameters.

Case Two : This option should be chosen when the difference over time for the same site is to be evaluated; the percent diference compares the individual parameters.

**Included in the Output:**

List of each paramter used in calculations
List of each parameter with the Subindex Value
List of each parameter with the Subindex Rating
Table of Subindex Rating Distribution
Table of WQI Scale Values
Table of WQI Rating
Plot of Subindex Value
Plot of Subindex Rating Distribution
Total WQI value
Total WQI rating
Total Number of Parameters Used
Percent Difference between Data Sets
Plot of Percent Difference

***Option 3 : Spatial Evaluation***

Click to use Option 3: Spatial Estimation

This option should be used for the following two cases:

*Case One* : This option was designed to be used for evaluation of any combination of all 8 sites. The overall WQI values for the sites are then entered into a relative spatical plot of the UD Farm. Values for the stream between the sites are then interpolated and entered into the stream path. To have the spatial 3D plot function properly the flow values for Sites 1, 3, and 4 must be entered into the INPUT page. (3D Plot is an estimation of trends and needs Sites 1 - 6 to function properly.)

*Case Two* : This option can be used for the evaluation of up to 8 different data sets. (3D Plot Not Applicable for Case Two)

**Included in the Output:**

List of each paramter used in calculations
List of each parameter with the Subindex Value
List of each parameter with the Subindex Rating
Table of WQI Scale Values
Table of WQI Rating
3D Spatial Estimation of WQI throughout the UD Farm
Total Number of Parameters Used
Table of Subindex Rating Distribution
Plot of Subindex Rating Distribution
Total WQI value
Total WQI rating

**Figure 3.32 KWQI Model - Main Menu Options.** This is a screen shot of the options page within the model. It shows the options and cases for each option as well as the output included after the model is ran.

For this example, the option that was chosen was the “Side by Side Evaluation”. Once the button is clicked, the model will automatically direct you to the “Side by Side Evaluation” tab where the dialog box (Figure 3.33) will appear on top of the input page. As stated before, the user is now able to choose to continue to the page itself, create their own data set or to choose from the many predefined parameter sets created within the model.

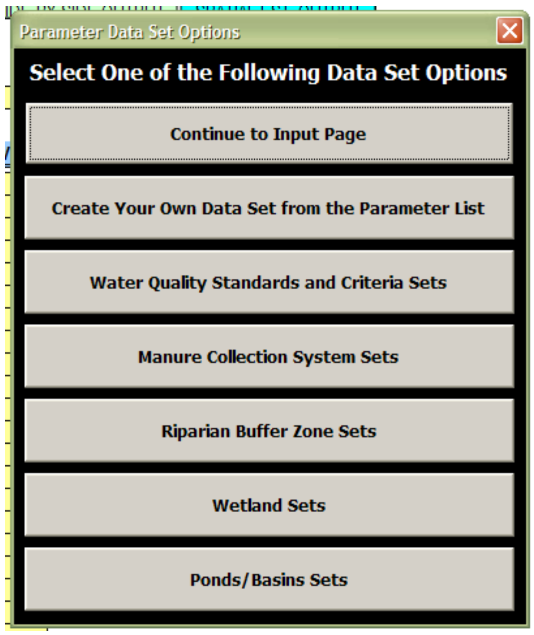



**Figure 3.33 KWQI Model - Parameter Data Set Options Box.** This is a screen capture of the parameter data set options box; this shows the seven main options available to the user for the selection of parameters.

For this example, the evaluation of the effect of a wetland on water quality will be done using monitoring data from two sampling sites. One site is located on the stream before the water enters the wetland and the second data set will be from a monitoring site at the wetland outlet. To save time, the user clicks on the 'Wetland Sets' button and will continue onto the data entry. The first step leading to the actual entering of data is to pick one of the pre-programmed data sets. This selection should be based on how rigorous the evaluation will be.  For all the data sets except the Manure Collection System Sets, there are at least three options provided.  The first option is always the one that contains the smallest number of parameters.  This is referred to as the minimum number of parameters that should be evaluated when assessing the BMP.  It will provide a very basic parameter set that will only use the parameters that are most commonly affected by the BMP in question.  The general sets combine the minimum data set with additional parameters that would be associated with the general health of the water body.  The final choice is defined as the maximum which includes any additional water quality parameters that could be affected by the BMP.  Each popup set dialog box includes a 'GO BACK' button so that if the user is unsure of which set they would like to use, they can easily change their selection. Figure 3.34 shows the parameter sets that have been preprogrammed for wetland evaluation.  This example uses the minimum parameter set for evaluation of wetland efficiency for water quality improvement.

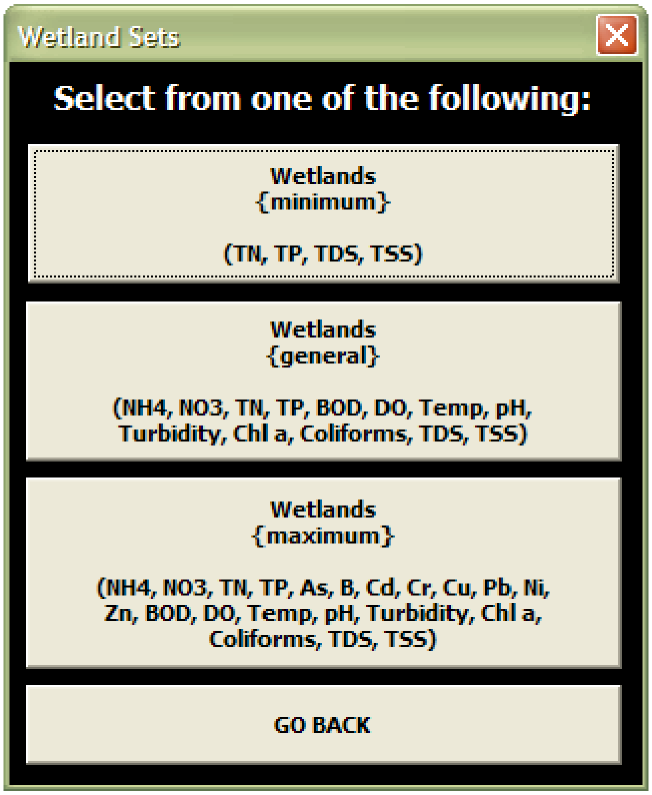



**Figure 3.34 KWQI Model - Wetland Parameter Sets.** This screen shot of the model shows one of the seven parameter data set options available. From this you can see that there are multiple options available and that the parameters for each option are listed.

After choosing the parameter set button, the box will close and the user must click the 'Continue to Input Page' button to input the data. The print screen in Figure 3.35 shows the parameters that were entered into the parameter spaces automatically by choosing that option. The user may also change the parameters at this point. Each of the parameter input spaces have a drop box built into them that contains a list of all the parameters that are available for use in this model. The drop box menu is shown in Figure 3.36.

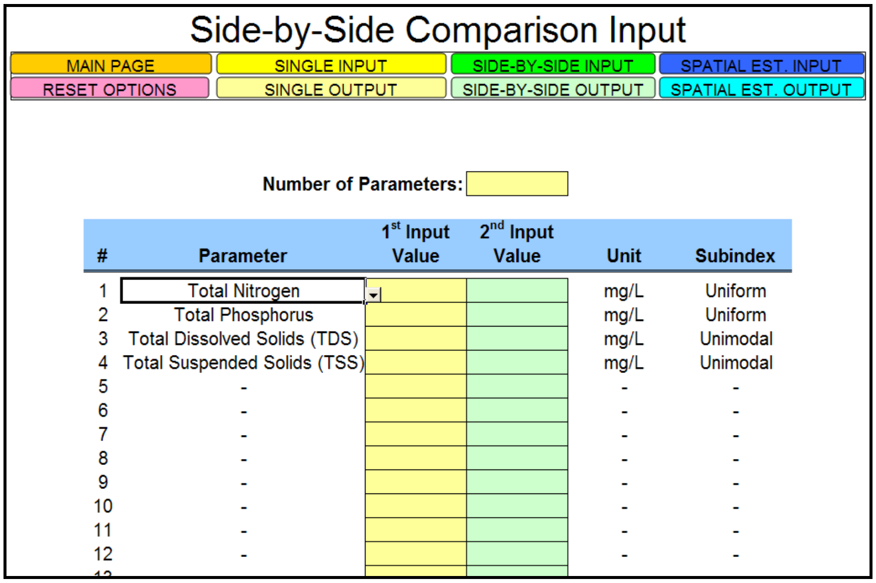



**Figure 3.35 KWQI Model - Entered Parameters and Drop Down Menu –** Automated selection using the models predetermined parameter set.

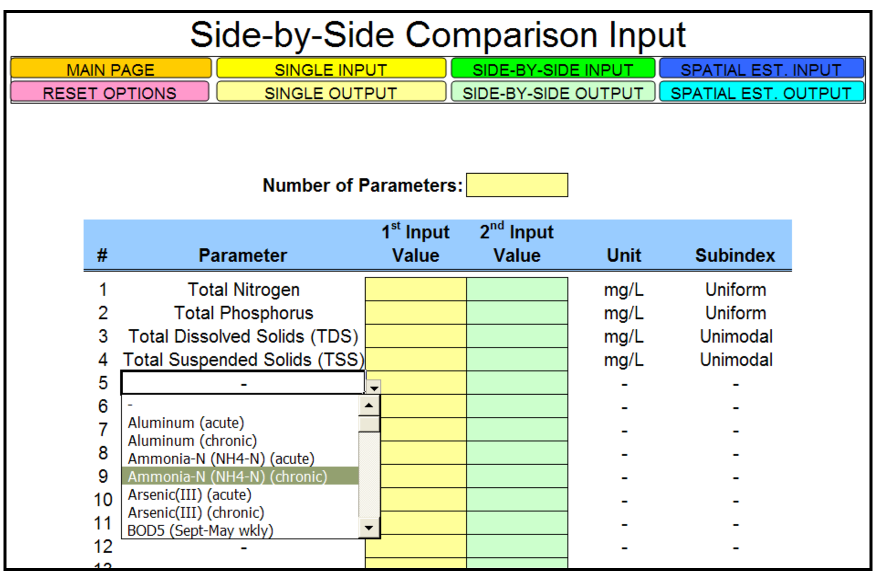
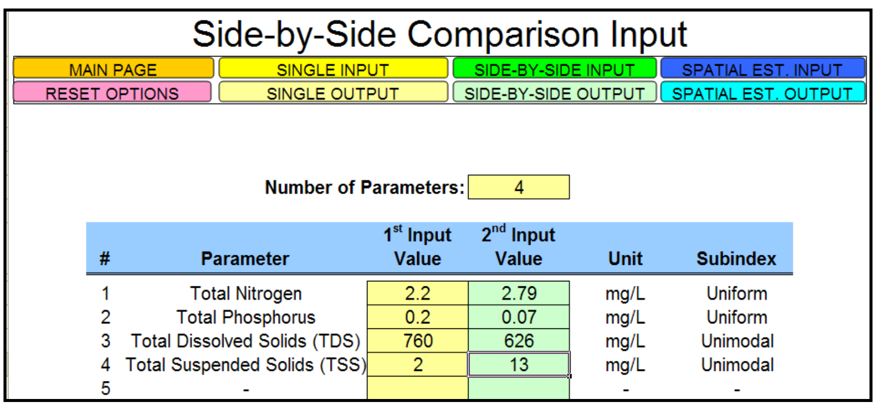



**Figure 3.36 KWQI Model - Entered Parameters and Drop Down Menu –** Parameter selection using the dropdown menu.

The user will then have to enter the concentration values of the selected parameters into the program and define how many parameters are being used. To help keep track of the number of parameters entered, a counter has been added to the page view. It is important to correctly input the total number of parameters used because the equation that calculates the final KWQI value is dependant upon this number. This will also be useful when evaluating a greater number of parameters. After filling in the values, as shown in Figure 3.37, the user will then push the “Click to Run Analysis” button (Figure 3.38). This appears on every input sheet and will run the program, output the data to another work sheet within the model and then switch the view to the newly created output page.

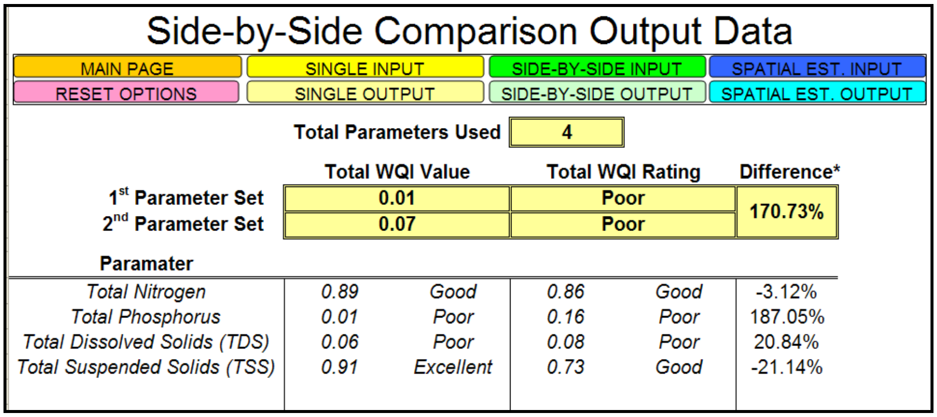



| # | Parameter | 1st Input Value | 2nd Input Value | Unit | Subindex |
|---|---|---|---|---|---|
| 1 | Total Nitrogen | 2.2 | 2.79 | mg/L | Uniform |
| 2 | Total Phosphorus | 0.2 | 0.07 | mg/L | Uniform |
| 3 | Total Dissolved Solids (TDS) | 760 | 626 | mg/L | Unimodal |
| 4 | Total Suspended Solids (TSS) | 2 | 13 | mg/L | Unimodal |
| 5 | - | | | - | - |

**Figure 3.37 KWQI Model - Completed Example Input.** This screen shot of the model provides an example of the input page from the side by side comparison of four parameters.


**Figure 3.38 KWQI Model - Click to Run Analysis button.** This is a screen shot of the button that is pushed to run the model for each of the three main options.

Once the model directs the user to the output page, the first set of analysis appears on the screen (Figure 3.39). The main items on the output page related to the final KWQI value have been highlighted with the light yellow background. As seen in the figure, these values are the number of parameters used in the calculation, the final KWQI value, the rating of the KWQI value and the percent difference between the two data sets.



Side-by-Side Comparison Output Data

| | | | |
|---|---|---|---|
| MAIN PAGE | SINGLE INPUT | SIDE-BY-SIDE INPUT | SPATIAL EST. INPUT |
| RESET OPTIONS | SINGLE OUTPUT | SIDE-BY-SIDE OUTPUT | SPATIAL EST. OUTPUT |

Total Parameters Used: 4

| | Total WQI Value | Total WQI Rating | Difference* |
|---|---|---|---|
| 1st Parameter Set | 0.01 | Poor | 170.73% |
| 2nd Parameter Set | 0.07 | Poor | |

| Paramater | | | | | |
|---|---|---|---|---|---|
| *Total Nitrogen* | *0.89* | *Good* | *0.86* | *Good* | -3.12% |
| *Total Phosphorus* | *0.01* | *Poor* | *0.16* | *Poor* | 187.05% |
| *Total Dissolved Solids (TDS)* | *0.06* | *Poor* | *0.08* | *Poor* | 20.84% |
| *Total Suspended Solids (TSS)* | *0.91* | *Excellent* | *0.73* | *Good* | -21.14% |

**Figure 3.39 KWQI Model - Side-by-Side Example Output.** This is a screen shot of the output data that is automatically created when the model is run for the side by side output evaluation.

In this case, the water quality of the stream both before and after it travels through the wetland received a rating of poor. However, the KWQI value did increase by about 171%. When analyzing data for policy makers, it would be safe to say that the water body is still impaired but that the wetland has made some improvements in general water quality. Below the final KWQI information, the page lists each individual parameter used in the calculation, its sub-KWQI value and the percent difference of the sub-KWQI between the two data inputs. This allows the user to evaluate the change in each individual water quality parameter and to identify problems areas that could specifically be addressed when trying to make future improvements in wetland efficiency. In this example, the amount of total nitrogen increased causing the KWQI to decrease, however, the value only changed by 3%. It could be said that the wetland is keeping the nitrogen levels within tolerable ranges. On the other hand the concentration of TSS increased, causing a 21% decline in the sub-KWQI value. In this case, both sets of values are within the acceptable ranges, but if the trend continues over time than implementation of other BMPs or a reevaluation of the wetland may be needed to understand why the concentration of TSS is increasing.  For those using the model as a rating tool, the percent difference between the sub-KWQI for each water quality parameter can help define where the most improvements in water quality have been made.  In this example, the amount of total phosphorus that was in the system has decreased enough to make the change in the calculated sub-KWQI value increase by about 187%.  The plot in Figure 3.40 is also created in the model to provide a visual of the changes in the individual sub-KWQIs. This plot will be most helpful when using larger parameters sets so that the parameters with the greatest changes can be easily seen.

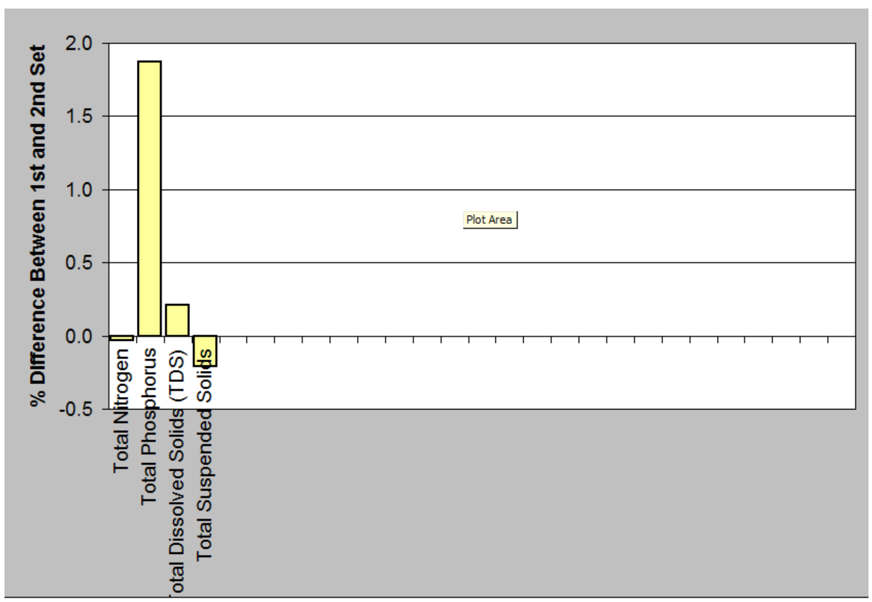



**Figure 3.40 KWQI Model - Example of Plot Showing the Percent Difference between Sub-KWQI Values.**

The plot in Figure 3.41 is adapted for use in all three model options and was added to the model to show the distribution of sub-KWQI values per parameter. Similar to the percent different plot, it can be used to quickly identify the parameters that are the most impaired among the parameter set run. Using this plot, the reason behind low KWQI values can be justified. In this example, the TP and TDS sub-KWQIs were very low for both sets of data compared to the sub-KWQIs for TN and TSS. Since the KWQI uses an aggregation method that does not mask the lower scoring subindices with averages, these low scoring parameters caused the final KWQI value to be low.

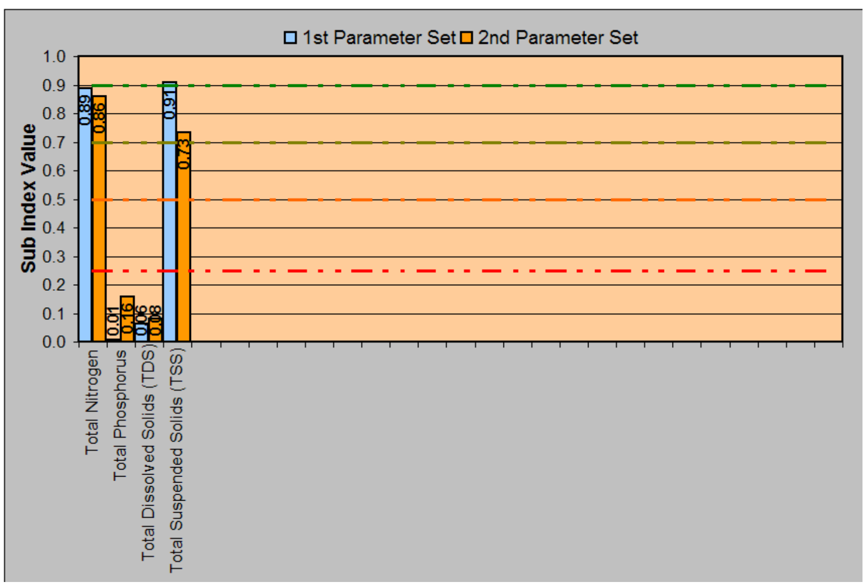



**Figure 3.41 KWQI Model - Example of Output Plot of Side by Side Comparison of Sub-KWQI Values**

Another output set that is included in the model assessment can be seen in Figure 3.42. The green section of the table in Figure 3.42 shows the rating scale and the associated WQI rating scale values. The blue section of the figure shows a breakdown of the five sub-KWQI ratings achieved and lists the number of parameters falling within that sub-index rating. This is available for all three of the model options.

| Rating Scale | WQI Rating Scale | Rating Scale | Number per 1st Set | Number per 2nd Set |
|---|---|---|---|---|
| Poor | 0 - 0.25 | Poor | 2 | 2 |
| Fair | 0.26 - 0.50 | Fair | 0 | 0 |
| Average | 0.51 - 0.70 | Average | 0 | 0 |
| Good | 0.71 - 0.90 | Good | 1 | 2 |
| Excellent | 0.91 - 1.00 | Excellent | 1 | 0 |

**Figure 3.42 KWQI Model - Example of Rating Scale Table and Number of Parameters per sub KWQI Rating**

A plot of the sub-index ratings is generated to graphically show the distribution of the number of parameter sub-indices falling within each of the five rating categories (Figure 3.43).

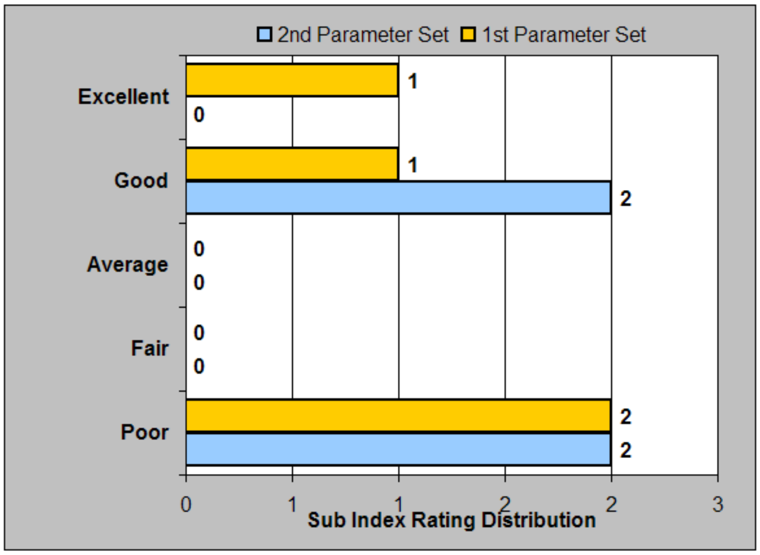



**Figure 3.43 KWQI Model - Example of Chart of Sub Index Rating Distribution**

The most important feature of a user-friendly model is the ability to navigate with ease within the model pages. A tool bar was created to add this feature (Figure 3.44). The tool bar consists of color coded tabs that allow the user to switch between any of the pages by clicking the desired destination. If the user would like to change which main section of the model they are in, going back to the main page will allow them to re-read the option descriptions and decide which one to use.

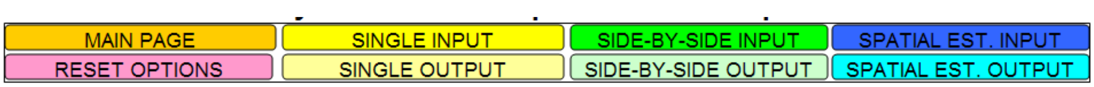



**Figure 3.44 KWQI Model - Navigation Tool Bar.** This is a screen shot of the navigation tool bar that is intended to be used while using the model. The user will scroll over and click the buttons to activate them.

The reset options will allow the user to choose what they would like to have reset within the model section they are working. Figure 3.45 shows the subsequent options available after selecting the ‘Reset Options’ button. Before performing the “reset” task, the model will ask the user if they are sure they want to perform the specific reset task. This is to give the user a second chance if they accidentally chose the wrong reset option.

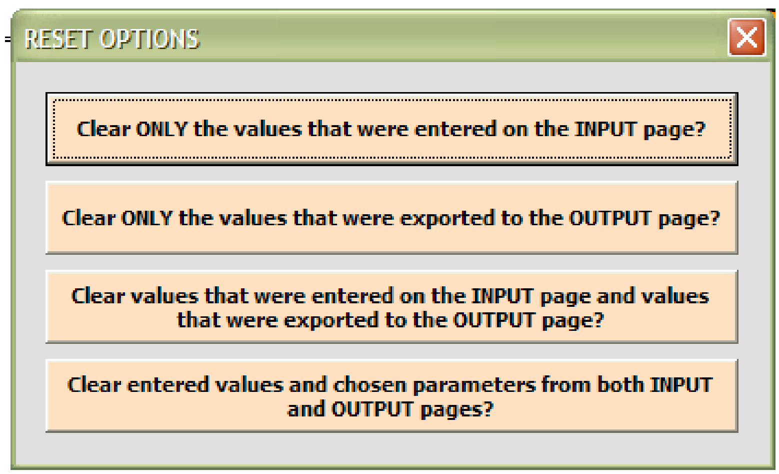



**Figure 3.45 KWQI Model - Reset Options.** This screen shot shows the options that are available to the user in the model when the RESET button is clicked.

When the model is done being used, the user can close the program just like other Excel files. Before closing, it will automatically reset all the sheets within the model and put the model back on the ‘Main Page’. This is to make sure that the model is ready for the next time it will be used. The file will not ask the user to save once the closing tasks have begun so the user must copy any data that they wish to save into a separate file.

**Model Design Assessment: Comparing Kiliszek WQI Ratings to Harrell (2002) Grading Scale**

The purpose of research done by Harrell (2002) was to update a water quality assessment method developed by student researchers funded by the UD Water Resources Agency (UDWRA). The goal of Harrell's project was to update and utilize the older water quality rating system so that it would link stream health to land use. The end result was an updated report card on stream health that could be applied to any sampling site within the UDEW. The report card was meant to be simple enough so that changes could easily be made.

There were 18 water quality parameters monitored for the report card assessment project (Harrell, 2002). Only 9 of those parameters were utilized in the current research. The parameters that were not used from Harrell's (2002) work are alkalinity, chloride, chlorine, hardness, phosphate, turbidity, odor, sheen, and hydrocarbon. Parameters that were used include ammonia, chromium, copper, dissolved oxygen, BOD, iron, nitrate, pH, and conductivity.

The first step that was done to test the model was to make a comparison of the two grading scales. The two grading scales can be seen in Table 3.9, the Harrell scale has been related to the KWQI scale to compare the rating ranges. From the table it is clear that the distribution is different between the two scales. The Harrell states that any value below a 0.40 will receive a rating of POOR where the KWQI value must be below 0.25. The EXCELLENT rating scales are similar to each other only differing by 0.03 points in both scales. The range for each of the individual ratings is approximately the same size but as stated previously the main difference is the score in which the quality variable will receive a rating of POOR.

**Table 3.9 Rating Range Guides for Harrell (2002) and Kiliszek WQI.** This table shows the distribution of the rating scales for the Harrell method and the KWQI.

| | Harrell | Kiliszek WQI |
|---|---|---|
| Excellent | 1 .00 - 0.88 | 1.00 - 0.91 |
| Good | 0.87 - 0.65 | 0.90 - 0.71 |
| Average | - | 0.70 - 0.51 |
| Fair | 0.65 - 0.40 | 0.50 - 0.25 |
| Poor | <0.40 | <0.25 |

Table 3.10 compares the parameter scoring guides for the Harrell (2002) and the KWQI models. There are many similarities between the two grading systems which makes them comparable. However, there are some major differences between the scales as well.

The first similarity is that both model rating scales use excellent, good, fair and poor. The KWQI model has one additional rating category, which is average, falling in between good and fair. Another similarity is that there is no weighting scale for each parameter, they are all equal and carry equal weight when the total rating is calculated. This is one of the points that Swamee and Tyagi (2000 & 2007) stressed in their research, *i.e.*, weighting will skew the grading scale. Although, using a strict average of individual parameter ratings will mask the lower scoring parameters resulting in a rating that is not representative of the entire picture.

**Table 3.10 Parameter Scoring Guides for Harrell (2002) and Kiliszek WQI.** These tables illustrate the ranges and ratings that were used in the Harrell method and the KWQI.

**Grading Guide Harrell (2002)**

| Parameter | Unit | Excellent | Good | Fair | Poor | Max Limit |
|---|---|---|---|---|---|---|
| Ammonia | ppm | < 1 | 2-2.9 | 3-4 | >5 | 10 |
| Chromium | ppm | < 0.0003 | 0.003-0.01 | 0.01-0.03 | >0.04 | 0.05 |
| Copper | ppm | < 0.03 | .03-0.3 | 0.3-0.6 | >0.6 | <1 |
| DO | ppm | 5-6 | 4 | 3 | < 2 | 5-6 |
| BOD | ppm | 5-6 | 4 | 3 | < 2 | 5-6 |
| Iron | ppm | < 0.1 | 0.1-0.15 | 0.15-0.2 | >0.2 | 0.3 |
| Nitrate | ppm | <4 | 4-5 | 6-8 | >8 | 40 |
| pH | | 7 | 6.5-6.9 or 7.1-7.5 | | < 6.0 or >8.0 | 5.0-8.5 |
| Conductivity | | >50 | 50-100 | 100-150 | >200 | |

**Kiliszek WQI Guide**

| Parameter | Unit | Excellent | Good | Average | Fair | Poor | Max Limit |
|---|---|---|---|---|---|---|---|
| Ammonia | mg/L | < 1.5 | 1.5 - 5.5 | 5.5 - 11.0 | 11.0 - 23.7 | >23.7 | 24 |
| Chromium (VI) | mg/L | < 0.0072 | 0.0072 - 0.01 | 0.01 - 0.012 | 0.012 - 0.016 | >0.016 | 0.016 |
| Copper | mg/L | >0.006 | 0.006 - 0.008 | 0.008 - 0.01 | 0.01 - 0.013 | >0.013 | 0.0134 |
| DO | mg/L | 6.9 - 10.2 | 5.9 - 6.9 or 10.2 - 12.6 | 5.1 - 5.9 or 12.6 - 15.9 | 4.0 - 5.1 or 15.9 - 24.6 | < 4.0 or > 24.6 | min of 4 |
| BOD | mg/L | <0.3 | 0.3 - 1.1 | 1.1 - 2.2 | 2.2 - 5 | >5 | 5 |
| Iron | mg/L | < 0.45 | 0.45 - 0.63 | 0.63 - 0.77 | 0.77 - 0.98 | >0.98 | 1 |
| Nitrate | mg/L | < 0.6 | 0.6 - 2.3 | 2.3 - 4.6 | 4.6 - 10 | >10 | 10 |
| pH | | 6.4 - 7.6 | 5.8 - 6.3 or 7.6 - 8.3 | 5.3 - 5.8 or 8.3 - 8.9 | 4.3 - 5.3 or 8.9 - 10.3 | < 4.3 or > 10.3 | 6.5 - 8.5 |
| Conductivity | mS/cm | 0.24 - 0.51 | 0.16 - 0.24 or 0.51 - 0.69 | 0.1 - 0.16 or 0.69 - 0.9 | 0.05 - 0.1 or 0.9 - 1.4 | < 0.05 or > 1.4 | 0.05 - 1.5 |

The major difference between the models is the disparity between the water quality parameter criteria values. Only one parameter has the same maximum limit, or limit range. This could be due to changes in the criteria and regulations that Delaware and the USEPA use over the past eight years. This is also seen in the ranges that are set for the rating scale intervals. In the KWQI calculations, parameters such as DO, pH and, conductivity are based on an optimum value within a range of acceptable values. The Harrell (2002) rating process uses only a single range for DO and conductivity without optimum values.

Table 3.11 compares the final ratings calculated for the individual water quality parameters using both models based on the values provided in Harrell (2002). There were five sites that Harrell (2002) used that that were related to sites used on the UDAESF. Two sample locations were the same in both projects, CP3CR (known as UDAESF Site 2) and CP2CR (known as UDAESF Site 5). Sample locations CP6T3 (known UDAESF Site 3) and CP5T2 (known as UDAESF Site 4) were taken just north of the Amtrak railroad tracks were this project sampled south of the railroad tracks. The final similar sample location was CP4T1 (known as UDAESF Site 7/8) which is located at a stormwater grate that is between Sites 7 and 8 on the farm.

**Table 3.11 Kiliszek WQI *vs* Harrell (2002) Grading System.** This table compares the KWQI Subindex values to the Harrell Sub-rating values. The overall rating from both the KWQI and Harrell method are also shown with the respective rating scales.

| Parameter | Site 2 (CP3CR) sub-WQI | Har | Site 3 (CP6T3) sub-WQI | Har | Site 4 (CP5T2) sub-WQI | Har | Site 5 (CP2CR) sub-WQI | Har | Site 7/8 (CP4T1) sub-WQI | Har |
|---|---|---|---|---|---|---|---|---|---|---|
| Ammonia | G | G | E | E | E | E | E | E | G | F |
| Chromium | E | E | E | E | E | E | E | E | E | E |
| Copper | E | E | E | E | E | E | E | E | P | P |
| DO | F | E | G | E | P | P | P | G | E | E |
| BOD5 | E | P | G | F | E | P | E | P | G | F |
| Iron | E | E | P | P | E | E | F | P | P | P |
| Nitrate | P | P | P | P | A | E | P | P | E | E |
| pH | G | F | F | F | A | G | A | G | E | E |
| Conductivity | A | P | P | E | n/a | n/a | F | P | F | P |
| Value Determined by Indiviudal System {WQI 0 - 1.0} {Harrell 1 - 4 } | | | | | | | | | | |
| WQI | 0.24 | | 0 | | 0.03 | | 0.12 | | 0 | |
| Harrell | | 2.67 | | 2.89 | | 3.13 | | 2.44 | | 2.33 |
| **OVERALL** | **P** | **F** | **P** | **G** | **P** | **G** | **P** | **F** | **P** | **F** |

*E = Excellent G = Good A = Average F = Fair P = Poor*

Despite the differences in criteria limits used in the two models to calculate the sub-indices and their associate ratings, many of the individual water quality parameter ratings were the same for the two models. The ratings developed by each model for chromium and copper concentrations were the same for all 5 monitoring sites. The concentrations of Cr found in the water at the monitoring sites were low enough to earn a rating of excellent. Surface water concentrations of copper received an excellent rating at all the sites except for Site7/8 where elevated copper levels resulted in a rating of poor. The rankings calculated by both models for ammonia differed only at Site 7/8. Ammonia levels were considered excellent at sites 3, 4, and 5. Site 2 earned a rating of good for ammonia concentration by both models. The rating calculated for ammonia concentration at Site 7/8 was good and fair for the KWQI model and the Harrell model, respectively. Similarly, the rankings calculated by both models for iron differed only at Site 5. Iron levels for considered excellent at sites 2 and 4 but poor at sites 3 and 7/8. The rating calculated for iron concentration at Site 5 was fair and poor for the KWQI model and the Harrell model, respectively. The rankings calculated by both models for nitrate differed only at Site 4. Nitrate levels were considered excellent at site 7/8 but poor at sites 2, 3 and 5. The rating calculated for nitrate concentration at Site 4 was average and excellent for the KWQI model and the Harrell model, respectively. The rankings calculated by both models for pH agreed only at Sites 3 (FAIR) and 7/8 (EXCELLENT). At Sites 4 and 5, the ratings for pH were average and good for the KWQI model and the Harrell model, respectively. At site 2, the rating calculated for pH was good and fair for the KWQI model and the Harrell model, respectively.

These differences could be attributed to the lack of 5$^{th}$ ranking in the Harrell (2002) model. The differences could also be explained by the variation in parameters limits and the division of the limits over the two different rating scales.

The rankings calculated by both models for DO agreed only at Sites 4 (POOR) and 7/8 (EXCELLENT). At Site 3, the ratings for DO were good and excellent for the KWQI model and the Harrell model, respectively. At Sites 2 and 5, the rating calculated for DO differed by at least two ranking categories. The DO criteria used in the KWQI model had a range of acceptable concentrations where concentrations greater than 24.6 or less than 4.0 mg $l^{-1}$ would receive a rating of poor. In the Harrell model, only concentrations below 2 mg $l^{-1}$ would receive a rating of poor.

The rankings calculated by both models for conductivity did not agree for any of the monitoring sites. However, the rankings for Sites 2, 5 and 7/8 only varied by one ranking category. The ratings for conductivity calculated by both models for Site 3 were poor and excellent for the KWQI model and the Harrell model, respectively. This difference was directly related to the concentration limits used in the calculation. The KWQI model allows for a wider range of acceptable values in conductivity. However, the data point in this case still fell outside the acceptable range resulting in the poor rating.

The ratings developed by each model for BOD were different for all 5 monitoring sites. The BOD had three similar situations where the KWQI indicated that the BOD was within the tolerable limit but that the Harrell method indicated that the parameter was not. This was due to differences in the relationship between the sub-index value and the concentration of BOD. In the KWQI model, the higher the BOD concentration, the lower the sub-KWQI value it received. The Harrell model indicated that the higher the BOD concentration, the higher the ranking values, where the opposite is true in the KWQI model. Normally, a higher BOD concentration indicates higher levels of organic compounds present in the water, which would tie up the oxygen during biological and chemical degradation, thus resulting in lower water quality.

The overall rankings calculated by the models were very different for all of the 5 monitoring locations. All five sites received a KWQI rating of poor due to the fact that at each of the sites, there were water quality parameters that received a sub-KWQI value of zero or near zero. Using the Harrell (2002) method, Sites 2, 3, 4, 5, and 7/8 received the grades of fair, good, good, fair and fair, respectively. The major difference between the two models is in the type of aggregation equation used to calculate the final index and corresponding rating value. Harrell (2002) averaged all the values that were assigned to each parameter. Given that the scale went from 1 to 4, where 1 was poor and 4 was excellent, your total grade would be between 1 and 4. Simply averaging the values may cause the poorly rated parameters to be masked by the high ranking scores thereby resulting in an overall water quality rating higher than expected. The KWQI model uses an aggregation equation developed by Swamee and Tyagi (2000 & 2007) that does not weight the individual parameters but does not let parameters with low sub-index values be masked by parameters receiving high sub-index values. Therefore the KWQI model will indicate impairment in stream health when the concentration of only one water quality parameter falls below the established criteria. A single, very low sub-index value can cause the final KWQI to fall within the poor rating category. For this reason, the KWQI model program shows the individual parameter sub-indices and ratings as well as the overall index and rating value. The model was designed to function as a tool to identify problems in stream health and to identify which individual water quality parameters have the greatest influence on the overall rating.. The model's assessment allows the user to monitor the stream's changes in overall water quality as well as the change in concentration of each individual monitored parameter.

**Selection of Parameter Sets for KQWI Model Assessments**

A summary of the parameter sets is shown in Table 3.12 indicating the number and type of parameters used in each of the different assessment scenarios.

The first section of parameter sets in the table is based on the DWQS for fresh water and is used for assessments of general fresh water stream health. This set contains 6 basic parameters: temperature, DO, pH, turbidity and coliform bacteria. The second set of parameters will include the DWQS set with the addition of the Delaware Water Quality Criteria for the Protection of Aquatic Life (DWQCPAL). The additional parameters include: aluminum, ammonia, arsenic, cadmium, chromium, copper, lead, nickel and zinc. The third set of parameters will combine the DWQS and the DWQCPAL in addition to the Delaware Water Quality Criteria for the Protection of Human Health (DWCPHH), adding nitrate to parameter set. The fourth set of parameters includes the DWQS, DWQCPAL and the DWCPHH with the addition of the USEPA criteria for nutrients; additional parameters include total phosphorus, total nitrogen and chlorophyll a. The fifth parameter set includes all 22 parameters that were monitored in the Cool Run. The sixth set in this section will include only parameters the USEPA state as early indicators of stream impairment, these are nitrate, total phosphorus, turbidity and chlorophyll a.

| | DE WQ Standards | DE WQ Standards WQ Crit Aqua Life | DE WQ Standards WQ Crit Aqua Life WQ Crit Hmn Hlth | DE WQ Standards WQ Crit Aqua Life WQ Crit Hmn Hlth EPA Nutrient | ALL | Early indicator | Manure Sytm {min} | Manure Collection | Riparian {min} | Riparian Buffer | Riparian {max} | Wetland {min} | Wetland | Wetland {max} | Ponds/Basins {min} | Ponds/Basins | Ponds/Basins {max} |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Group #** | | | **I** | | | | **II** | | | **III** | | | **IV** | | | **V** | |
| **Set #** | **1** | **2** | **3** | **4** | **5** | **6** | **1** | **2** | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** |
| **# Parameters** | **6** | **14** | **15** | **18** | **22** | **4** | **5** | **10** | **6** | **10** | **18** | **4** | **13** | **21** | **3** | **8** | **11** |
| **Ammonia** | | y | y | y | y | | y | y | y | y | y | | y | y | | y | y |
| **Tot N** | | | | y | y | y | y | y | y | y | y | | y | y | | y | y |
| **Nitrate** | | | y | y | y | | y | y | y | y | y | y | y | y | | y | y |
| **Tot P** | | | | y | y | y | y | y | y | y | y | y | y | y | y | y | y |
| **Arsenic** | | y | y | y | y | | | | | | y | | | y | | | |
| **Boron** | | | | | y | | | | | | y | | | y | | | |
| **Cadmium** | | y | y | y | y | | | | | | y | | | y | | | |
| **Chromium** | | y | y | y | y | | | | | | y | | | y | | | |
| **Copper** | | y | y | y | y | | | | | | y | | | y | | | |
| **Lead** | | y | y | y | y | | | | | | y | | | y | | | |
| **Nickel** | | y | y | y | y | | | | | | y | | | y | | | |
| **Zinc** | | y | y | y | y | | | | | | y | | | y | | | |
| **BOD** | | | | | y | | | y | | | | y | y | y | y | y | y |
| **DO** | y | y | y | y | y | | | y | | | | | y | y | | y | y |
| **Temperature** | y | y | y | y | y | | | y | | y | y | | y | y | | | y |
| **pH** | y | y | y | y | y | | | y | | y | y | | y | y | | | y |
| **Conductivity** | | | | | y | | | | | | | | | | | | |
| **Turbidity** | y | y | y | y | y | y | | | | y | y | | y | y | | | |
| **Chlorophyll a** | | | | y | y | y | | y | | y | y | | y | y | | | |
| **Coliforms** | y | y | y | y | y | | y | y | | | | | y | y | | | y |
| **TDS** | | | | | y | | | | y | y | y | | y | y | | y | y |
| **TSS** | y | y | y | y | y | | | | y | y | y | y | y | y | y | y | y |

**Table 3.12 Parameter Sets – Table shows the parameters sets based on analysis criteria.**

The other assessment groups were designed for the model in order to evaluate the impacts on water quality of the Cool Run after implementation of the different BMPs on the NRECF. The second group was designed to assess the effects of the Manure Collection System, which was installed in order to reduce the amount of nutrients and coliform bacteria in surface runoff entering the stream. The five parameters chosen for the first set in this assessment group include ammonia, total nitrogen, nitrate, total phosphorus and coliform bacteria. The second set of parameters in this group includes the previous five parameters with the addition of BOD, DO, temperature, pH and chlorophyll a. These parameters were added to help characterize the overall health of the stream because of the indirect effects that manure leachate components may have on geochemical processes that could result in changes in their concentrations.

The third group of parameter sets was designed to assess the effects of riparian buffer zones on stream water quality. Buffer zones can be used to help control bank erosion, remove nutrients and prevent sediment from entering the stream. The minimum number of parameters that were chosen to rate the effect of the riparian buffers included six parameters; ammonia, total nitrogen, nitrate, total phosphorus, TDS and TSS (Group III - Set 1). The set 2 in this group included the previous set as well as the addition of temperature, pH, turbidity and chlorophyll a. These parameters were added to help determine the overall health of the stream in addition to the parameters directly influenced by buffer zones. The final parameter set (Set 3) in this group adds 8 different metals. The metals include arsenic, boron, cadmium, chromium, copper, lead, nickel and zinc. The addition of the metals was included to help determine if the vegetation along the stream is able to uptake the metals as potential micronutrients for growth from the water as it moves through the system.

The fourth group of parameter sets was designed to assess the effect a wetland has on the water as it flows through. Wetlands are designed to remove the total amount of nitrogen, settle out solids and reduce the amount of phosphorus in the water moving through the system. The minimum parameter set that is to be used for the evaluation of the wetland includes 4 parameters; total nitrogen, total phosphorus, BOD, and TSS (Group IV - Set 1). The second set of parameters in this group was designed to determine more specifically which nitrogen species have been degraded in the wetland by the addition of ammonia and nitrate; turbidity has also been added. To check on the general health of the wetland, DO, temperature, pH, chlorophyll a, coliform bacteria and TDS were added to this set. The final parameter set in this group (Group IV - Set 3) includes all of the parameters from the previous set with the addition of the metals arsenic, boron, cadmium, chromium, copper, lead, nickel and zinc. Similar to the riparian buffer zone, the plants within and surrounding the wet areas of the wetland should take up some of the metals as micronutrients.

The fifth and final group of parameters that are listed in the Table 3.12 were designed to assess the productivity of a pond/storm water basin. These basins are typically known for their ability to decrease the amount of phosphorus and BOD and for providing a place for sedimentation to occur. The first set of parameters in this group only evaluates the pond’s effect on phosphorus, BOD and TSS concentrations. These parameters are very limited and provide a very small but specific picture of what is actually occurring in the stream. The second set of parameters in this group adds ammonia, total nitrogen, nitrate, DO and TDS to the previous parameters. This will provide a little bit more information about the general health of the pond/basin. The final set of parameters (Group V - Set 3) use all the above listed parameters and adds temperature, pH and coliform bacteria. These three parameters were added because they are considered indicators of stream health for fresh waters.

The KWQI Worksheet Model was used to calculate the KWQI values using the average 2009 monitoring data for Site 4. The individual sub-index values for all 22 parameters previously listed in Table 3.12 are shown in Table 3.13. This was done to show the range of values that would be used in the aggregation process that determines the final KWQI for the different parameter sets. It is clear from the table, that the sub- KWQI values range from 0.07 to 1.00. Although there were many “Excellent” ratings in this set, it also contained parameters that received a low rating of “Poor”. This set was chosen to show the impact of choosing different parameters for aggregation on the final KWQI value. This set of parameters was used to determine the effects on the addition of parameters for all the different groups of parameter sets.

Once the subindices were calculated for each of the 22 parameters, the KWQIs for each of the parameter sets within each of the groups listed in Table 3.12 were determined. Table 3.14 is a summary of the calculated KWQI values. Each previously described group was kept separate to make comparisons.

**Table 3.13 Sub-KWQI Using Average 2009 Data from Site 4.** These show the individual subindex values for each of the parameters that will be used to determine the variability in the KWQI using different sets of parameters.

| | | | | | |
|---|---|---|---|---|---|
| Ammonia-N | 0.99 | Excellent | Zinc | 0.83 | Good |
| Nitrates | 0.59 | Average | BOD5 | 0.82 | Good |
| Total Nitrogen | 0.16 | Poor | DO | 0.97 | Excellent |
| Total Phosphorus | 0.81 | Good | Temperature | 0.90 | Good |
| Arsenic(III) | 1.00 | Excellent | pH | 0.83 | Good |
| Boron | 1.00 | Excellent | Conductivity | 0.50 | Fair |
| Cadmium | 1.00 | Excellent | Turbidity | 0.80 | Good |
| Chromium (III) | 1.00 | Excellent | Chlorophyll a | 0.71 | Good |
| Copper | 0.16 | Poor | Coliforms | 0.22 | Poor |
| Lead | 1.00 | Excellent | TDS | 0.07 | Poor |
| Nickel | 1.00 | Excellent | TSS | 0.96 | Excellent |

The Group I dealt with standards, criteria and the early indicator parameter sets. The early indicator parameter set (Set 6) containing the minimum number of water quality parameters was used as a basis for comparison of the other parameter sets in this group. Percent difference in Table 3.14 refers to the difference between the KWQI of the early indicator set (Set 6) and to the KWQI of the other sets within the standards based assessment group. The KWQI was calculated to be 0.148 for the early indicator set resulting in a rating of "Poor". A negative value for the percent differences indicates a decrease in the KWQI. Conversely, a positive value indicates an increase in the KWQI. There was a 36.8% difference between the KWQI calculated for the early indicator set (Set 6) and the DWQS Set (Set 1). The percent difference between the KWQI for Set 2 composed of the DWQS and the DWQCPAL and the early indicator set was 1.6%. The addition of the metals and ammonia into the equation for this group caused only a slight difference when compared to the difference between the Early Indicator set (Set 6) and the DWQS set (Set 1), respectively.

**Table 3.14 Parameter Set WQI Value –** This table was constructed using the average values from 2009 for each of the six sites. Individual parameters that make up each set can be seen in Table 3.12.

| Parameter Set Name | KWQI | % Diff |
|---|---|---|
| **Early indicator** | 0.148 | **0.0%** |
| **DE WQ Standards** | 0.215 | **36.8%** |
| **DE WQ Standards<br>WQ Crit Aqua Life** | 0.151 | **1.6%** |
| **DE WQ Standards<br>WQ Crit Aqua Life<br>WQ Crit Hmn Hlth** | 0.151 | **1.6%** |
| **DE WQ Standards<br>WQ Crit Aqua Life<br>WQ Crit Hmn Hlth<br>EPA Nutrient** | 0.130 | **-13.1%** |
| **ALL** | 0.071 | **-70.9%** |
| | | |
| **Manure Sytm {min}** | 0.126 | **0.0%** |
| **Manure Collection** | 0.142 | **11.8%** |
| | | |
| **Riparian {min}** | 0.067 | **0.0%** |
| **Riparian Buffer** | 0.070 | **4.6%** |
| **Riparian {max}** | 0.071 | **4.9%** |
| | | |
| **Wetland {min}** | 0.061 | **0.0%** |
| **Wetland** | 0.071 | **15.1%** |
| **Wetland {max}** | 0.071 | **14.1%** |
| | | |
| **Ponds/Basins {min}** | 0.677 | **0.0%** |
| **Ponds/Basins** | 0.070 | **-162.7%** |
| **Ponds/Basins {max}** | 0.070 | **-162.5%** |

The addition of nitrate in Set 3 did not change the KWQI compared to Set 2. The low rating of the copper sub-KWQI caused both final KWQIs to fall into a lower rating category because the parameter concentration value greatly exceeded the threshold limit criteria. The difference between the Early Indicator KWQI (Set 6) and Set 3 KWQI was 1.6%. Set 4 included the DWQS, DWQCPAL, DWQCPHH and the USEPA criteria for nutrients. The addition of the three parameters to this set decreased the KWQI by about 13.1% from the KWQI of Set 6. Using all the monitored parameters (Set 5) to calculate KWQI resulted in a 57.8% decrease from Set

4.  The final parameters that were added to Set 5 were BOD, conductivity and TDS.  In this example, the BOD and conductivity were within tolerable ranges when the sub-index values were calculated.  The TDS was significantly out of range for tolerable quality standards; therefore, the KWQI reflected this impairment in the stream water quality.  This resulted in an 70.9% decrease in the KWQI calculated for the early indicator set.

The second group of parameters was used for the evaluation of the manure collection system.  The KWQI calculated for the two parameter sets differed by only 11.8%.  Addition of the 5 other water quality parameters resulted in a slightly higher KWQI.  The 5 additional parameters had high sub-KWQIs that ranked either excellent or good resulting in the slight increase of the overall KWQI.  However, the KWQI still indicated a rating of POOR because of the high concentration of coliform bacteria. The model output with the listing of the individual sub-KWQIs for all the water quality parameters use to calculate this final KWQI can identify those parameters responsible for the low rating.  This is a very helpful tool for scientists, engineers and decision makers who need to address the changes in stream health and work towards improvement of water quality.

In assessment Group III, the 3 parameters sets designed to evaluate riparian buffer zones resulted in slight variances in KWQIs.  There were six parameters used in the base comparison - Set 1, ten used in the general comparison - Set 2 and then twenty used in the max comparison - Set 3.  With the addition of the first four parameters the KWQI increased by 4.6%.  The final addition of ten extra parameters resulted in a KWQI difference of less than 0.3%.  This leads to the conclusion that when judging the riparian buffer zone that the parameters chosen for the general and maximum sets are not as sensitive as the parameter sets that have been used in the previous two sets.

Assessment Group IV, for wetland evaluation used five parameters in the minimum comparison-Set 1, thirteen in the general comparison- Set 2 and twenty-one in the maximum comparison-Set 3. The percent difference between the calculated KWQI of the minimum and general sets was 15.1%, however the difference between the general and the maximum set KWQI was only -1.0% respectively. Although the additional parameters of Sets 2 and 3 decreased the KWQI significantly from that of Set 1 it seems a better representation of what is actually occurring in the stream. It is recommended that the general or maximum parameter sets are used when trying to define stream health. The minimum parameter set will provide an over estimated KWQI indicating a healthier stream than the other two parameter sets. This minimum analysis can be used for a quick evaluation of water quality.

The final group (Group V) of parameter sets were created to rate the effects on water quality of ponds/basins within the stream flow pattern. The parameters sets that were created behaved in a similar fashion to the ones that were created for the wetland evaluation. The decrease in the KWQI value between the minimum and general parameter sets was 162.7% with the addition of five parameters. The increase in the KWQI between the general and the maximum was only 0.2% with the addition of three more parameters. For calculation purposes the general or maximum parameter sets should be used. However, for a simple evaluation of the change in certain water quality parameters, the minimum parameter set would suffice.

The goal of this WQI is to not get the highest WQI value by using the least amount of parameters in the calculations, but to show any signs of stream impairment.

As shown in the example of using the model having the individual sub-indices can be useful when making comparisons for specific parameters. The total index value is good indicator of stream health and can help identify areas needing improvement. In this case, it can be seen that Copper, TDS and coliform bacteria are the problem parameters that need to be addressed.

## Cool Run KWQI Model Assessments

The KWQI Model was used to assess changes in water quality in the Cool Run based on actual monitoring data. The model was also used to determine the impacts of BMP implementation on water quality of the Cool Run within the NRECF. This was done using the developed parameter sets described previously.

### Analysis of Changes between 2001 and 2009 (Sites 2, 3, 4 and 5)

Using available data from Harrell (2001), changes in the water quality of the stream from 2001 to 2009 was assessed using monitoring data collected from Sites 2, 3, 4, and 5. These were the sites along the main stream that paralleled the sample locations from Harrell (2001). The parameter set used to calculate the final KWQI values was different than the model pre-sets because of the lack of comparable data between the two projects. The parameters included in the analysis were ammonia-N, nitrate-N, chromium, copper, BOD, DO, pH and conductivity. The individual sub-KWQI values are listed in Table 3.15.

**Table 3.15 2001 and 2009 Sub-KWQI Values for Sites 2, 3, 4, and 5.** This table shows the break down of the individual parameter subindex values for the four sites during the two study periods. The values are color coded based on the rating received.

| | Site 2 | | Site 3 | | Site 4 | | Site 5 | |
|---|---|---|---|---|---|---|---|---|
| | **2001** | **2009** | **2001** | **2009** | **2001** | **2009** | **2001** | **2009** |
| **Ammonia-N (NH4-N) (acute)** | 0.88 | 0.95 | 1.00 | 1.00 | 1.00 | 0.99 | 0.97 | 0.98 |
| **Chromium (III) (chronic)** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Copper (acute)** | 1.00 | 0.11 | 1.00 | 0.01 | 1.00 | 0.16 | 1.00 | 0.50 |
| **DO (daily average)** | 0.17 | 0.58 | 0.35 | 0.94 | 0.00 | 0.71 | 0.07 | 0.96 |
| **BOD5 (Sept-May mthly)** | 1.00 | 0.80 | 0.85 | 0.82 | 0.92 | 0.82 | 1.00 | 0.80 |
| **Nitrates (NO3-N)** | 0.25 | 0.62 | 0.14 | 0.60 | 0.69 | 0.59 | 0.14 | 0.63 |
| **pH** | 0.71 | 0.81 | 0.30 | 0.93 | 0.58 | 0.83 | 0.58 | 0.86 |
| **Conductivity** | 0.65 | 0.60 | 0.08 | 0.45 | - | - | 0.44 | 0.62 |
| | Excellent | Good | Average | Fair | Poor | | | |

The final KWQI values are listed in Table 3.16. Base on the KWQI values, two out of the four sites have improved since 2001. The overall rating at Site 4 has increased by 4160%, The rating did not change from 'Poor' but improvements up campus such as the installation of the rain garden have helped to increase the KWQI from 0.004 to 0.16. The KWQI for Site 3 has decreased from 0.08 to 0.01 corresponding to an 80% difference from 2001 to 2009. Site 2 KWQI values have decreased from 0.15 to 0.11 corresponding to a 28% difference from 2001 to 2009. At Site 5 where the Cool Run exits the NRECF, the KWQI has increased from 0.06 to 0.39 since 2001. The 500% increase in the KWQI value changed the rating from 'Poor' in 2001 to 'Fair' in 2009.

**Table 3.16 2001 and 2009 KWQI Values for Sites 2, 3, 4 and 5.** This table shows the final KWQI aggregated index value for the two years of the study broken down by the individual sites.

| | 2001 | 2009 |
|---|---|---|
| Site 2 | 0.15 | 0.11 |
| Site 3 | 0.08 | 0.01 |
| Site 4 | 0.004 | 0.16 |
| Site 5 | 0.06 | 0.39 |

The percent differences in the individual sub-KWQI ratings are shown in Table 3.17. The negative values indicate a decline in the sub-KWQI while a positive value indicates an increase. This table shows how the different parameters have changed within the last eight years.

**Table 3.17 Percent Change between 2001 and 2009 Quality Variables.** This table breaks down the percent difference between 2001 and 2009 average values. Each individual site is also broken down by the parameters that were used in the KWQI calculation.

| | ***Percent Difference*** | | | |
|---|---|---|---|---|
| **Parameter** | **Site 2** | **Site 3** | **Site 4** | **Site 5** |
| Ammonia-N (NH4-N) (acute) | 8% | 0% | -1% | 1% |
| Chromium (III) (chronic) | 0% | 0% | 0% | 0% |
| Copper (acute) | -89% | -99% | -84% | -50% |
| DO (daily average) | 238% | 170% | 18813% | 1305% |
| BOD5 | -20% | -4% | -10% | -20% |
| Nitrates (NO3-N) | 148% | 334% | -14% | 354% |
| pH | 14% | 210% | 42% | 47% |
| Conductivity | -8% | 447% | - | 40% |
| Change in Total KWQI | -28% | -80% | 4160% | 500% |

Copper concentrations have increased at all the Sites resulting in a decrease in the sub-KWQI. Dissolved oxygen concentrations increased and BOD concentration decreased, both resulting in an increase in the sub-KWQI. The concentration of ammonia for all the sites in both projects always resulted in a rating of ‘Good’ to ‘Excellent.’ The concentration levels for chromium were well below the criteria limit and received a rating of ‘Excellent’ in both studies. The copper concentration was one of the main contributors to the low KWQI values observed. In 2001, the copper concentrations at all the sites resulted in a rating of excellent, but for the 2009 monitoring data, the ratings were ‘Poor’, ‘Poor’, ‘Poor’, and ‘Fair’ for Sites 2, 3, 4 and 5, respectively. Between 2001 and 2009, there was an increase in copper leaching into the stream and entering the farm from Sites 3 and 4. The point source of this copper input is unknown; however, the residential land area surrounding these 2 sites was developed on an industrial property. Although the sites within the NRECF are impaired by the copper levels the concentration in the water as the stream exits at Site 5 is within tolerable range of less than 0.0134 mg/L for the acute exposure rate. The concentration of DO in the water has increased between 39% and 140% between 2001 and 2009. The nitrate levels that were observed in 2001 resulted in a rating of ‘Poor’ at 3 of the 4 sites. The sub-KWQI calculated from the concentrations observed at Sites 2, 3 and 5 have decreased by 85%, 125% and 128%, respectively and now all have an ‘Average’ rating. The pH values have changed but are still within the tolerable limits that promote a healthy stream. Conductivity concentrations remained relatively the same or increased toward the optimum criteria value in the KWQI concentration curve (Figure 3.25).

Overall the general health of the stream improved during the 8 years following the 2001 monitoring. The Kiliszek Model was very useful in assessing the impacts of the implementation of BMPs and other farm management practices on water quality in the Cool Run

**<u>Analysis of Gore Hall Wetland (Sites 1, 2, 3 and 4)</u>**

The analysis of the wetland will be done using two of the pre-designed parameter sets; the General Wetland, Group IV - Set 3 and the DWQS + DWQCPAL, Group I - Set 2 (Table 3.12). The analysis of the wetland will be completed in two parts. The first part will be to calculate the actual KWQIs for Sites1, 2, 3 and 4 using the 2009 average data. The second part will examine the pattern of flow between the sample sites and how the water quality of the upstream tributaries may affect the water quality downstream. The tributaries of sample Sites 1, 3 and 4 converge and then flow into the main branch, which is sampled at Site 2 (Figure 2.6). In part 2, the water quality parameter concentrations used to calculate the KWQI for Site 2 will be estimated from composite values based on the 2009 average concentrations and average flow rates from Sites 1, 3, and 4. A comparison will be made between the Site 2 KWQI value from part one and the estimated Site 2 KWQI from part two.

The KWQI values calculated for Sites 1, 2, 3 and 4 in part one are listed in Table 3.18. The KWQI values for each of the tributaries differed between the two parameter set assessments. The wetland parameter set resulted in lower KWQI values for all of the tributaries while the KWQI values calculated with the parameter set based on Delaware standards and criteria were approximately twice the amount. However, the KWQI for Site 2 was the same for both parameter set assessments. This KWQI value was used for the comparison to the estimated composite KWQI value.

**Table 3.18 Wetland Analysis and Parameter Set Comparison.** The table compares the values for Sites 1, 2, 3 and 4 using the General Wetland (GroupVI – Set 2) and then for using the DWQS + DWQCPAL (Group I – Set 2) parameter sets for determining the KWQI value.

| | **General Wetland** | **DWQS + DWQCPAL** |
|---|---|---|
| Site 1 | 0.000 | 0.012 |
| Site 3 | 0.023 | 0.015 |
| Site 4 | 0.070 | 0.150 |
| | | |
| Site 2 | 0.004 | 0.004 |

The estimated composite concentrations for Site 2 are calculated from the sum of the pollutant loads flowing from the three tributaries (Equation 3.1). This is a simplified estimation which assumes that no physical or chemical processes affect the pollutant loadings.

$$C_2 = \left( \frac{(C_1 * Q_1) + (C_3 * Q_3) + (C_4 * Q_4)}{(Q_1 + Q_3 + Q_4)} \right) \tag{3.1}$$

Where $C_1$, $C_2$, $C_3$ and $C_4$ are the individual parameter concentrations for Sites 1, 2, 3, and 4, respectively and $Q_1$, $Q_2$, $Q_3$ and $Q_4$ are the average flows for Sites 1, 2, 3 and 4, respectively. The estimated $C_2$ was determined for each of the water quality parameters utilized in the parameter set assessments.

The sub-KWQI values are shown in Tables 3.19 and 3.20 for both the actual and estimated composite value that would be expected at Site 2 based on Equation 3.1. The charts have been color coded by the received rating to help illustrate if the actual and estimated values received the same rating, if the actual was better than expected, or if the actual was worse than the expected value. Specific sub-KWQI values were provided to quantify the changes within the same rating range.

**Table 3.19 Actual and Estimated sub-KWQI for Site 2 (General Wetland).** The table breaks down the individual sub-KWQI values by parameter into the actual and estimated value determined using Equation 3.1 based on the General Wetland (Group VI – Set 2) parameter set.

| | Actual | Estimated |
|---|---|---|
| Ammonia-N (NH4-N) (acute) | 0.95 | 0.99 |
| Nitrates (NO3-N) | 0.62 | 0.60 |
| Total Nitrogen | 0.11 | 0.16 |
| Total Phosphorus | 0.33 | 0.39 |
| BOD5 (Sept-May wkly) | 0.80 | 0.82 |
| DO (instantaneous) | 0.91 | 1.00 |
| Temperature | 0.91 | 0.91 |
| pH | 0.81 | 0.90 |
| Turbidity | 0.00 | 0.51 |
| Chlorophyll a | 0.01 | 0.06 |
| Coliforms (1 sample) | 0.26 | 0.24 |
| Total Dissolved Soilds (TDS) | 0.09 | 0.07 |
| Total Suspended Solids (TSS) | 0.39 | 0.51 |

| |
|---|
| Excellent |
| Good |
| Average |
| Fair |
| Poor |

**Table 3.20 Actual and Estimated sub-KWQI for Site 2 (DWQS +DWQCPAL).** The table breaks down the individual sub-KWQI values by parameter into the actual and estimated value determined using Equation 3.1 based on the DWQS + DWQCPAL (Group I – Set 2) parameter set.

| | Actual | Estimated |
|---|---|---|
| Ammonia-N (NH4-N) (acute) | 0.95 | 0.99 |
| Arsenic(III) (acute) | 1.00 | 1.00 |
| Cadmium (acute) | 0.94 | 0.97 |
| Chromium (III) (acute) | 1.00 | 1.00 |
| Copper (acute) | 0.11 | 0.03 |
| Lead (acute) | 1.00 | 1.00 |
| Nickel (acute) | 1.00 | 1.00 |
| Zinc (acute) | 0.95 | 0.68 |
| DO (instantaneous) | 0.91 | 1.00 |
| Temperature | 0.91 | 0.91 |
| pH | 0.81 | 0.90 |
| Turbidity | 0.00 | 0.51 |
| Coliforms (1 sample) | 0.26 | 0.24 |
| Total Suspended Solids (TSS) | 0.39 | 0.51 |

| |
|---|
| Excellent |
| Good |
| Average |
| Fair |
| Poor |

There were many differences between the actual and estimated sub-KWQI values for Site 2. By comparing the estimated values to the actual values, an evaluation of the impact of the wetland on water quality can be made. The installed BMPs should help to maintain the current health of the stream or hopefully improve the quality of the water.

Using the General Wetland Parameter set (Group IV – Set 2), the estimated pH sub-KWQI received a lower rating than the actual (0.91 and 0.81 respectively); both ratings were within the tolerable pH ranges for stream quality. The sub-KWQI for turbidity was much lower for the actual data than the estimated value (0.00 and 0.51 respectively). Receiving such a low POOR value with the sub-KWQI value will have an overall effect on the KWQI once the total value is aggregated. The values for the TSS sub-KWQI were also lower for the actual value than for the composite value (0.39 and 0.51 respectively); these were both within the AVERAGE range. The TDS, Chl *a*, and TP sub-KWQI values had almost no difference between the actual and estimated values; all received ratings of POOR. Ammonia, nitrate, TN, BOD5, DO, temperature, and coliform bacteria all were the same range or had little or no variance between the actual and composite values. If wetland was functioning properly, you would expect to see a significant reduction in the turbidity, TDS and TSS, reductions could be up to an estimated 58% of the solids as previously stated in Chapter 1. These three parameters are all still very problematic at Site 2. It is possible that loose stream bedding may constantly be deposited and removed through natural stream cycles. As mentioned previously, the weir at the outlet of the wetland was in disrepair for quite awhile. Now that it has been repaired, the solid concentrations should be reduced.

Using the DWQS and DWQCPAL Parameter set (Group I – Set 2) a different view of the wetland can be looked at. As previous stated the actual ammonia, DO, temperature and coliform bacteria were approximately the same to the estimated values. The pH, turbidity and TSS behaved as previously described in the General Wetland Parameter set. The major changes in this analysis were the addition of metals to the parameter set and the subtraction of nitrate and TP. For arsenic, cadmium, chromium, lead, and nickel the values were very similar all receiving a rating of EXCELLENT. The copper received a rating of POOR, however the actual sub-KWQI value was 0.11 while the expected value was 0.03, and this means that copper was removed within the wetland area. Zinc values in the actual sample received a rating of 0.95 where the estimated value was 0.68; this shows that there is zinc being removed.

Based on the analysis of these two parameter sets the individual sub-KWQI values can be estimated with some accuracy. However, using only the estimate values could lead to some of the actual problems being masked. Conversely, areas of great improvement of the water quality can also be masked.

The KWQI values for Site 2 determined in part one and two for both parameter sets are shown in Table 3.21.

**Table 3.21 Actual and Estimated KWQI for Site 2.** The table shows the actual and estimated values that were calculated for Site 2 using the General Wetland (Group VI – Set 2) parameter set and then by using the DWQS + DWQCPAL (Group I – Set 2) parameter set.

| | **General Wetland** | **DWQS + DWQCPAL** |
|---|---|---|
| Site 2 | 0.004 | 0.004 |
| EST. Site 2 | 0.026 | 0.027 |

The values for the KWQI were significantly different than was expected based on the values in the sub-KWQIs (Tables 3.19 and 3.20). The KWQI was relatively the same regardless of the parameter set used; major differences occurred between the actual values and the estimated values. These differences occurred because of the differences in the lowest ranking sub-KWQI values. Since in the aggregation process the lowest scoring values are favored to prevent masking of impairment, the low scoring actual turbidity value had a significant affect on the total KWQI value. In conclusion, the estimation can be used when no other data is available but should not be relied on solely to provide accurate accounts of what is occurring at Site 2 for the individual parameters or the total index rating.

**Analysis of Riparian Buffer Zone between Sites 2 and 6**

Riparian buffer zones are a very common BMP and once stabilized are generally low maintenance. A riparian buffer zone lines the stream between Sites 2 and 6 as described previously. The analysis for the riparian buffer zone will be completed using the Minimum (Group III-Set 1) and the General (Group III-Set 2) riparian buffer parameter sets (Table 3.12). The two parameter sets were chosen to show the difference between the calculated KWQI based on parameters affected by the BMP and the calculated KWQI based on those BMP parameters as well as other general stream health parameters. Calculations are based on yearly averages.

The sub-KWQI values calculated using the Minimum parameter set is shown in Table 3.22 and the plot of the KWQI is shown in Figure 3.46. The low KWQI values were caused by the excessive levels of TN, TP and TDS that were present at both sites during the study (Table 3.19). Ammonia levels stayed the same over the four years of the study maintaining a constant high sub-KWQI resulting in a rating of 'Excellent' at both sites. The nitrate sub-KWQI values increased up to 7% from 2006 to 2009. However, the associated ratings at both sites received 'Average' ratings for all years in the study. The TSS sub-KWQI decreased 27% during 2006; however, it increased 52% from 2007 to 2009. The associated ratings for TSS fluctuated between 'Fair' and 'Average'. If the goal of a 25% reduction in TN, TP and TDS was reached, the sub-KWQI would increase by 58%, 23% and 131%, respectively. Even with a 25% increase in the sub-KWQI, the TN and TP will still have a rating of 'Poor' while the TDS will receive a rating of 'Fair". Estimating a KWQI based on desired water quality parameter concentrations and/or targeted reductions could help demonstrate the possible outcome of a proposed BMP.

**Table 3.22 Sub-KWQI Values Using Minimum Riparian Buffer Zone Set.** The table breaks down Sites 2 and 6's individual parameters by year and shows the subindex value for each. The parameter set used was the Minimum Riparian Buffer Zone set (Group III – Set 1).

| | **2006** | | **2007** | | **2008** | | **2009** | |
|---|---|---|---|---|---|---|---|---|
| | **Site 2** | **Site 6** | **Site 2** | **Site 6** | **Site 2** | **Site 6** | **Site 2** | **Site 6** |
| Ammonia-N (NH4-N) (acute) | 0.98 | 0.98 | 0.96 | 0.79 | 0.95 | 0.97 | 0.95 | 0.97 |
| Total Nitrogen | 0.15 | 0.17 | 0.09 | 0.13 | 0.13 | 0.18 | 0.11 | 0.15 |
| Nitrates (NO3-N) | 0.62 | 0.65 | 0.57 | 0.81 | 0.64 | 0.68 | 0.62 | 0.62 |
| Total Phosphorus | 0.22 | 0.25 | 0.29 | 0.00 | 0.47 | 0.44 | 0.33 | 0.44 |
| Total Dissolved Soilds (TDS) | 0.41 | 0.37 | 0.10 | 0.07 | 0.07 | 0.08 | 0.09 | 0.08 |
| Total Suspended Solids (TSS) | 0.66 | 0.51 | 0.33 | 0.19 | 0.51 | 0.66 | 0.39 | 0.66 |

| | | | | |
|---|---|---|---|---|
| **Excel.** | **Good** | **Avg.** | **Fair** | **Poor** |

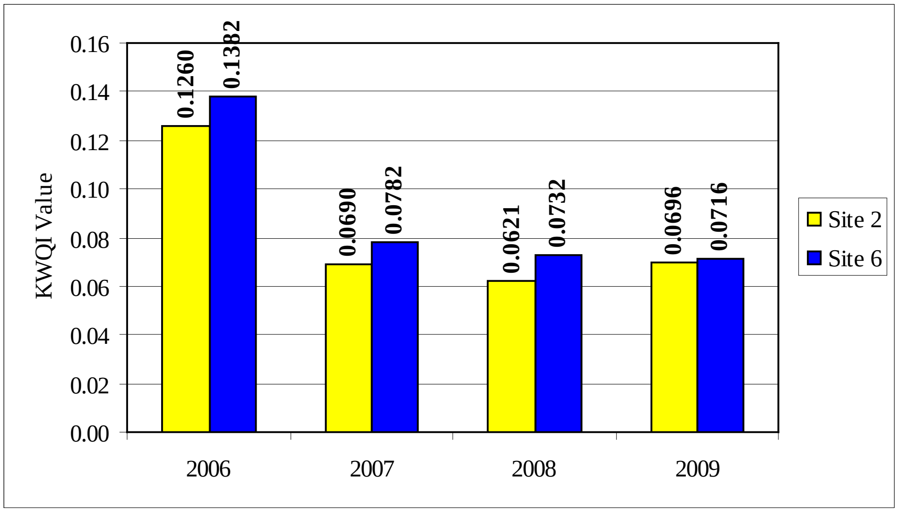



**Figure 3.46 KWQI Values Using Minimum Riparian Buffer Zone Set.** This figure shows the KWQI values based on the yearly averages for Sites 2 and 6 using the Minimum Riparian Buffer Zone Set (Group III – Set 1).

The sub-KWQI values calculated using the General parameter set is shown in Table 3.23 and the plot of the KWQI is shown in Figure 3.47. Site 6 KWQI values decreased dramatically between the two parameter set assessments. This decrease in KWQI values was due to the high concentration of chlorophyll *a* found during all four years. Based on the first assessment, water quality between Site 2 and Site 6 showed little to no improvement between 2007 and 2009 (Figure 3.46). However, based on the larger parameter set assessment, the resulting KWQI values show that the stream is more impaired after traveling through the riparian buffer zone as it enters the pond area at Site 6 (Figure 3.47). This second set of parameters was run to show that although the buffer zone can improve certain water quality parameters, there are other problems that need to be addressed. Therefore, the system should not be evaluated piecewise in terms of just the performance of BMPs;

additional parameters should be run if the overall quality of the stream is to be evaluated.

**Table 3.23 Sub-KWQI Values Using General Riparian Buffer Zone Set.** This table shows the subindex values of each parameter used in the calculation of the KWQI and is based on the yearly average for Sites 2 and 6.

| | 2006 | | 2007 | | 2008 | | 2009 | |
|---|---|---|---|---|---|---|---|---|
| | Site 2 | Site 6 | Site 2 | Site 6 | Site 2 | Site 6 | Site 2 | Site 6 |
| Ammonia-N (NH4-N) (acute) | 0.98 | 0.98 | 0.96 | 0.95 | 0.95 | 0.97 | 0.95 | 0.97 |
| Total Nitrogen | 0.15 | 0.17 | 0.09 | 0.12 | 0.13 | 0.18 | 0.11 | 0.15 |
| Nitrates (NO3-N) | 0.62 | 0.65 | 0.57 | 0.59 | 0.64 | 0.68 | 0.62 | 0.62 |
| Total Phosphorus | 0.22 | 0.25 | 0.29 | 0.31 | 0.47 | 0.44 | 0.33 | 0.44 |
| Temperature | 0.98 | 0.98 | 0.85 | 0.83 | 0.75 | 0.75 | 0.91 | 0.82 |
| pH | 0.75 | 0.87 | 0.54 | 0.69 | 0.51 | 0.67 | 0.81 | 0.89 |
| Turbidity | 0.16 | 0.26 | 0.08 | 0.11 | 0.24 | 0.33 | 0.00 | 0.01 |
| Chlorophyll a | 0.08 | 0.02 | 0.01 | 0.01 | 0.08 | 0.00 | 0.01 | 0.00 |
| Total Dissolved Solids (TDS) | 0.41 | 0.37 | 0.10 | 0.10 | 0.07 | 0.08 | 0.09 | 0.08 |
| Total Suspended Solids (TSS) | 0.66 | 0.51 | 0.33 | 0.46 | 0.51 | 0.66 | 0.39 | 0.66 |

| Excel. | Good | Avg. | Fair | Poor |
|---|---|---|---|---|

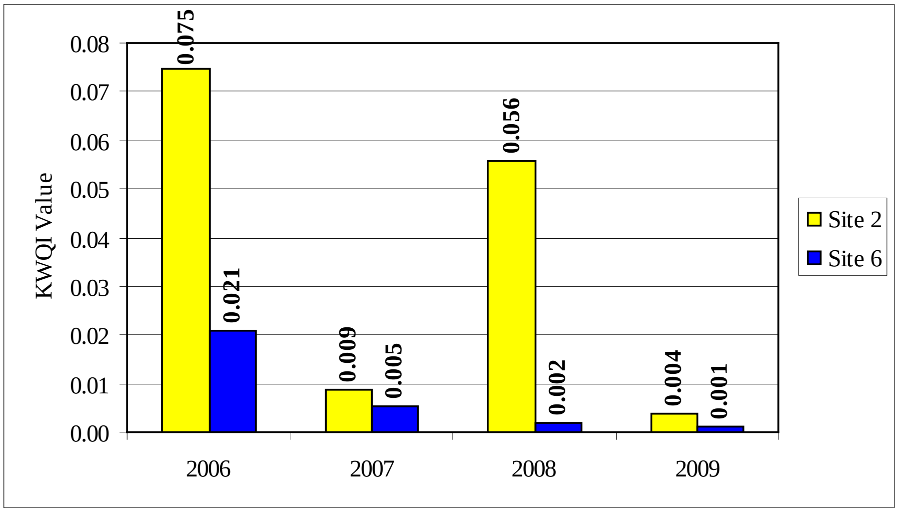



**Figure 3.47 KWQI Values Using General Riparian Buffer Zone Set.** This figure shows the KWQI values based on the yearly averages for Sites 2 and 6 using the General Riparian Buffer Zone Set (Group III – Set 2)

There are some problems that occur between Sites 2 and 6 that were noticed during stream exploration that may be affecting the calculated KWQI for Site 6. Site 6 has two culverts with the main channel flowing through the smaller of the two culverts. This small culvert is almost fully clogged with debris on the other side of Route 72 just upstream of the sampling location at Site 6. This is causing the stream to cut though and erode a new path in the banks so the excess water and associated sediments now flow through the larger storm culvert. If the blocked culvert is cleared it will allow the stream to flow through the main channel with little soil erosion and enter into Site 6 as a smooth flowing stream instead of a slow seep. This will prevent ponding upstream of Site 6 where possible water quality impairment is occurring. Another possible pollutant load entering the Cool Run upstream of Site 6 is the surface runoff coming from the Newark Concrete Plant. The permitted discharge from the Newark Concrete Plant moves across agricultural fields before entering the Cool Run. The quality of this discharge water should be reevaluated as well as its overall effect within the ecosystem. Future monitoring should be done to evaluate the impact if any that this water is having on stream health.

**Analysis of Riparian Buffer Zone and Pond (Sites 5 and 6)**

As described in Chapter 2, a small pond has formed over time directly downstream of Site 6. The stream then travels through a well vegetated riparian buffer zone until it reaches Site 5. This assessment was run to evaluate the effectiveness of the pond and riparian buffer zone to improve water quality. The parameters that were used to calculate the KWQI were the combined minimum parameter sets for the pond (Group V - Set 1) and the riparian buffer zone (Group III - Set 1). This assessment was used to evaluate the changes in the major water quality parameters affected by the processes occurring within ponds and riparian buffer zones. It will examine the reduction in TP, BOD and TSS concentrations within the Cool Run before the water continues through the riparian buffer zone. It will also examine the changes in ammonia, nitrate, TN, TP, TDS, and TSS concentrations that may enter the stream from the adjacent beef cow pastures.

The resulting sub-KWQI values for the combined minimum parameter sets are shown in Table 3.24 and the KWQI values are shown in Figure 3.38. Despite the low values of the KWQI, there was an increase in the KWQI value between Sites 6 and 5 for three of the four years in the study. The sub-KWQI values for TN, TP and TDS remained POOR or in the lower FAIR range at all monitoring sites during the study period. These high concentrations have resulted in low KWQI values during the aggregation process. The ammonia, BOD and nitrate have remained fairly constant during the study period constantly received ratings of EXCELLENT, GOOD and AVERAGE, respectively. The increase in KWQI values in 2008 and 2009 were the result of the reduction in TSS.

**Table 3.24 Sub-KWQI Values Using Minimum Riparian Buffer Zone and Pond Set.** This table shows the subindex values of each parameter used in the calculation of the KWQI and is based on the yearly average for Sites 5 and 6.

| | 2006 | | 2007 | | 2008 | | 2009 | |
|---|---|---|---|---|---|---|---|---|
| | Site 5 | Site 6 | Site 5 | Site 6 | Site 5 | Site 6 | Site 5 | Site 6 |
| Ammonia-N (NH4-N) (acute) | 0.99 | 0.98 | 0.97 | 0.95 | 0.98 | 0.97 | 0.98 | 0.97 |
| Total Nitrogen | 0.17 | 0.17 | 0.12 | 0.12 | 0.16 | 0.18 | 0.16 | 0.15 |
| Nitrates (NO3-N) | 0.62 | 0.65 | 0.58 | 0.59 | 0.63 | 0.68 | 0.63 | 0.62 |
| Total Phosphorus | 0.33 | 0.25 | 0.29 | 0.31 | 0.57 | 0.44 | 0.44 | 0.44 |
| BOD5 | 0.82 | 0.82 | 0.75 | 0.76 | 0.82 | 0.82 | 0.80 | 0.82 |
| Total Dissolved Soilds (TDS) | 0.38 | 0.37 | 0.10 | 0.10 | 0.07 | 0.08 | 0.09 | 0.08 |
| Total Suspended Solids (TSS) | 0.90 | 0.51 | 0.35 | 0.46 | 0.97 | 0.66 | 0.86 | 0.66 |

| Excel. | Good | Avg. | Fair | Poor |
|---|---|---|---|---|

The low KWQI values indicate impairment in stream water quality due to high concentrations of the parameters that the BMPs have been shown to reduce. This type of analysis can help identify which water quality parameters are not improving within a system influenced by the BMPs but will not provide information on the general health of the stream. Modification of the parameter set used in the assessments can be made to address particular concerns.

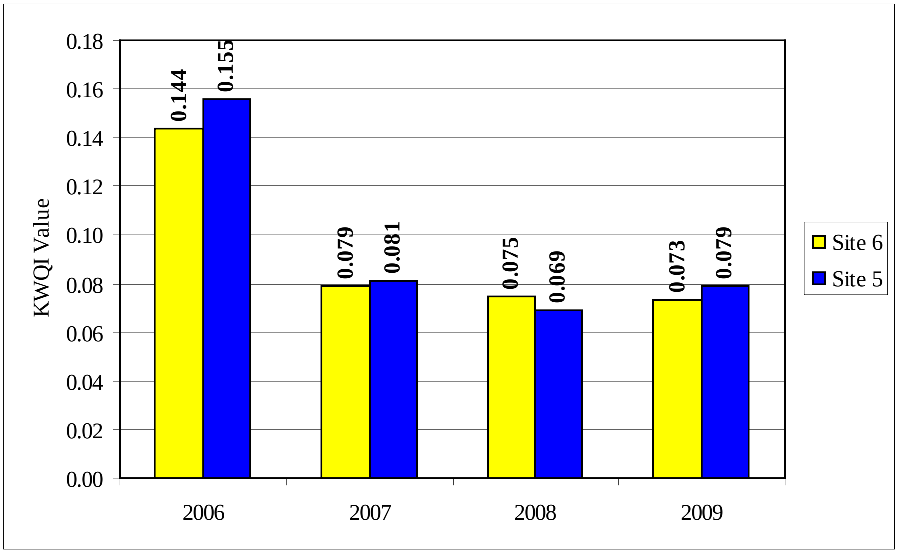



**Figure 3.48 KWQI Using Minimum Riparian Buffer Zone and Ponds/Basins Combined Parameter Sets.** This figure shows the KWQI values based on the yearly averages for Sites 5 and 6 using the Minimum Riparian Buffer Zone Set (Group III – Set 1)

**Analysis of Manure Collection System (Site 8)**

Since the start of storm sample collection at Site 8 in 2007, there have been a total of 15 storm flow samples collected. The yearly averages were used in the calculation of the sub-KWQI values to determine if there have been improvements in the quality of stormwater that runs through the fields and into the storm grate after installation of the manure collection system. The Manure Collection Set (Group II-Set 2) was used to calculate the final KWQI values. The total number of samples collected in 2007, 2008 and 2009 were 6, 8, and 1, respectively.

The sub-KWQI values for parameters included in the assessment are shown in Figure 3.49.

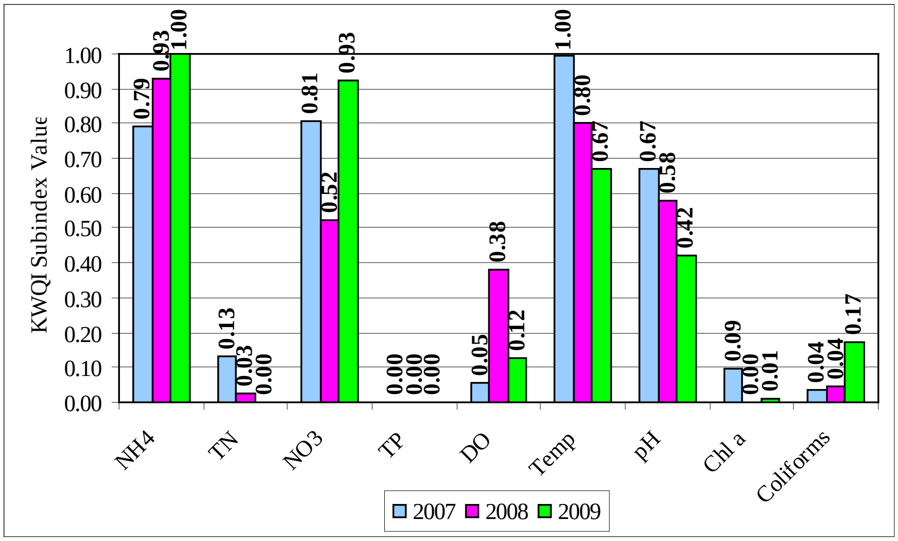



**Figure 3.49 KWQI Using General Manure Collection System Parameter Set.** This figure shows the distribution of the subindex values for Site 8 using the General Manure Collection System (Group II – Set2) and the yearly averages for each parameter.

As seen by the sub-KWQI values for TN, TP and Chl *a* the concentrations of these 3 parameters are well above the tolerable limits. All three TP sub-KWQI values are basically zero as well as the 2008 value for Chl *a* and the 2009 TN value. The main function of the collection system is to prevent excess nutrients from entering the stream system by reducing the rate of manure application to the fields and to prevent the piling of manure on the field for later application. The removal of waste from the field and prevention of manure laden leachate from reaching the stream has in just one year shown an improvement in the sub-KWQI values for ammonia. Nitrate concentrations showed no definite trend. However there was a significant increase in the sub-KWQI between 2008 and 2009. The TN sub-KWQI has been decreasing since 2007 despite the improvement in the ammonia and nitrate values. This decrease in the

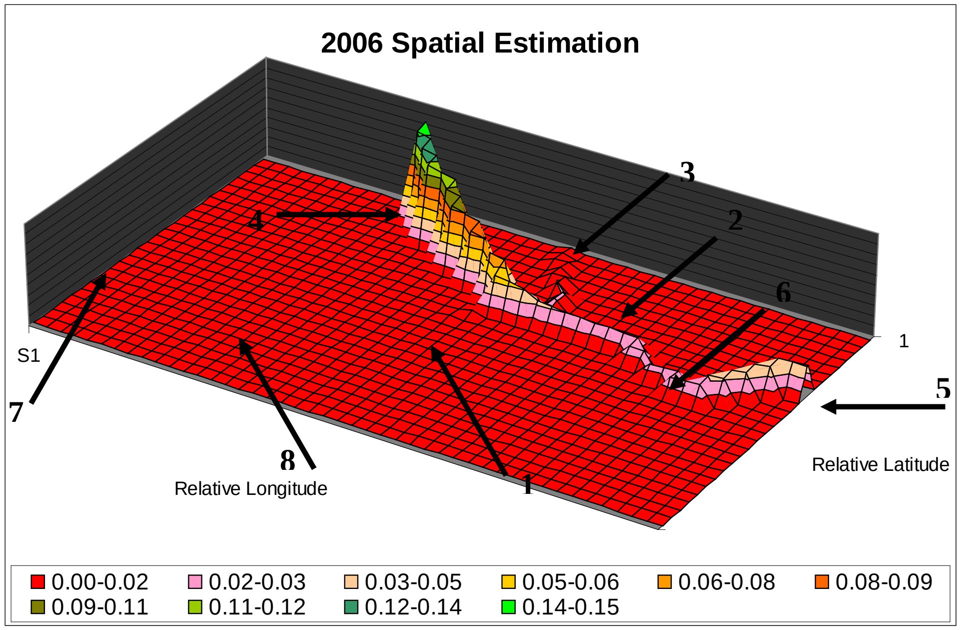
TN sub-KWQI suggests that organic nitrogen is the main species of nitrogen present at site 8. The DO sub-KWQI values have varied over the three years. This is suspected to be the result of the outlet being clogged, grown over, and having very little water movement. The most significant change can be seen in the coliform count resulting in significant changes in the coliform sub-KWQI values. The improvement may not seem that great based on the low sub-KWQI values. However, the colony forming units (CFU) per 100 ml in 2007 was estimated to be 1.19 million. This was the year the manure collection system was being installed. The first year the system was in operation the CFU per 100 ml dropped to 596,740. The estimated values for 2009 are 3,600 CFU per 100 ml. This change in numbers represents a 1000 fold decrease in coliform bacteria between 2007 and 2009. This is a significant change and if this trend continues, the CFU per 100 ml for the site should reach the acceptable value of less than 925 CFU per 100 ml as regulated by the state of Delaware. Temperature and pH varied through the years. However, the sub-KWQI values were within the tolerable ranges with ratings of “average” to “excellent”.

Some physical evidence can be seen were drainage problems still occur at Site 8. During and after rain events the areas surrounding the storm grate flood and will remain wet for weeks. A second major problem at this site occurs where the stream opens up into a free flowing channel. The exit culvert is buried under vegetation that has over grown the outlet and partially filled in the stream channel. This is preventing the water from flowing freely from the site and continuing downstream to Site 1.

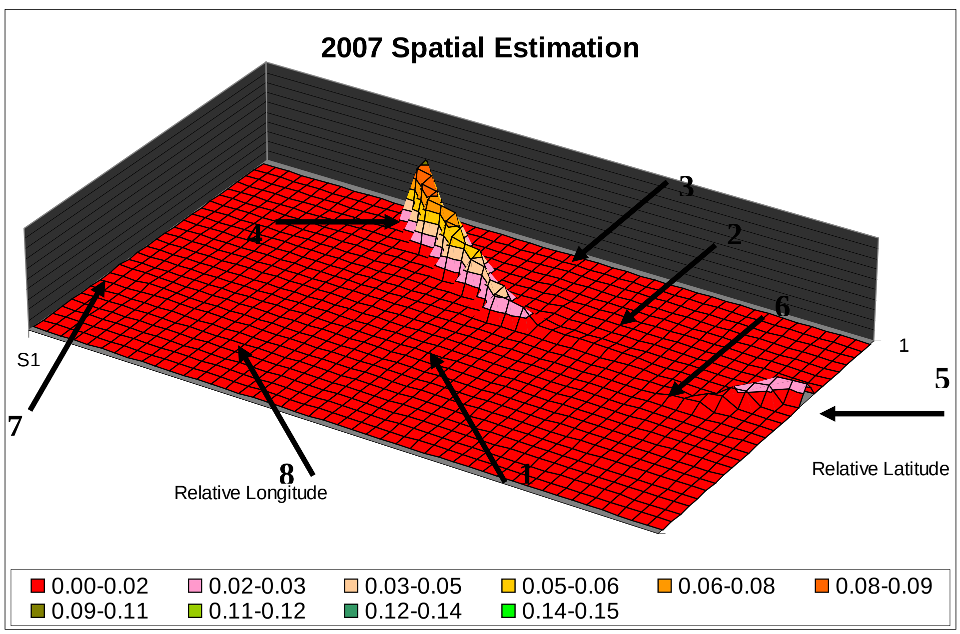
**Analysis of UD Farm (Standards and Criteria Approach)**

Two approaches were used to analyze the total water quality of the Cool Run within the NRECF. The first approach, the Standards and Criteria Approach (SCA), uses a single set of parameters to evaluate the farm at each of the base flow sites. The second method uses the general BMP parameter sets to determine the KWQI based on changes in the water quality parameters most affected by the BMPs. A major problem affecting the outcome of this assessment approach is the very low KWQI values at most of the sites resulting in a rating of very poor. These low ratings reduced the effectiveness of the spatial estimation plots. Another limitation that occurred was that the individual sites could not be marked within the spatial plot. Arrows and site numbers were added separately to illustrate the site locations because of the difficulty in determining the individual peak at site locations.

The spatial estimation section of the model was used to create the plots that are in Figure 3.50. Only 2006 plot does not include data from Sites 7 and 8, monitoring for those sites started in 2007. Spatial plots were created using the combined parameters in the DWQS, DWQCPAL, DWQCPHH and the USEPA nutrient criteria (combined, known as Group 1 – Set 4) to determine the KWQI. In order to show the differences in the sites the normal scale of 0 to 1 for the KWQI values was decreased to 0 to 0.15 on all four of the plots. The peak of the elevation plot is the path of the stream as it flows through the farm. Color changes indicate a change in elevation range for the KWQI value. The values calculated using the KWQI between 2006 and 2007 all decreased. This can be seen in the figure by the decreases in the elevation of the peaks. In 2008, the quality of water coming from Site 4 decreased while the rest of the NRECF began to show an increase. You can see where Site 1 starts to enter into the stream but at a much lower KWQI than those coming from Sites 4 and 3. The spatial estimation tool can be more useful in the evaluation of the farm when there have been significant improvements in the many parameters that are impaired. For now the tool can show only a portion of the changes in water quality of the Cool Run that is occurring within the NRECF.

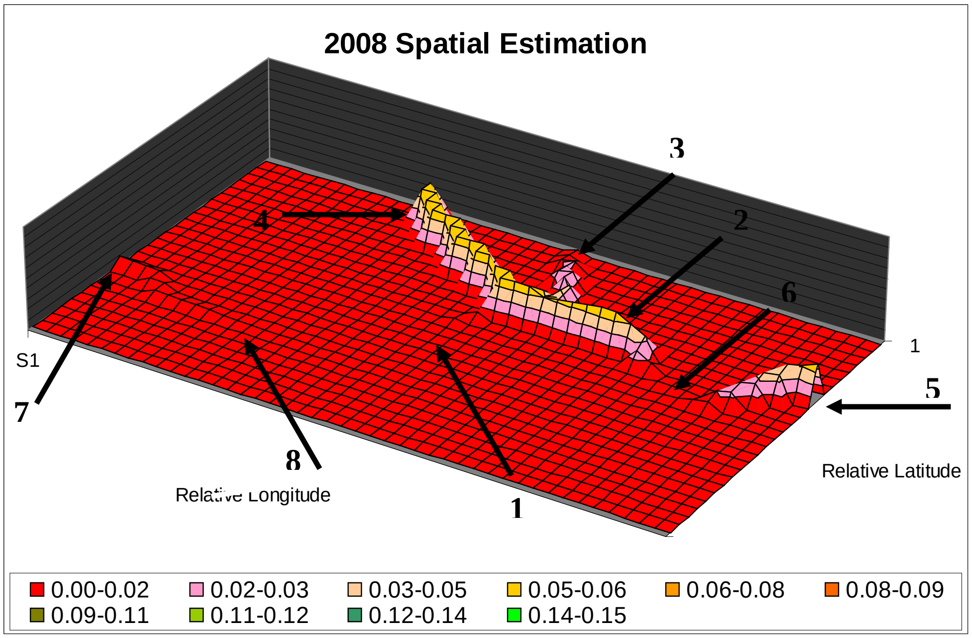



a)

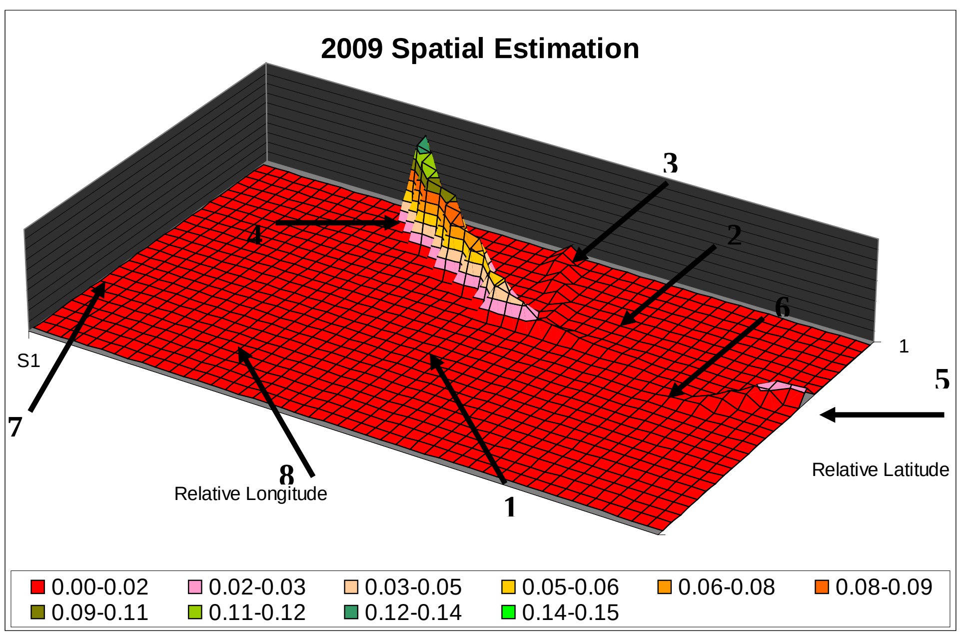



b)

**Figure 3.50 Spatial Estimation Using DWQS + DWQCPAL + DWQCPHH + USEPA nutrient criteria –** a) 2006 yearly averages, b) 2007 yearly averages.




c)

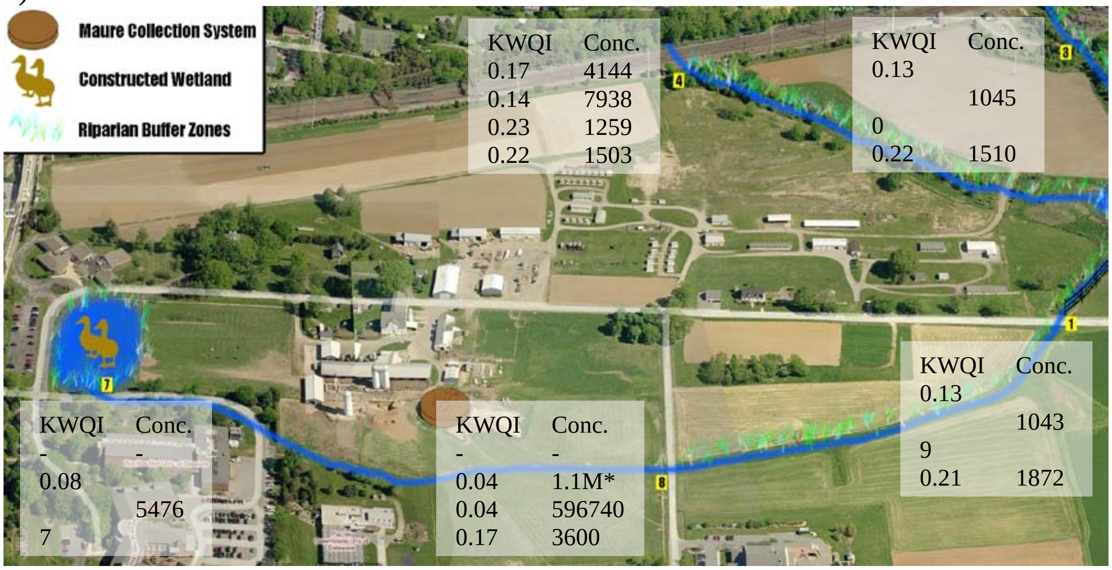



d)

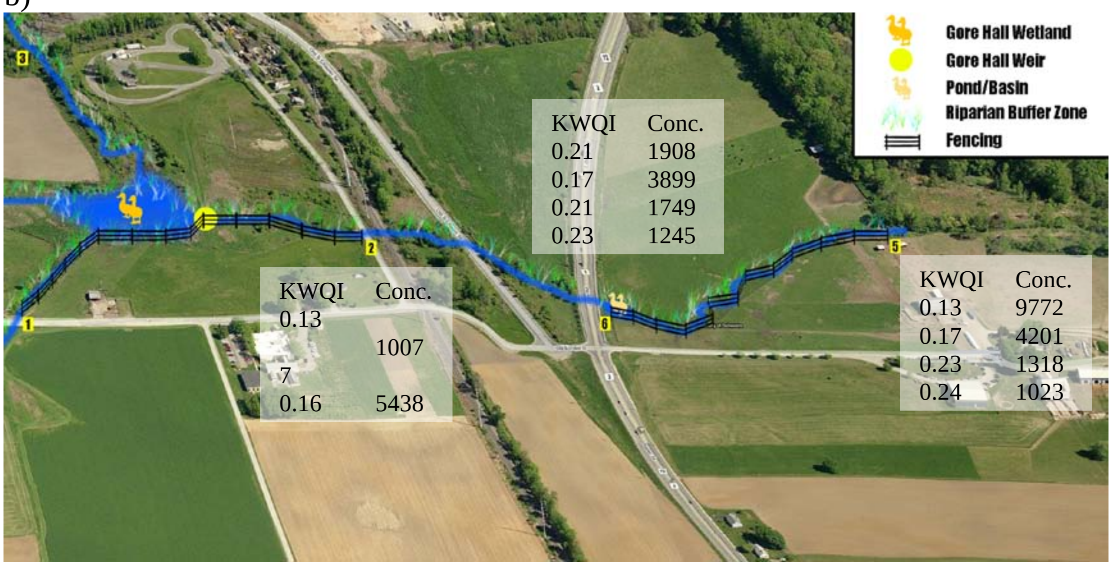
**Figure 3.50 cont. c) 2008 yearly averages, d) 2009 yearly averages**

The distribution of coliform bacteria across the NRECF is shown in Figure 3.51. The most western monitoring station, Site 7, is located at the wetland exit. Both the sub-KWQI values and the coliform bacteria concentrations at Site 7 indicated that a significant decrease (94.5%) of the coliform bacteria occurred since 2007. Site 8, located downstream of Site 7, had a 99.7% reduction in the coliform bacteria, representing a thousand fold decrease in coliform numbers from 2007 to 2009. At Site 4, the coliform concentrations fluctuated over the four years of the study but had a 63.7% reduction in the coliform concentration. The sub-KWQI at Site 1 also fluctuated during the study. Despite a fluctuation in concentration, coliform bacteria decreased 22.7% from 2006 and 2009. Between 2006 and 2007, the greatest change in the coliform bacteria sub-KWQI values occurred at Site 3. Further reductions in coliform bacteria were recorded in 2008 and 2009. The overall reduction at Site 3 during this study period was 92.0%, which reduced the coliform concentration to the State of Delaware's target goal for instantaneous coliform count for secondary contact. Water from Sites 1, 3 and 4 converge and flow into the stream at Site 2. The coliform sub-KWQI at Site 2 increased every year representing a 91.9% reduction in coliform concentration. This site also reached the State's target criteria for instantaneous measurements for secondary contact. The coliform sub-KWQI value at Site 6 fluctuated within 0.06 during the study period but there was an overall reduction of 34.7%. The lowest point on Cool Run that is sampled within the NRECF is located at Site 5. Values for the coliform sub-KWQI at Site 5 increased during the study period with a reduction of 89.5% in coliform concentration since 2006.

a)




b)

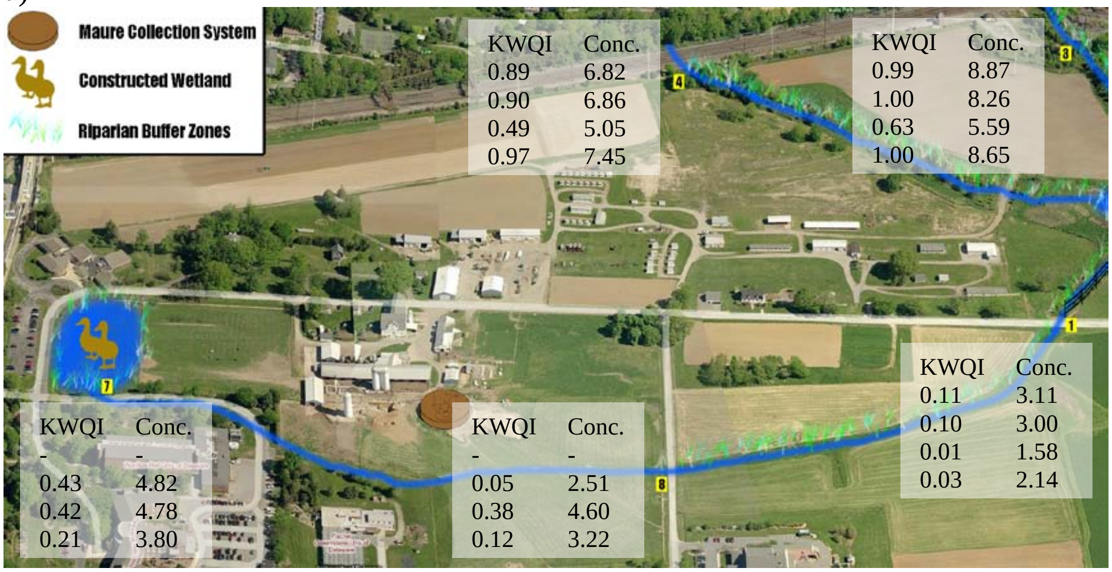



***M represents a million colonies/100mL**

**Figure 3.51 Spatial Coliform Distribution on UDAESF –** a) West Side – Sites 1, 3, 4, 8 and 7 b) East Side – Sites 2, 5, and 6. The figure shows the KWQI and concentration (colonies/100mL) for each monitoring site for 2006, 2007, 2008 and 2009 respectively. (Image: Alison Kiliszek and bing.com)

The distribution of dissolved oxygen (DO) concentrations across the NRECF is shown in Figure 3.52. There was a 21.2% decrease in the DO concentration at Site 7 since 2007 resulting in a continuous decrease in the DO sub-KWQI during the study period. There was an increase of 28.3% in the overall DO concentration at Site 8, although DO concentration has fluctuated over the past three years. Neither Sites 7 nor 8 meet the State of Delaware's DO minimum concentration. Despite the fluctuation of DO concentration at Site 4 during the four year study, there was an overall increase of 9.2% in the average DO concentration. Fluctuations of DO concentrations and resulting sub-KQWI values during the study also occurred at Site 1. Based on the DO concentrations measured from 2006 to 2009, a 31.2% reduction in DO occurred. However, the 2009 DO concentrations did not meet the Delaware standards. At Site 3, the DO concentrations showed some variations with a lower average value occurring in 2008. However, during all the other years of the study, DO concentrations met the required 4.0 mg/L for instantaneous grab sample value. At Site 2, the DO sub-KWQI ratings varied within the EXCELLENT range for 3 of the 4 years of the study. Although a decrease of 4.0% in DO occurred since 2006, the 2009 sub-KWQI values were still in the EXCELLENT range. At Site 6, the measured DO concentrations fluctuated but never had yearly averages below the DE standard. The DO concentration measured at this site increased by 5.0% during the study period. Values for the sub-KWQI values at Site 5 decreased during the study period with a reduction of 3.3% in DO concentration when compared to the 2006 values.

a)




b)

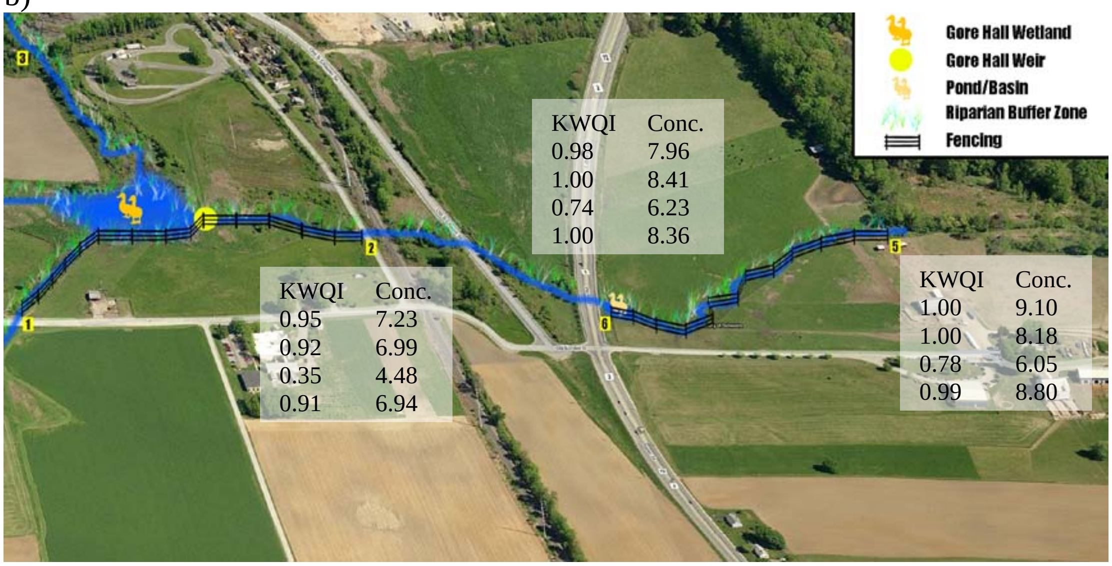
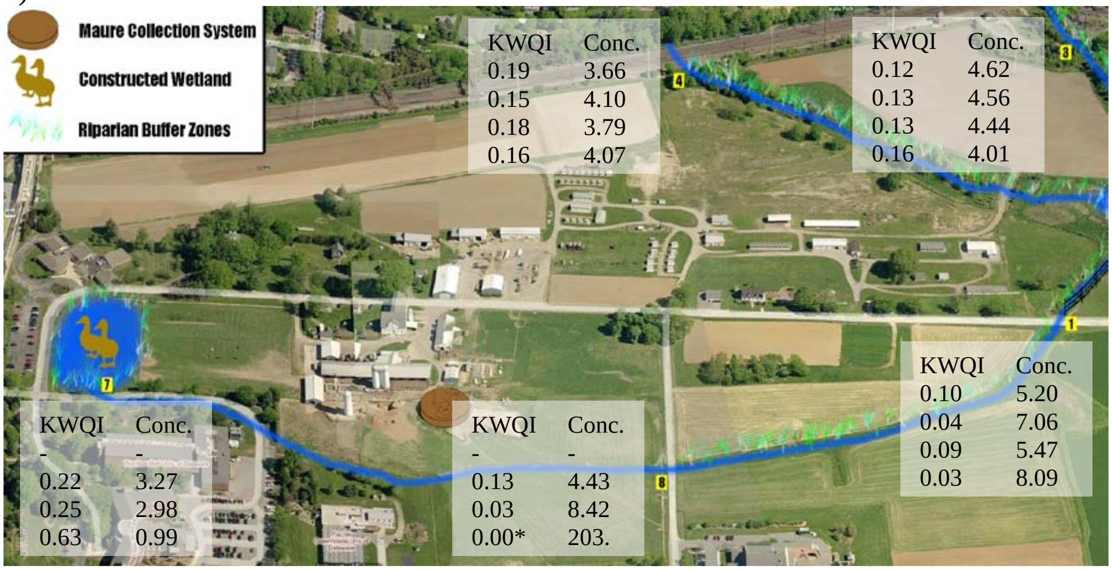


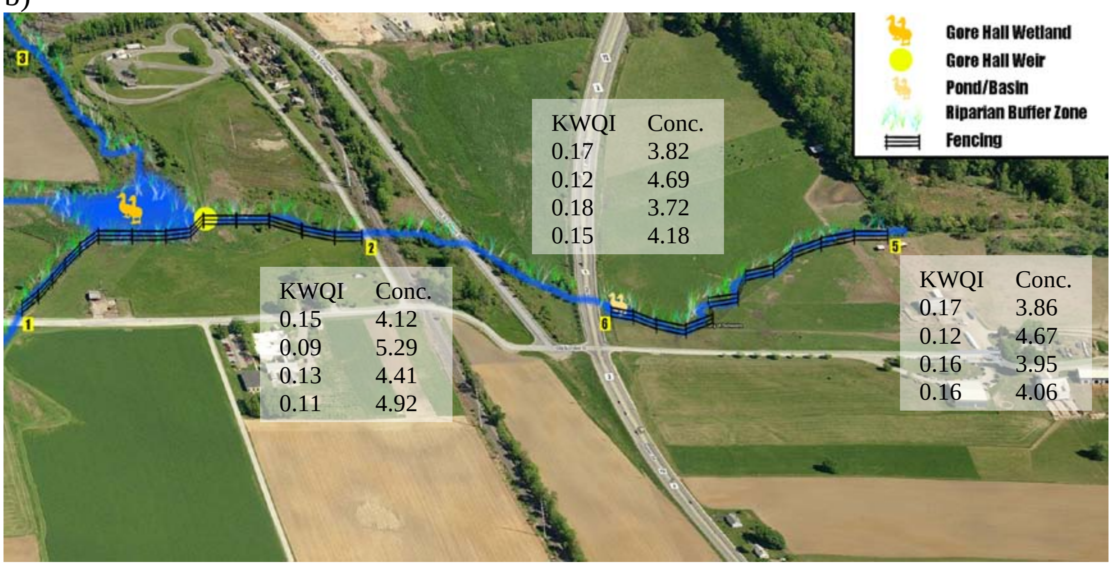

**Figure 3.52 Spatial Dissolved Oxygen Distribution on UDAESF –** a) West Side – Sites 1, 3, 4, 8 and 7 b) East Side – Sites 2, 5, and 6. The figure shows the KWQI and concentration (mg/L) for each monitoring site for 2006, 2007, 2008 and 2009 respectively. (Image: Alison Kiliszek and bing.com)

The distribution of Total Nitrogen (TN) concentrations across the NRECF is shown in Figure 3.53. There was a 69.7% decrease in the TN concentration at Site 7 during the study. Yearly averages of TN concentrations decreased consistently since 2007 resulting in a consistent increase in the sub-KWQI. At Site 8, located down stream of Site 7, there was a 4482% increase in the TN concentration. This extremely high concentration was attributed to a single measurement that may have been an error in the analysis. However, the flow at Site 8 has been problematic with ponding occurring for days after a rain event. The concentration of TN at Site 4 fluctuated during the study, but there was an overall increase of 11.2%. However, the TN concentration at this site did not meet the target goal of 3 mg/L as an upper limit stated in the 2008 Delaware 305(b) report. The TN sub-KWQI value at Site 1 fluctuated during the study. The concentration of TN increased 61.2% from 2006 to 2009. The TN concentration at this site also did not meet the State's target level. The TN sub-KWQI at Site 3 gradually increased between 2006 and 2009. The overall reduction in TN during this study period was 13.2%. Total Nitrogen concentrations at Site 2 fluctuated, but had an overall increase of 19.4% in TN concentration. The TN sub-KWQI at Site 6 varied by 0.06 during the study period, but there was an overall increase in concentration of 9.4%. Values for the sub-KWQI values at Site 5, the lowest monitoring station on Cool Run, decreased during the study period resulting in an increase in TN of 5.2% since 2006. The TN concentrations at Sites 2, 6 and 5 do not meet the DE standards for the targeted TN concentration goals.

a)




b)

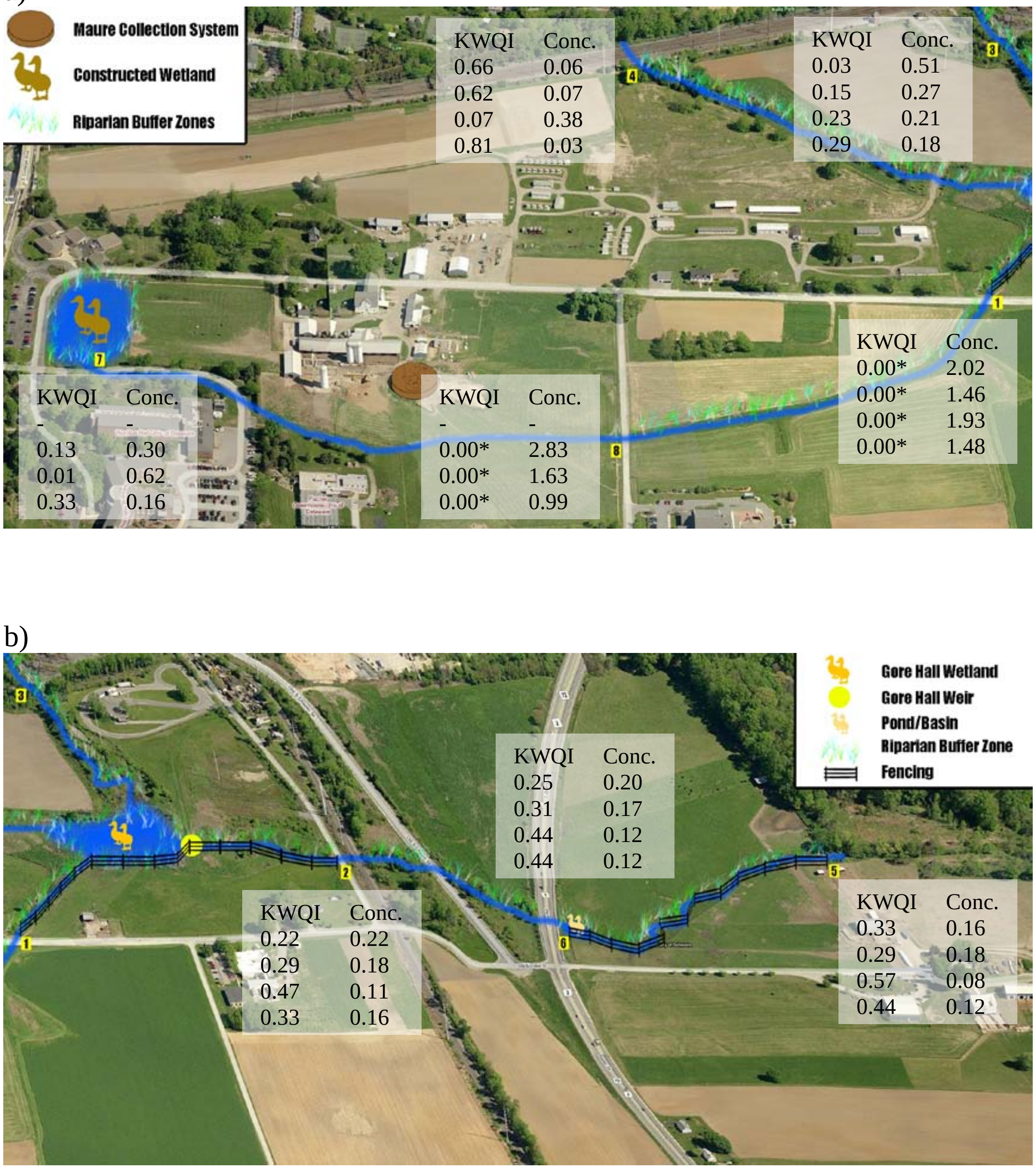



***Subindex values are less than 0.005**

**Figure 3.53 Spatial Total Nitrogen Distribution on UDAESF -** a) West Side – Sites 1, 3, 4, 8 and 7 b) East Side – Sites 2, 5, and 6. The figure shows the KWQI and concentration (mg/L) for each monitoring site for 2006, 2007, 2008 and 2009 respectively. (Image: Alison Kiliszek and bing.com)

The distribution of Total Phosphorous (TP) concentrations across the NREDF is shown in Figure 3.54. During the 2008 construction of the wetland, the soils at the wetland outlet (Site 7) were disturbed coinciding with a significant peak in the TP levels with resulting decreases in the sub-KWQI values. Despite the high average TP concentration measured in 2008, there was a 46.7% reduction between 2007 and 2009. There was a 65% reduction in TP concentration at Site 8 during the study. The sub-KWQI value at this site was reported as 0.00 because the high TP concentration resulted in a sub-KWQI of less than 0.005. The TP concentration at Site 4 fluctuated during the study with a peak concentration in 2008. Despite the 2008 increase, the total reduction in TP between 2006 and 2009 was 50%. At Site 1, the TP concentration also fluctuated during the study with similar sub-KWQI values as Site 8 (all values < 0.005). However, there was a 36.6% reduction in TP concentration between 2006 and 2009. Since 2006, the TP concentration at Site 3 was reduced 64.7%. In 2009, the TP concentration at Site 3 was no longer above the 0.20 mg/L target concentration of the 2008 Delaware 305(b) report. The TP sub-KWQI at Site 2 increased during the first three years of the study, with a slight decrease occurring in 2009. The yearly average TP concentration at Site 2 met the State's upper concentration target level since 2007. The sub-KWQI at Site 6 consistently increased during the study period with a corresponding 40% reduction in TP. Although all the TP concentration levels were in the upper range of the State's target levels, the yearly TP average at this site never exceeded the target value. Values for the sub-KWQI at Site 5 have increased during the study period with a TP reduction of 25% from 2006 to 2009. Total P impairment of the Cool Run within the NRECF occurred but water leaving Site 5 and the farm did not exceed the State's upper level target concentration.

a)



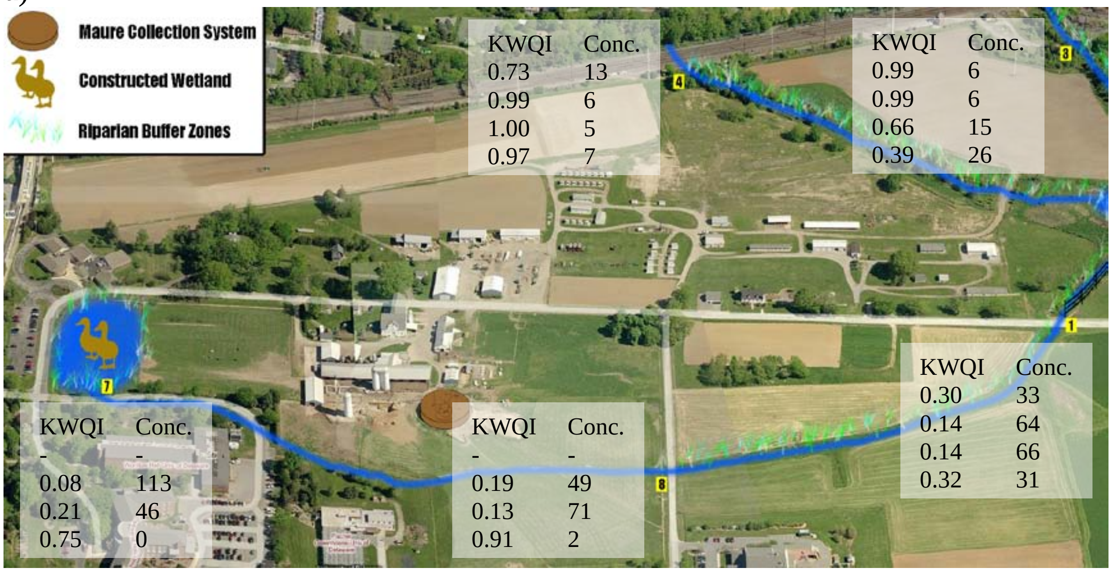

***Subindex values are less than 0.005**

**Figure 3.54 Spatial Total Phosphorus Distribution on UDAESF -** a) West Side – Sites 1, 3, 4, 8 and 7 b) East Side – Sites 2, 5, and 6. The figure shows the KWQI and concentration (mg/L) for each monitoring site for 2006, 2007, 2008 and 2009 respectively. (Image: Alison Kiliszek and bing.com)

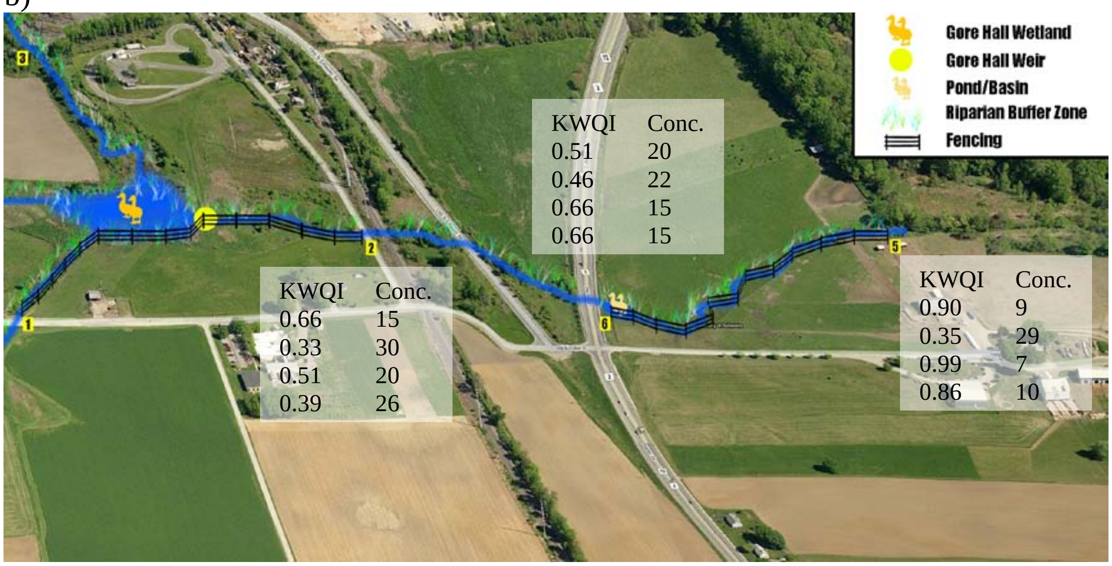
The distribution of Total Suspended Solids (TSS) concentrations across the NRECF is shown in Figure 3.55. There was a 100% reduction in TSS concentration at Site 7 between 2007 and 2009. A low concentration of TSS is desired within a water body which is why the sub-KWQI is not 1.00 at 0 mg/L TSS. At Site 8, located down stream of Site 7, there was an 85.9% reduction in the TSS concentration. The TSS concentrations at Site 4 fluctuated during the study but remained below 10 mg/L for the last three years of the study representing a total reduction of 46.2%. The TSS concentrations at Site 1 doubled from 2006 to 2008 but returned to 2006 levels in 2009. There was a 333.3% increase in TSS concentration at Site 3 during the study resulting in a drop in the sub-KWQI rating from EXCELLENT to FAIR. There was a 73.3% increase in TSS at Site 2, but the sub-KWQI value remained in the FAIR range. However, there has been a visible increase in deposited sediments at the site over the course of the study. The TSS concentration at Site 6 slowly but consistently decreased during the study period with an overall 25% reduction. Values for the TSS sub-KWQI at Site 5 increased during the second year of the study then decreased during the third year of the study resulting in an 11.1% increase. Despite the increase, the rating remained in the upper GOOD range of the sub-KWQI.

The use of the total KWQI value is to aid in a general assessment of water quality in the area. It is also a tool that can easily determine if a stream is impaired in some way. The additional use of the subindices can identify which water quality parameters have the greatest impact on stream health. Examining the changes in the individual water quality parameters and their associated sub-KWQI values over time can provide a more detailed description of the effects of BMP implementation in a watershed.

a)




b)



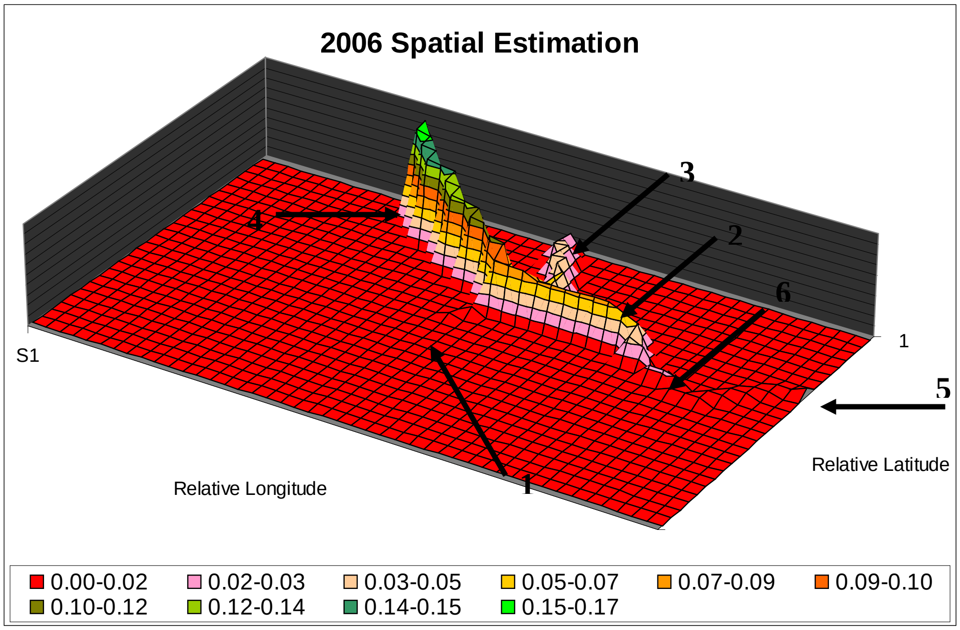

***Subindex values are less than 0.005**

**Figure 3.55 Spatial Total Suspended Solids Distribution on UDAESF -** a) West Side – Sites 1, 4, 8 and 7 b) East Side – Sites 1, 2, 3, 5, and 6. The figure shows the KWQI and concentration (mg/L) for each monitoring site for 2006, 2007, 2008 and 2009 respectively. (Image: Alison Kiliszek and bing.com)

**Analysis of UD Farm (BMP Approach)**

This analysis approach involved using a variable set of parameters per site to calculate the KWQI. This option is not available in the final version of the model. Using a mixture of the BMP parameter sets, allowed for each site to be rated on the parameters most affected by the BMPs. This method is to be used for the evaluation of the BMPs within the farm with some general water quality health standards mixed in. The analysis was only preformed on Sites 1 through 6. Site 1 KWQI was calculated using the general manure collection system parameters (Group II - Set 2). Site 2 KWQI was calculated using a combination of the general wetland and riparian buffer zone parameter sets (Group IV - Set 2 and Group III - Set 2). The KWQIs for Sites 3, 4 and 6 were all calculated using the general riparian buffer zone set (Group III - Set 2). Site 5 KWQI was calculated using the general riparian buffer zone (Group III - Set 2) and the pond/basins sets (Group V - Set 2).

The spatial plots of the calculated KWQI for the four years of the study are shown in Figure 3.56. Again, they represent the change in the KWQI of the Cool Run as it moves through the NRCF. From 2006 to 2007, there seems to be a general decrease in the KWQI values over the whole farm. In 2008, the KWQI increases at certain sections of the Cool Run indicating improvement in stream health at those locations. Improvements can be seen near the location of the Gore Hall Wetland and the riparian buffer zone that follows the stream after the pond/basin at Site 6. The 2009 spatial estimation shows a general decline in the water quality as it approaches Site 6. However after passing this site the KWQI increases slightly. The parts of the stream can be seen in the 2009 Spatial Estimation plot in Figure 3.56 illustrating that although the stream is impaired, there has been an improvement in the quality of water that is leaving the farm.

a) 

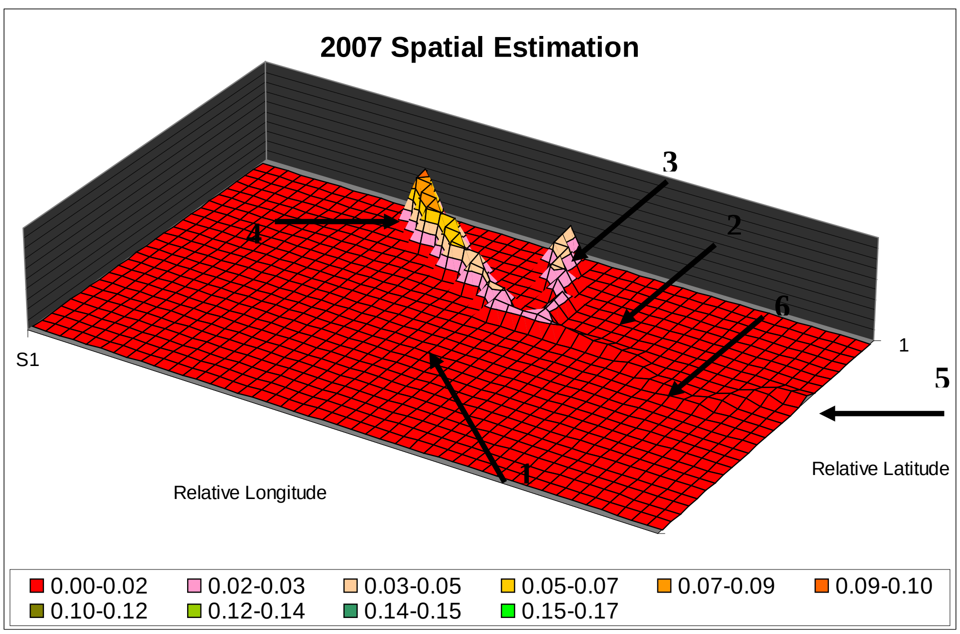
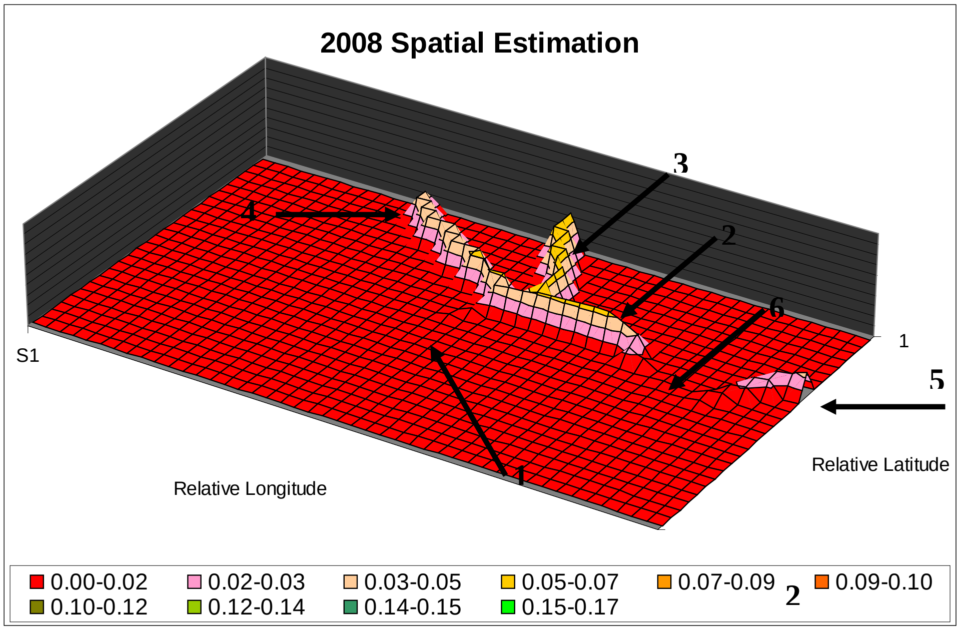
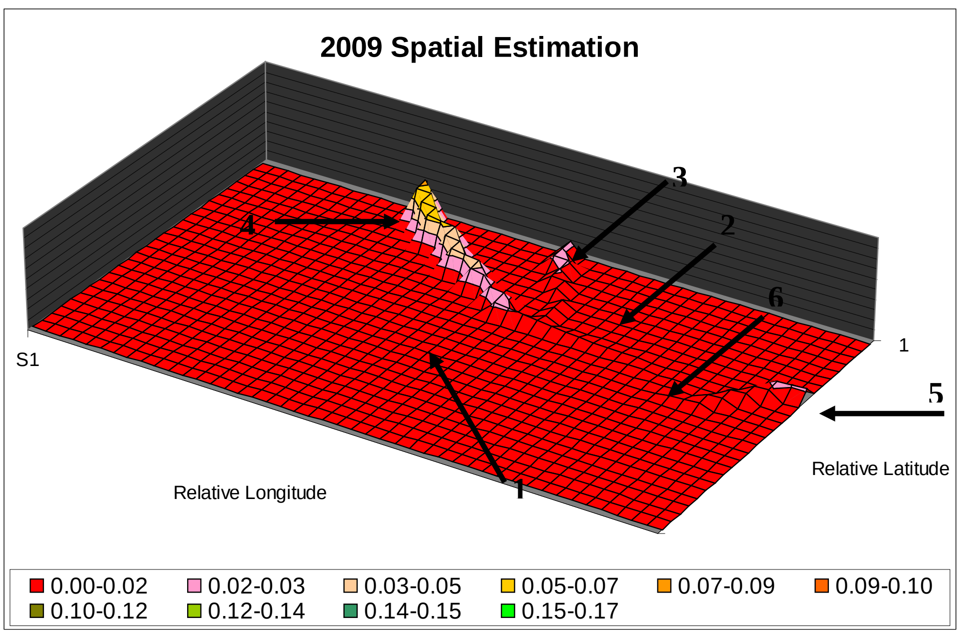

b) 


**Figure 3.56 Spatial Estimation Using Multiple BMP Evaluation Parameter Sets** – a) 2006 yearly averages, b) 2007 yearly averages




c)




d)

**Figure 3.56 cont.** – c) 2008 yearly averages, 2009 yearly averages

# CHAPTER 4

# CONCLUSIONS AND FUTURE GOALS

There are many conclusions that can be drawn from this project. One of the objectives of the project was to answer the question "Are the BMPs helping to improve the quality of water within the UDEW?" The answer to this question is yes. The BMPs are having a positive impact on the watershed when looking at the whole picture. The monitoring time table for this project is too short of a period to make long term analyses of the BMPs and their effects on the water quality of the Cool Run as it leaves the NRECF. The BMPs implemented during the course of the project now have a basis for future evaluation. As discussed previously, many of the ecosystem processes involved in pollutant removal take a significant amount of time. Improvements in the watershed may not become evident for years. However, assessments using the KWQI Model can help identify small changes that may occur in relatively short time periods. A main goal for the future is to improve the health of the Cool Run stream throughout the NRECF so that it is not impaired as it enters into the Christina River. Setting smaller goals at certain key points along the stream where there is the most impairment will hopefully have the greatest impact on the downstream regions of Cool Run. For instance, repairing the riparian buffer zone between Sites 8 and 1 and then from Site 1 until the Gore Hall Wetland should greatly reduce the amount of nutrients and solids entering the stream. Improving water quality in the upper reaches of the Cool Run on the NRECF should improve downstream water quality and eventually increase the KWQI value at Site 5 as the water leaves the area. Setting a reasonable goal to be reached within 5 years will allow the riparian buffer zone to stabilize from the initial reconstruction.

One of the changes that should be made to the pasture and crop land would be to install better drainage systems. There are many fields that have large areas that do not drain becoming deposition areas that then get flushed during the next storm event. These flushing events could cause abnormal spikes in the concentrations of the parameters being measured. The dairy cow pasture near Site 8 and the beef cow pasture area adjacent to Site 5 should be the first two sections worked on. These areas flood every storm event and take up to a few weeks to dry out naturally.

The final future goal is to reduce the overall cost of the monitoring project by decreasing sample events while still maintaining a good representation of data for each of the parameters. To achieve this, a simple statistical analysis was performed on the last twelve data points for each of the parameters for Sites 1 through 6 to determine the minimum number of sample events required. Using the average of the values, a standard deviation and confidence interval was determined. The confidence interval was set at 95% for this analysis. The goal was to determine the minimum number of samples that could be taken and still have an average between the upper and lower limit of the confidence interval for all six sites. Using this method the parameters ranged from being taken once a year to 6 times a year. The parameters that should be taken every other month are coliform bacteria, copper, total nitrogen and nitrate. Parameters that should be taken 5 times during the year are chlorophyll *a*, nickel, chromium, cadmium and ammonia. Samples should be analyzed for total suspended solids, dissolved oxygen, lead, arsenic, and total phosphorus at least once every three months. The zinc can be monitored quarterly. Turbidity should be measured once every six months.  Parameters such as total dissolved solids, conductivity, pH, temperature, BOD, and boron only need to be monitored once a year to be within the estimated confidence interval.

Storm samples from Sites 7 and 8 should still be monitored quarterly or after a storm event lasting an extended amount of time or after a large storm event. Extended storm events would include rain that falls over a period of more than 8 hours or events that last a series of days.  Large storm events would include events that are expected to have 2-4 inches or more of rain within a 24 hour period or shorter. Samples should be collected within 72 hours after the end of the storm event.  Storm flow samples from Sites 1 through 8 should be collected at least twice a year so that an analysis of storm event pollutant loading can be calculated and compared to base flow situations.

## REFERENCES

Biswas, Asit K., 1997. "Water Resources: Environmental Planning, Management, and Development". McGraw-Hill Inc. Washington, D.C.

Bryant, Curtis W., 1987. "Lagoons, Ponds, and Aerobic Digestion". Journal of Water Pollution Control Federation 59(6): 401-403.

Campagnini, J. and Kauffman, G., 2001. "Development of the University of Delaware Experimental Watershed Project". University of Delaware, Pp. 1-31.

Carruthers, T. and C. Wazniak, 2004. "Development of a water quality index for the Maryland coastal bays." Maryland's Coastal Bays: Ecosystem Health Assessment, Chapter 4.4. pp. 4-59—4-65. Maryland Department of Natural Resources, Annapolis, Maryland. http://www.dnr.state.md.us/coastalbays/sob_2004.html. Accessed September 8, 2008.

Clesceri, L. S., Greenberg, A. E., Trussell, R. R. (Eds), 1989. "Standard Methods for the Examination of Water and Wastewater". 17th ed., American Public Health Association, American Water Works Association and Water Pollution Control Federation, Washington, D.C., pp.4-75-4-81.

Coles-Ritchie, M. C., D. W. Roberts, J. L. Kershner, and R. C. Henderson. 2007. "Use of a wetland index to evaluate changes in riparian vegetation after livestock exclusion." Journal of the American Water Resources Association (JAWRA) 43:731-743.

Corbitt, Robert A. 1990. "Standard Handbook of Environmental Engineering." Mc Grawl-Hill Inc. Washington, D.C.

Cude, C. G. 2001. "Oregon water quality index: tool for evaluating water quality management effectiveness." Journal of the American Water Resources Association 37(1): 125-137.

Delaware River Basin Commission, 2009. "Basin Facts." <http://www.state.nj.us/drbc/thedrb.htm>. September 14, 2009.

DNREC, 2004. "State Of Delaware Surface Water Quality Standards As Amended, July 11, 2004." Department of Natural Resources and Control. Dover, Delaware. pp 46.

DNREC, 2008. "State of Delaware 2008 Combined Watershed Assessment Report (305(b)) and Determination for the Clean Water Act Section 303(d) List of Waters Needing TMDLs." Department of Natural Resources and Control. Dover, Delaware. pp 204.

Edwards, C. L., R. D. Shannon and A. R. Jarrett, 1999. "Sedimentation Basin Retention Efficiencies for Sediment, Nitrogen, and Phosphorus from Simulated Agricultural Runoff". American Society of Agricultural and Biological Engineers 42(2): 403-409.

Emerson, Clay H., Claire Welty, and Robert G. Traver, 2005. "Watershed-Scale Evaluation of a System of Storm Water Detention Basins". Journal of Hydrologic Engineering 10(3): 237-242.

Environmental Laboratory. 1987. Corps of Engineers wetlands delineation manual. US Army Engineer Waterways experiment Station. Vicksburg, MS, USA. Technical Report Y-87-1.

Gupta, A. K., Gupta, S. K. and Patil, Rashmi S.(2003) 'A Comparison of Water Quality Indices for Coastal Water', Journal of Environmental Science and Health, Part A, 38 (11): 2711-2725

Harrell, Tara. 2002. "Linking Stream Health and Land Use in the University of Delaware Experimental Watershed." University of Delaware Senior Thesis.

House, M. A. 1990. "Water quality indices as indicators of ecosystem change." Environmental Monitoring and Assessment 15: 255-263.

Kaurish, F. W. and T. Younos. 2007. "Developing a standardized water quality index for evaluating surface water quality." Journal of the American Water Resources Association 43(2): 533-545.

Kovacic, David A., Mark B. David and Lowell E. Gentry, 2000. "Effectiveness of constructed wetlands in reducing nitrogen and phosphorus from agricultural tile drainage". Journal of Environmental Quality 29(4):1264-1274.

Line, D. E., W. A. Harman, G. D. Jennings, E. J. Thompson, and D. L. Osmond, 2000. "Nonpoint-Source Pollutant Load Reductions Associated with Livestock Exclusion". Journal of Environmental Quality. 29(6):1882-1890.

Maret, T. R., D. E. MacCoy, and D. M. Carlisle, 2008. "Long-Term Water Quality and Biological Responses to Multiple Best Management Practices in Rock Creek, Idaho". Journal of the American Water Resources Association (JAWRA) 44(5):1248-1269

McDermott, Jenny. 2009. Email correspondence on BMPs

McDermott, J and J.T. Sims. 2007. Request for Funding to Monitor Cool Run Surface Water at the College of Agriculture and Natural Resources, University of Delaware (UD-CANR). Prepared November 14, 2005.

Meals, Donald W., Steven A. Dressing, and Thomas E. Davenport, 2010. "Lag Time in Water Quality Response to Best Management Practices: A Review". Journal of Environmental Quality. 39:85-96.

Meindl, Christopher F., (2005). "Wetland Diversity: The Limits of Generalization". Journal of Geography 104(6): 243-256

Meyer, D. Morse, I. Garnett, and J. C. Guthrie, 1997. "A Survey of Dairy Manure Management Practices in California". Journal of Dairy Science 80:1841-1845.

Ott, W.R., 1978. Environmental Indices. Theory and Practice. Ann Arbor science. Washington, D.C.

Pesce, S. and D.A. Wunderlin. 2000. "Use of water quality indices to verify the impact of Córdoba City (Argintina) on Suquía River." Water Research 34(11): 2915-2926.

Phillips, Jonathan D., 1990. "Fluvial Sediment Storage in Wetlands". Journal of the American Water Resources Association. 25(4):867-873.

Powell, J. Mark, Daniel F. McCrory, and D. B. Jackson-Smith, and H. Saam, 2005. "Manure Collection and Distribution on Wisconsin Dairy Farms". Journal of Environmental Quality. 34(6):2036-2044.

Reinhardt, Miriam, Beat Müller, René Gächter and Bernhard Wehrl. 2006. "Nitrogen Removal in a Small Constructed Wetland: An Isotope Mass Balance Approach." Environmental Science and Technology 40(10): 3310-3319.

Schoeneberger, P.J., D.A. Wysocki, D.A. Benham, and W.D. Broderson. 2002. Field book for describing and sampling soils. Ver. 2.0. Natural resources Conservation Service, National Soil Survey Center, Lincoln, NE, USA.

Sims, J.T. and J. McDermott, 2008. Best Management Practices to Improve Water Quality in an Impaired Tributary and as an Educational Resource for the Environmental Sustainability Initiative at the University of Delaware. Proposal for Delaware Department of Natural Resources and Environmental Control. CWA 319 Funding pp 1-8.

Strahler, Arthur N. "Geology Part II." *Handbook of Applied Hydrology*. Ed. Ven Te Chow. Vol. 8. New York: McGraw Hill Book Company, 1964. 39 – 76.

Swamee, P. K. and A. Tyagi. 2000. "Describing Water Quality with Aggregate Index." Journal of Environmental Engineering 126(5): 451- 455.

Swamee, P. K. and A. Tyagi. 2007. "Improved method for aggregation of water quality subindices." Journal of Environmental Engineering 133(2): 220-225.

Tabacchi, Eric, Luc Lambs, Helene Guilloy, Anne-Marie Planty-Tabacchi, Etienne Muller, and Henri Decamps, 2000. "Impacts of riparian vegetation on hydrological processes". Hydrological Processes 14: 2959-2976.

Todd, Albert H. 2008. "Riparian Ecosystems and Buffers: Working at the Water's Edge." Water Resources IMPACT 10(3):3-5.

US EPA, 1987. “Quality Criteria for Water 1986 [The Gold Book].” Rep. 440/5-86-001. USEPA Office Of Water Regulations and Standards, Washington, DC.

US EPA, 2000. “Ambient Water Quality Criteria Recommendations.” Rep. 822-B-00-022. USEPA Office of Water (4304), 1200 Pennsylvania Avenue, NW, Washington, DC.

US EPA. 2006. “Volunteer Stream Monitoring: A Methods Manual.” USEPA Rep. 841-B-97-003. USEPA Office of Water (4503F), 1200 Pennsylvania Avenue, NW, Washington, DC.

US EPA, 2008. “EPA Region 7 4B Rationale.” <http://www.epa.gov/region7/water/pdf/upper_delaware_river_cedar_creek_review.pdf>.

US EPA, Water Quality Criteria. “Ecoregional Criteria: Summary Table for the Nutrient Criteria Documents.” <http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/files/sumtable.pdf>. October 22, 2009.

USDA, NRCS. 2002. Field indicators of hydric soils in the United States, Version 5.0. G.W. Hurt, P.M. Whited, and R.F. Pringle (eds.). USDA, NRCS in cooperation with the National Technical Committee for Hydric Soils, Fort Worth, TX

Varadharajan, Raman D., Reinier Bouweester and Mohan S. 2009 “Fuzzy Logic Water Quality Index and Importance of Water Quality Parameters” Air, Soil and Water Research 2:51-59

Vidon, Phillippe, Craig Allan, and Richard Lowrance. 2008. "Generalizing Riparian Zone Function at the Landscape Scale." Water Resources IMPCAT 10(3): 12-14

Watershed Professionals Network, 1999. "Oregon Watershed Assessment Manual" June 1999. Prepared for the Governor's Watershed Enhancement Board. Salem, Oregon.