PROCEEDINGS
SEVENTH BIENNIAL STORMWATER RESEARCH AND WATERSHED MANAGEMENT CONFERENCE

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FOREWORD

This conference is the seventh in a continuing series of symposia sponsored by the Southwest Florida Water Management District and the Florida Department of Environmental Protection to disseminate the findings of current stormwater research, as well as the latest developments in watershed management. The conference is designed to provide a forum from which a wide range of stormwater treatment and watershed management ideas and issues can be discussed and debated, and where research results can receive initial peer review.

This year's conference included papers emphasizing watershed modeling, retrofitting watersheds, meeting government mandates, understanding nutrient cycling and providing public-private partnerships. Twenty-four professional papers and five posters offered engineers, scientists, and regulators with the most current ideas and data available so that more efficient and cost-effective best management practices and predictive models can be developed and implemented.

Betty Rushton
Eric Livingston

ACKNOWLEDGMENTS

JoAnne Rehor, the Sr. Administrative Assistant for the Environmental Section and **Gwen Brown**, Administrative Supervisor for the Resource Management Department, were responsible for planning and administering the Seventh Biennial Stormwater Research and Watershed Management Conference. **Dean Rusk**, Manager of the District's Visual Communications Section, designed the conference logo and provided graphic support. **McRae & Company, Inc.** helped coordinate many aspects of the conference. **Amy Folsom** of McRae & Company, Inc., was the District's key contact and was also responsible for compiling and assembling the Proceedings. **John Frascone**, of the District's Office Support Section, oversaw the printing of all conference materials, including the Proceedings. **Philip Rhinesmith** of the Resource Management Department and **Scott Harbison** of the General Services Department coordinated the audio-visual aspects of the conference. Finally, **Josie Guillen** of the Resource Management Department provided additional valuable administrative support for the conference.

TABLE OF CONTENTS

SESSION 1 – WATERSHED MODELING

SESSION 2 – ASSESSMENT TECHNIQUES

SESSION 3 – RETROFITTING WATERSHEDS

SESSION 4 – PUBLIC PARTICIPATION

SESSION 5 – GOVERNMENT MANDATES

SESSION 6 – BMP ALTERNATIVES

SESSION 7 – NUTRIENT CYCLING

AN INNOVATIVE MODEL FOR WATERSHED MANAGEMENT AND THE DEVELOPMENT OF NARRATIVE TMDLS

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ABSTRACT

Water quality standards in Georgia are intended to provide protection for designated uses. TMDL (Total Maximum Daily Load) targets are based on these water quality standards. In cases where numeric water quality standards are not available, narrative standards are used for developing TMDLs. These narrative standards cannot be allocated, hence there is a need to link the narrative standards to pollutant loads generated from the watershed.

The Web-WISE (Watershed Improvements through Statistical Evaluations) Model has been designed to link the watershed pollutant loads to narrative standards, i.e. biological indices. Specific biological standards based on biological indices such as IBI (Index of Biological Integrity), Fish Score and ICI (Invertebrate Community Index) are used as measurement tools and are linked to various pollutant loads from the watershed. The Web-WISE model allows the user to view various scenarios based on desired goals and make technically sound decisions for developing narrative TMDLs. The "what-if" scenarios allow the user to screen various combinations of BMPs (Best Management Practices) and present a reality check by way of cost-benefit analyses. The model also allows local governments to track new developments and control the amount of pollutants carried by runoff from the site by use of BMPs.

KEYWORDS

TMDLS, Watershed Protection, Sustainable Development, Compliance, Web-WISE Model

INTRODUCTION

Proposed rules being developed by the U.S. Environmental Protection Agency (EPA) to revise requirements related to TMDLs distinguish, for the first time, waters that are impacted by "specific pollutants" and those that are impacted by "pollution". Waters that are impacted by specific pollutant(s) are considered to not be meeting the uses associated with that pollutant (e.g., aquatic life, water supply, recreation, etc., depending on specific state water quality standards) and must be included on state impaired waters lists [303(d) lists]. TMDLs must be developed and implemented for these listed waters in accordance with a prioritization established by states and the EPA in accordance with the rules. Waters that are considered impaired because of assessments *not* related to specific pollutants or water quality criteria, such as impaired biotic criteria, are also required to be included on the 303(d) lists, but a specific schedule for assessing and correcting the impairment is not required by the proposed rules.

In Georgia, the state agency requires local governments to conduct detailed watershed assessments and develop management plans in order to continue to expand municipal point source discharges. The agency requires the assessments for specific 303(d) listed waters as well as all watersheds associated with the service areas (sewersheds) for the specific wastewater facilities. The watershed assessments include watershed characterizations (water quality monitoring, biological monitoring, and habitat assessments) and various levels of watershed pollutant modeling.

Watershed characterization data and modeling results have been used to develop statistical relationships between biological conditions and various watershed parameters. Indices of benthic macroinvertebrate and/or fish community biotic integrity (as dependent variables) versus habitat conditions, watershed imperviousness, and pollutant loads have been developed for the various watersheds. The best statistical relationships resulted in cases where there is a wide range of biological impairment, including severely degraded urban streams.

The Web-WISE Model has been designed to link the watershed pollutant loads to narrative standards, i.e., biological indices. Specific biological standards based on biological indices such as Index of Biological Integrity (IBI), Fish Score, and Invertebrate Community Index (ICI) are used as measurement tools and are linked to various pollutant loads from the watershed. Once data are entered, the model automates the watershed improvement guideline (goals set for biological integrity) derivation process. The model allows decisions to be based on multi-parameter relationships Web-Wise works as a preliminary screening tool for BMP scenario evaluation and allows the user to view various scenarios based on desired goals and make technically sound decisions for watershed protection.

MODEL OVERVIEW

Web-Wise has three components:

- Watershed improvement guideline derivation
- BMP scenario analysis
- New Development Performance Review

Watershed Improvement Guideline Derivation

Purpose

The purpose of the watershed improvement guideline derivation analysis is to identify meaningful relationships between in-stream biological conditions (representing stream health) and subbasin conditions (including habitat and pollutant loadings). The ultimate objective of this component is to use the findings to develop guidelines for meeting the community's watershed protection and/or improvement goals. The correlation and regression analyses are based on the assumption that good biological conditions depend on both good water quality and adequate habitat.

Methods

The impacts analysis consists of a series of correlation and regression analyses. These analyses are performed using biological, habitat, and pollutant loading data from the two study areas and the four reference stations used in both studies. In-stream biological conditions (including fish and macroinvertebrate scores) are classified as dependent variables, and subbasin characteristics (including pollutant loadings and habitat scores) are classified as independent variables.

Independent Variables. Independent variables are those that can influence or limit the dependent variables (i.e., in-stream biological conditions). The following parameters were evaluated as independent variables for each monitoring point in the study:

- Stream habitat score (raw score)
- Subbasin area effective imperviousness (percent)
- Annual pollutant loading rates for each pollutant of interest (in pounds per acre per year)

Dependent Variables. Two basic dependent variables were considered in this analysis: fish score using the IBI, and macroinvertebrate score using the Georgia Biological Protocols. These two dependent variables are measures of stream aquatic integrity. The IBI, which is an aggregate of several fish metrics, comprises the fish score. The sum of seven community and population metrics makes up the macroinvertebrate score.

Overview

This component of the model uses a four-step process: data entry, correlation analysis, regression analysis, and derivation.

Data Entry**.** The main objective of this step is to compile all information in ***one*** database. The Excel sheet format allows data from biological and modeling results (PLOAD) to be linked with ease. Linking restores the data integrity and minimizes the QA/QC process considerably. The data entry module allows easy export into Microsoft Access® for web-site and database purposes. Figure 2 illustrates the data entry module.

Database for Correlation Analysis Back to Main Menu

Station/ Subbasin	Total Upstream Acreage	Total Flow (MG)	Fish Raw Score[2]	Fish Rating	Benthic Score	Benthic Rating	TSS (lb/ac/yr)
STN 1	3,832	2,841	NA	NA	7	Poor	1,815
STN 2	5,922	4,205	40	Fair	18	Good	1,744
STN 3	5,192	3,486	NA	NA	16	Poor	2,086
STN 4	3,357	2,027	32	Poor	16	Poor	2,116
STN 5	14,094	8,841	NA	NA	19	Good	1,649
Reference Stations							
REF-1	46,372	29,053	46	Fair-Good	30	--	590
REF-2	5,146	5,146	42	Fair	28	--	687
REF-3	4,694	4,694	46	Fair-Good	30	--	856

Figure 2 - Data Entry Module

Correlation Analysis. The correlation analysis is used to review and evaluate relationships between dependent and independent variables. The results of this analysis are exported in a correlation matrix (Figure 3), which is based on a strictly linear correlation and shows the degree of association between the various dependent and independent variables.

The correlation coefficients (r-values) shown on Figure 3 range between negative 1 and positive 1. A correlation value of 0 indicates no correlation between the independent and dependent variables, and a value of either –1 or +1 indicates full correlation. A positive correlation coefficient indicates that as one variable increases, the other variable also increases; conversely, a negative correlation indicates that as one variable increases, the other variable decreases. Correlations greater than 0.5 (absolute values) indicate a strong relationship and are shown in boldface print in the correlation matrix.

Correlation Analysis Back to Main Menu

Correlation Matrix	TSS (lb/ac/yr)	Zinc (lb/ac/yr)	Habitat Raw Score	Benthic Raw Score	Fish Raw Score
TSS (lb/ac/yr)	**1.00**				
Zinc (lb/ac/yr)	**0.59**	**1.00**			
Habitat Raw Score	-0.48	-0.33	**1.00**		
Benthic Raw Score	**-0.65**	**-0.59**	0.47	**1.00**	
Fish Score	**-0.62**	**-0.64**	0.47	**0.61**	**1.00**

Figure 3 – Correlation Matrix

Regression Analysis. Using one or a few numerical summaries to characterize the relationship between dependent and independent variables runs the risk of missing important features and making erroneous conclusions. Graphical interpretation of scatter plots captures the salient features of the relationship among variables that may otherwise be missed. One major feature of a scatter plot is that it shows *all* the data. Figure 4 presents the graphical interface designed for the regression analysis and explains each feature.

Guideline Derivation. The Guideline Derivation Module brings together the results for the correlation and regression modules and displays them in a user-friendly interface. This module allows the guidelines to be based on the benthic macroinvertebrate, fish, and habitat data using each variable's relationship with the pollutant parameters. Figure 5 presents the Guideline Derivation interface.

The "Choose Guideline" function in the Guideline Derivation Module allows guidelines to be based on several statistics. For example, if the TSS relationship with macroinvertebrates, fish, and habitat is strong, the user can derive a guideline using a mean or a median of the three. However, if the TSS relationship with fish and habitat is strong, but with macroinvertebrates is weak, then the user has an option of deriving the guidelines based on only the fish and habitat. Figure 6 presents a snapshot of the "Choose Guideline" function.

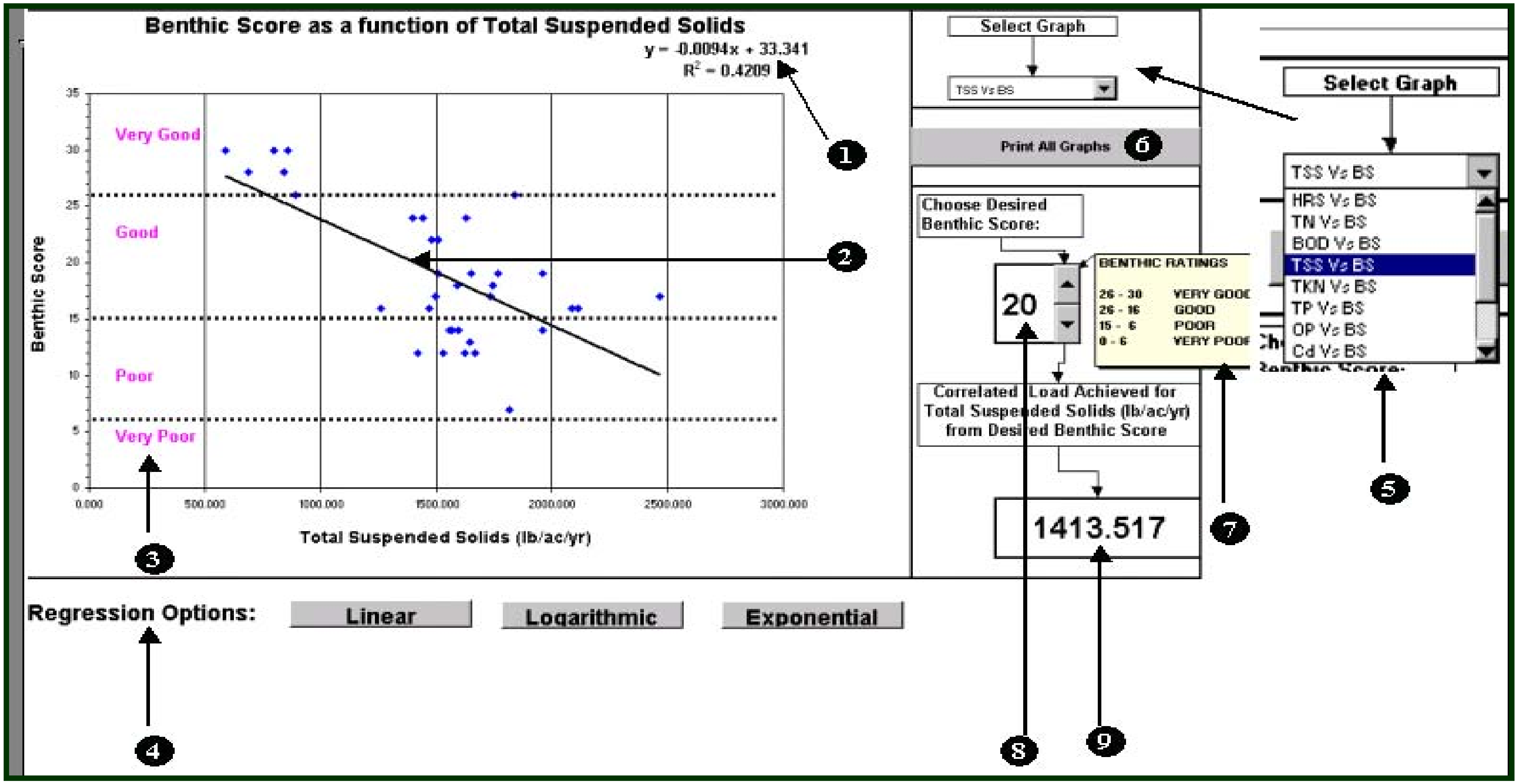
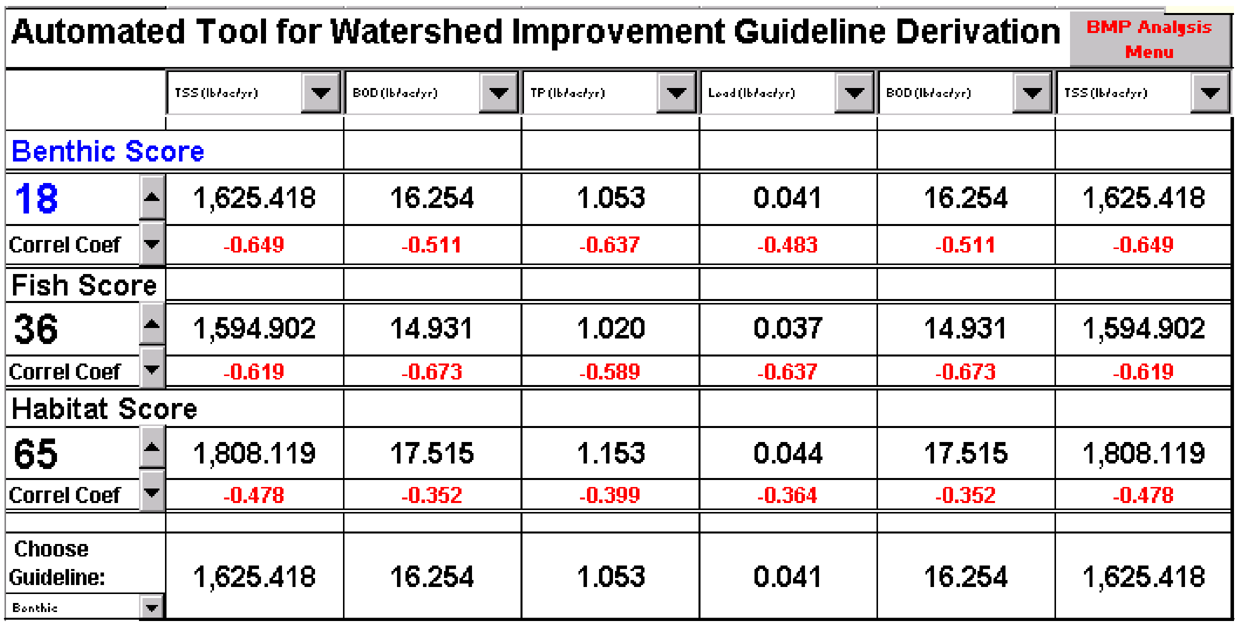


Figure 4 – Graphic Interface for Regression Analysis

Notes:

1. The regression equation and the regression coefficient are presented to assess the relationships among the variables.
2. The regression plots are automated.
3. Integrity ratings for the benthic macroinvertebrates and fish are presented in the graphical output.
4. Regression lines can be plotted using linear, logarithmic, and exponential relationships.
5. Various relationships can be viewed within this graphical interface.
6. The print option allows the user to print all the graphs with the push of a button.
7. Integrity ratings are documented with the interface.
8. This option allows the user to choose the desired aquatic integrity rating as a goal for watershed management.
9. This function uses the regression curve (1) to predict the required pollutant loading rate based on the desired aquatic integrity goal



Automated Tool for Watershed Improvement Guideline Derivation						BMP Analysis Menu
	TSS (lb/ac/yr)	BOD (lb/ac/yr)	TP (lb/ac/yr)	Load (lb/ac/yr)	BOD (lb/ac/yr)	TSS (lb/ac/yr)
Benthic Score						
18	1,625.418	16.254	1.053	0.041	16.254	1,625.418
Correl Coef	-0.649	-0.511	-0.637	-0.483	-0.511	-0.649
Fish Score						
36	1,594.902	14.931	1.020	0.037	14.931	1,594.902
Correl Coef	-0.619	-0.673	-0.589	-0.637	-0.673	-0.619
Habitat Score						
65	1,808.119	17.515	1.153	0.044	17.515	1,808.119
Correl Coef	-0.478	-0.352	-0.399	-0.364	-0.352	-0.478
Choose Guideline: Benthic	1,625.418	16.254	1.053	0.041	16.254	1,625.418

Figure 5 – Watershed Improvement Guideline Derivation

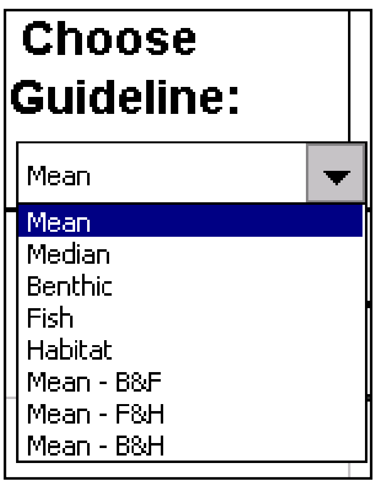


Figure 6 – "Choose Guideline" Function

<u>BMP Scenario Analysis</u>

The BMP Scenario component is a tool designed to evaluate scenarios for watershed management planning. It allows users to choose BMPs for the different land use types in a study area, and outputs the loads for the scenario using the future modeled loads from PLOAD. This component realistically evaluates the validity of the improvement guidelines by comparing existing and futureloads (i.e., worst-case scenarios without any controls) with the loads predicted for each scenario. The main characteristics of this component are described below:

- Analysis can be performed on any delineated sub-watershed in a study area (Figure 7).

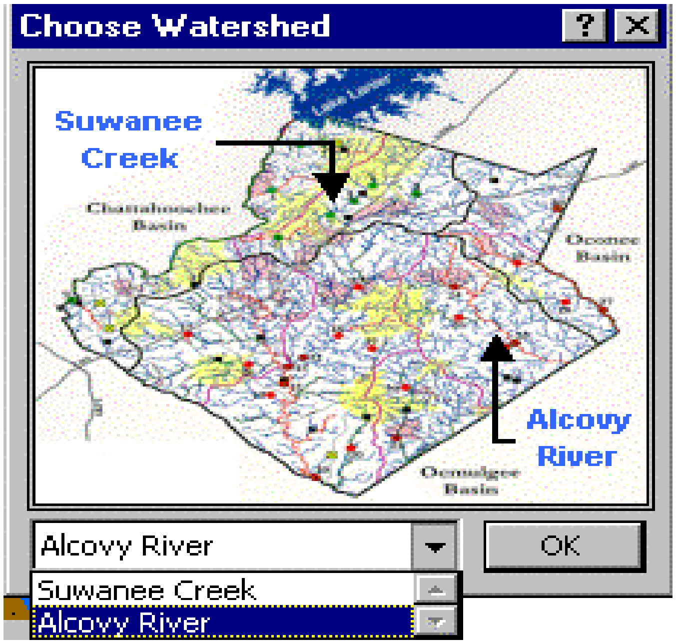
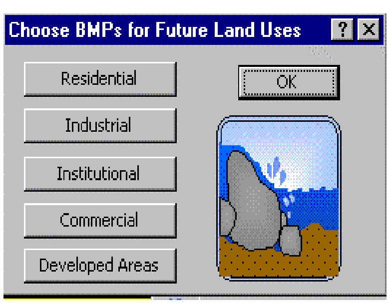


Figure 7 – Screen Capture of "Choose Watershed" Dialog Box

- The "Choose BMPs" function allows users to select BMPs (including multiple combinations) for various land-use types. This function analyzes implications of guidelines and scenarios on new developments and allows screening of scenarios for retrofitting of existing developments.

  Figure 8a presents the BMP analysis menu and Figure 8b presents the types of BMPs used in the model. Note that the option for "Developed Areas" on Figure 8a allows for screening retrofit scenarios.

(a)



(b)

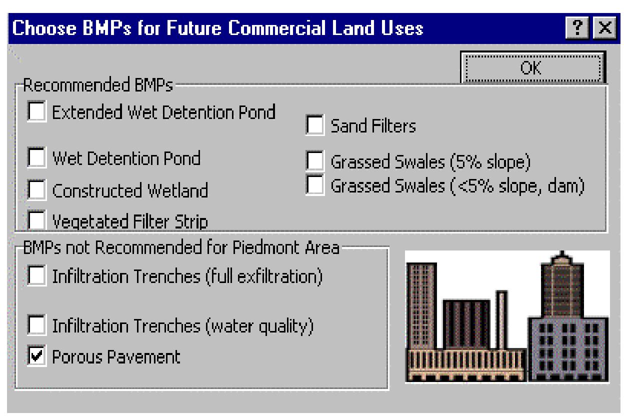


Figure 8 – BMP Analysis Options

- Figure 9 presents the results display of the BMP Analysis Component. This interface presents scenario results in comparison with baseline and worst-case conditions, and provides a planning level cost analysis. The results interface also presents the current and future land-use distribution for the chosen study area.

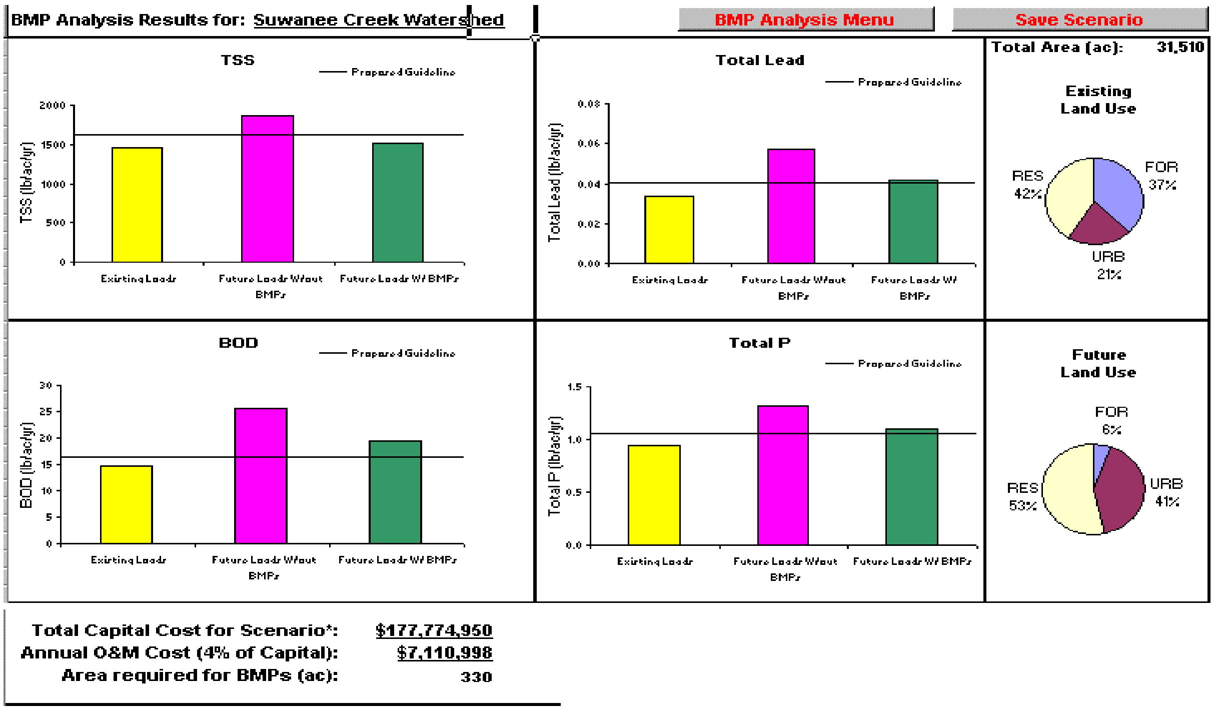
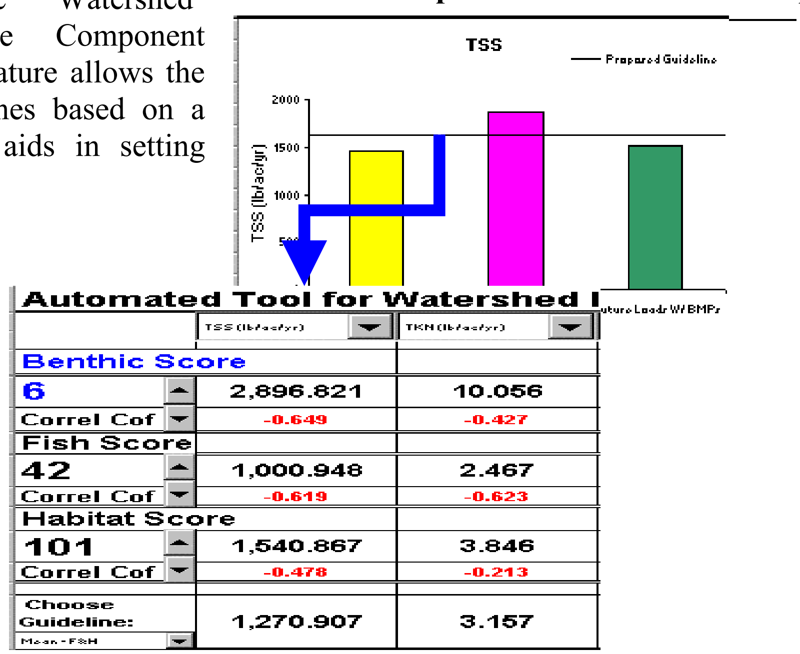


Figure 9 – BMP Analysis Component Results

- The BMP analysis component allows interaction with the Watershed Improvement Guideline Component (See Figure 10). This feature allows the user to edit the guidelines based on a predicted scenario and aids in setting realistic goals.

Figure 10 – Interaction of BMP Analysis and Watershed Improvement Guideline Components



New Development Performance Review

Introduction

This automated tool was developed to facilitate the evaluation of new developments in Gwinnett County in accordance with the TSS performance criterion. The tool was developed with the strategy of providing disincentives for installation of impervious surfaces and incentives for leaving key areas (particularly riparian buffers) undisturbed.

The review protocol identifies four distinct types of land area on each site:

- **Impervious Area** – e.g., driveways, rooftops, parking lots, roads, sidewalks, etc.
- **Disturbed Pervious Area** – e.g., lawns, gardens, landscaped areas, any area that was cleared, grubbed and graded
- **Undisturbed Upland Area** – e.g., upland woods, meadows, and other areas not cleared, grubbed and graded, porous pavement
- **Undisturbed Stream Buffers** – e.g., riparian buffers contiguous to streams, lakes, and wetlands, including areas in the floodplain

The tool estimates TSS loadings commensurate with potential contributions from land types. The sum of the products of the areas and their corresponding TSS loading rates (see Main Form for the TSS rates for each land area type) represent the total uncontrolled load from the site. The approach is simple to use and encourages site design that takes advantage of the natural site amenities and minimizes impervious surfaces.

The computerized form automatically calculates and graphs the loading value, and provides options for implementing BMPs on the site and designating the tributary drainage area to each BMP. The form compares the uncontrolled and controlled loading rates to the TSS criterion. This tool can be used iteratively in the site design process.

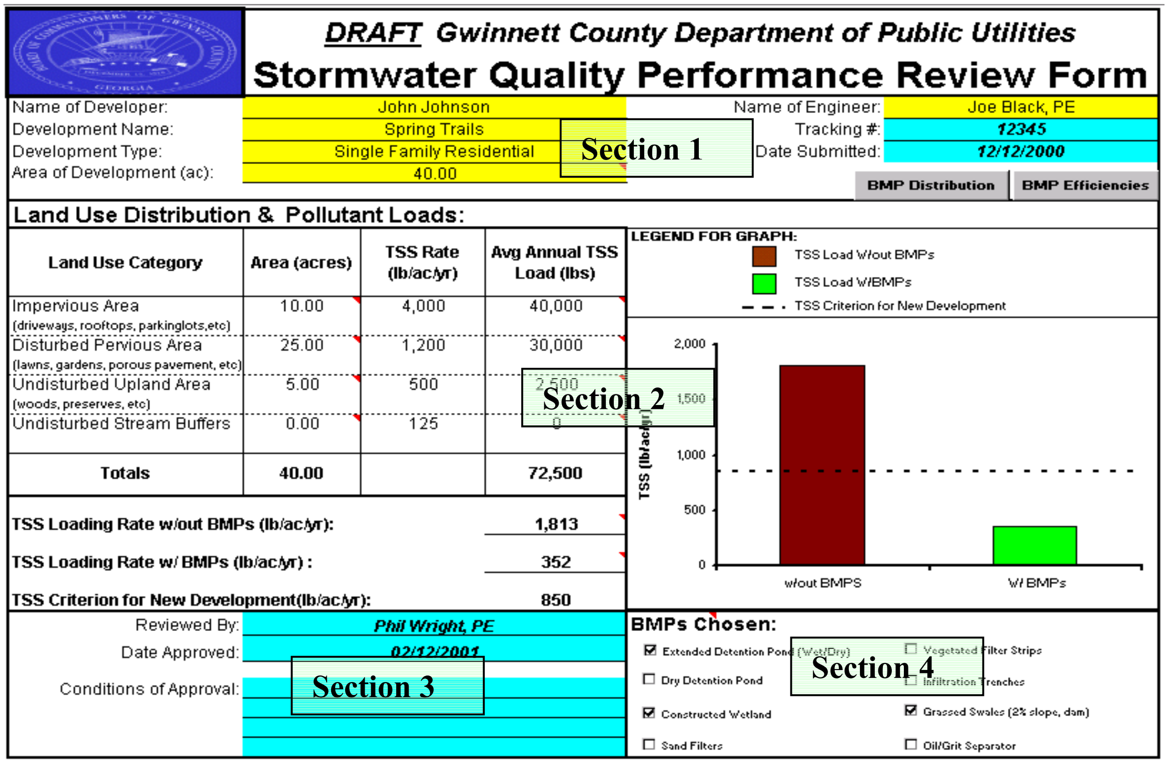
There are 3 main components to this spreadsheet:
1. Main Form
2. BMP Distribution Sheet
3. BMP Efficiencies Sheet

The following scheme should be followed when working with the tool:

- All cells highlighted in yellow require user input.
- All cells highlighted in blue require input from the Gwinnett County Department of Public Utilities.
- All dropdown menus require user input.
- All other cells are password protected and cannot be changed.

Main Form

The Main form has 4 sections (see figure below).



1) The first section requires the user to fill out general information for the site. Inputs include: Name of Developer, Name of Development, Type of Development, Area of Development, and Name of Engineer.

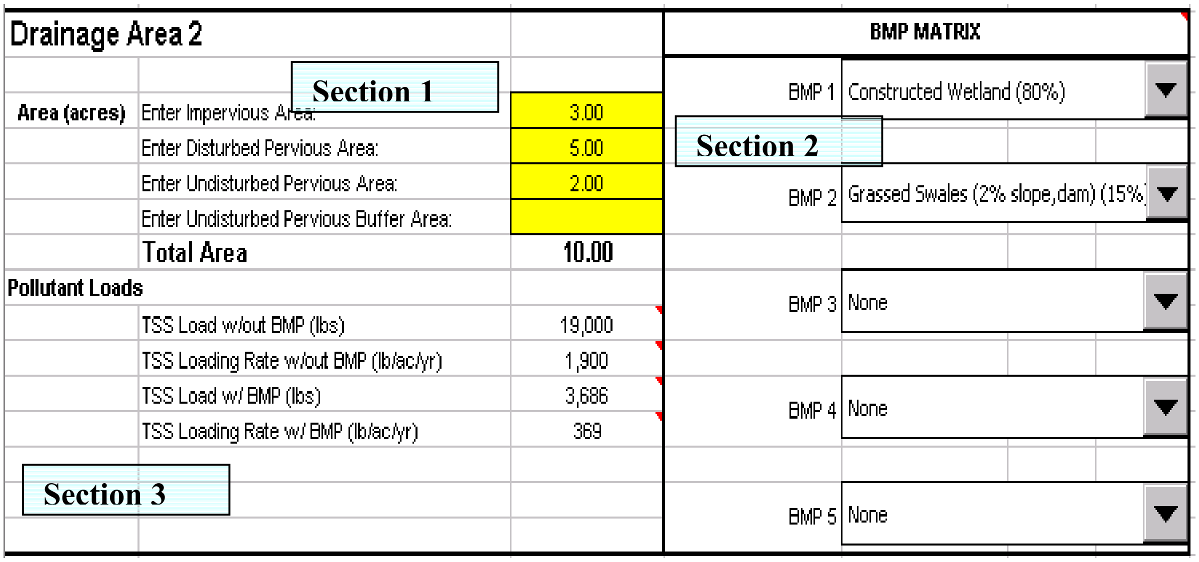
2) The second section consists of the Land Use Distribution and Pollutant Loads. It is a summary of information from the different drainage areas in the BMP Distribution Component. Each computed cell in this section has pop-up notes that enable the user to understand the processing of data. This component provides a summary of the TSS loading rates (with and without BMPs) produced by the site. It then generates a graph to compare the two TSS loading rates with the New Development Criterion.

3) The third section functions as a tool to track the review process for all new developments.

4) The fourth section of the Main Form is a summary of all the different BMPs chosen for the given site. It summarizes the BMP information by drainage area from the BMP Distribution Sheet and displays them.

BMP Distribution

In most developments, it is not physically possible to treat the entire site with one BMP. The BMP Distribution Component aids in dividing up the development into several different drainage areas. For example, a particular development of 40 acres may have 30 acres treated by a constructed wetland and 10 acres are treated by grassed swales. The reduction efficiencies for the two BMPs are different (80% and 15%, respectively). Hence the two areas should be entered into the BMP Distribution Component as Drainage Area 1 (30 acres) and Drainage Area 2 (10 acres); the BMPs in each drainage area should be chosen in the BMP Matrix section. The tool then computes the TSS loading rates for each drainage area. A weighted average is then computed to give an overall post treatment loading rate for the development and presented in the Main Form Component of this tool. Currently the BMP Distribution Component allows a particular development to be split into 20 drainage areas. There are three sections in the BMP Distribution Component (see figure below).



1) Section 1 requires the user to input the different land area types within a given drainage area.

2) Section 2 is the BMP Matrix. The drop-down menus in the BMP Matrix present the types of BMPs and their removal efficiencies. This section requires the user to input the BMP that treats the given drainage area. The BMP Matrix allows the user to pick multiple combinations of BMPs or BMPs in sequence; i.e., if 10 acres of a given site are drained by a Constructed Wetland which in turn is drained by Grassed Swales, the 10 acres are being treated by a combination of the two BMPs. The user should indicate this scenario by picking the Constructed Wetland as BMP1 and the Grassed Swales as BMP2 in the BMP Matrix. However, one should note that if this scenario arises, the removal efficiency of the second BMP will be lower than its highest potential (i.e. the efficiency listed in the BMP Efficiency Component). The reason for the reduction is that most of the heavy (easily removed) solid matter will be reduced by the first BMP, and the smaller particles (which are much harder to treat) will be treated by the second BMP. These smaller particles would reduce the potential of the BMP to remove TSS at its utmost efficiency.

When BMPs are in a series, the equation used to estimate the removal efficiency of the second

BMP is as follows:

Example Site: 10 acres drained by a Constructed Wetland followed by Grassed Swales

BMP1: Constructed Wetland	Removal Efficiency:	80%
BMP2: Grassed Swales	Removal Efficiency:	15%

Adjusted removal efficiency for BMP2:

= Removal Efficiency BMP2 X (1 - Removal Efficiency BMP1)

= 15% X (1 - 80%)

= 3%

Another important note to keep in mind when inputting a series of BMPs in a scenario is that the tool recognizes the BMP with the highest removal efficiency as the first in series. For example, there are 10 acres in a site being treated in the following order:

BMP1: Grassed Swales	Removal Efficiency:	15%
BMP2: Constructed Wetland	Removal Efficiency:	80%
BMP3: Vegetated Filter Strip	Removal Efficiency:	50%

The tool recognizes the sequence in the following order:

BMP1: Constructed Wetland	Removal Efficiency:	80%
BMP2: Vegetated Filter Strip	Removal Efficiency:	50%
BMP3: Grassed Swales	Removal Efficiency:	15%

The adjusted removal efficiencies can be estimated as follows:

Adjusted removal efficiency for BMP2 (Vegetated Filter Strip):

= Removal Efficiency BMP2 X (1 - Removal Efficiency BMP1)

= 50% X (1 - 80%)

= 10%

Adjusted removal efficiency for BMP3 (Grassed Swales):

= Removal Efficiency BMP3 X [1 - (Removal Efficiency BMP1 + Adjusted Removal Efficiency BMP2)]

= 50% X [1 - (80% + 10%)]

= 1.5%

3) Section 3 summarizes the TSS loading rates (with and without BMPs) for the drainage area. Pop-up notes are inserted in each cell to inform the user about the equations being used.

BMP Efficiencies

This component lists the types of BMPs that can be used for the New Development Review Protocol. It presents the BMP reduction efficiencies for TSS for each BMP type.

The following is a list of sources used for the BMP reduction efficiencies:

Schueler, Thomas R., 1987. Controlling Urban Runoff: A practical manual for planning and designing urban BMPs, Metropolitan Washington Council of Governments, Washington, DC.

Schueler, Thomas R., 1992. Design of Stormwater Wetland Systems: guidelines for creating diverse and effective stormwater wetlands in the mid-Atlantic Region, Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T. R., Kumble, P. A., Heraty, M.A., 1992. A Current Assessment of Urban Best Management Practices, Metropolitan Washington Council of Governments, Washington, DC.

Strecker, Eric, 1995. The Use of Wetlands for Stormwater Pollution Control. Presented at the National Conference on Urban Runoff Management, March 30 to April 2, 1993, Chicago, IL

USEPA, 1992. Guidance Specifying Management Measures For Sources of Nonpoint Pollution In Coastal Waters, Office of Water, United States Environmental Protection Agency, EPA 840-B-92-002.

USEPA, 1996. Municipal Wastewater Management Fact Sheets: Storm Water Best Management Practices, Municipal Technology Branch, United States Environmental Protection Agency, Washington, DC, EPA 832-F-96-001

USEPA, 1993. Guidance Specifying Management Measures For Sources of Nonpoint Pollution In Coastal Waters, Office of Water, United States Environmental Protection Agency, EPA 840-B-92-002.

GCSM, 1998. Gwinnett County Stormwater Manual (Draft). Ogden Environmental and Energy Services.

CONCLUSION

The development of guidelines for watershed characteristics is largely driven by imperviousness and land use. Use of this approach allows watershed management strategies to be targeted for biotic integrity. It also allows integration of "pollution control" strategies for specific pollutants where characterization and subsequent assessment show that pollution control is necessary. In conclusion, the WEB-WISE Model offers the following benefits:

- Is a user-friendly model that helps develop narrative TMDLs by linking pollutant loads to biological indices. This model is ideal for all stakeholders and state agencies responsible for developing TMDLs.
- Allows users to view various management scenarios based on desired goals.

- Allows users to make technically sound decisions for watershed protection.

The WEB-WISE model is an excellent tool for evaluating watershed protection strategies. It allows the user to set realistic goals for watershed protection using existing and future loadings, biotic and habitat data, and costs.

A NEW GIS APPROACH TO WATERSHED ASSESSMENT MODELING

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ABSTRACT

The GIS Watershed Assessment Model (WAM) was recently adopted for the ArcView platform making it more user-friendly and accessible to engineers and planners. This model, now called WAM*View*, simulates spatial water quality loads based on land use and soils and then routes and attenuates these source cell loads through uplands, wetlands and streams to watershed outlets. The model is almost entirely GRID based providing a higher resolution of results than models that rely on polygon coverages. The model includes a menu interface written in ArcView Avenue with the Spatial Analyst extension to let the user create modified land use scenarios and compare the results side-by-side with the results of the existing land use conditions.

New setup utilities have been added to the model to increase its adaptability to new watersheds. Because of the programming complexity, the model could previously only be customized for a specific watershed by the original developers. The model has since been designed to allow water resource engineers and planners, with limited GIS experience, to set up and customize the interface for their particular region. Algorithms originally in ARC/INFO AML format have been converted to ArcView Avenue scripts and step-by-step procedures have been established to guide the user through the model development process.

Other model enhancements include the addition of point sources, municipal waste treatment service areas, urban street sweeping, and BOD simulation. Known point sources of discharge can be added at any location within the watershed to simulate wastewater treatment plants or industrial dry weather contributions. In addition, wastewater treatment plant service areas can be added to signal the model that certain processes are occurring so that the model can make appropriate adjustments. These new features strengthen the urban component of the model, which is already recognized for its agricultural and rural applications.

KEY WORDS

WAM, WAM*View*, Water Quality, Watershed, Attenuation, GLEAMS, Arc/Info, ArcView, Grid

INTRODUCTION

Watershed Assessment Model (WAM) is a Geographic Information System (GIS) based model that allows engineers and land use planners to interactively simulate and assess the environmental effects of various land use changes and associated land use practices. WAM was originally developed with an Arc/Info interface for the entire Suwannee River Water Management District (SRWMD - 19,400 km2 of northern Florida) (SWET, 1998) and has since been customized for the St. Johns River Water Management District (SJRWMD) in northeast Florida (SWET, 2000), the National Institute of Water and Atmospheric Research in New Zealand (NIWA, 2000), and the Okeechobee and Myakka watershed in south Florida to accommodate their special regional and geological characteristics. WAM*View* (ArcView interface version) provides hourly time series of flow, total suspended solids (TSS), BOD, and nutrients for all the contributing watersheds within a basin. For the St. Johns River project, these data are being used as boundary conditions for a main-stem river model being developed by the US Army Corps of Engineers.

The GIS based processing and user interface in the WAM*View* model allows for a number of user options and features to be provided for grid sizes down to 0.1 ha, features include:

- Source Cell Mapping of TSS and Nutrient Surface and Groundwater Loads
- Tabular Ranking of Land Uses by Constituent Contributions
- Overland, Wetland, and Stream Load Attenuation Mapped Back to Source Cells
- Accommodation of Point Source Information
- Adjustments based on WWTP Service Area locations
- Hydrodynamic Stream Routing of Flow and Constituents with Annual, Daily or Hourly Outputs
- User Interface to Run and Edit Land Use and BMP Scenarios

WATERSHED ASSESSMENT APPROACH

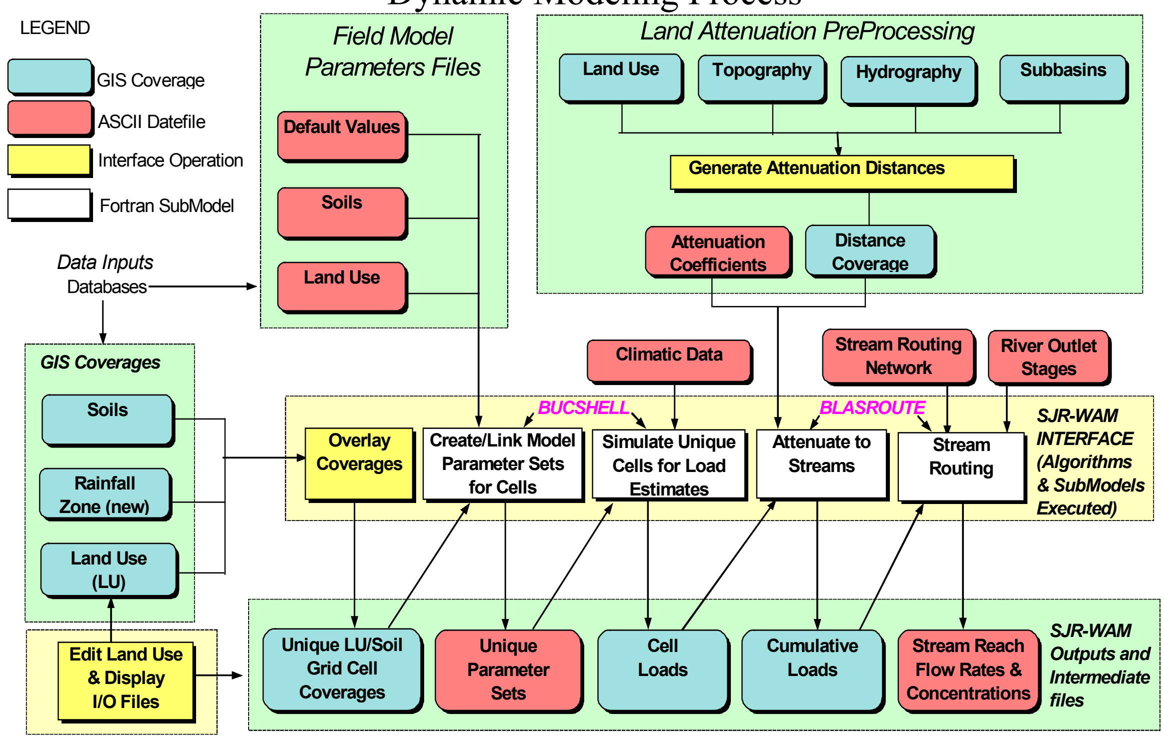
The water quality parameters (impact parameters) simulated within the model include: Water quantity, soluble nitrogen (N), particular N, groundwater N, soluble phosphorus (P), particulate P, groundwater P, total suspended solids (TSS), and biological oxygen demand (BOD). Additional fractionation of N and P for refractory forms and the addition of organic carbon are currently being added to the model.

The water quality assessments utilize detailed hydrologic and contaminant transport modeling. The method used depends on the watershed assessment parameter of interest. Based on current and anticipated future land uses, it is estimated that nutrients (N and P) and sediment have the greatest potential for causing adverse impacts in the streams, wetlands, rivers and estuaries within the areas to which the model has been applied thus far. The fact that only hydrologic/nutrient transport models have been effectively tested for use in watershed assessments supported the decision that only the water, nitrogen, phosphorus and sediment loads would be simulated dynamically. These parameters may vary for other regions and the model would be adjusted accordingly.

The modeling approach uses the watershed characteristic data from existing GIS coverages to select the appropriate input data (model parameter sets). These data are used to calculate the combined impact of all the watershed characteristics for a given grid cell. Once the combined impact for each unique cell within a watershed is determined, the cumulative impact for the entire watershed is determined by first attenuating the constituent to the sub-basin outlets for the load generated at each cell. Constituents are attenuated based upon the flow distances (overland to nearest water body, through wetlands or depressions and within streams to the sub-basin outlet), flow rates in each related flow path and the type of wetland or depression encountered.

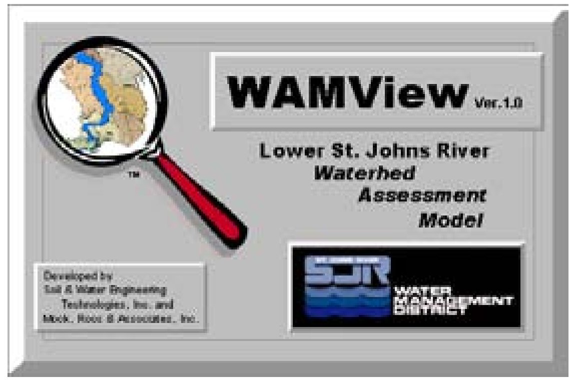
The hydrologic contaminant transport modeling is accomplished by first simulating all of the unique grid cell combinations of land use, soils, and rain zone (New Zealand version adds land slope) by using one of several source cell models including GLEAMS (Knisel, 1993), EAAMOD (SWET, 2000), a wetland module, and an urban module. The time series outputs for each grid cell is then routed and attenuated to the nearest stream and then through the entire stream network of the watershed. The figure below shows a flow diagram of the hydrologic contaminant transport modeling component of the overall WAM*View* model.

Dynamic Modeling Process

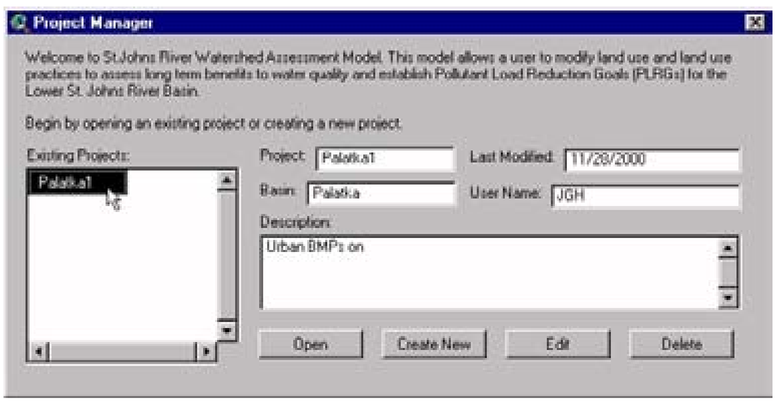


GIS MODEL INTERFACE

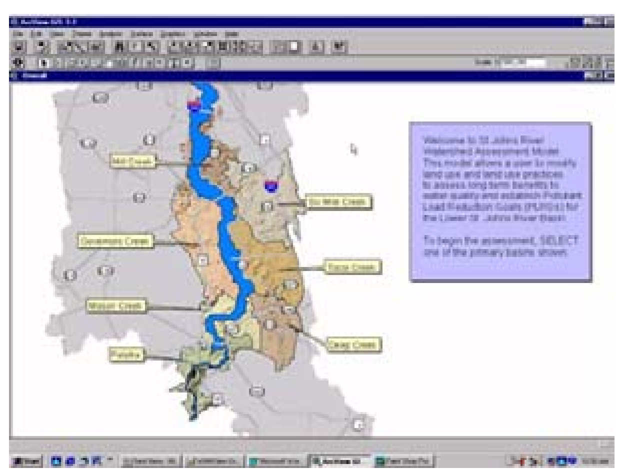
Getting Started



WAM*View* was developed to bring WAM to the average personal computer user. WAM*View* was written for ArcView 3.2 (or higher) with Spatial Analyst 1.1 (or higher). The programming language known as Avenue is provided by ArcView and allows complex functions and menu manipulation. ArcView itself comes with many features that users have become proficient on and accustomed to. The concept of WAM*View* is to leave the existing functionality of ArcView for the more experienced users and to add the WAM functions that were developed in the original Arc/Info version of WAM. The ArcView interface is modified in a way, however, that simplifies its use and does not require extensive experience with ArcView.

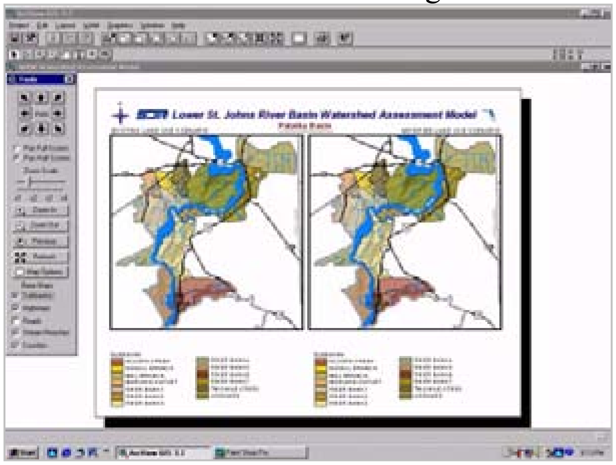


The interface begins with a dialog box that shows the user a list of previously saved projects along with the attributes of each project. This is called the Project Manager and provides a means to track, delete, open or create new projects. Pertinent information is stored about each project including the name, basin, date, user name and a project description. When creating a new project the user is prompted for this information.



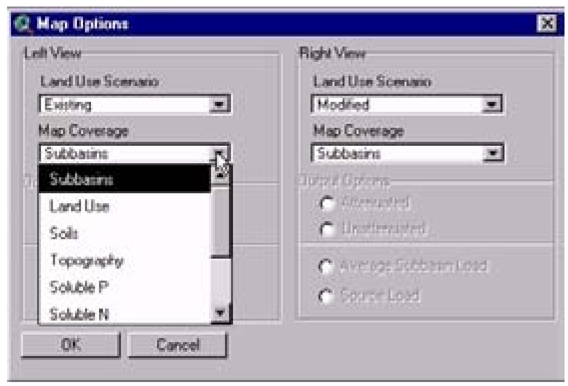
After the project information is entered, the user is then prompted to graphically select a primary basin for analysis. A map (or coverage) of the available primary basins is presented for the selection. A primary basin is defined as a collection of subbasins that discharge to a common waterbody via a network of streams, sloughs, ditches, etc. The user simply clicks on to the desired primary basin.

When the primary basin is selected, an ArcView layout appears that includes dual view ports, legends and a tool palette. The dual view ports are provided to allow for side by side comparisons of land use scenarios, but could also be used to compare land use or soils with model output to visually observe the relative effects each have on the model results. By default, subbasins are shown with existing vs modified land use scenarios. The tool palette provides basic



panning, zooming and other mapping options including overlaying base maps such as roads, county boundaries, etc. The zooming and panning tools are designed to perform simultaneously on both view ports.

The Map Options tool allows the user to change the GIS coverages in the display. Map Options includes two basic choices for each view port. The land use scenario can be existing or modified. By default, when a new project is opened, the modified land use model output coverages are equal to the existing land use scenario and will remain such until the land use is modified by the user and the model has been run.

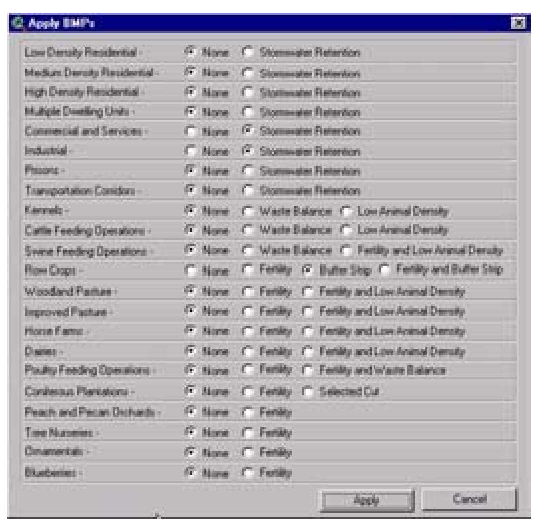


In Map Options the map coverage can be a variety of GIS coverages including model output for several pre-run water quality parameters. The user can display any two of the provided coverages such as subbasins, land use, soils, or topography. The user can view output in a variety of coverages as discussed later in this paper.

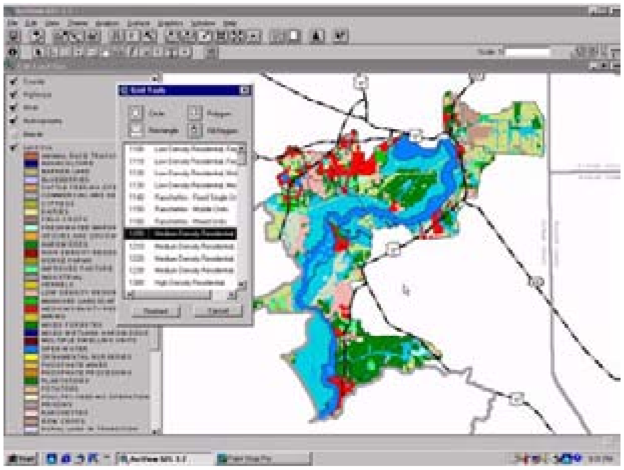
WAM*View* includes all of the standard tools and options familiar to most ArcView users. A new menu item, however, has been added to provide functions specific to WAM*View*. The options begin with three methods to create a modified land use scenario. The remaining options allow the user to run the model and view the output.

Modifying Land Use

There are three methods provided to create a modified land use scenario. One or all three methods can be applied to create a new scenario. Several Best Management Practices (BMPs) can be applied that are developed specifically for individual regions. BMPs may include reduced fertilizer applications or stormwater retention, for example. The available BMPs are land use dependant and may include several BMPs per land use.



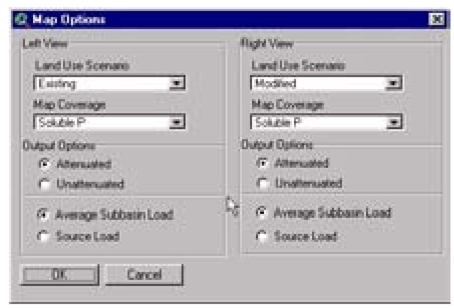
Land use swapping is useful for assessing government incentive programs to encourage land owners to change their land use or practices. Both options (Applying BMPs and Land Use Swapping) apply changes at a global scale within the selected primary basin. The changes are applied by altering the land use code numbers.

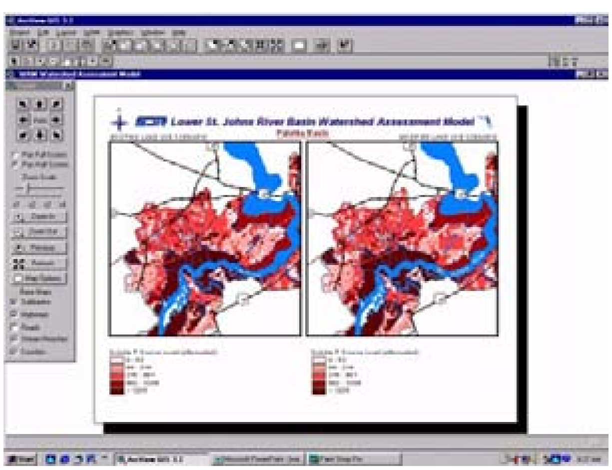


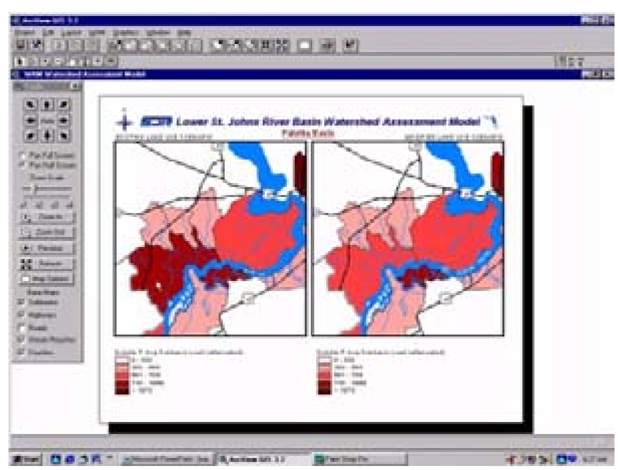
The final option to modify land use involves editing individual land use with a variety of tools. "Paint shop" type tools are provided to allow the user to literally paint on a selected land use. The user can select from a list of available land uses and draw shapes onto the existing (or previously modified) land use coverage. Land uses with BMPs can also be selected and added to the coverage which provides a means to include land uses both with and without BMPs. The fill tool can be used to change an individual land use with one click of the mouse button. BMPs to individual agricultural or urban developments can be added with the same ease and specificity.

Creating and Viewing Model Output

After the desired land use changes are made, the water quality model can be run. This is accomplished from the WAM functions on the main menu. WAM*View* creates a list of unique land use, soil and rainfall zone combinations based on the modified land use coverage. The information is compiled into a format needed for the BUCSHELL and BLASROUTE models. The models are then run sequentially. A DOS window will appear showing specific screen output for each model and a prompt will appear in ArcView instructing the user to press 'OK' when the models are complete. This pauses the interface while the models are running. The DOS window will close when the models are complete.

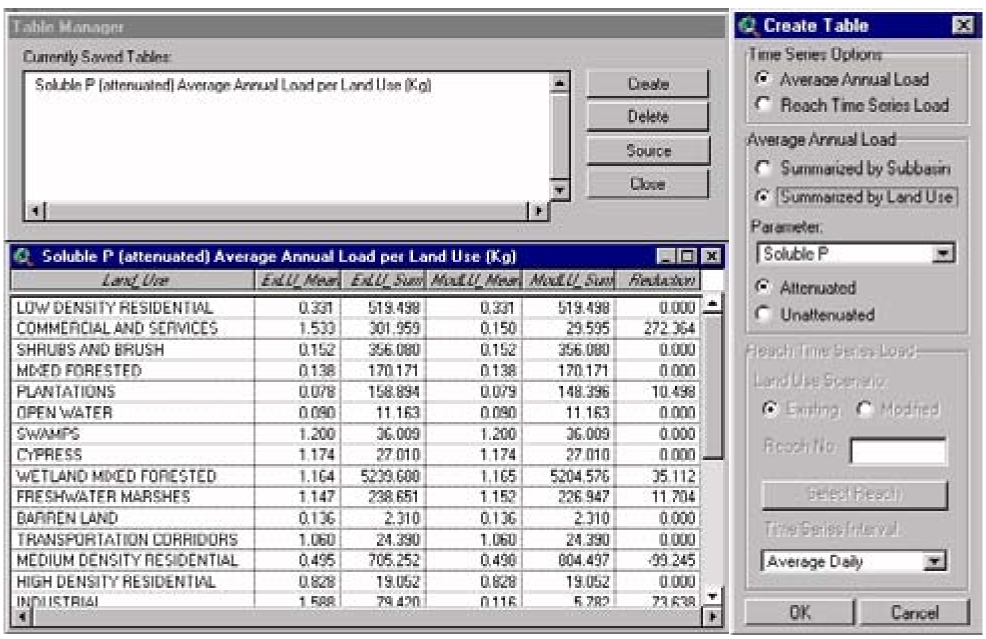






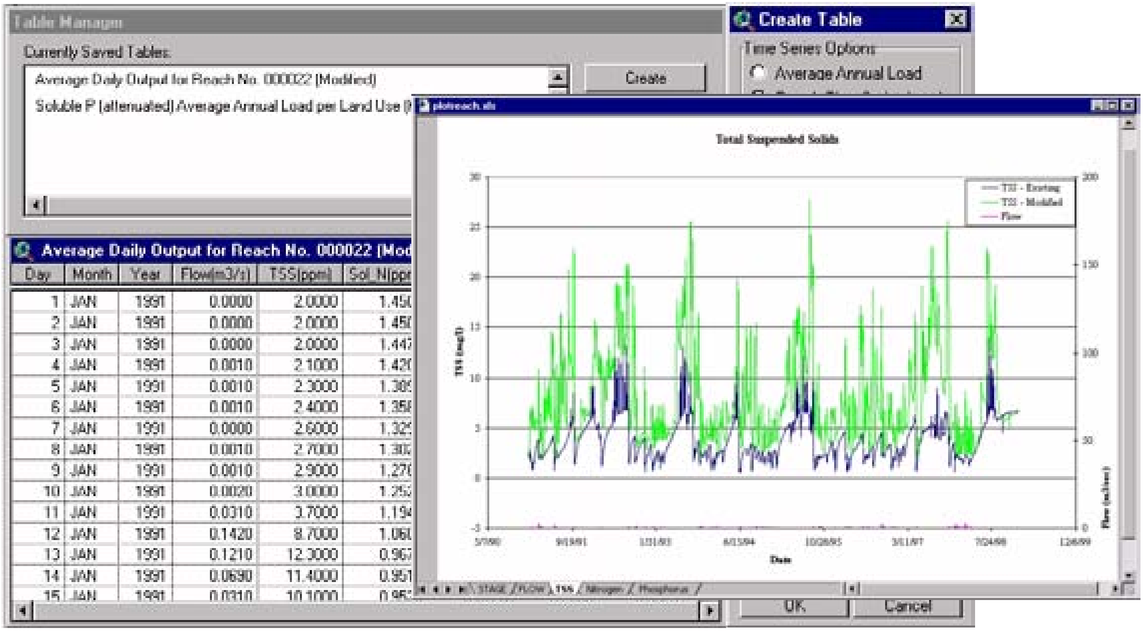
There are three basic options for viewing model output – maps, tables and graphs. Map Options can be used to begin viewing the results as GIS coverages. Output coverages include Soluble Phosphorus (P), Soluble Nitrogen (N), Total Suspended Solids (TSS), Sediment P and Sediment N. When selecting an output coverage, two sets of options are available: Attenuated vs. Unattenuated and Average Subbasin Load vs. Source Load. Attenuation represents load reduction (in most cases) based on the physical processes that occur as the runoff moves via overland flow wetland conveyance. Selecting Unattenuated provides the estimated load at the source of the runoff. Average Subbasin Load represents the mean value of a parameter over each subbasin. The resulting map will include one value per subbasin. Selecting Source Load provides a map with values placed on the grid cell where the runoff originated (attenuated or unattenuated).

The table manager provides a means of viewing the results in tabular form. The table manager includes features to list, view, create and delete tables specifically created in WAM*View*. The manager itself keeps track of tables specifically created by WAM*View* and will list them as Currently Saved Tables. There are two basic choices when creating a table. The average annual



loads reflect summaries of the output coverages. The reach time series includes hydro-dynamically modeled output for a selected stream reach. The average annual tables include choices to summarize the data based on subbasins or land use, attenuated or unattenuated. The user then selects a parameter. The resulting table includes a comparison of existing and modified land use scenarios.

The time series tables include choices regarding land use scenario and reporting interval. The user can enter a reach number, if known, or press 'select reach' and select from a variety of reaches available within the primary basin. The resulting table includes a complete list of the modeled parameters along with the estimated flows.



The final output option includes graphs of the time series data. Because of ArcView's limited graphing capabilities, WAM*View* has been designed to open the graphs in Excel. The user is again provided with a means to enter or select a reach. After the reach is selected, the model will automatically open Microsoft Excel and apply a macro to insert the model output datasets into pre-configured graphs of runoff, nitrogen, TSS and phosphorus.

Setting up WAMView

Previously, WAMView could only be setup by the original model developers, which presented concerns regarding "sole source" contracting. In response, setup routines have been written and an extensive help file has been developed including a set of tutorials to setup an interface for an overall watershed and to setup individual primary basins.
Detailed instructions are provided to obtain and setup the required GIS datasets. Typical sources of data are listed including USGS, water management districts, local governments, etc. Requirements for database fields and attributes are included. Similar instructions are provided to setup or edit model parameter files. The remainder of the setup is automated with onscreen instructions.

The watershed interface setup has been divided into four steps:
Step 1: Select Base Maps
Step 2: Select BMPs
Step 3: Setup Watershed View
Step 4: Customize Interface Layout

Five steps have been developed for setting up primary basins:
Step 1: Create Project and View
Step 2: Generate Reaches
Step 3: Generate Depressions
Step 4: Generate Distances
Step 5: Create Default Output

Training is also available to help guide users step-by-step through the setup process. Typically, three days of training are required to begin setting up a watershed. A follow-up session is recommended to answer additional questions and address any site specific issues that may arise.

SUMMARY AND CONCLUSIONS

WAMView allows engineers and planners to create new modified land use coverages by changing land uses and/or applying Best Management Practices through the use of graphical user interface. The user can then run water quality models and compare the results side-by-side with other land use scenarios. The model provides maps, tables and graphs for various nutrients.
WAMView provides an excellent tool for regional planners to determine and rank current areas under environmental stress, estimate future impacts of land use management decisions, set achievable pollution load reduction goals and establish Total Maximum Daily Loads (TMDLs). The model is continually being upgraded to meet planners' needs. The latest additions include point source accommodation and user setup and installation routines.

ADDITIONAL INFORMATION

Please visit our website at **www.swet.com** to download PowerPoint demonstrations of WAM and WAM*View* or contact SWET, Inc. tollfree at (888) 881-8507 for additional information.

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GIS DECISION SUPPORT TOOLS FOR WATERSHED WATER QUALITY PLANNING

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ABSTRACT

A simple non-point source (NPS) screening model was developed as an ArcView Utility and was applied to USGS sub-watersheds in the Tampa Bay area. This geographic information system (GIS) based tool contains customized graphical user interface (GUI) utilities for predicting the gross pollutant-load-potential based on landuse, soil, rainfall and storm event pollutant concentration parameters. The tool also contains utilities that facilitate the delineation of a watershed areas of interest (AOI), the updating of landuse and the estimation of best management practice (BMP) effectiveness. The presentation describes the tool and demonstrates its application by estimating historic (1995), present (1999) and future (2010) pollutant loading potentials for selected watersheds in the Tampa Bay area. The presentation will also discuss the proper application of the tool and possible future modifications to the tool.

INTRODUCTION

The concept of a watershed plan is not new, ancient Egyptians and Indo-Europeans developed complex plans for land management that included the construction of irrigation canals, water management methods, crop rotation and weather forecasting (ICS, 1999) In more recent times, communities attempted to deal with flooding problems by developing large engineering projects with the goal of moving water from residential and farm lands to adjacent water bodies in the most expeditious and cost effective manner possible. In the last ten years or so, the results of the ditch and dike methodology have been better understood, and a call for new approaches to water resource management ushered in the watershed management methods employed today.

In the early 1970s, several groups of scientists and policy makers began to look for new tools to attack old problems like flooding and natural system destruction. The United States and Europe in the early 1970s began to employ an approach that was later termed "integrated assessment" (ICS, 1999). This methodology can be described as an "interactive, process where integrated insights from the scientific community are conveyed to the decision-making community, and experiences and insights from the decision-makers are then taken account of in the integrated analysis". When applied to water-resource planning, this approach brings together such scientific disciplines as engineering, water chemistry, hydrology, hydrogeology, geography, biology, community planning, communications and education.

The watershed approach integrates these disciplines around a watershed focus. The resulting plan is comprehensive and inclusive in that it allows the evaluation of problems both from a detailed engineering perspective, and from a scientific and sociological perspective. On the local level, the "flood plans" have grown into watershed plans that address not only a flooding problem, but also the water quality and possible natural systems and human community issues that are related to a flooding issue (Hillsborough County, 2000). On a regional or state level, activities of multiple agencies have been focused into an integrated assessment approach to solve large regional watershed problems (TBEP, 1996), and on a national level, this approach combines regional efforts to address the larger national issues.

The state of Florida's five water districts maintain extensive GIS databases and develop watershed plans on a regional basis. The Southwest Florida Water Management District, (SWFWMD) for example, has divided the District boundary into eleven watersheds that correspond in most cases to the USGS catalog units. SWFWMD is in the process of developing comprehensive watershed management (CWM) plans for each of the watersheds (SWFWMD, 2001).

To assist the CWM process, SWFWMD is developing a CWM Decision Support System (DSS). The objectives of the DSS effort are to improve the support provided by the GIS section to District CWM teams and local government, and to develop a future condition prediction capability for water quality, natural habitat, flood protection and water supply. Ultimately SWFWMD will use this capability to evaluate local government plans and community development plans (SWFWMD, 2000). One element of this DSS effort is the development of a GIS-based non-point-source pollutant load tool (NPLT). This tool and its application are the focus of this paper.

MATERIALS AND METHODS

The general relationship employed for the estimate of pollutant loading for a parcel of a specific landuse is:
Annual Loading for Pollutant, i = Σ (EMC(i) x Annual Runoff Volume x Area in Each Landuse (Harper, 2001).

The DSS NPLT is an ArcView utility that employs a slightly more formal statement of this relationship called the USEPA Simple Method (USEPA, 1992) . Runoff volume estimates are used with event mean concentration (EMC) values for particular landuses to calculate gross pollutant loads; subsequently, this information is used in combination with BMP information to determine net loads. The EMC is determined by collecting stormwater samples over several storm events where the stormwater runoff originates from a single landuse (or set of closely related landuses). The EMC is the concentration that has a 50% probability of being exceeded during a storm event; thus, over the course of time, half of the storms will produce concentrations higher than the EMC and half of the storms will produce concentrations lower than the EMC. The mean of the pollutant concentrations is then determined and expressed normally in mg/L. The Simple Method relationship for nonpoint source pollutant loads employs the following formula:

$$L = 0.227 \bullet P \bullet CF \bullet RC \bullet C \bullet A$$

Where :

L = Pollutant load (lb/period)
P = Precipitation (in/ period)
CF = Correction factor for storms that do not produce runoff
RC = Weighted average runoff coefficient based on impervious area and hydrologic soil classification
C = Event mean concentration of pollutant (mg/L)
A = Catchment area contributing to outfall (acres)

GIS themes representing landuse, soil classification, basin boundaries, and best management practice (BMP) coverage are used as input. These inputted spatial-database components are used in combination with user-defined tables to calculate pollutant loads. User-defined tables include EMCs, runoff coefficients, and BMP efficiencies. EMCs are specified per landuse, runoff coefficients are specified per soil group and landuse, and BMP removals are specified by removal efficiencies.

Within the model, GIS themes of soils, landuse, and drainage basin polygons are intersected to produce a new theme. Mass loads are calculated for each resulting polygon (*calculation element*) and added as attributes to the theme table of this new theme. Each unique combination of basin, soils, and landuse, hereafter referred to as a *calculation element* has the following minimum attributes:

Calculation Element

- Hydrologic Soil Group
- Landuse
- Element Shape – used to calculate area
- Basin Identification - Multiple field, as needed, to fully characterize the shape from the smallest delineated basin division (i.e., Basin B) to the largest division for which loads are to be summarized (i.e., Big Creek Watershed)
.

Note: [1] EMCs are commonly assumed to follow a lognormal distribution

Calculation Element

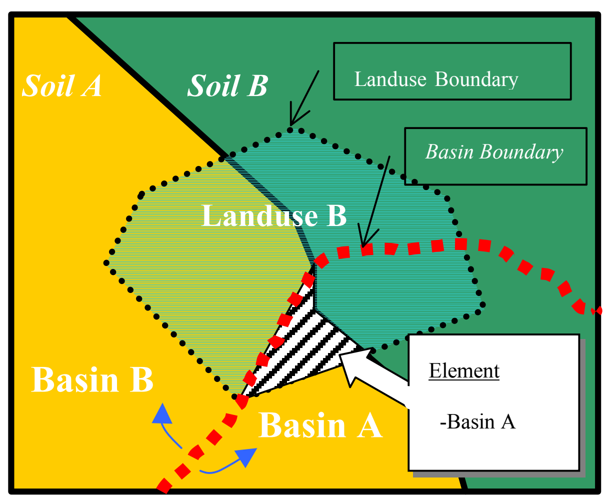

Figure 1. Elements of Calculation Element

In the model, the average annual runoff expected from each specific *calculation element* is computed as the product of the rainfall amount times the corresponding runoff coefficient. A correction factor (CF) to account for the numerous small rainfall events that do not result in any runoff may be specified explicitly or "built-in" to the runoff coefficients. The total volume of runoff for a basin, or other area of interest, is then determined by summing the calculated runoff volumes for each *calculation element* within that basin.

Pollutant loads are calculated in much the same way- that is, each *calculation element* is assigned an EMC based on landuse (via a table join) which is multiplied by the *calculation element's* runoff volume to estimate mass loads. The mass loads for each *calculation element* contained within a feature of interest (i. e., basin) are summed to produce mass loads for that particular feature. The model divides mass loads into three parts: gross load, removed load, and net load. The **gross load** is the mass of pollutant generated (washed off of land surface) and is calculated according to the methodology described above. The **removed load** is the mass removed by the BMP and is calculated based on user-supplied BMP information. The **net load** is the difference between gross load (wash-off load) and removed load.

BMP locations and types are specified by pointing and clicking on the individual BMP locations and selecting a BMP type from a user-defined table. Through this process, a point theme of BMPs is created. Attributes from this point theme are transferred to a user-specified polygon theme representing BMP coverage through a spatial join. Finally, the BMP coverage theme is intersected with the *calculation element* theme resulting in a new theme, or new *calculation element* polygons. This new theme contains polygons for each unique soils/landuse/ basin/BMP combination. Pollutant removals are calculated and subtracted from the gross loads to produce net loads. Removed and net loads for a basin or another area of interest (AOI) are summed according to the procedure described in the preceding.

RESULTS

The NPLT is used on a regional (USGS watershed, a CWM basin etc.), local (USGS drainage basin, county or city basin) or a catchbasin level (lake drainage basin etc). When used regionally, the primary functions are: (1) calculation and display of estimated gross pollutant loads or potential pollutant loads, (2) determination of areas of potential high pollutant load; or (3) determination of areas where the pollutant load has changed over time. On a local level, in addition to these functions, the NPLT provides specialized sub-tools that allow: (1) selection of a smaller area or interest (AOI) and recalculation of pollutant load; (2) the change of landuse for an area of interest and the recalculation of pollutant load; and (3) the location of BMPs within an area of interest and calculation of gross, removed and net loads for that area of interest. All of these functions are also applicable on a catchbasin basis.

The Hillsborough River watershed, the local Hillsborough County Cypress Creek watershed, and a catchbasin within the Cypress Creek watershed will be used to illustrate the various functions of the NPLT (Figure 2). To begin, pollutant load layers are built based on the SWFWMD landuse, soils and USGS drainage basin layers. This is either accomplished within the ArcView environment or through a separate ArcInfo job. In the following example, potential pollutant load layers (PPLL) were built for 1995 and 1999 landuse-soils layers and for both the wet season and dry season load estimates. This allows seasonal and time comparison of pollutant potential.

For visual comparisons, a standard ArcView legend is developed for each pollutant of interest. Unfortunately, the figures are not in color in this paper; however, in actual use the legend (color-coding) allows rapid spatial analysis. Normally, the wet season PPLL is used to ensure the legend scale covers all possible pollutant load levels. The PPLL database can also be used with database or spreadsheet applications outside the ArcView environment to develop comparison tables. The legend in Figure 2 is designed for spatial comparison with nitrogen as the pollutant of interest. The scale is based on the wet season loads with units of pounds per acre for the period of interest (normally a season). The legend is then applied to all landuse/season layers and visual comparisons are made.

Potential Pollutant Load Layer (PPLL)

- PPLL polygons
- Standardized View Legend (lbs/acre)
- Basis for further analysis
- Can "cut" layer using local boundaries
- Potential Pollutant Loads for nitrogen, phosphorus, TSS, BOD, lead and zinc.

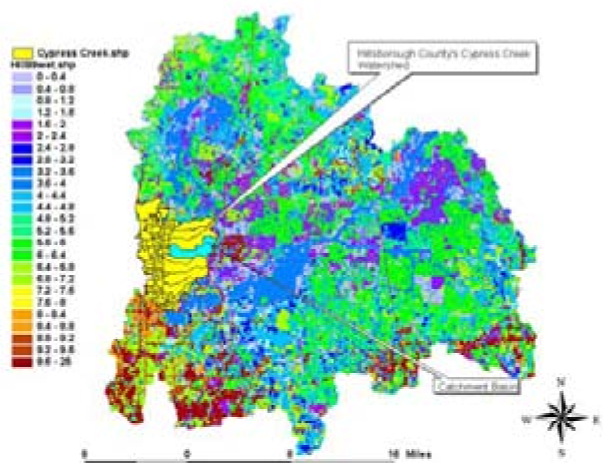

Figure 2. Hillsborough CWM 1995 Wet Season Potential Total Nitrogen Pollutant Load Layer

Figure 3 shows the Cypress Creek watershed PPLL view for nitrogen. The area of interest tool (AOI) is used to develop this view by "cutting" the regional level (CWM) PPLL and recalculating the loads forming a new PPLL. The resulting layer can then be used for pollutant load analysis on a local level. For example, Figure 3 shows several areas where potential non-point source pollution loading may be an issue. The areas that have the highest nitrogen pollutant loads are large traffic arteries and areas of dense population. By comparing this view with one developed using 1995 landuse, an estimate of potential pollutant load change can be determined.

A more precise estimate is accomplished using the database developed as part of the PPLL creation process. The database tables can be compared using a standard database program or spreadsheet. The local area PPLL has the same properties as that of the larger regional PPLL and can be used in the same manner.

Hillsborough County's Cypress Creek Watershed (Local Government) (PPLL)

- PPLL polygons
- Standardized View Legend (lbs/acre)
- Basis for further analysis
- Can "cut" layer using local boundaries
- Potential Pollutant Loads for nitrogen, phosphorus, TSS, BOD, lead and zinc.

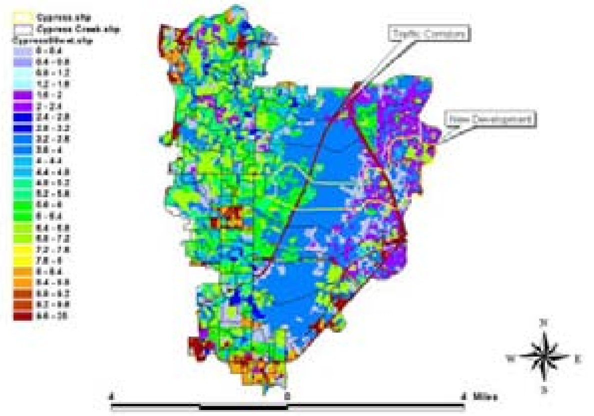

Figure 3. Cypress Creek PPLL (TN lbs/acre)

The AOI tool can also be used to "cut" the catchbasin PPLL from either the regional or local PPLL. Figure 4 shows a comparison of the same catchbasin but for different year groups. The comparison of these views will allow the determination of relative changes in the catchbasin area due to growth.

Catchbasin PPLL

- Comparison of PPLL for 1995 and 1999
- Standardized View Legend (lbs/acre)
- Smallest level of analysis
- Can "cut" layer using local boundaries
- Potential Pollutant Loads for nitrogen, phosphorus, TSS, BOD, lead and zinc.

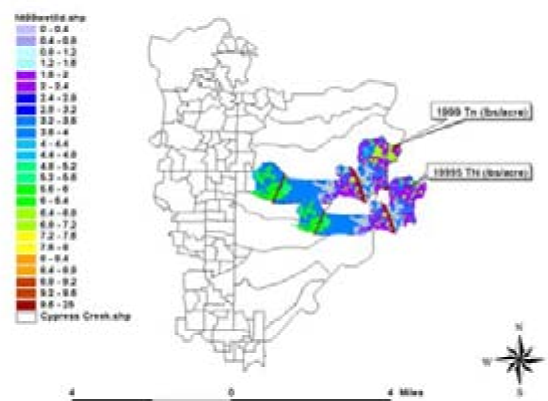

Figure 4. PPLL view for catchbasin (TN lbs/yr)

The catchbasin PPLL is best used to evaluate changes in pollutant loads and to evaluate alternatives that might be used to manage these pollutant loads. Smaller catchbasins can be also developed using the AOI tool. For example, in Figure 5 the northeast tip of the catchbasin is shown. This is an area of rapid urban growth in New Tampa. The comparison of 1995 and 1999 PPLLs points to this area as one of concern for increased pollutant loads and where additional investigation is warranted. In the figue, several areas are immediately indicated by the color of the polygons (red and green-yellow areas) as having high pollutant load potential. Since the difference between the two PPLLs is time, this difference in load can be attributed to growth. The orthophotoquad, which is shown below the PPLL, illustrates the type of growth and original landuse. These types of ArcView displays can be useful when evaluating the impact of growth on an area.

Sub-Catchbasin PPLL

- 1999 PPLL showing areas of increased pollution potential
- Standardized View Legend (lbs/acre)
- A smaller catchbasin developed using a delineation tool and AOI tool.
- Potential Pollutant Loads for nitrogen, phosphorus, TSS, BOD, lead and zinc.
- BMP placement and Landuse Change after 1999 shown

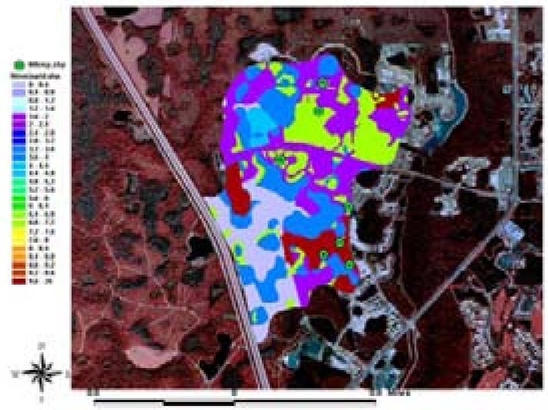

Figure 5. 1999 PPLL overlaid on 1999 aerial.

One of the problems found in reviewing watershed plans is that, because they are based on landuse layers that may be several years old when the analysis begins, the estimates based on older layers are not a good reflection of existing conditions. The NPLTs **Change Landuse (CL) tool** is an attempt to correct this problem. This tool allows the planner to derive information from field mapping or recent aerial photography and develop a change polygon that is then used to update the landuse of the PPLL. Figures 5 and 6 illustrate the use of this tool and the AOI tool to better characterize the changes occurring in the section of New Tampa north of U.S Highway I-75. The catchbasin is divided using I-75 as the division line and the AOI tool is used to build a new PPLL for the 1995 and 1999 layers. The CL tool is then used to modify areas that the aerial indicates are being developed with primarily high density housing. Table 1 shows the potential pollutant non-point source loading to Cypress Creek from this updated PPLL as compared to the base (1995) condition. Figure 6 is a spatial comparison of the change.

Comparison of Catchbasin PPLLs

- Two new PPLLs Created using AOI tool
- 1999 PPLL is updated using CL tool
- Spatial Comparison of the two PPLs shows an updated picture of change in area in terms of nitrogen non-point-source pollutant load.

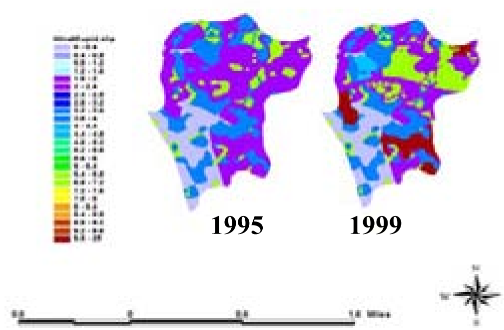

Figure 6. Comparison of two sub-catchbasins.

Table 1. Comparison of non-point source pollutant-loading potential to Cypress Creek.

Cypress Creek Non Point Source Load Potentials	Area (acres)	Runoff Volume (acre-ft)	Total Nitrogen (lbs/yr)	Total Phosphorus (lbs/yr)	Total Suspended Solids (lbs/yr)	BOD_5 (lbs/yr)	Zinc (lbs/yr)	Lead (lbs/yr)
Gross Load 1999 Land Use	622	742	2,384	260	25,553	7,617	38	72
Gross Load 1995 Land Use	622	662	1,777	97	16,956	4,528	21	50
Gross Load Change	0	80	606	163	8,597	3,089	17	22
Net Load 1999 Land Use	662	742	2,235	218	20,123	6,569	31	57

Table 1 provides the potential results in terms of runoff volume and pollutant load from the types of growth occurring in this New Tampa region. It is important to note that the results of the NPLT analysis shown in the "Gross Change" row are potential pollutant loads from non-point sources. No calculation of load and runoff volume reductions from existing or planned BMPs and/or natural elements such as wetlands has been carried out to this point. The BMP tool was developed to allow an estimate of these types of effects. Figure 5 indicates where BMPs were located during the BMP tool assisted analysis. The "Net Load" row in Table 1 is a result of BMP placement and load reduction calculations accomplished with the BMP tool. The "Net Change" row provides an estimate of the expected change in pollutant load to Cypress Creek. Because the catchbasin area includes drainage to Trout Creek a similar analysis (not shown) was performed for that drainage area. The analysis shows that urban growth in this New Tampa area will result in a predicted increased load to both Cypress and Trout Creeks even when BMP effects are considered.

DISCUSSION

Several improvements are currently under consideration for the model. These improvements are aimed at extending the usefulness of the model and improving results. Some of the key areas to be addressed are **perpetuity** of the tool and the **calculation** engine**.**

Ensuring perpetuity of the tool.

The Avenue scripting language is fading from use along with other ArcView 3.x products. The tool will not function in ArcView 8.x; therefore, it is advisable to migrate away from Avenue and place software development efforts in a product that has a more secure future. This presents a bit of a dilemma in that most users are still using the ArcView 3.x version yet improvement to the tool using ArcView 3.x technology (Avenue) is ill advised. Grouping the model functionality into two classes – a class that performs spatial operations and a class that performs “number crunching” and reporting functions can ease this migration.

New development for the tool should occur in Visual Basic (VB). Grouping the model functionality into the two groups described above will allow this to occur without loss of usage or software investment due to compatibility problems. Spatial operations performed by the tool could remain much as they currently exist. New "number crunching" and reporting routines would be written in Visual Basic accepting the database files from the tool as inputs. To accommodate ArcView 8.x users, the spatial analysis components would be incorporated into the ArcView version of Visual Basic for Applications (VBA), or users could build a theme meeting certain specifications and proceed from there with using the tool. In the future, the new VB code could be either incorporated into ArcView's VBA (available in ArcView 8) or a standalone model using Environmental Systems Research Institute Inc. (ESRI) "Map Objects". Either way, all code would be reusable, and the model could still be used as the gradual migration from ArcView 3x to ArcView 8x occurs among the user base. Use of a COM-compliant programming language, such as VB, will also greatly improve functionality in regards to other potential improvements.

Incorporate EPA SWMM as Calculation Engine

One of the limitations of the tool rests in the fact that each basin "stands alone"; that is, connectivity is not considered. This inhibits efforts to determine loadings at particular points of interest and prohibits simulation of multiple BMPs. In addition, the use of continuous simulations would improve model results, as would the ability to consider hydraulic and water quality-loading rates in BMP evaluations. The ability to incorporate point source loads and use different "buildup" and "washoff "algorithms would also represent significant improvements to the tool. For these reasons the incorporation of EPA's Stormwater Management Model (SWMM) into the tool is under consideration.

The application of SWMM need not be overly complicated; in fact, minimal SWMM elements could be incorporated to improve results without increasing the complexity associated with tool usage. For example, the tool could use the SWMM Runoff Block to determine runoff volumes. This could be accomplished by using only those parameters that are most sensitive in regards to flow volume. Parameters that have minimal effect on volume (i.e., impervious area roughness) could be specified as defaults or calculated internally (i.e., subcatchment width). The volume-sensitive parameters would be specified per landuse and landuse/soil combination just as they are now. The result would be improved runoff volume, and therefore pollutant mass, estimates.

Taking this idea one step further, the Runoff Block can be used for routing and BMP simulation with minimal inputs due, in large-part, to recent improvements to the SWMM model made by Dr. Wayne Huber of Oregon State University (OSU). OSU's SWMM Version 4.4 allows for runoff from one sub-catchbasin to be directed to another sub-catchbasin instead of having to flow into a channel or pipe, thus allowing for summing of masses without the need for hydraulic information. This improvement also allows for simulation of riparian zone and overland flow BMPs. In addition, Version 4.4 contains removal mechanisms in the Runoff Block thus eliminating the requirement of having a transport model to simulate BMPs.

On the surface the use of SWMM may appear to be contrary to some of the tool's key advantages, i.e., ease of use and simplicity; however, most of the "SWMM horror stories" in circulation are related to the Extran Block, SWMM's hydraulic routing model. On the other hand, Runoff Block calculations are straightforward and model-stability is not a concern.

CONCLUSION

This paper describes an ArcView GIS decision support system that can be employed by anyone with ArcView training and access to ArcView version 3.1 and the proper data files. The tool allows planning on a regional, local or catchbasin basis and is most valuable when used to develop initial estimates or when used to evaluate a watershed management plan. The tool employs the SWFWMD landuse and soils data sets and look-up tables for landuse categories (aggregates), runoff coefficients, Event Mean Concentrations (EMC) and BMP pollutant load removal. Runoff coefficients are provided for wet season and dry season and are taken from the Tampa Bay Estuary Program (TBEP) pollutant load model (TBNEP, 1966). EMC values are taken from TBEP sources and BMP values are literature values (Harper, 2001). Additionally, the user can specify the percentage of storms that do not result in runoff. Table values can be changed as better information becomes available.

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"LIVE" WATERSHED MODEL

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ABSTRACT

The goal of engineering-based watershed modeling is to predict the hydrologic response of a particular watershed to historical and/or synthetic rainfall events. Watershed models are often used as planning tools for flood control studies and for regulatory decision-making. Because a wide variety of engineering hydrologic models are commonly used, often within a single regulatory jurisdiction or political boundary, data management can be a daunting task for the watershed manager. Use of Geographical Information Systems (GIS) for watershed studies promotes the use of standard formats for the graphic representation, storage, and retrieval of watershed information, including flood study results.

Rapid advances in GIS over the past decade have led to the increased usage of existing spatial data sets, or "coverages" (i.e. soil cover, land usage, and topography) as input into engineering-based hydrologic modeling. This is known as creating a "linkage" between a GIS and a hydrologic model. In addition to the simple one-way linkage often employed, it is advantageous to create a two-way linkage, whereby the computer modeling software provides input into the GIS. This allows the complete model input and output data set to be viewed entirely within the GIS platform, including hydraulic model information obtained from comprehensive ground surveys and other sources, as well as model results. This system provides for a fully linked engineering data management system that can promote the exchange of information in a readily usable format.

Keeping the information current or "live" is a daunting task for the watershed manager. The GIS allows the user of the system to achieve this goal, by updating the model and the GIS at the same time when changes occur. Photographs of the various features, new model run results, existing pipes and other projects implemented in the watershed can be brought into the GIS and hydraulic model soon after they are built.

In this paper, the development and the application of a fully linked GIS-based data management system is presented for the graphic representation, storage, and retrieval of engineering data for the Stevenson Creek Watershed in the City of Clearwater, Pinellas County, Florida. GIS data in ESRI's ArcView3.2 is linked with AdICPR hydraulic model data in a graphical user interface. This information is also presented on a web site for public and watershed managers use.

INTRODUCTION

Parsons Engineering Science in Tampa, Florida has completed a year-long study of the Stevenson Creek watershed, which began in March of 2000. The primary objective of the project is to develop a watershed management plan for the Stevenson Creek basin, in accordance with a cooperative agreement between the Southwest Florida Water Management District (SWFWMD) and the City of Clearwater. It is being used as a tool in the planning, regulation, and management of the Stevenson Creek Watershed for future development, and as a basis for identifying, analyzing, and prioritizing capital improvements. This objective has been met in part, by conducting an analysis of the watershed in order to characterize the existing watershed conditions, and recommending improvements for flood protection, natural systems, habitat, water quality, erosion control, public awareness and involvement, and regulatory control.

The first task in the analysis process was to collect, record, and organize all potentially useful existing information relevant to the watershed. Once the data were collected and analyzed, any data deficiencies were noted and the missing data were gathered. The information-gathering process included such activities as a literature search and review of existing data, field reconnaissance and ground-truthing of aerial photography, ground surveying of stream channels and drainage facilities, streamflow monitoring, surface water sampling and testing, habitat assessment, interviews with City operations personnel, and input from residents of the watershed.

Engineering-based watershed modeling software and GIS were employed to gain a thorough understanding of basin-wide hydrologic and hydraulic processes. The watershed model was used, in conjunction with the GIS, as a planning tool to assess the existing flooding problems. Subsequently, it was used to determine the most effective means of alleviating the flooding problems and to optimize the flood protection benefits of the proposed improvements.

The Advanced Interconnected Channel and Pond Routing Model, Version 2.2 (AdICPR) was chosen for the hydrologic and hydraulic modeling analysis, in part because of its ability to mathematically represent the time-dependent processes that govern flow and stage in low-relief coastal watersheds such as Stevenson Creek. Furthermore, it was necessary to select a model that has been accepted by the Federal Emergency Management Agency (FEMA) for flood insurance studies, since the results of the analysis will be used to support a request for revision of the applicable FEMA flood insurance rate maps.

Environmental Systems Research Institute's (ESRI) ArcInfo7.02 suite of solutions, primarily ArcView Version 3.2a (ESRI, 1996), was chosen as the GIS software. It was selected because of the readily available data in this format provided by the SWFWMD, the City of Clearwater, and other state and federal agencies. Applicable data in other formats such as AutoCAD, Microstation, and tabular data were converted to ESRI shape files. Some data not available digitally was digitized on screen, and later attributed.

Information from the GIS was used in the development of the hydrologic model. Spatial data sets such as soil cover, land use, subbasin delineation, storm sewer data, surface water storage features, and open channel alignments were all used in the development of input parameters in the AdICPR model. Results of the hydrologic model, such as flow, peak flood elevation and flood profiles for the synthetic rainfall events (model storm events) are then linked back to the GIS for the purpose of error checking, data storage, and data retrieval. This provides a two-way linkage, where all data is available to be viewed within the GIS. It is inherently more useful to view watershed model data in a spatial frame, where distances and direction are preserved. Additionally, an aerial photography background can be used, which provides context to the investigator.

STUDY SITE: STEVENSON CREEK WATERSHED

The Stevenson Creek Watershed, the largest and most urbanized watershed within the City of Clearwater, drains 25 km^2 (6,286 acres) in west central Pinellas County (refer to Figure 1). Of this area 65 percent are within the Clearwater city limits. The remaining 35 percent of the basin is within the City of Dunedin 20%, unincorporated Pinellas County 14% and the City of Largo about 1%. Terrain in the watershed is flat to mildly sloping. Native soils are primarily fine sands.

Stevenson Creek discharges to Clearwater Harbor and St. Joseph's Sound. The majority of the creek has been channelized or otherwise altered, and little of the historic floodplain remains intact. Land uses within the basin are predominantly medium- and high-density residential, commercial, and open space. Approximately 90 percent of the watershed has been developed, and the vast majority of the development occurred prior to the implementation of regulatory requirements for floodplain preservation, environmental protection, stormwater treatment and attenuation. Several developments have been constructed within the creek's floodplain and have experienced severe flooding. In addition, the creek and its tributaries experience moderate to severe erosion problems due to steep embankments, improper maintenance, highly erodable soils, and inadequate right-of-way.

METHODS: GIS LINKAGE TO HYDROLOGIC MODEL

It is now standard practice to provide one-way linkage to between the GIS and hydrologic modeling. The GIS is traditionally employed to provide a measure of the lands stormwater runoff susceptibility. The hydrologic model used for this study is the SCS (NRCS) Runoff Curve Number (CN) and Unit Hydrograph Method contained within AdICPR. This method computes a runoff (flow) versus time relationship (hydrograph) for each subbasin, given a set of hydrologic input parameters.

The GIS was used to subdivide the heavily urbanized Stevenson Creek watershed into a total of 307 discrete subbasins that range in size from 4000 m^2 to 800,000 m^2 (1 to 197 acres). The average subbasin size is 83,000 m^2 (20.5 acres). The delineation of individual subbasins was dictated to a large extent by the complexity of the drainage network itself and the need to define the contributing drainage area to modeled elements of the conveyance system (refer to figure 2).

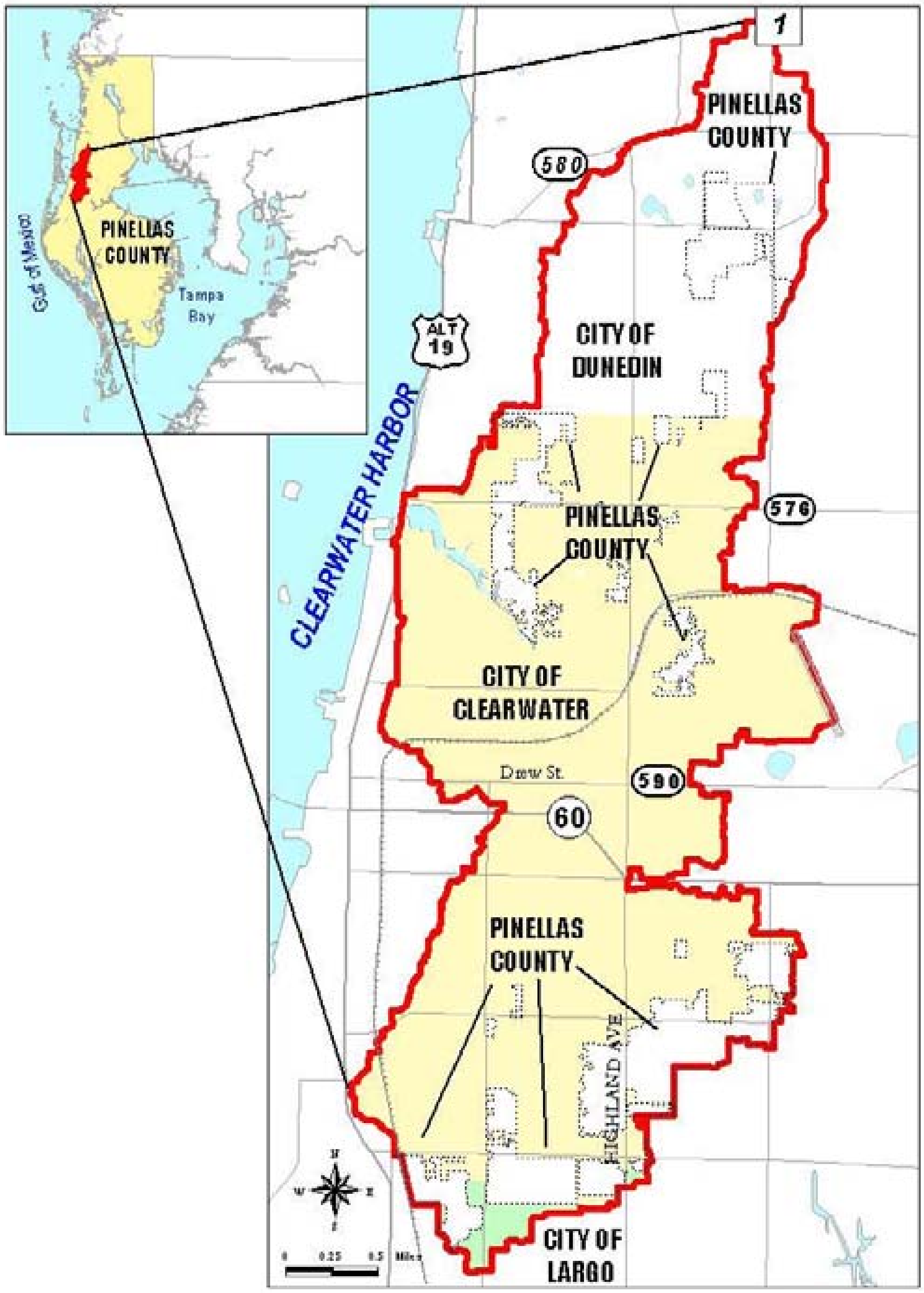

Figure 1 – Stevenson Creek Watershed Location Map

The soils, land use, and subbasin coverages were intersected using ArcInfo and then crossed referenced with a CN table for soil/land use pairs. In this method, a unique curve number is assigned to each possible combination of hydrologic soil group and land use category. The program then computes an area-weighted value based on the percentages of these soil/land use combinations found within the particular subbasin.

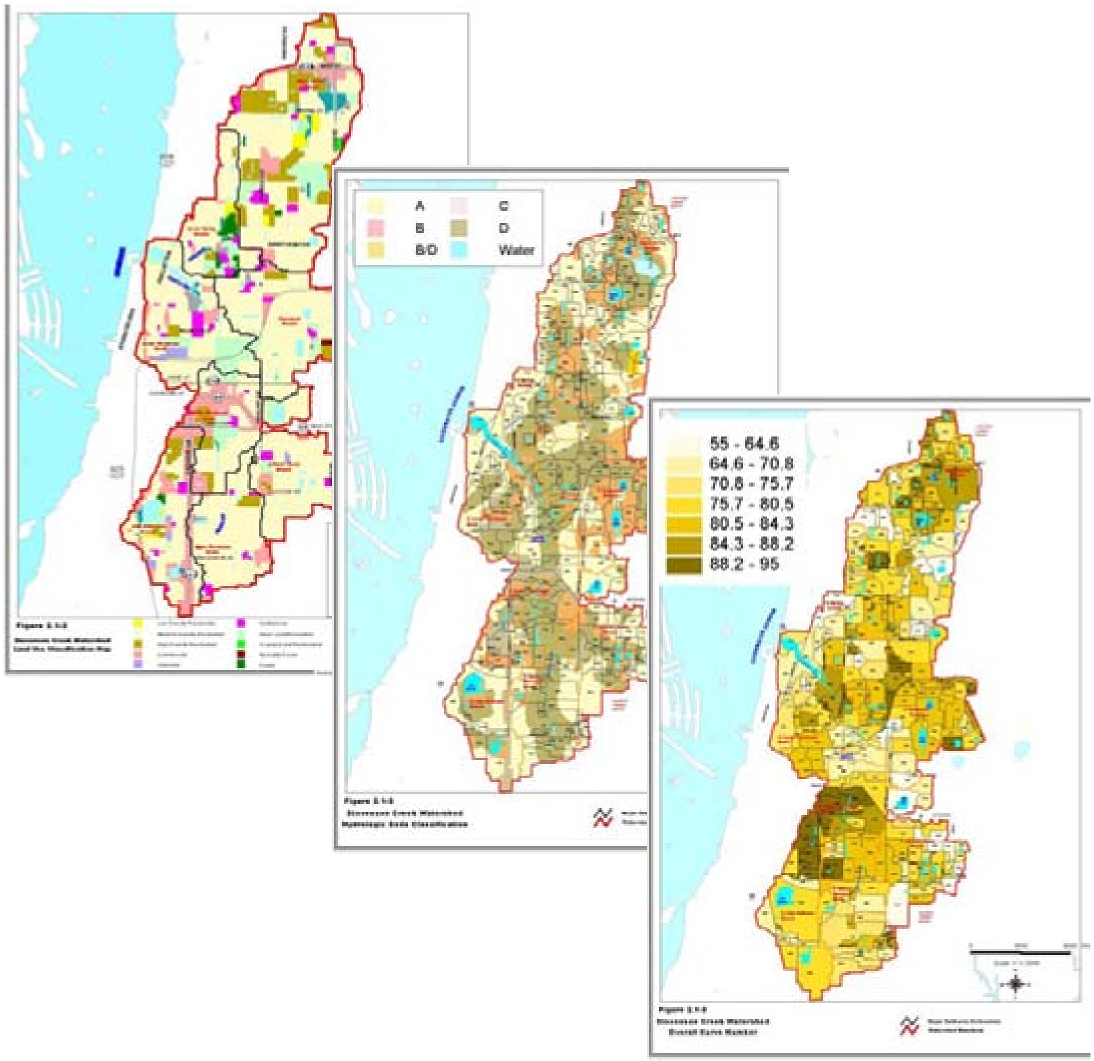

Figure 2 – Land use/cover, Hydrologic Soils, Curve Number (left to right)

METHODS: HYDRAULIC MODEL DEVELOPMENT

The Stevenson Creek conveyance system consists of a network of open channel segments, culverts, bridges, storm sewers, weirs, lakes, ponds, and wetlands. The AdICPR software used for this study contains a one-dimensional unsteady flow hydraulic routing routine in which a link-node concept to idealize the "real world" drainage system (Streamline Technologies, 1995). A node is a discrete location in the system where conservation of mass (continuity) is maintained. Links, or "reaches" are the connections between nodes and are used to convey water through the system. The hydraulic routing model receives hydrograph input at specific nodes by file transfer from the hydrologic model. The model performs dynamic routing of stormwater flows through the defined conveyance system to the points of outfall in the receiving waterbody. The program will simulate branched or looped networks; backwater due to tidal or non-tidal conditions; free-surface flow; pressure flow or surcharge; flow reversals; flow transfer by weirs, orifices, and pumping facilities; and storage. Types of reaches that can be simulated include pipes, weirs, open channels of regular or irregular cross section, bridges, and drop structures (weir and pipe in series). Simulation output takes the form of water surface elevations and discharges at each node and reach within the model network, reported at user-specified time intervals.

The basic AdICPR software package does not have a method of viewing the node and links graphically, thus the GIS was used to map the physical location of nodes and links. Nodes and reaches (links) were entered and attributed into the GIS at their true geographic location (Figure 3). Links are represented in the GIS by arcs while the nodes represent the ends of the links at the connection point to other links. Each node and link were given a unique identification number based on the subbasin numbering scheme, except that node identifiers begin with the letter “N”. Reach identifiers begin with a letter prefix pertaining to the type of reach. Channel primary flow direction is preserved in the GIS. In general, direction of flow is from higher node-number to lower node-number. In all, the model includes 383 nodes, 252 pipe reaches, 176 open channel reaches, 171 irregular cross sections, 98 weir reaches, 39 drop structure reaches, and 6 bridge reaches.

LINKAGE TO THE GIS

In addition to providing a vehicle for retrieval and conversion of existing data sets for development of model input parameters, the resulting model input and output data was used to create new GIS coverages and data tables. The new GIS coverages included the subbasin, network, and floodplain coverages described in the previous sections. This section describes the various data tables that were linked to the new GIS coverages.

To facilitate the linkage of the model data with the GIS, model input and output was first converted to data tables. The Southwest Florida Water Management District currently is promoting data standards for such tables (SWFWMD, 2000). These data standards prescribe specific tabular formats for the various categories of model input, as well as summary model results. A separate table is created for each category of model input and output, including NRCS basin, which contains hydrologic information and is linked to the subbasin coverage. Channel, bridge, culvert, riser, and weir reach tables are linked to the arc attributes of the reaches and contain the applicable physical information pertaining to the reach. Node storage (i.e. stage versus area) and summary results are linked to the node attributes.

SWFWMD GIS standards (SWFWMD, 2000) were implemented in this project for a variety of reasons principally because:

- Model input and output can be viewed entirely within the GIS platform.
- GIS allows graphical and tabular data to be viewed simultaneously on screen.
- Location, distance, and direction attributes are preserved (geographical context).
- Data created with various proprietary and government agency software packages can be standardized.

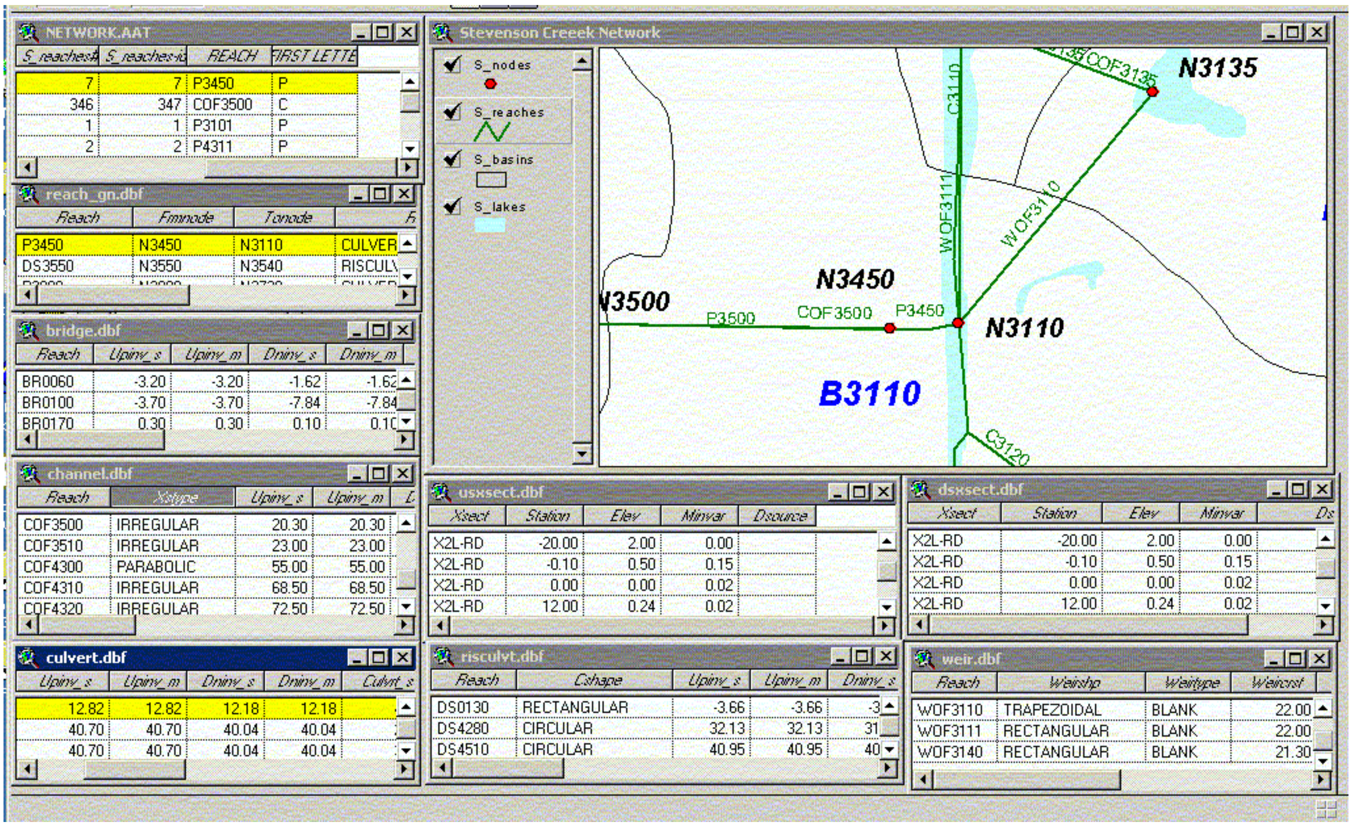

Figure 3 - SWFWMD GIS Standards hydraulic model representation

RESULTS: ENHANCEMENTS TO THE DATA STANDARDS

In the Stevenson Creek Watershed Management Plan, using a graphical user interface enhanced the two-way linkage between the hydraulic model and GIS. Within the ArcView environment several simple enhancements were made (refer to figure 4); USGS Digital Ortho Quarter-Quads (DOQQ's) were added, photographs of structures and open conveyance and storage features were linked to nodes, floodplain extent and flood susceptible structures were mapped and water quality data such as pollutant loading rates were joined to each subbasin.

Additionally, by using pull down menus and customized selection tools, the investigator is able to select model input and output parameters, and photographs. By using the pointer the user chooses the node or link for which the information is required (refer to Figure 5), and the parameter or result of interest such as total flow or stage for a particular design flood event (25-year, 100-year etc). Since each node and link has a unique identification number, data stored in a tabular database are retrieved. Additionally, flood hydrographs can be generated based on the selected node or reach and the requested rainfall event. The total flow and peak flow hydrographs are generated from a time series table. This table is compiled from AdICPR results manually. However, this activity is not time consuming and the benefits of interactively selecting the results and seeing the graphical representations are many.

When necessary, model output is relatively easily updated by re-running the hydrologic /hydraulic model, and then simply replacing the tables. The tables are created in a spreadsheet program such as Excel or Lotus, by parsing model output saved in ASCII text format through the modeling software. Updating the tables outside of the GIS is sufficient. When the application is reopened all information is updated, because the tables are stored outside the application, and the application only holds links to those tables.

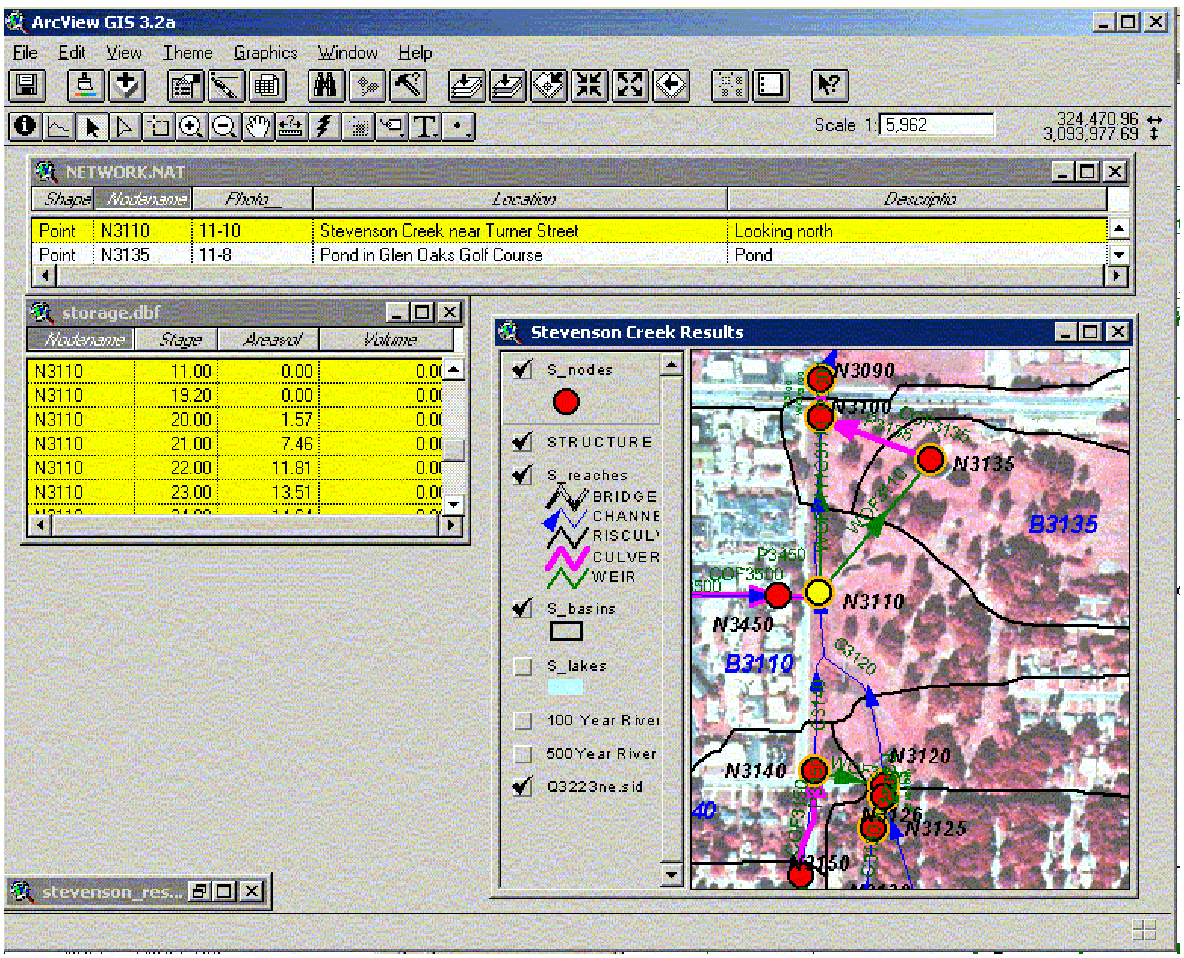

Figure 4 – Graphical Enhancement to the standard

CONCLUSION

Because a wide variety of engineering hydrologic and hydraulic models are commonly used, often within a single regulatory jurisdiction or political boundary, input and output from modeling studies conducted within neighboring watersheds often takes different forms. The linkage of watershed modeling and GIS allows for the complete viewing of model input and output data sets in one location. This facilitates the exchange of information between different engineering-based modeling software. Data from other modeling software packages such as EPA-SWMM/EXTRAN and the U.S. Army Corps of Engineers HEC suite of modeling software may be brought into the GIS and linked to the nodes and reaches trough a spatial connection in a similar manner. Storage and retrieval of the hydraulic model data sets are made easier, when a spatial query (a selection based on geography) is made. The primary advantage of such a system is increasing the uniformity and accessibility of information that is crucial to making informed decisions regarding many aspects of watershed management.

The GIS allows for the update of information in one location. Now that the two-way linkage between the GIS and the Hydraulic model has been established it is easier to keep the two synchronized. The ability to visualize flood hydrographs and perhaps view them as conditions change during "scenerio" running is invaluable and is planned as future enhancements.

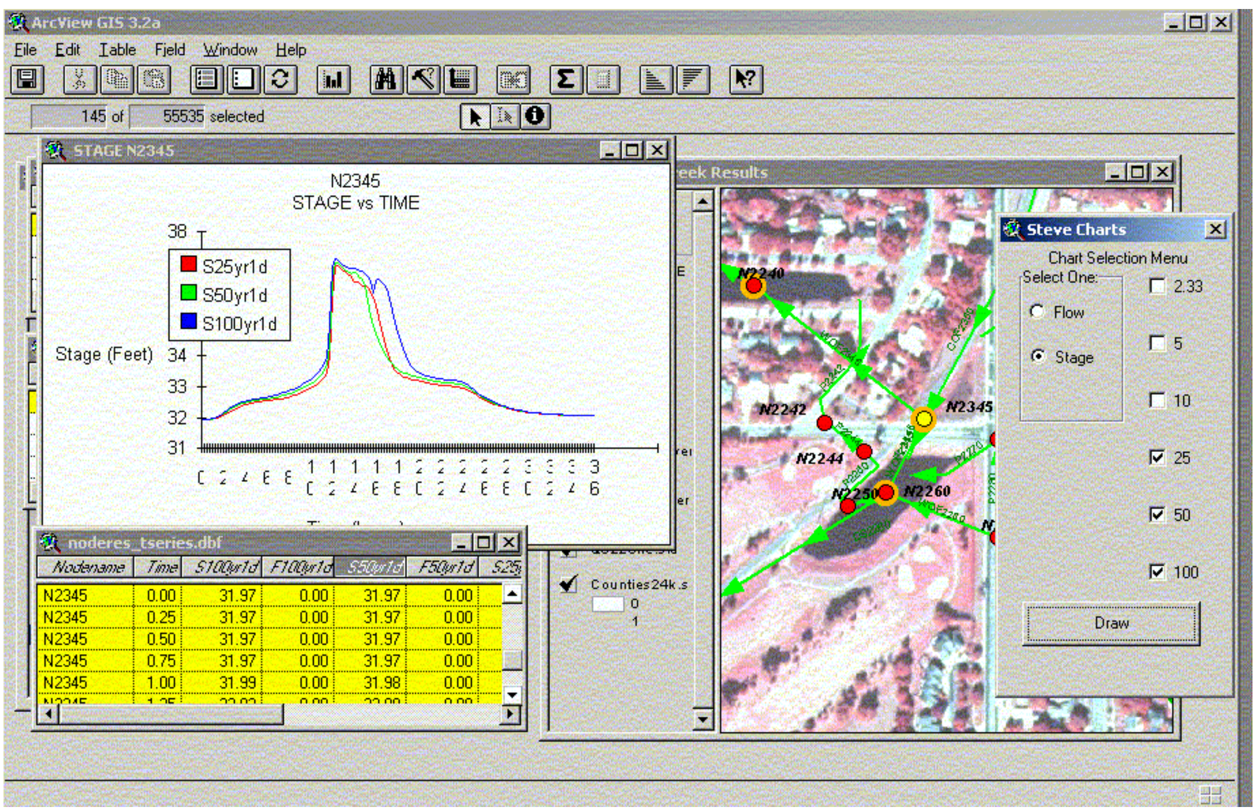

Figure 5 – Flood Hydrograph graphical output and selection menu

PUBLIC INFORMATION WEB SITE

Through the interactive GIS-based data management system, display of input/output information on the World Wide Web is made possible. A non-expert user can relate to a geographically based map (using aerial photography for example), and interactive watershed features with ease. Model reaches, nodes and photographs of drainage structures are presented on a public information website at:
http://www.clearwater-fl.com/City_Departments/public_works/engineer/projects/stevenson/

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DIRECTLY CONNECTED IMPERVIOUS AREAS AS MAJOR SOURCES OF URBAN STORMWATER QUALITY PROBLEMS-EVIDENCE FROM SOUTH FLORIDA

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ABSTRACT

This paper reports on early results from a US EPA sponsored project on optimization of urban wet-weather controls for managing water quality. The emphasis of this research is on micro-scale systems in order to evaluate the efficacy of decentralized controls such as on-site storage and infiltration. Micro-scale is defined as objects that are the basic components of urban parcels including roofs, streets, parking, driveways, and pervious areas. Private parcels and rights-of-way are evaluated separately. An international search for high quality wet-weather quantity and quality data led to the U.S. Geological Survey's database on South Florida. This data was collected in the 1970's for four sites: residential houses, apartments, commercial, and highway (Miller 1979). Our evaluation of this data indicates that runoff can be partitioned into two components:

- Runoff from the directly connected impervious area (DCIA) that occurs rapidly and comprises the bulk of the runoff from urbanized areas.
- Runoff from all other areas that occurs only after the soil moisture zone has reached saturation and surface ponding causes runoff. This type of runoff occurs much less frequently and is only associated with the larger storms.

The separation of these two phenomena is clearly supported by the intra-storm and storm event data. These results indicate that strong emphasis should be given to minimizing runoff from DCIA's by reducing the use of curb and gutter drainage.

INTRODUCTION

The purpose of this paper is to quantify the sources of urban runoff from the smaller storms that have the largest impact on urban stormwater quality. Data from four sites in South Florida are used to develop separate rainfall-runoff relationships for directly connected impervious area (DCIA) and the other area (OA). These calibrated relationships are used to run a 50-year simulation using hourly data for Miami, Florida to estimate the percentage of total runoff that comes from DCIA and OA. Based on these findings, recommendations are made regarding drainage design and evaluation practices for Florida and other areas.

Study Sites

The four study sites in South Florida, shown in Table 1, are used to evaluate rainfall-runoff relationships and how they are affected by DCIA. An international search for high quality wet-weather quantity and quality data led to the U.S. Geological Survey's database on South Florida. This data was collected in the 1970's for four sites: residential houses, apartments, commercial, and highway (Miller 1979). It remains one of the best databases in the world for evaluating rainfall-runoff relationships. DCIA ranges from a low of 5.9 % for the low-density residential area to 98.0 % for the commercial area. The number of storm events sampled varied from 16 to 27.

Table 1. General characteristics of four study sites in South Florida (Miller 1979).

Land Use	Location	Area (ha)	Total IA	DCIA	Storms
HD Residential	Miami	5.95	70.7%	44.1%	16
LD Residential	Pompano Beach	16.51	43.9%	5.9%	25
Commercial	Ft. Lauderdale	8.26	98.0%	98.0%	27
Highway	Pompano Beach	23.59	36.2%	18.0%	25

Precipitation Patterns

The rainfall database at the Miami WSCMO Airport, Miami, Florida covers the period from August 1948 to December 2000 with a 1-hour frequency. A rainfall event is assumed to end if it hasn't rained for six consecutive hours. During this period, the total number of rainfall events was 7,204 and the depth of total rainfall was 77,809 mm. The cumulative density function for the rainfall events is shown in Figure 1. Event based rainfall depths are plotted against the percent of the rainfall events that are less than or equal to the indicated value. For example, about 91% of the rainfall events are less than or equal to 30 mm in total depth. Typical drainage designs use the 2 to 10 year recurrence interval for their evaluation. However, as is shown in Figure 1, events with a recurrence interval of less than or equal to one month comprise over 90% of the total rainfall that occurs in Miami. Thus, control of these frequent events is the most critical component of urban stormwater quality management.

Rainfall-runoff models and long-term analysis

For developing a runoff depth estimation model, runoff was analyzed as a function of rainfall using the U.S. Geological Survey's rainfall-runoff database for each study site. To calculate excess rainfall, 2.54 mm of initial abstraction (or depression storage) is assumed for both impervious and pervious area. Total runoff can be estimated by combining runoff from DCIA and other areas. The conceptual model is shown below and models developed for the four sites are presented in next section.

$$Total\ runoff = DCIA\ runoff + Other\ runoff \quad (1)$$

$$DCIA\ runoff = \frac{DCIA}{Total\ area}(Excess\ rainfall) \quad (2)$$

$$Other\ runoff = \mathrm{a}\ (Excess\ rainfall) + \mathrm{b} \quad (3)$$

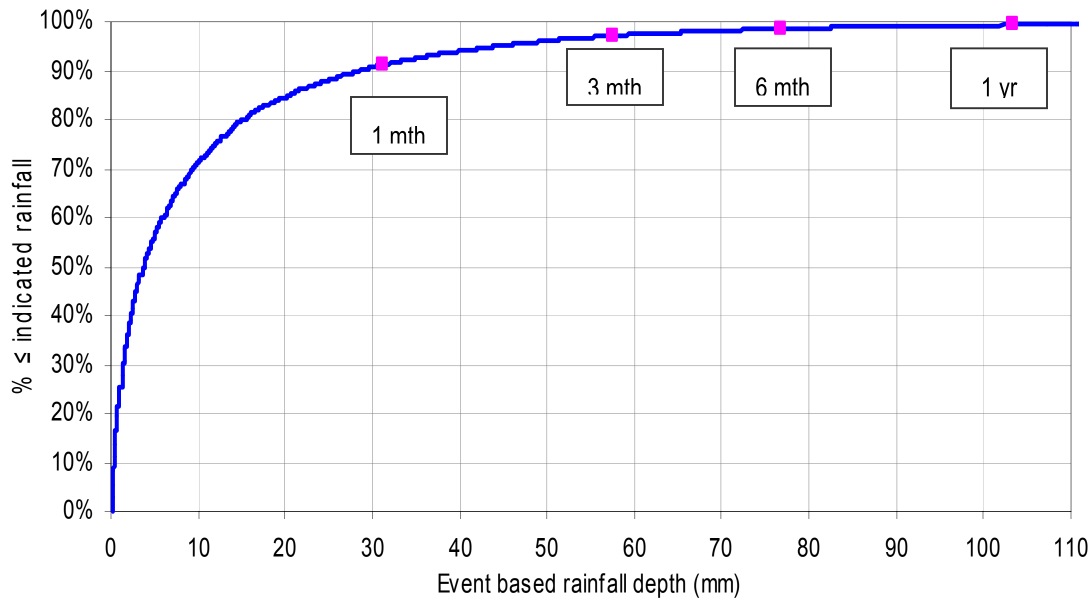


Figure 1. Event based rainfall depth in Miami, Florida:1948-2000.

About 50 years of long-term rainfall data are applied to the runoff depth estimation models. The one-hour rainfall data was collected from August 1948 to December 2000 at the Miami WSCMO Airport, Miami, Florida. The data are reported to the nearest 0.254 mm. A rainfall event is assumed to end if it hasn't rained for six consecutive hours. To calculate excess rainfall, 2.54 mm of initial abstraction is assumed for both impervious and pervious area. DCIA runoff and other runoff are estimated by developing rainfall-runoff models. The infiltration loss is calculated by subtracting the initial abstraction, DCIA runoff and other runoff from the total rainfall. A math balance equation of rainfall-loss-runoff is shown in below:

$$Rainfall = Initial\ abstraction + Infiltration\ loss + DCIA\ runoff + Other\ runoff$$

1. Residential-High Density

The Kings Creek site is a 5.95 hectare drainage basin that is part of an apartment complex in Dade County in South Florida. The impervious area is 2.62 hectares. Rainfall and runoff data for 16 storms were reported at 5 minute intervals. Key references for Kings Creek are Hamid (1995) and Hardee et al. (1979). Hamid (1995) has compared simulations using the SCS method with SWMM simulations of the study area partitioned into 13 subcatchments. Hardee (1977) presents the database for the study. The resulting rainfall-runoff relationship indicates that DCIA accounts for virtually all of the runoff for rainfalls up to about 12.5 mm. The runoff from Kings Creek was separated into two components as shown in below:

$$\textit{DCIA Runoff} = 0.441\ (\textit{Excess Rainfall}) \quad (4)$$
$$\textit{Other Runoff} = 0.3636\ (\textit{Excess Rainfall}) - 5.542 \quad (5)$$

The rainfall-runoff model and results of the long-term analysis are shown in Figure 2. Using the one-month rainfall of 30 mm, you see that the bulk of the runoff from 90% of the rainfall is DCIA runoff.

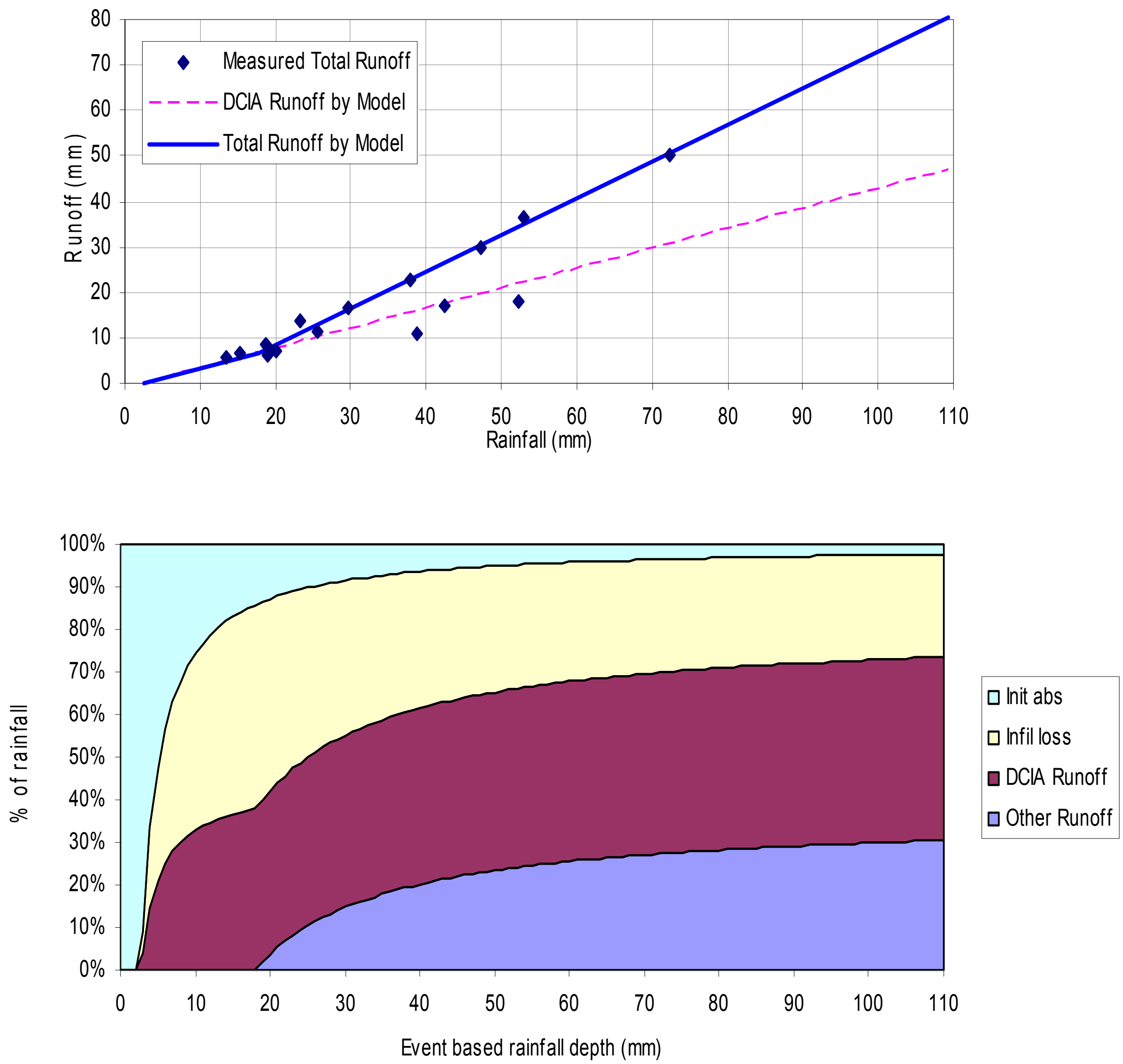
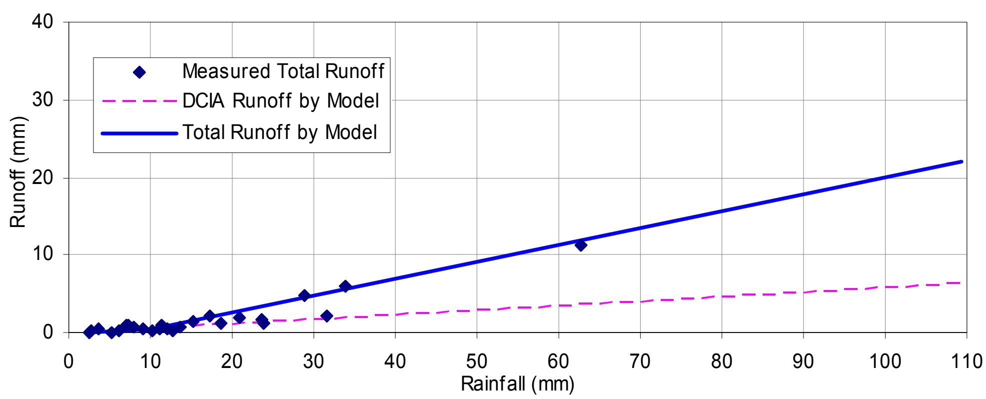


Figure 2. Rainfall runoff relationship and long-term analysis at the high density residential site in Miami, Florida.

2. Residential-Low Density

The low-density residential neighborhood has only 5.9% DCIA. It is almost exclusively swale drainage. Even in this extreme case, the runoff from storms up to about 10 mm is primarily from the DCIA. For larger storms, the other areas begin to contribute. The results are shown in Figure 3 and the runoff estimation model is shown in below:

$$\textit{DCIA Runoff} = 0.059\ (\textit{Excess Rainfall}) \qquad (6)$$
$$\textit{Other Runoff} = 0.1579\ (\textit{Excess Rainfall}) - 1.203 \qquad (7)$$



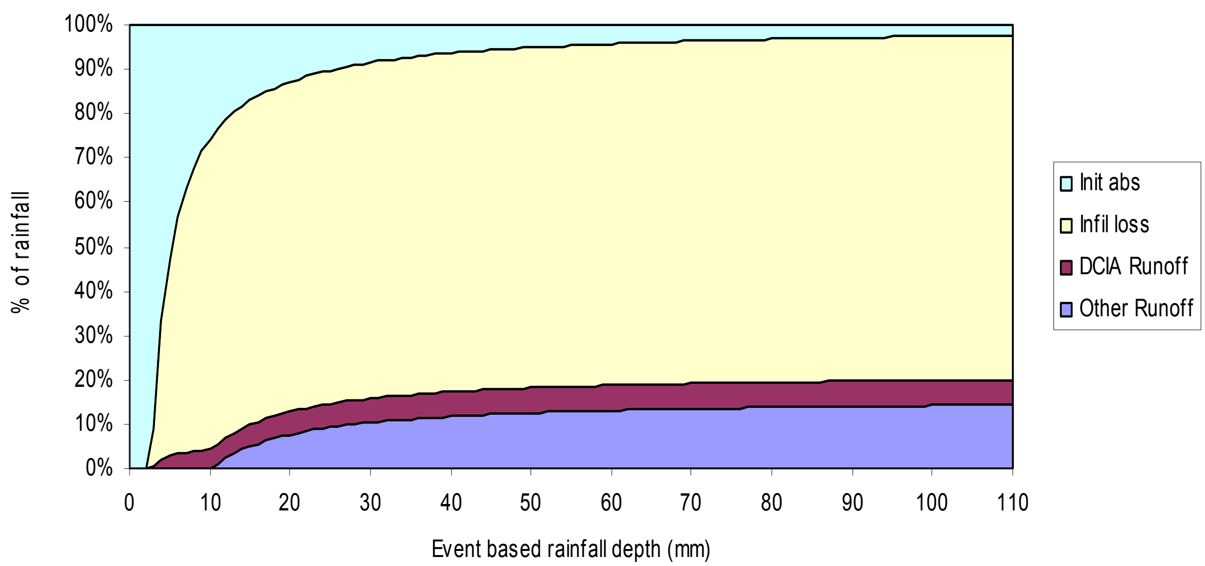


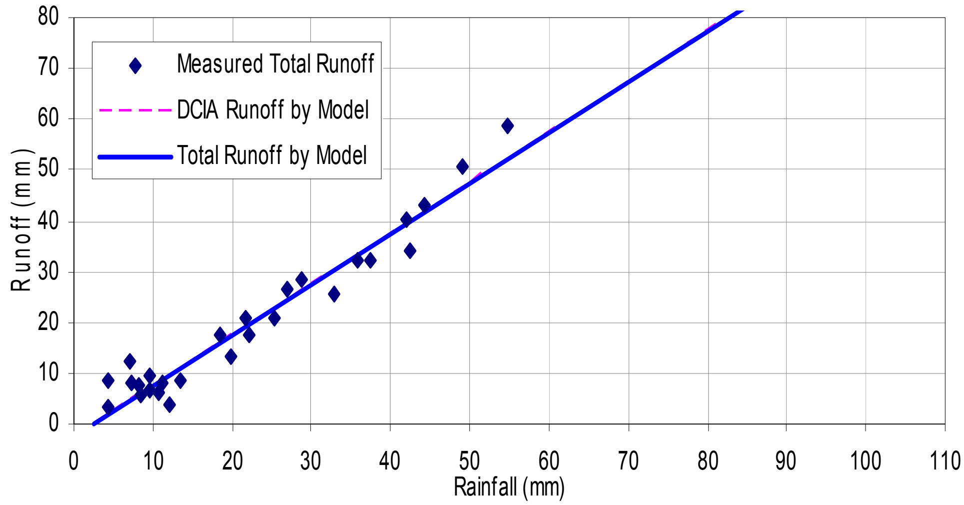
Figure 3. Rainfall runoff relationship and long-term analysis at the low density residential site in Pompano Beach, Florida.

3. Commercial Site

The results for the commercial area with a very high DCIA of 98% indicate virtually a one to one relationship between rainfall and runoff. The results are shown in Figure 4. They indicate a simple rainfall-runoff response with no significant infiltration due to the complete DCIA system.

$$\textit{DCIA Runoff} = 1.0\ (\textit{Excess Rainfall}) \quad (8)$$

$$\text{Other Runoff} = 0.0 \quad (9)$$



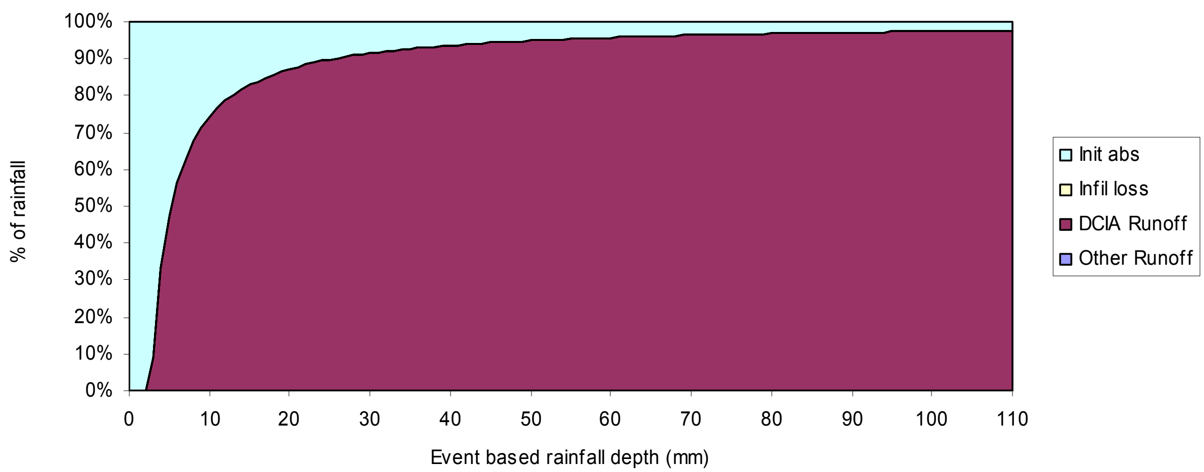
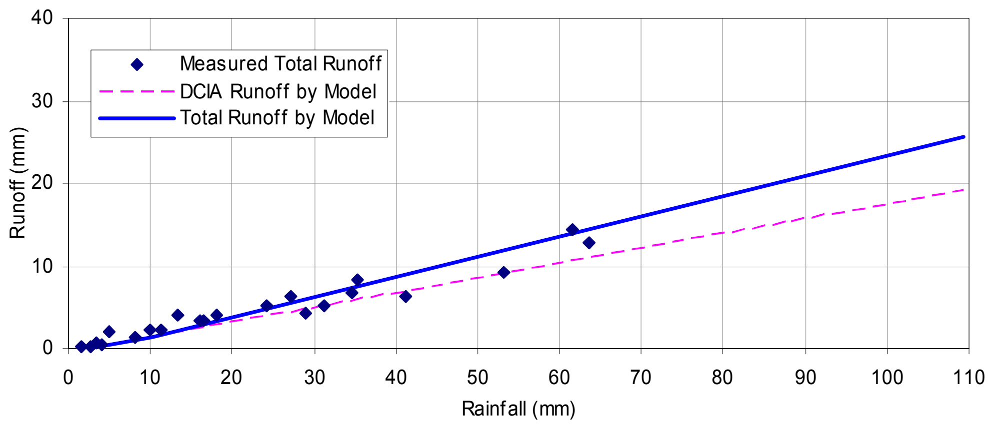


Figure 4. Rainfall runoff relationship and long-term analysis at the commercial site in Fort Lauderdale, Florida

4. Highway Site

Rainfall and runoff data are available for 25 storm events for the highway runoff site in Pompano Beach, Florida. The highway site is partially curb and gutter and partially swale drainage. Using DCIA only to estimate the rainfall-runoff relationship provides nearly identical results as one gets when the total area and a runoff coefficient are used. The results are shown in Figure 5. The non-DCIA area begins to contribute runoff for larger rainfalls only.

$$\textit{DCIA Runoff} = 0.180\,(\textit{Excess Rainfall}) \quad (10)$$
$$\textit{Other Runoff} = 0.0636\,(\textit{Excess Rainfall}) - 0.485 \quad (11)$$



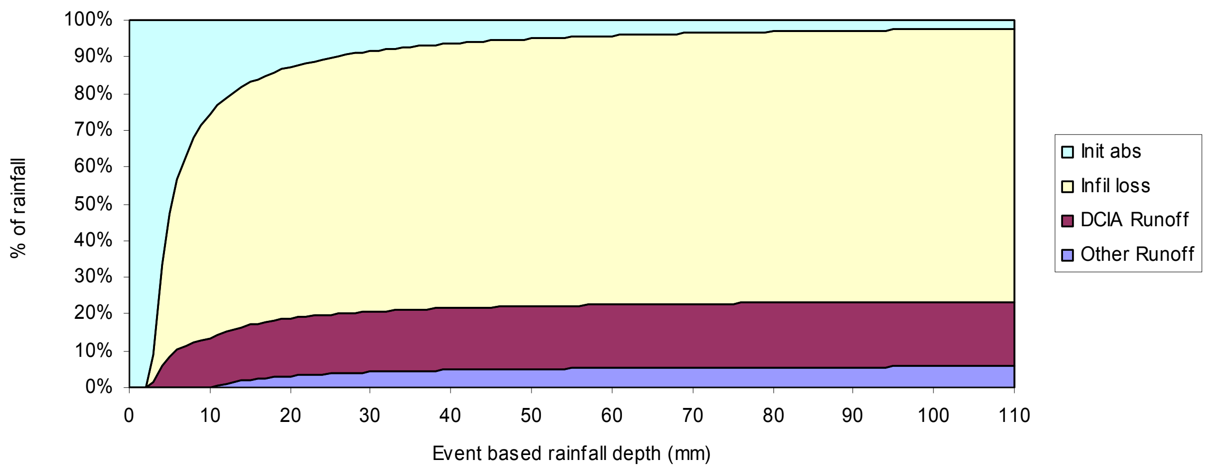


Figure 5. Rainfall runoff relationship and long-term analysis at the highway site in Pompano Beach, Florida.

Summary of long-term rainfall-runoff analysis for the entire period

The results of long-term rainfall-runoff analysis are summarized in Table 2 for the entire period. A total of 7,204 precipitation events occurred during this 52.4 year period. About 43 % of these events are less than or equal to 2.54 mm. Runoff from non-DCIA areas occurs only for the larger storms. The statistics for the runoff events are shown in Table 3. They indicate that 50 to 100 percent of the runoff is from the DCIA. The relative importance of each land use in terms of depth is shown in Table 4. DCIA runoff exceeds other runoff for all of the sites except the low-density residential site. The disproportionate importance of DCIA is evident in Figure 6. For example, while DCIA represents about 6% for the low density residential, it contributes about 36% of the total runoff. Similarly, over 80% of the highway runoff is from DCIA even though it is only 18% of the total area.

Table 2. Summary of results based on rainfall events.

	HD Residential	LD Residential	Commercial	Highway
Total Events	7,204	7,204	7,204	7,204
No Runoff	43.1%	43.1%	43.1%	43.1%
DCIA Runoff only	39.8%	28.7%	56.9%	28.7%
Runoff from everywhere	17.1%	28.1%	0.0%	28.1%

Table 3. Summary of results based on runoff events.

	HD Residential	LD Residential	Commercial	Highway
Runoff Events	4,098	4,098	4,098	4,098
DCIA Runoff only	70.0%	50.5%	100.0%	50.5%
Runoff from everywhere	30.0%	49.5%	0.0%	49.5%

Table 4. Summary of results based on rainfall depth.

	HD Residential	LD Residential	Commercial	Highway
Rainfall (mm)	77,809	77,809	77,809	77,809
Init. Abs.	17.6%	17.6%	17.6%	17.6%
DCIA Runoff	36.3%	4.9%	82.4%	14.8%
Other Runoff	14.0%	8.5%	0.0%	3.4%
Infiltration	32.1%	69.0%	0.0%	64.1%

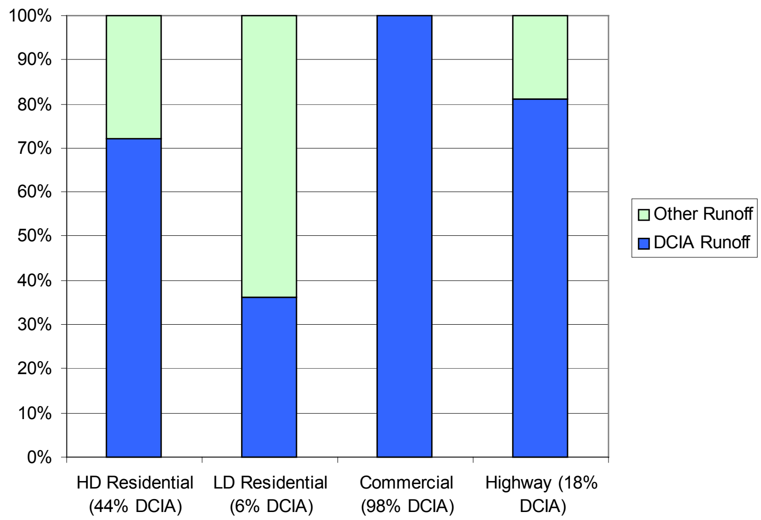


Figure 6. Summary of results based on runoff depth.

Use DCIA to Estimate Water Quality Impacts?

The oldest and still most widely used method for storm drainage design is the Rational Method (Mays 2001). The method was firstly introduced by the Irish engineer Mulvaney (1850), the American Kuichling (1889), and the British Lloyd-Davies (1906). While Mulvaney worked on agricultural areas, Kuichling and Lloyd-Davies described rainfall-runoff relationships in urban area. The basic assumptions of the Rational Method are that the rainfall intensity during the time of concentration is steady, and the frequency of peak runoff and the rainfall causing it are the same. While the American Rational Method uses the runoff coefficient according to rainfall characteristics and total land area ($Q_p = CiA$), the British Lloyd-Davies method only considers 100 percent runoff from the directly connected impervious area (DCIA) ($Q_p = iA_{DCIA}$). The results of this analysis indicate that the decision to convert land into DCIA has the greatest impact on stormwater runoff from the frequent events that are of concern in protecting water quality. Alternatively, minimizing DCIA is a very good way to protect stormwater quality. Current evaluation methods do not make this vitally important distinction between impervious area and directly connected impervious area. They also rarely separate out the right of way area as a separate land use even though it is the cause of most of the DCIA.

CONCLUSIONS

The purpose of this paper is to evaluate the importance of directly connected impervious area (DCIA) in generating urban runoff from the smaller events that are most critical for urban wet-weather flow management. Rainfall-runoff data from four sites in South Florida were evaluated. The results indicate that virtually all of the runoff from smaller storms is from DCIA. Even for larger storms it is a primary source of stormwater. This DCIA runoff moves relatively rapidly to the nearby receiving water with little or no attenuation of its pollutant load. Thus, the decision to use DCIA instead of other drainage options has a profound effect on urban storm water quality.

ACKNOWLEDGEMENTS

This study was made possible because of the high quality data collected by the USGS in South Florida as part of the Nationwide Urban Runoff Program (NURP) over 25 years ago. It remains one of the best databases in the world for evaluating the impact of urbanization on urban stormwater quality. We thank the USGS team for their excellent work. Members of the USGS team include Jack Hardee, Ron Miller, and Hal Mattraw.

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NEW METHODS OF RETRIEVAL AND ANALYSIS OF RAINFALL DATA

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ABSTRACT

Rainfall data combined with good engineering principles can help resolve many stormwater problems. The data often can illustrate the significance of a rain event or indicate that other answers need to be sought to explain flooding events.

Rainfall data comes in various forms and can be analyzed using several techniques. We have encountered many events where a first quick look at an event would cause you to draw the wrong conclusions. Therefore, we have developed good evaluation, monitoring and analysis processes to help develop information about storm events that can then be used to analyze flooding impacts accurately and in a very short time.

This paper will address monitoring of rainfall using both gages and radar methods as well as several techniques used to analyze the data. We will also address the processes we use to determine rainfall's impact on flooding. Several real-world problems will be used to illustrate the techniques and processes used to formulate our conclusions.

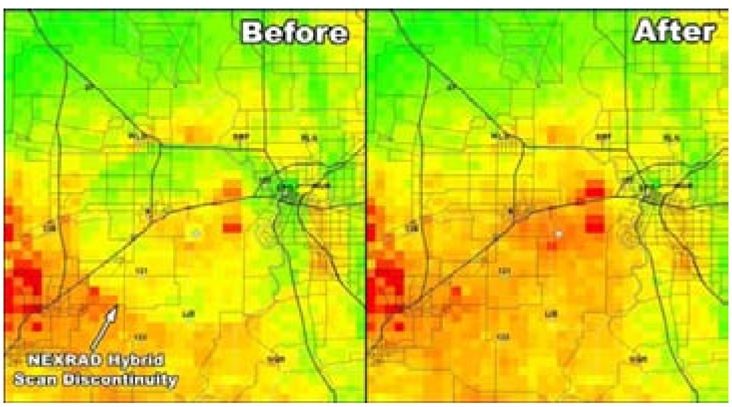
DESCRIPTION OF THE RAINFALL RADAR DATA

Since the early 1990s when the National Weather Service first started deploying the WSR-88 radars, commercial companies, hydrologists, meteorologists and engineers have been trying to get a handle on this thing called "radar rainfall estimates." Very early in the deployment, many people thought we would be able to rid ourselves of rain gauges and the maintenance cost and problems associated with them. Several commercial companies began marketing products and broadcast TV meteorologists began showing images to their audiences about how much rain had fallen at certain locations.

There was also a difference of opinion about which algorithm should be used to convert reflectivity data to rainfall estimates. The National Weather Service settled on the Marshall-Palmer Z-R relationship and at least one private company settled on an empirical lookup table to determine rainfall rates. Both approaches have their strengths and weaknesses, but neither give accurate rainfall estimates as initially anticipated.

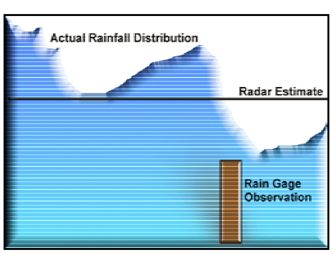
However, it did not take long for individuals to begin to understand the limitations of radar and how those limitations affect the accuracy of rainfall estimates. Radar has inherent problems such as anomalous propagation (AP), and false echoes are a tremendous problem in using radar products. AP is a false reflectivity echo on radar, an echo that is NOT precipitation. A common form of AP and false echo signatures is ground clutter: This is the most common false echo. Ground clutter is most common when low elevation beam angles are used in cases where a low-level inversion is in place. These and other types of AP create a serious obstacle to deriving rainfall rates from radar. For example, at distances close to individual radars, ground clutter can create anomalous radar echoes in the lowest elevation scan. To minimize this problem, radar-rainfall estimation algorithms switch to higher elevation scans which rise above nearby hills, towers, trees etc. This procedure is called a hybrid-scan. The higher elevation scan may overshoot rainfall near the radar and underestimate rainfall accumulations. As a result, discontinuities can appear in the radar image at the distance where the scan elevation changes. Quality control of data input to your rainfall algorithms becomes crucial to prevent as much contamination as possible to deriving values — garbage in, garbage out.

The before image below shows what occurs when discontinuity happens due to hybrid scanning and the after image shows what it should look like if one uses good quality control algorithms.



You will notice in the before image, the ring in the center of the image appears as if data were placed there with a cookie cutter. NEXRAIN has developed a GIS based correction procedure to correct this problem. If you look at the after image you will see the impact of using the procedure. The discontinuity has disappeared and the image shows dramatically higher and probably more accurate rainfall estimates for the same area.

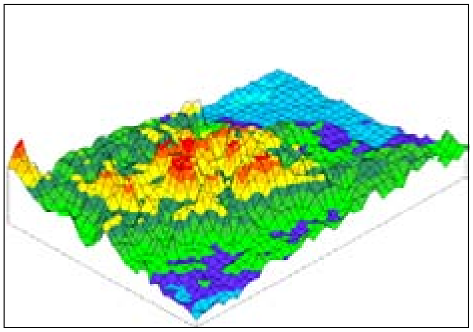
Once the limitations of rainfall data were recognized and accepted, there was a need to determine how it was useful for rainfall estimates. Most in the community determined that it was of some use because it provides information about rainfall between the gauges. For too long we had been making gross estimates of rainfall over a large area using several 12-inch diameter rain gauge measurements. For the first time, we had a way to see activity between the gauges in relatively good resolution (2km).



Some believed that radar provides a rainfall distribution signature over an area and what was needed was a way to calibrate the data. The natural calibration tool for radar is a rain gauge. The rain gauge measures rain at a certain point, radar rainfall data attempt to provide an areal view of the amount of rain over a 2km or 1km square area. The illustration to the left attempts to show the difference between what a rain gauge measures as opposed to radar. An important point to keep in mind is that a rain gauge located in a pixel could have a different value than the pixel and they could both be correct.

Once again there were different opinions on how to use rain gauges as a calibration tool. There

are those who believe in scaling the radar pixel to the value of the rain gauge and then use some linear interpolation to determine the values of the pixels between the gauges. The approach of setting the radar pixel to a gauge amount and using linear interpolation methods has serious problems.
If we accept the fact that radar may not be accurate, but provides us with a spatial distribution signature of the rainfall, this will permit us to view the data as a template similar to the one below. The spatial distribution signature provides an accurate relationship between the neighboring pixels and scaling should only adjust the template, not alter the pixel relationship.



Therefore, the correct approach to calibration is to determine a coefficient that can be used to adjust a template representing all pixels. This method will retain the relationship between pixels and provide more consistent results over a time period. However, if a very large area is to be scaled, it probably will work best to break the area up into smaller pieces. A method to use in determining the coefficient would be the average of the sum of the gauges used divided by the average of the sum of the radar pixels that contain gauges. This coefficient can then be used to scale the radar template up or down to produce consistent radar-rainfall values.

In using radar rainfall estimates there are two important steps which must be remembered to guarantee consistent rainfall estimate results.

- Quality control of radar data
- A sound approach to calibration of the data

It is important to emphasize the word consistent, not accurate, because with radar rainfall, consistency is the goal. It is not perfect, but it is better than the alternatives.

FIELD APPLICATION

The radar rainfall data was applied to the analysis of a flooding event that occurred in October 2001 at the city of Pompano Beach, Florida. The analysis included the area known as Basin 1 in the north part of the city. A sudden storm event resulted in extensive road flooding and numerous cases of house flooding. It was reported that water depth at some locations amounted to more than three feet. Local residents who have lived in the area for a long time reported that such flooding conditions had not been experienced during previous events, including Hurricane Irene in October 1999. In addition, the city staff regularly inspects the stormwater system to make sure it is operating properly. Full inspections were conducted approximately one year ago and again this past June. The system is also inspected weekly to make sure that inlets and catch basins are free of obstructions. A field visit was conducted as part of this work effort to determine the condition of the drainage outfalls after the storm. The visit confirmed that the system was free of significant obstructions and debris. It was concluded that pipe blockage could not have been a factor causing the flooding conditions.

The unusual flooding conditions required development of a rapid public information program, particularly because it required quick acquisition of accurate rainfall data. Although rainfall gauges exist both north and south of Basin 1, measured data were not available within the required time frame and reports did not seem to match observed conditions during the rainfall event. The analysis of radar data, in addition to being available on short notice, revealed that a rainfall pattern of high intensity had occurred along a narrow band that included the flooded area. A one-square mile area that includes the northern portion of Basin 1 accumulated about 6 inches of rainfall in a short period of time. Analysis indicated that the rainfall event of October 2001 was equivalent to the 100-year 24-hour design storm event in terms of rainfall depth accumulated during a three-hour peak period.

Although the flooding conditions that occurred in the city of Pompano Beach in October 2001 were caused not only by the high rainfall intensity, but by a combination of various factors such as high groundwater table and a high tailwater elevation, the analysis of the rainfall patterns using radar helped explain the observed conditions.

SIGNIFICANCE OF LITTORAL ZONE VEGETATION AND POND DEPTH ON WET DETENTION POND PERFORMANCE

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ABSTRACT

Wet detention ponds have become one of the most popular alternatives for stormwater treatment in the State of Florida. These systems, which are capable of providing flood attenuation as well as pollution abatement, provide substantial attenuation of runoff pollutants through a combination of physical, chemical, and biological removal processes. However, regulations governing the design of wet detention ponds vary widely throughout Florida, particularly with respect to pond depth, minimum detention time, and littoral zone vegetation.

A mass balance water quality model was developed for nutrients, TSS, BOD, and common heavy metals to evaluate pond performance and water quality characteristics under a wide range of design conditions. The model includes hydrologic and mass inputs from runoff and bulk precipitation, with losses occurring as a result of evaporation, water column processes, vegetative uptake, and outfall discharges.

Pond performance appears to be primarily regulated by detention time, suggesting that water column removal processes are the most significant removal mechanisms. Littoral zone vegetation appears to provide little direct uptake of pollutants from the water column, since rooted emergent macrophytes obtain nutrients primarily from the sediments. However, littoral zone vegetation may provide an indirect water quality benefit by providing a diversity of habitat for other significant removal processes. Pond depth should be regulated by the anticipated photic zone of the pond which can be predicted using standard lake trophic state models.

Over-excavation of ponds can be beneficial to overall performance, provided that the pond depth does not exceed the photic zone depth, by increasing pond volume and detention time, providing additional dilution of inputs and extended opportunities for pollutant attenuation.

This paper was not available at the time these Proceedings were compiled. Therefore, only the abstract has been printed. The paper will be provided at the conference and future printings will include the paper in the back of the Proceedings.

USING BACTERIAL SOURCE TRACKING AND OTHER INNOVATIVE TECHNIQUES TO IDENTIFY SOURCES OF FECAL CONTAMINATION IN STORMWATER

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ABSTRACT

Stormwater runoff can transport a variety of pollutants including heavy metals, excess nutrients, sediments, trash, etc. Several studies dating back to the 1970s have shown that a number of human pathogens are often present in stormwater and can lead to serious health risks. The resulting health and economic impacts can be significant since the presence of elevated concentrations of microorganisms can lead to closures of shellfish harvesting areas and recreational beaches. Exceedence of microbiological standards is a common Total Maximum Daily Load (TMDL) impairment not only in Florida, but also throughout the U.S. Unfortunately, the process to directly enumerate disease-causing bacteria and viruses is time-consuming and expensive, making it virtually impossible to test for all possible pathogens in a water sample. As a result, certain types of bacteria (typically total and fecal coliform bacteria and/or enterococci) are used by regulatory agencies as indicators of microbiological water quality. Unfortunately, the fecal coliform standard has often been disputed with respect to its predictive capabilities since several recent studies have shown that this group of bacteria is capable of surviving in tropical climates outside its human host. Other studies have shown that it may not always be present in conjunction with other microbial pathogens. A number of relatively new techniques have been developed to assess microbiological water quality including antibiotic resistance pattern analysis, gene probes, polymerase chain reaction (PCR), and biosensors. These various techniques will be discussed, including their strengths and limitations and applicability for use in stormwater evaluations and development of best management practices.

INTRODUCTION

Certain types of bacteria are used by regulatory agencies (U.S. Environmental Protection Agency, Florida Department of Health, Florida Department of Environmental Protection) to assess microbiological water quality. The indicator bacteria are intended to act as warning signals that the water may be contaminated with feces from animals and/or humans. The presence of fecal material in water increases the likelihood that humans who drink, swim in, or consume uncooked shellfish from those waters will contract a waterborne disease. Regulatory agencies routinely use the fecal coliform group of bacteria as a fecal indicator. The current standards for fecal coliform bacteria and several other indicators of fecal pollution are presented in Table 1 below. Enterococci has recently been adopted by the U.S. EPA as the preferred indicator organism for marine waters.

Table 1. Guidelines for indicators of fecal pollution in surface waters.

Parameter	Guideline
Fecal Coliforms	EPA and State of Florida recommended guideline for a single sample not to exceed 800 cfu/100ml or a monthly geometric mean of 200 cfu/100ml.
E. coli	EPA recommended guideline for a geometric mean of 126 cfu/100ml.
Enterococci	EPA recommended guideline for a single sample of 104 cfu/100ml or a geometric mean of 33-35 cfu/100ml for marine and freshwater, respectively.
Clostridium perfringens	Guidelines based on University of Hawaii study (Fujioka) of 50 cfu/100ml for fresh/brackish water and 5 cfu/100ml for marine waters.
Coliphage	Guideline based on University of South Florida studies (Rose) of 100 pfu/100ml.

The goal of bacteriological water quality testing is to predict the risk of disease based on measured levels of bacteria and/or bacterial products. This goal has been elusive, in part, because of the limitations of existing, approved methods. It is difficult, time-consuming and expensive to directly enumerate all of the potential disease-causing bacteria and viruses that may be present in a water sample. As a result, resource management agencies typically measure the numbers of indicator bacteria, whose presence more or less reflects the probability pathogens are present in a given waterbody. However, the fecal coliform indicator is a poor predictor of viral pathogens, and may well be present in waters where there are few or no pathogens of any kind (viral, bacterial or protozoan). Although the enterococci may be better predictors of viral pathogens in some areas of the country, they may also be present when pathogens are absent.

One of the major reasons that fecal coliforms and enterococci are inadequate indicators is that they are present in the gastrointestinal tract of all warm-blooded animals. Some animal feces, i.e. those of humans, cattle, and swine, have a higher probability of containing human pathogens than the feces of most other species, therefore these animals are included in the "high risk" group. Very low levels of fecal indicator bacteria from a high risk animal group would indicate a greater potential health hazard than higher levels of indicator bacteria from a low risk animal group. Currently, there is no routine testing method that can be used to determine the origin of fecal indicator bacteria, however such a method would allow much more accurate risk assessment than that which can be achieved with standard testing methods. This would also allow regulatory agencies to more effectively identify and eliminate the source of bacterial contamination, which could lead to the reopening closed shellfish beds, and fewer health advisories postings at recreational beaches.

Accurate detection and identification of fecal contamination in surface waters (including stormwater) is a critical component of the federal Total Maximum Daily Load (TMDL) initiative. At the state level, over 15% of the reported waterbody impairments in Florida (303[d] list) were due to exceedences of fecal coliform bacteria concentrations. However, it is not known, definitively, whether these exceedences represented actual contamination of organisms capable of causing diseases in humans.

This presentation will include a discussion of several newer methodologies and technologies to identify sources of fecal contamination in surface waters (and stormwater). A methodology for the detection of fecal contamination problems and a diagnostic process to identify potential sources will also be discussed along with potential solutions (BMPs) to reduce concentrations of pathogens.

METHODS

Fecal Contamination Assessment

A case study using the Hillsborough River watershed is presented as an example of a fecal contamination assessment followed by a bacterial source tracking study (Kurz and Harwood, 2001). Historical fecal coliform concentrations in the upper Hillsborough River have exceeded state standards on numerous occasions. This frequent exceedence of water quality standards was identified in the SWFWMD's Hillsborough River Comprehensive Watershed Management Plan as an issue requiring further evaluation.

In order to identify the most fecally contaminated areas of the watershed, data were collected for the project area through the Hillsborough River Watershed Management project performed for Hillsborough County's Stormwater Management Section. Sources of data were from STORET, the Hillsborough County Environmental Protection Commission (HCEPC), and Ayres Associates (for water quality sampling performed during the year 2000).

Within the Hillsborough River study area, analyses of recent data indicated that the Class III standard of 200 cfu/100ml is exceeded at HCEPC stations 108 and 143 within the Blackwater Creek region as well as stations 118 and 148 representing the adjacent Lake Thonotosassa/Pemberton/Baker Creek drainage area (Figure 1). A more detailed evaluation of monthly trends between 1988 and 2000 for stations in the Blackwater Creek area are shown in Figure 2. Trends in fecal coliform concentrations have generally declined since the late 1980s. One reason for this trend may be due to the closing of several dairies in the watershed (Richard Boler, HCEPC, pers. comm.). However, concentrations at both stations frequently exceed both the 200 and 800 cfu/100 ml Class III standard which has resulted in the closure of the upper Hillsborough River to swimming/contact activities.

A number of recent studies have investigated methods for predicting trends in fecal indicators including a study conducted by Lipp et al. (in press) and McLaughlin et al. (in prep.) for the Charlotte Harbor and Tampa Bay estuaries, respectively. These studies were developed and funded by the SWFWMD to identify the presence or absence of human pathogens and to develop better indicators of microbial pollution. Both studies evaluated streamflow and rainfall conditions as predictors of microbial indicator concentrations. Both studies found significant positive relationships between hydrologic conditions and indicator concentrations. An analysis of data from EPC 143 did not, however, indicate a strong relationship between flow and fecal coliform concentrations (Figure 3a) in the case study area.

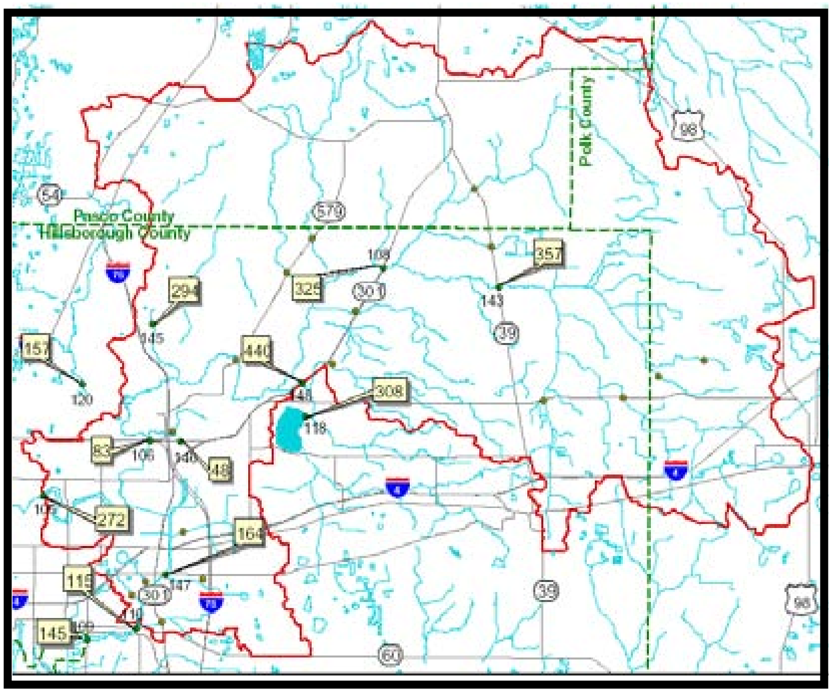


Figure 1. Fecal coliform concentrations in the Hillsborough River watershed between 1995 and 1999 (HCEPC data). (Map source: Ayres Associates, Hillsborough River Watershed Management Plan, 2001)

A similar analyses of fecal coliform concentrations at EPC 143 and rainfall from the nearby Plant City rain gauge did show a weak but significant positive relationship between these two parameters (Figure 3b). The consistently elevated concentrations found at EPC 143 indicates that one or more persistent sources of fecal contamination may exist in the region such as poorly constructed on-site wastewater treatment systems (OWTS), free-ranging livestock, or failing package plant wastewater treatment systems. The positive relationship with rainfall indicates that stormwater runoff facilitates transport of fecal material downstream from the various sources in the watershed.

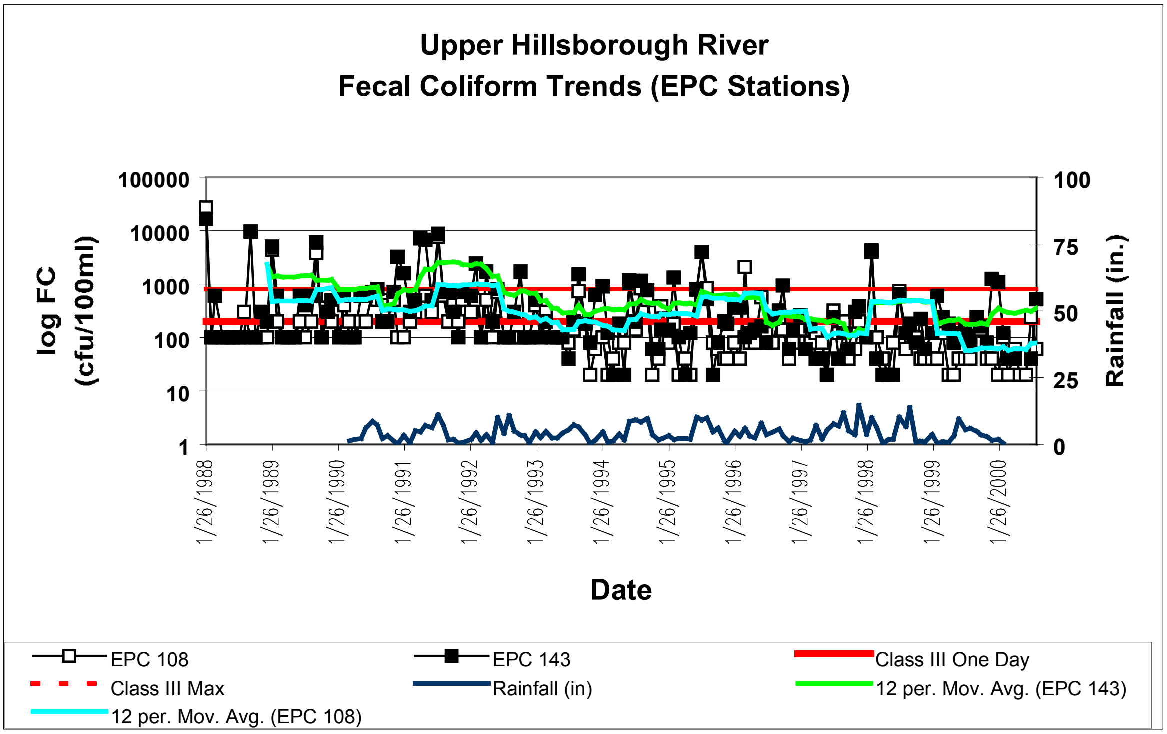
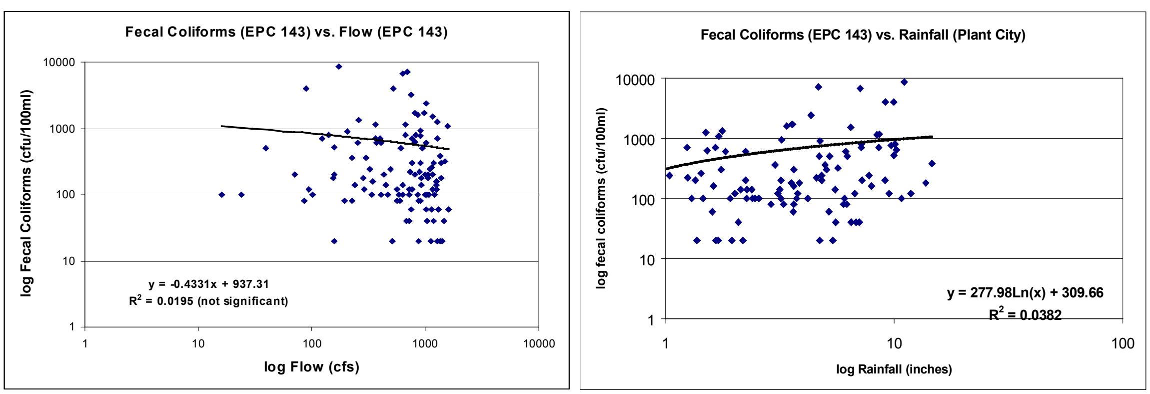


Figure 2. Trends in monthly fecal coliform concentrations at EPC stations 108 and 143 between January 1988 and June 2000. Twelve (12) month moving averages are shown as solid colored lines for each station. Rainfall depths are for the Plant City gauge. (Source: Kurz and Harwood, Upper Hillsborough River Bacterial Contamination Assessment Plan of Study, 2001)



Figures 3a and 3b. Scatterplots and regression analyses between fecal coliform concentrations and flow (left) and rainfall (right) for EPC 143 in the Blackwater Creek region. (Source: Kurz and Harwood, Upper Hillsborough River Bacterial Contamination Assessment Plan of Study, 2001)

Hillsborough County had collected more recent data at several tributary sites in the upper Hillsborough River region in 2000 (Figure 4). Many of these samples were taken during or after rain events since little to no flow occurs during the dry season in these smaller stream reaches. In 2000, exceedences of both the 200 and 800 cfu/100ml standard occurred during the summer months between June and October at least once for all the stations in this region. Stations located in the upper Blackwater Creek area (HR 15 and 16), Itchepackesassa Creek (HR 14), and Hollomans Branch (HR 10) appear to be the most contaminated and had frequent exceedences of the 800 cfu/100 ml standard during the wet season.

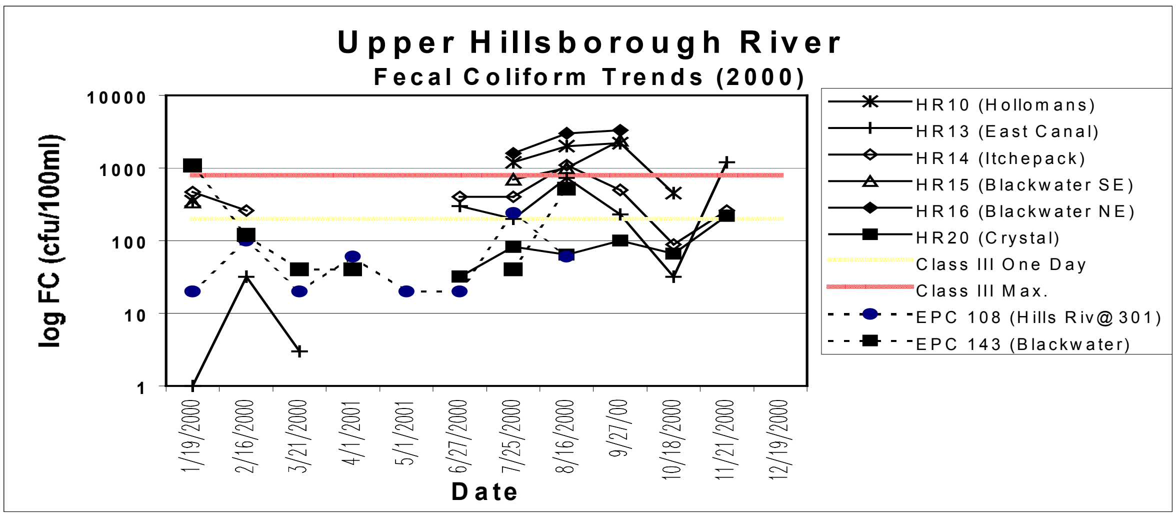


Figure 4. Trends in monthly fecal coliform concentrations at several stations within the upper Hillsborough River area for the year 2000. (Source: Kurz and Harwood, Upper Hillsborough River Bacterial Contamination Assessment Plan of Study, 2001)

Despite the longer term trends showing a decline in fecal coliform concentrations presented in Figure 2, the more recent data from the year 2000 (Figure 4) showed frequent, elevated levels of bacteria. However, neither the specific location nor the sources of this contamination could be identified based solely on this fecal coliform bacteria data. As a result, additional methods for analyzing water quality were necessary to identify sources of fecal contamination in the watershed.

Alternative Methods for Identify Sources of Fecal Contamination

Using discriminant function analysis, a multivariate statistical technique using antibiotic resistance analysis (ARA) was proposed as a method to identify the source of fecal coliforms and *E. coli* in the upper Hillsborough River/Blackwater Creek area. This method is being carried out by the University of South Florida (Dr. Jody Harwood). Dr. Harwood has developed a regional database of antibiotic resistance patterns (ARPs) of indicator bacteria from known animal sources. Other investigators currently using this technique (Hagedorn and Wiggins) use fecal streptococci or enterococci as the indicator organism. For this study, fecal coliforms and, more specifically, *E. coli*, is being used as the indicator organism. This study is currently underway (2002) and should be completed within one year.

Other methods for identifying sources of bacterial contamination include the use of a combination of alternative indicator organisms (enterococci, *Clostridium perfringens*, coliphage), gene probes, polymerase chain reaction (PCR), inert tracers, and fiber optic biosensors. Several recent studies in southwest Florida have evaluated the use of multiple indicator organisms to identify microbiological water quality conditions in estuaries (Lipp *et al*., 2000; Rose *et al*., 2001). The results of these studies vary, depending on geographic location, land uses and wastewater disposal practices within contributing basins for a given sampling point, and atmospheric conditions (El Nino events) that affect streamflow. Several investigators in the Florida Keys (Paul *et al*. 1995; Paul *et al*., 2000) have used inert and viral tracers to identify transport mechanisms in groundwater; these techniques could also be used where groundwater and surface water interactions are linked (e.g. areas having shallow groundwater tables, springs/karst areas).

Gene probes and PCR are highly specific and sensitive molecular techniques which basically involve the identification of specific portions of DNA (deoxyribose nucleic acids) or RNA (ribosomal nucleic acids) in microorganisms present in a water sample. The identification process involves the use of gel electrophoresis that results in the production of a banding pattern on a gel plate (Figure 5).

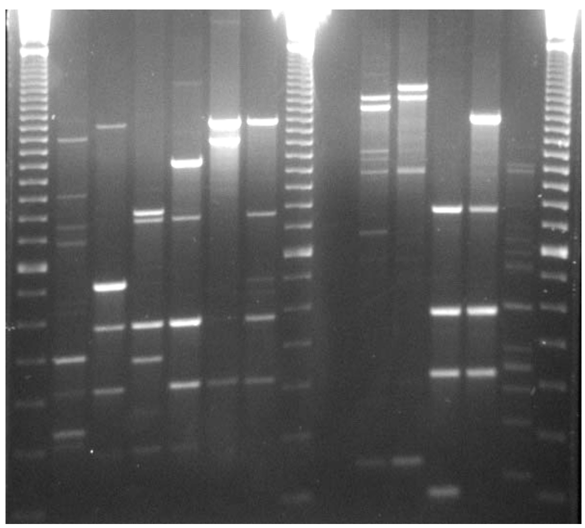


Figure 5. Results of a gel electrophoresis analysis.

Finally, one of the newest technologies currently being tested for efficacy is the use of fiber optic biosensors for identification of microorganisms (Lim, 2000; Lim, 2001; Tims *et al.*, 2001). Fiber optic biosensors utilize fiber optic waveguides to direct electromagnetic energy in an evanescent wave. Photographs of a prototype unit and associated laptop computer for data analysis are shown as Figure 6. Detection antibodies, receptor molecules, and/or nucleic acid probes immobilized on the waveguide selectively bind specific target analytes. By attaching a fluorescein-labeled antibody to the analyte antigen in a "sandwich" assay, the fluorophore can be excited by the evanescent wave to generate a detectable signal. This innovative system has been used to successfully detect pathogens such as *E. coli* O157:H7 directly (without enrichment) from ground beef, apple juice, and raw sewage at levels as low as 100 organisms per ml. Other microbial pathogens, including *Salmonella typhimurium*, *Listeria monocytogenes*, *Vibrio cholerae*, and *Cryptosporidium*, have been successfully detected with the fiber optic biosensor. This research, which is performed in close collaboration with federal and local public health agencies, food processors, water utilities, and the Department of Defense, can significantly improve public health through rapid detection of microbial pathogens and reduction of disease morbidity and mortality.

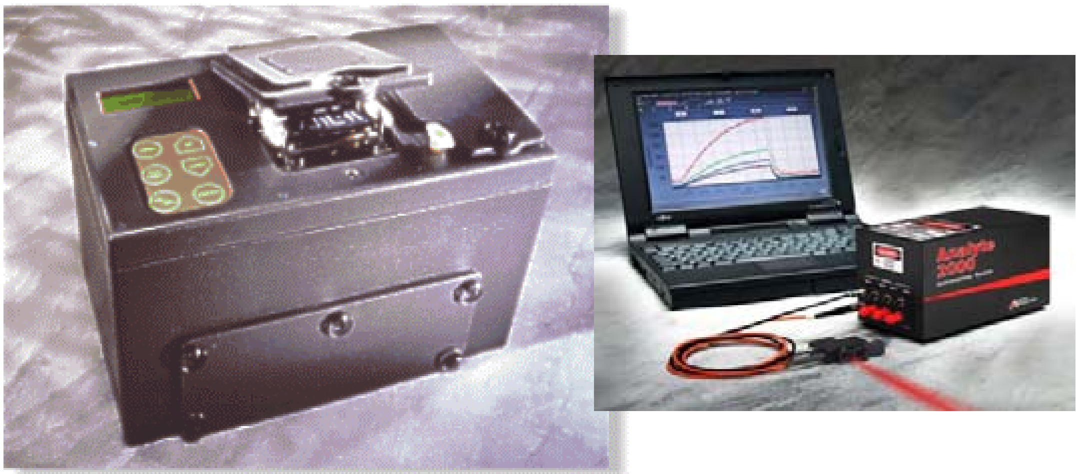


Figure 6. Photograph of a prototype fiber optic biosensor unit (left). Unit is approximately the size of a car battery.

Analyzing the Data and Identifying Solutions

Once data have been collected regarding actual sources of fecal contamination, various GIS analyses can be performed to pinpoint potential land uses/activities which may be contributing to elevated bacterial concentrations. Using existing land use, FDEP wastewater treatment plant permits, and Department of Health septic system permitting records, areas utilizing package plants or septic systems can be identified if human sources are identified by the ARA analyses. This data can then be intersected with soils data to identify areas utilizing septic systems which may be constructed in inadequate soils conditions (i.e., high water tables, poor filtration properties) or in close proximity to streams or ditches. Package plants can also be identified on a map to identify proximity to sampling stations and streams. Agricultural land uses (e.g., pastures, cattle operations) that are adjacent to streams or ditches can be identified as potential sources. Field observations may then be necessary to identify whether livestock are being excluded from streams or other waterbodies.

Best Management Practices Evaluation

A number of structural and non-structural best management practices have been developed to improve water quality. Structural systems include wet detention ponds, alum treatment, sand filtration, off-line retention, and many other combinations of systems that have traditionally originated from the wastewater treatment industry. Although most structural systems have been designed to reduce nutrient, suspended solids, or metal contaminants from stormwater runoff, these systems have also been shown to remove microbiological contaminants given certain design considerations (Kurz, 1998). Hagedorn et al. (1999) has shown that simple fencing of pastures to exclude cattle from streams can result in significant reductions in fecal coliform concentrations in a rural watershed.

Non-structural practices include proper waste management at dairies and poultry farms, livestock management (exclusion) near waterbodies and streams, good housekeeping and facilities management at wastewater treatment plants, and proper site planning and management of on-site wastewater treatment systems. Both structural and non-structural systems should be evaluated for their potential to reduce fecal contamination once an accurate assessment of the source and nature of the contaminant is identified within a given watershed.

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STORMWATER RETROFIT OF LONG LAKE, LITTLETON, MA –USING LOW IMPACT DEVELOPMENT APPROACHES

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ABSTRACT

Long Lake in Littleton, Massachusetts has experienced rapid eutrophication as a result of conversion of summer cottages to year-round housing, on-site wastewater disposal on small lots, and an extensive network of stormwater collection and conveyance piping with direct discharge to the Lake. A network of stormwater catch basins and conveyance piping currently directs the vast majority of stormwater immediately into Long Lake through over 18 piped discharge points. The current stormwater conveyance system provides minimal opportunity for stormwater to come in contact with soils and vegetation, settle solids, and remove nutrients and other pollutants.

This Section 319 comprehensive stormwater retrofit project for the restoration of Long Lake, the first of its kind in Massachusetts, employs a Low Impact Development (LID) approach that will include: selected disconnection of the existing stormwater collection system; design and site location of infiltration swales, and a wetland treatment cell, bioretention cells, depression storage, porous pavement, and parking lot storage; homeowner involvement through education including: installation of rain barrels, lawn care education, water conservation, and other management practices. In addition to the Section 319 grant, the Town recently received a $300,000 State Lake and Pond Demonstration Grant to help implement many of the controls. The new grant will support economic incentives to encourage homeowners to purchase no phosphorus lawn fertilizer under a rebate program.

This paper will describe the comprehensive and innovative approach that Littleton is using to retrofit this area, improve water quality in this recreational lake, involve residents, and help to meet the local Stormwater Phase II requirements and provide a pilot project for similar lakeshore communities developing Phase II programs.

INTRODUCTION

Long Lake is a 99-acre recreational (i.e., swimming and fishing) kettle pond in Massachusetts with over 600 houses on small lots, that has been subject to a deterioration of water quality and recreation use caused by a proliferation of nuisance aquatic macrophytes (Figure 1). Results of a water quality study conducted as part of a Diagnostic/Feasibility Study in 1990 and further documented through a current S.319 project indicate that Long Lake is undergoing cultural eutrophication, mainly due to nutrient inputs from its 1.5 square mile watershed. Phosphorus is considered the most important limiting nutrient for primary production (plant growth) in the lake. The phosphorus arrives principally through the surface tributaries, storm drainage runoff from road surfaces and the groundwater. An updated phosphorus budget was completed for the S.319 Project (Figure 2). A network of stormwater catch basins and conveyance piping currently directs the vast majority of stormwater immediately into Long Lake and quickly discharges stormwater through over 18 piped discharge points. The current stormwater conveyance system provides minimal opportunity for stormwater from impervious source areas to come in contact with soils and vegetation, settle solids, and remove nutrients and other pollutants (Figure 3). Stormwater is the major source of pollutants to the lake and accordingly a program has been developed to address this source through retrofit of the existing stormwater collection system with grass and vegetated swales, a constructed wetland, boat ramp and parking area redesign, and distributed controls on private residential lots in the watershed. Current S.319 funding is limited and will only help to implement a portion of the required controls.

Figure 1. Noxious Aquatic Macrophytes and Emergents at Long Lake

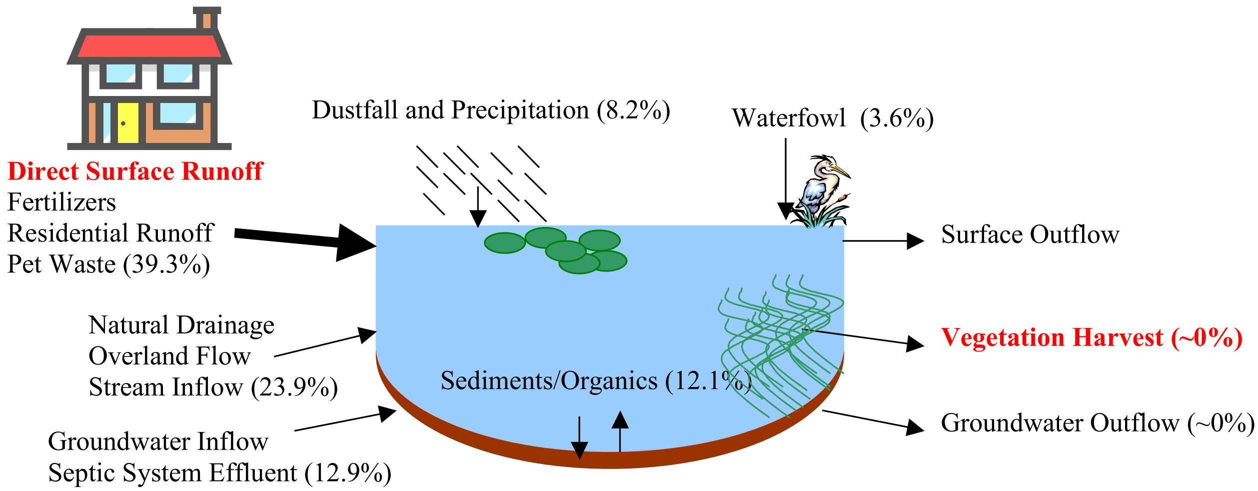


Figure 2. Phosphorus Budget at Long Lake, Littleton

Figure 3. Direct Stormwater Discharges into Long Lake, Littleton

THE PROBLEM

Long Pond is identified on the Massachusetts 303(d) list for noxious aquatic plants, and water quality may be threatened by high phosphorous loading. Long Pond is in the Fort Pond Brook Tributary Basin and serves as the headwaters into the Assabet River, which is also identified on the Massachusetts 303 (d) list. The Assabet River is currently undergoing a "Total Maximum Daily Load" analysis. Eutrophication has led to extremely dense macrophyte growth along the shoreline of the pond, with subsequent degradation of the recreational utility of this water body. Storm events bring flooding and direct discharge of sediment, nutrient, and pollutants directly into the Lake (Figure 4), causing rapid buildup of sediment along the shoreline of the Lake.

Figure 4. Flooding and direct discharges of sediment into Long Lake during March 21, 2001 storm event.

The water quality impacts of storm drains and septic systems in the Long Pond watershed are also a concern. Restoration of recreational activities and mitigation of present and future influences are desired.

Figure 5. Stormwater Outfall at Town Beach

Figure 6. Dye Testing To Determine Stormwater Drainage

RESTORATION PLANS

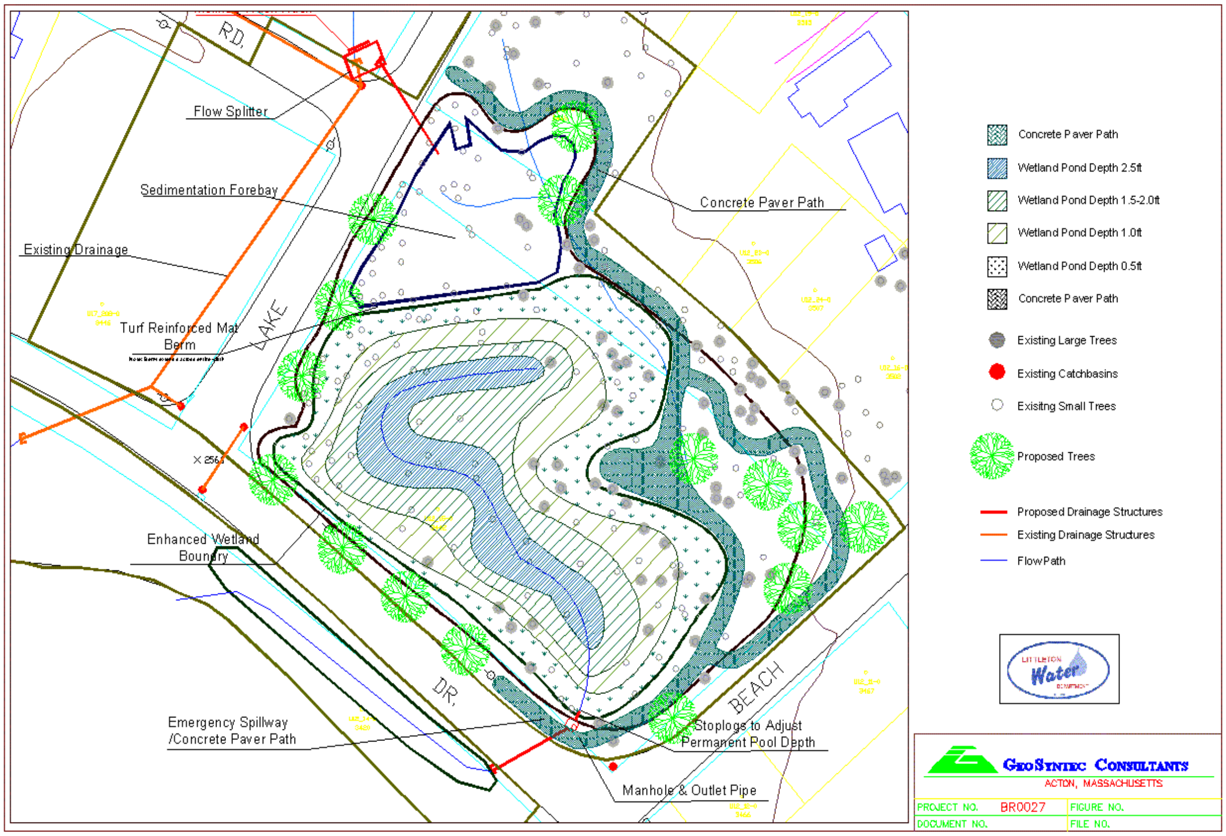
The Littleton Lakes Coalition (LLC), and the Long Lake Neighborhood Association (LLNA) have become active participants with the Town of Littleton to restore and protect the many lakes in the Town and promote cooperation among individual lake and pond associations. Many improvements and institutional changes in the Long Lake watershed have been accomplished over the last year. The community has agreed to promote the design and installation of a range of Low Impact Development (LID) controls within the watershed to Long Lake. LID controls are stormwater management techniques designed to reduce stormwater volume and improve the level of pollutant removal through distributed control techniques, including disconnection of flow paths, infiltration, retention, and biological uptake.

The specific goals of the Long Lake restoration project are to restore the value of the lake to the community through the implementation of in-lake and out-of-lake controls. The techniques being implemented are aimed at reducing or removing factors leading to pond degradation rather than merely treating pond conditions in isolation. These techniques include macrophyte chemical treatment (conducted in June of 2001) hydroraking of rooted macrophytes, stormwater treatment (i.e., LID controls), increased street sweeping, and education of watershed residents.

LID CONTROLS

Over 20,000 linear feet of drainage swales are designed and in the process of installation. Using a parcel-by-parcel and right-of-way analysis based on the Town's geographic information system (GIS). The design and layout of wet and dry drainage swales was accomplished. In this highly developed watershed, encroachment upon the roadway right-of-way was significant. Mailboxes, trees, shrubs, walls, fences, were all identified using the GIS. Where obstacles could be removed or avoided, a swale was designed. In Massachusetts, infiltrating stormwater control measures must have a setback of 100 feet from septic systems. Achieving this setback was almost impossible in this watershed. In response, the design of the swales was modified to include impervious membranes such that they will function as wet swales.

A constructed wetland cell (Figure 7) was designed to treat a 40-acre drainage area to Long Lake. The parcel is owned by the Town and is currently considered a non-buildable lot due to wetlands. Over 90% of the stormwater volume will flow through this constructed wetland resulting in a significant reduction in sediment and nutrient loading to the Lake. In addition, recreational opportunities for wildlife observation were incorporated into the project by including a porous paver walkway.



Other proposed LID controls include: the disconnection of roof drains that are directly connected to pervious surfaces; installation of rain barrels to capture roof drainage; installation of raingardens to hold small volumes of runoff on site; installation of several bioretention cells on public parcels throughout the watershed; creation of a watershed interpretative Low Impact Development walking trail in the watershed with a map, field signage, and pamphlet; and economic incentives to promote of the use of low phosphorus lawn fertilizers and natural lawn care products.

This last LID control involves providing watershed homeowners with rebates to purchase no phosphorus lawn care products. Excessive amounts of nutrients from lawn care activities are common sources of nutrient loading to lakes. Public educational materials were supplied to residents on alternative lawn care products that are low in phosphorus. There is considerable interest in using these products; however, their cost is slightly higher than commercial brands of lawn fertilizers. Corn gluten meal (10-0-0) is a commercially available lawn care product having no phosphorus and consisting entirely of dried protein separated from corn during the manufacture of starch in the food industry. Corn gluten also has properties that reduce weed seed germination, serving as a pre-emergent natural herbicide. This and other natural products are available locally at hardware stores and lawn care supply stores. The approach is to provide a $25 per bag rebate to homeowners in the watershed that purchase these products rather than fertilizer high in phosphorus. Rebates such as this have worked exceptionally well in the electric power industry (low-wattage light bulb coupons) and in the water conservation field (low-flow toilet retrofit rebates). This innovative approach to use economic incentives to change behavior in the purchasing of fertilizers can significantly reduce phosphorus loading from lawn care in the watershed. The rebates will be directly available to the consumer at the time of purchase. The retailer will be reimbursed for all rebate coupons accepted.

NPDES STORMWATER PHASE II COMPLIANCE

In 1999, the U.S. Environmental Protection Agency (EPA) instituted the NPDES Phase II Storm Water Regulations. Phase II affects 189 Massachusetts communities by expanding the NPDES program to include these municipal separate small sewer systems [MS4s] and small construction site activities (1-5 acres). Included in the MS4 category are municipal systems, state and federal departments of transportation, public universities, local sewer districts, public hospitals, military bases and prisons. Under the stormwater rule, all regulated small municipal separate storm sewer systems must develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants to the "maximum extent practicable" utilizing best management practices (BMPs). The program require the development and implementation of 6 minimum control measures including:

- Public education and outreach on storm water impacts
- Public involvement/participation in the development of the plan
- Illicit discharge detection and elimination including infrastructure mapping
- Construction site storm water runoff control
- Post-construction storm water management in new development and redevelopment
- Pollution prevention/good housekeeping for municipal operations

The Long Lake stormwater restoration project in Littleton will assist the community develop a stormwater control program for most of these minimum measures. Public education and involvement has been achieved. Infrastructure mapping is completed. Post-construction stormwater controls have been designed and several installed. Pollution prevention through street sweeping and catchbasin cleaning is a regular maintenance item in the watershed.

CONCLUSION

Over the next three years all of the stormwater control measures discussed above will be implemented. A water quality monitoring program will be conducted to measure the nutrient and sediment loading reductions from these distributed LID control measures. It is anticipated that the cost of the LID controls will be significantly less than the cost of a regional stormwater control facility. In addition to the water quality benefits, community involvement and aesthetic improvements through plantings in the bioretention cells, raingardens and swales will help to create vegetated buffers between the small residential lots. LID controls in a retrofit setting of high density lakeshore development holds the promise of achieving improved stormwater quality control while involving residents and improving aesthetics.

TOWN LINE BROOK URBAN WATERSHED STUDY MODELING INCREMENTAL IMPROVEMENTS

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ABSTRACT

Innovative approaches that are available for addressing stormwater pollution and flooding problems in highly urbanized areas are often not proposed as alternative solutions due to the complexity of analyzing the marginal benefit of a large number of low cost alternatives in favor of robust and often costly engineering solutions. Town Line Brook which drains significant potions of the cities of Revere, Malden, Everett, and Melrose just north of Boston, Massachusetts has repeatedly been the victim of oversimplified (and costly) proposed solutions to a complex series of water quality and quantity problems. This paper discusses the recent and ongoing efforts of the authors to address these problems in this 2.5 mile long tidal creek draining approximately 2500 acres of highly urbanized area. A proposed range of innovative approaches are proposed including: restoration of floodplain function through the creation of offline storage, salt marsh and freshwater wetland rehabilitation, self-regulating and conventional tide gate installation and optimization, in-channel sediment removal, bank and channel stabilization, erosion control, and removal and rehabilitation of engineered structures. Watershed hydrology and hydraulics have been modeled using a continuous simulation (based on 50 years of historical hourly tide and rainfall data) of both the main channel and the complex drainage system utilizing the SWMM model coupled to a project GIS. The methods used have significant implications for similar locations nationally demonstrating that the difference between inaction and implementation can lie in our willingness to embrace innovative and incremental solutions to complex water quality and flooding problems.

INTRODUCTION

The Massachusetts Environment Trust (MET) established this study of the Town Line Brook watershed and its two tributaries (Trifone Brook and Linden Brook) to provide recommendations for improvements to the existing drainage infrastructure and management of the watershed in order to address public safety hazards created by chronic flooding of the brooks and reduce pollution entering the Pines River and surrounding shellfish beds.

This paper focuses on the technical approach used in the study for assessment of low cost/high return flooding mitigation, channel and wetland restoration, and water quality improvement alternatives.

PROJECT SITE AND HISTORY

The Town Line Brook watershed is comprised of approximately 2500 acres of highly urbanized areas of four towns (Revere, Malden, Everett, and Melrose) located just north of Boston on the coast of Massachusetts (see Figure 1). Population densities in these three towns range from 16.5 per acre to 9.3 per acre.

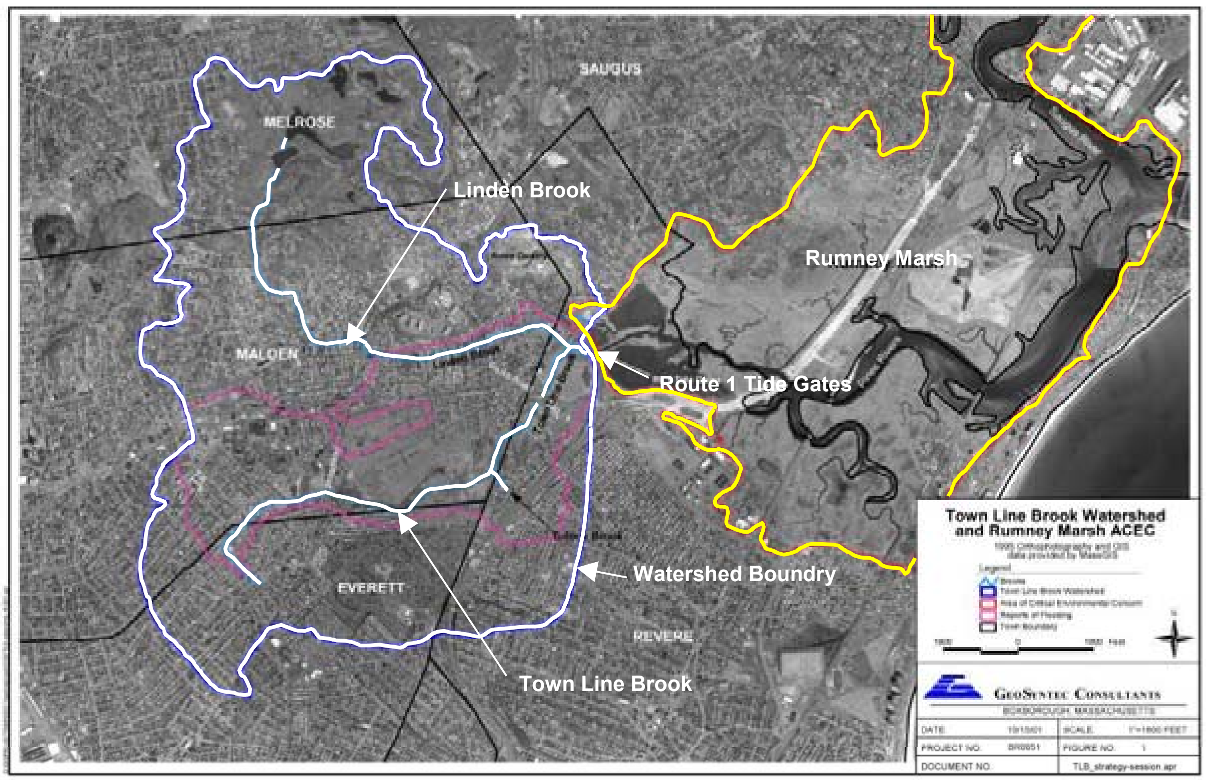

Figure 1. Site map showing watershed, main drainage channels, receiving water for the Town Line Brook watershed.

The main channel of Town Line brook is approximately 2.5 miles long. Until the late 1950s, the channel was under tidal influence. As part of a flood mitigation project that was intended to include a sizable detention facility and pump station, the upper reaches of the channel were excavated and concrete lined. At the same time, the major tributary of Town Line Brook, Linden Brook, which drains 1100 acres of the watershed, was almost completely enclosed in a system of culverts. The proposed detention facility and pump station were never constructed. However, tide gates were placed at the most downstream culvert to limit tidal flows into Town Line Brook and back into the drainage system.

Under current conditions, the main channel drains through a set of tide gates to Rumney Marsh, a state designated Area of Critical Environmental Concern (ACEC). The main channel and the tributary drainage system are subject to partial tidal influence as a result of the installation of a series of self-regulating and conventional tide gates (SRTs). The rehabilitated tide gate system was constructed in 2001 for the restoration of upstream salt marsh areas and flood protection. The tide gate structures present prior to 2001 were of a conventional design and in poor operating condition, which resulted in minimal flood protection and regular inundation of historical salt marsh areas.

Watershed hydrology has changed dramatically over the past 70 years due to the extensive development that has taken place. In addition, the floodplain has rapidly disappeared in this century. Field observations of encroachment activities are supported by historical orthophotographs of the area, which were obtained by the authors for each of the past seven decades.

Tidal fluctuations in the receiving water vary greatly with the astronomical tidal fluctuations being in excess of 12 feet and storm surges in excess of 14 feet (above mean lower low water) during extreme events.

METHODS

Model Selection

Based on the complexity of the hydrologic and hydraulic situation in the watershed (downstream tidal boundary conditions with self-regulating tide gates and upstream urban runoff) and the desire to understand the impacts that a variety of flood mitigation approaches would have on the frequency of flooding, the SWMM model was selected for modeling hydrology and drainage system and channel hydraulics. The authors felt that in order to provide stakeholders with some tangible evaluation of mitigated impacts under the conditions present in Town Line Brook and Linden Brook, a continuous simulation model would need to be developed. The continuous simulation approach allowed the authors to provide frequency analysis results on actual water surface elevations and flow rates in the Brook and drainage system as well as elevation-duration curves. In addition, the use of the SWMM model allowed the authors to examine the frequency and duration of frequent events to a much greater extent than would have been possible with steady state or single event models. Where tidal boundary conditions drive flooding, it is often difficult to assess the impacts of proposed flood mitigation alternatives for frequent events without a continuous simulation model. The typical modeling approach is to determine water surface profiles resulting from a synthetic storm event occurring during a specific tidal condition (e.g., flows resulting from the 50-year 24-hour rainfall combined with 50-year tidal elevations). Use of the SWMM model also allows for frequency analysis of events that result in the majority of pollutant loads to the receiving waters (i.e., smaller events that are often not of specific interest for flood mitigation.)

Model Setup

The SWMM model was developed from a variety of existing sources of information including:

- Historical hourly rainfall records (50 years)
- Historical hourly and 6 minute tidal data (80 years)
- GIS based land use data
- GIS based digital (or digitized hard copy) soil survey maps (MassGIS and National Resources Conservation Service)
- Digital elevation models and other digital topographical data of the watershed (United States Geological Survey, Massachusetts Highway Department, and MassGIS)
- Existing HEC-2 cross-sectional data for the main channel (previous study by Haden and Wegman)
- Scanned and digitized drainage maps (from Towns of Revere, Malden, Everett, and Melrose)
- Original design plans for the culverts and main channel improvements (obtained from the Metropolitan District Commission)
- Digital Orthophotography (MassGIS)
- Field survey, measurement, and documentation of channel sections, inverts, and outfalls.

Hydrology for the model was carried out using historic rainfall records in the SWMM Rain and Runoff modules. The Runoff module was developed based on available land use data, digitized soils data, digital elevation information, and other pertinent available information from a variety of references and sources (e.g., impervious percentages for land use categories as developed by MassGIS). The Runoff module contains 70 sub-watersheds.

Hydraulics were simulated by employing the Extended Transport (Extran) Module. Open channel hydraulics for the main channel were simulated utilizing irregular cross-section data available from existing HEC-2 models and new sections developed based on one-foot contour interval digital topographical maps. Pipes less than 24" in diameter were excluded from the SWMM model in order to strike a balance between accurately representing the drainage system and model complexity. The Extran module contains 125 conduits including open channel sections.

Water Quality Issues

Although Town Line Brook is subject to the typical suite of omnipresent urban pollutants, the primary pollutant of concern in Town Line Brook is fecal coliform contamination due to the large areas of shellfish beds downstream in the receiving water (Rumney Marsh). Water quality improvement opportunities for pollutants resulting from non-point sources in the watershed and Town Line Brook itself are limited by a number of factors, including availability of land. Typical approaches such as providing regional facilities for the removal of pollutants are limited in their applicability. Dry weather sources are being actively pursued in the watershed. Although illicit connections and leaking sanitary sewers may play a major role in the current water quality impairment, addressing these sources alone will most likely not bring the water quality of Town Line Brook below required levels (200 mpn/100ml) due to the abundance of non-point sources. The authors are currently conducting a wet weather and dry weather monitoring study to help identify wet weather sources and design both structural (constructed wetlands) and non-structural (public education and pet waste management programs) Best Management Practices (BMPs) aimed at reducing discharges of non-point fecal coliform pollution. The work conducted as part of the hydrology and hydraulics study are useful for better understanding the contributions of source areas and impacts on non-point source loads from proposed structural BMPs.

Assessment of Flood Mitigation Alternatives

One of the primary objectives of the project was to identify strategies and modifications to the drainage system that would result in decreased flooding (frequency and duration) in Town Line Brook. Mitigation strategies broadly fall into two categories in the alternatives analysis according to their assessment methodology: 1) strategies that can be quantitatively evaluated in the SWMM model; and 2) strategies that can be evaluated qualitatively or through non-modeling approaches. Alternatives considered both separately and in combination include:

- Install additional conventional tide gates at a variety of locations in the drainage system (modeled).
- Provide new main-stem offline storage and improved wetland and salt marsh environments (modeled).
- Diversion of flows from Linden Brook to existing wetlands for water quality improvement or complete diversion for flood control (modeled).
- Use of portions of the ACEC for water quality facilities and flood storage (modeled).
- Adjustment of the SRT closing setting and active management of the tide gates during and before extreme events.
- Channel dredging (capacity analysis)
- Channel removal and rehabilitation (qualitative evaluation).
- Upstream storage (qualitative evaluation and limited analysis).
- Development and Zoning (qualitative analysis).
- Increasing the height of dikes to protect the floodplain from large storm surge.

In addition to quantitative and qualitative assessment of the above alternatives, options were evaluated for their ability to be implemented. Some options were excluded prior to the alternatives analysis due to extreme cost and the historical precedent of the failure of proposed large-scale solutions.

As a guiding principal, alternatives that had potential to increase flooding in any part of the watershed above current conditions were excluded. Modeling of specific historical extreme events under alternative strategies identified a number of options that failed due to this criterion. Specifically, placement of tide gates at the Squire Road culvert (See Figure 2) would provide increased protection in some sections of the watershed (upstream of the Squire Road culvert), but also increased flooding in the Linden Brook Culvert.

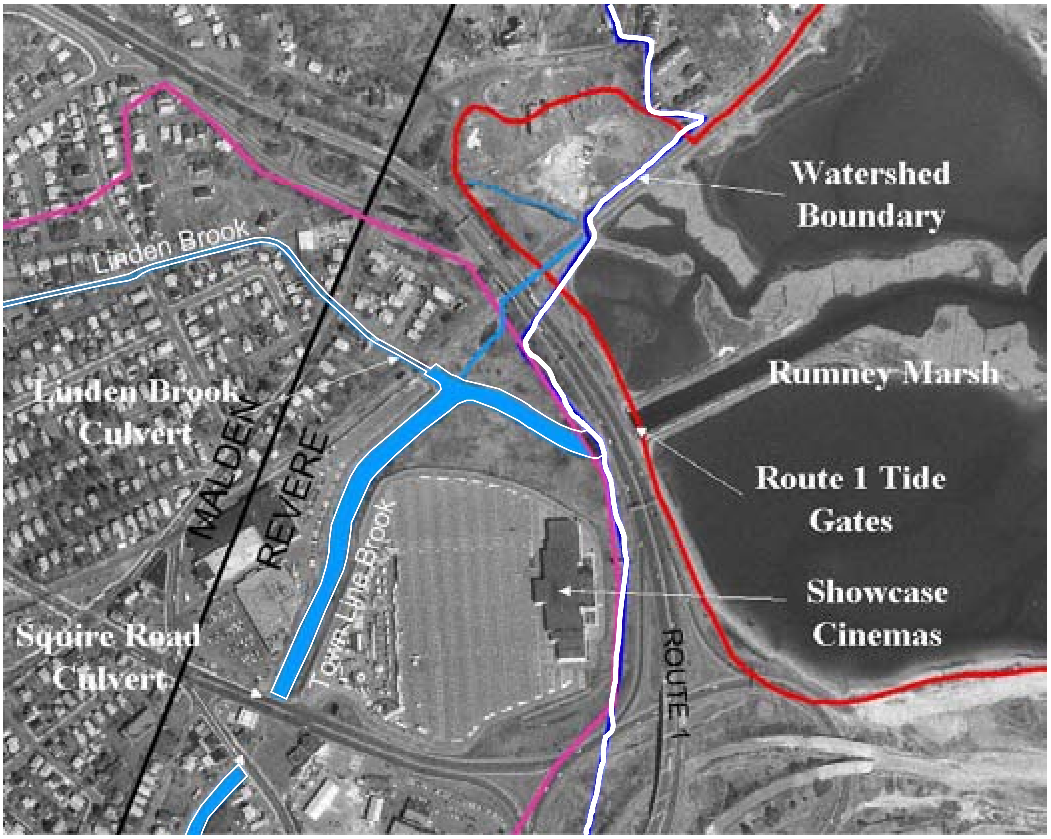

Figure 2. Map of Lower Reaches of Town Line Brook and Linden Brook

Although this alternative would prevent the storage of tidal flows in the channel above Squire Road, providing additional runoff storage volume, the increased capacity of the system is not "felt" by the Linden Brook watershed; in fact the flood storage volume of the channel and floodplain available to Linden Brook flows is significantly decreased. This is a result of the relative size of the area draining above and below the proposed tide gate location and the available storage capacity in the two sections of the channel. Placement of tide gates at Squire Road prevents storage of runoff from the 1100 acre Linden Brook watershed in areas above the potential tide gate location. Results such as these are difficult to demonstrate in this watershed without the use of the continuous simulation model. In fact a number of alternatives increased flooding during historical extreme events. A summary of some of the results from modeling a variety of flood mitigation alternatives under extreme historical conditions are provided in Table 1.

Table 1. Modeling Results for Flood Mitigation Alternatives During Historical Extreme Events

	February 6-7 1978 (2.86 inches – 100-year tide)				June 12-15 1998 (6.77 inches – No surge)			
	Tidal Elevation	Main Channel Above Rt. 1	Linden Culvert	Above Squire Road	Tidal Elevation	Main Channel Above Rt. 1	Linden Culvert	Above Squire Road
Scenario	Maximum Water Surface Elevation (ft, NGVD)				Maximum Water Surface Elevation (ft, NGVD)			
Current Conditions	9.72	6.40	6.43	6.44	5.86	5.87	5.93	5.92
Lower SRT Setting Elev. 3	9.72	6.02	6.03	6.02	5.86	5.42	5.44	5.42
Closed SRT	9.72	5.85	5.86	5.85	5.86	5.12	5.14	5.18
Conventional Tide Gates at Squire Road	9.72	**7.37**	**7.39**	5.62	5.86	5.86	5.91	5.15
Tide Gates at Squire and Offline Storage Upstream of Squire Road	9.72	**7.37**	**7.39**	4.74	5.86	5.86	5.91	4.71
Storage Above Squire Road Only	9.72	6.08	6.10	6.10	5.86	5.72	5.75	5.75
Complete Diversion of Linden Brook, Additional ACEC Wetland Storage for Linden Watershed (additional 4.6 ac), Tide Gates at Linden, Squire Road Tide Gates, Offline Storage Above Squire Road.	9.72	5.43	**6.71**	4.74	5.86	5.37	5.87	4.7

RESULTS AND DISCUSSION

The intent of this project was to identify flood and water quality improvements that could be implemented for Town Line Brook. The basic premise of the project was that innovative solutions that provided significant marginal benefit, but may not solve all of the problems in Town Line Brook could be found through continuous simulation modeling of hydrology and hydraulics. The authors found through modeling and qualitative analysis that several such solutions that could be implemented in combination to provide a noticeable improvement in not only flooding, but also water quality, and habitat. These solutions were compiled into a preferred approach. The preferred approach consists of the following:

- Install tide gates at the Linden Brook culvert to make available additional storage (as much as 10 to 13 ac-ft) at high tide when the SRTs are not set closed.
- Install tide gates on Trifone Brook culvert to protect upstream areas from excessive downstream water surface elevations.
- Set SRTs to close at elevation 2' NGVD (they are currently permitted to close at 4' during the winter months and 5' during the summer).
- Create approximately 60 ac-ft of offline storage on the main channel in combination with wetland restoration consistent with adjusted SRT closing elevation.
- Dredge the channel of approximately 4000 cubic yards of sediment that have accumulated in lined reaches.
- Increase flood dike height to 9' NGVD at all locations.

A number of the alternatives can be implemented independently. Specifically, installation of conventional tide gates at the Linden Brook culvert and at Trifone Brook can be carried out independently of other components. The most notable improvement in flood elevations results from the combination of setting the SRTs to low closing elevations and providing offline storage. SRT closing elevations cannot be lowered until significant upstream wetland rehabilitation is conducted to account for major changes in water elevations that result from the lower setting. In addition, the construction of offline storage areas should be conducted as an integral component of the wetlands/salt marsh restoration. The construction of offline storage areas also could include channel modifications such as removing sections of the channel to allow flows to enter into offline areas. The goal for the channel modifications would be to restore a more natural flow regime with interactions between the main channel and adjacent salt marsh offline storage areas. It is expected that if properly designed, offline storage areas and the wetland restoration work could aid significantly with water quality.

The SWMM model demonstrates the impacts of using the preferred approach. An elevation-duration curve provides a useful overview of the effects of the strategy (see Figure 3) on water surface elevations. Residential flooding occurs above elevation 6'. Figure 3 demonstrates that during the 10 year modeled period (1988-1998) the maximum water surface elevation upstream of the SRTs in the main channel is decreased from 6.5 feet under current conditions to 5.2 feet under the preferred alternative. It is also important to note that a considerable level of protection has been reached through the installation of the system of tide gates installed in 2001. Water surface elevations would be much closer to the downstream water surface elevations in Rumney Marsh if the tide gates had not been rehabilitated.

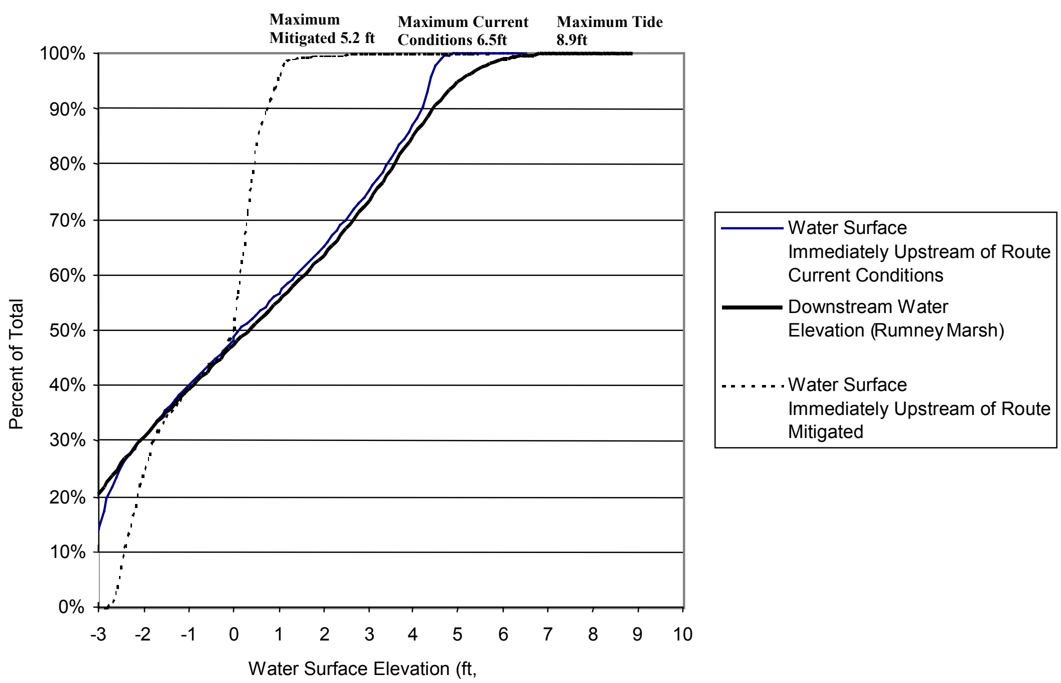

Figure 3. Percent of Total Model Duration where Water Surface Elevation is at or Below Indicated Level During Model Run During 11 Year Period 1-1-1988 through 1-1-1999

ACKNOWLEDGEMENTS

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POLLUTANT LOADING ANALYSIS FOR STORMWATER RETROFITTING IN MELBOURNE BEACH, FLORIDA

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ABSTRACT

As a result of perennial flooding along Oak Street in Melbourne Beach, Florida, Creech Engineers, Inc., was chosen by Brevard County Stormwater Utility to design and permit drainage improvements for the 51acre drainage basin. The drainage basin consisted of mixed roadway, park, school, residential, and church land uses. As is often seen in older areas of cities, there was no stormwater infrastructure to provide even minimal flood protection for several blocks of this collector street. To further compound the problem, Oak Street is a Brevard County maintained road, even though it lies mostly in the Town of Melbourne Beach. In order to address the problems along Oak Street, the County undertook several partnership opportunities with adjacent schools, parks, private residences, and the Town.

In September 2000, the first phase of improvements were made by Brevard County at the Gemini Elementary School on Oak Street to alleviate flooding to properties adjacent to the school. This was a joint effort between Brevard County and the School Board. The flooding was partially caused by runoff from Oak Street flowing across school property and into the yards. At the school site, three dry retention ponds totaling 7.28 acres were constructed to reduce flows which were leaving the school site through adjacent yards, as well as provide stormwater treatment where none existed. A new outfall pipe to the Indian River was constructed to funnel flows that were sheet flowing through yards and over streets. These improvements were part of a much larger project to address repeated flooding along the Oak Street corridor.

The second phase of the project addressed stormwater quantity and quality concerns along Oak Street from A1A to Cherry Street. Flooding of the road necessitated the construction of 2000 feet of new pipe system, which discharged into a residential canal system. This canal system was used by many of the adjacent residents for boating to the Indian River Lagoon (Bay). These canals were very politically sensitive since they were in need of dredging. The citizens requested the Town to dredge the canals even though the Town does not normally undertake dredging projects. The Town declined to dredge the canals. The residents were concerned that the new stormwater system would lead to further sedimentation of the canals.

To address citizen and permitting concerns, a stormwater treatment train consisting of a series of swales, berms, and dry ponds was designed to provide maximum volume retention on the park site. A series of inlets were designed at the park and along the road to provide an outfall for these basins. In addition, a series of swales, retention ponds, inlet traps, and baffle boxes were constructed to reduce overall pollutant loads entering the canals.

To quantify pollutant load reduction, an analysis for annual stormwater pollutant loadings was performed. In order to assure total load reductions, an additional 77 acres offsite of the project were retrofit with baffle boxes and inlet traps in resident's yards. These offsite areas in the Town required permitting and close coordination with Town officials.

This project was typical of the creativity, shareholder involvement, and partnerships necessary to retrofit urban areas.

INTRODUCTION

At Gemini Elementary School in Melbourne Beach, Florida, there has been a history of repeated flooding on the school grounds and in properties adjacent to the school. In 1999 Creech Engineers, Inc. (CEI) was chosen by Brevard County Stormwater Utility to design drainage improvements to alleviate these flooding conditions, as well as to provide for stormwater treatment within this 20.06 hectare drainage basin. The project was divided into two phases. Phase 1 improvements were made in order to accelerate initial flood control measures for homes downstream of the school. Phase 2 involved the design of more extensive flood and water quality control measures along Oak Street for further protection of school property and roadway flooding at nearby church property. This paper highlights the political challenges of retrofitting stormwater systems in developed areas, as well as demonstrates a methodology for performing a nonpoint source pollutant loading analysis.

EXISTING CONDITIONS

Gemini Elementary School is located on a 8.02 hectare, triangular shaped property along the south side of Oak Street, a two lane collector road in Melbourne Beach, about one half mile from the Atlantic Ocean. See Exhibit 1. Residential properties lie downstream of the school, along its southeast and southwest borders. 8.51 hectare Doug Flutie Park is on the north side of Oak Street. A soccer club uses the park and school grounds on a daily basis. There was no stormwater system at the park, along Oak Street, or on the school site. Stormwater flowed southward off Doug Flutie Park, across Oak Street, through the school site, and into the yards and homes south of the school. These yards, and the roads downstream of them, are very flat and only a few feet above sea level. Once water stages high enough in the yards, it gradually sheetflows down the adjacent roads a few hundred yards to the Indian River. The affected homeowners naturally blamed the school for allowing the school's water to flood them.

West of the school, a few hundred yards along Oak Street, was a low point in the road where water ponded and flooded the road and an adjacent churchyard. Due to a thin clay lens at 26 cm deep causing a perched water table, water stood in the road for several days after even a nominal rainfall. This drainage basin was almost completely built out, with no easy path for developing outfalls to relieve flooding.

This section of the Indian River is a Class 2 water body, with a Shellfish Harvesting classification bringing intense scrutiny from the St. Johns River Water Management District.

Corp of Engineers permitting is required for new outfalls in the area due to seagrasses near the shoreline.

The park, the school, and Oak Street lie in unincorporated Brevard County. The church, and properties west of the school are in Melbourne Beach. Being a collector road, all of the utility companies have major transmission lines in the road right-of-way.

As can be seen, this challenging project involved Brevard County, Melbourne Beach, the School Board, Brevard County Parks and Recreation Department, Brevard County Road and Bridge Department, Brevard County Stormwater Utility, a church, three different Homeowners Associations, a soccer club, the Water Management District, the Corp of Engineers, and several utility companies. Stakeholder involvement and partnerships were going to be critical to weave a solution through the many players involved.

PROPOSED IMPROVEMENTS

The first priority was to alleviate flooding in the homes adjacent to the school. As an interim measure, a berm was designed and constructed by County personnel along the south property lines of the school, with a swale behind the berm directing water to the southernmost point of the school property. At that location, an inlet and 18" outfall pipe were constructed in a utility easement through two heavily landscaped and fenced yards, to Pompano Street, where it was tied into an existing storm drain pipe.

A short time later, heavy rains overflowed the berms and swales and flooded homes adjacent to the school again. CEI was engaged at that point to provide more effective drainage improvements.

Fortunately, Gemini Elementary School had a significant area of vacant land on their site. The school entered into agreements with Brevard County allowing the construction of three dry retention ponds totaling 2.95 hectare to reduce flows leaving the school site, as well as provide stormwater treatment where none existed. These dry ponds were wound around several soccer and baseball fields. The soccer field's locations had to remain in place due to previous agreements with the school and Parks and Recreation Dept. The ponds were only 26-40 cm (12"- 18") deep and sodded, allowing the soccer teams to use the pond areas as practice fields when dry. When the ponds were excavated, the confining clay layer was removed to allow for infiltration though the beach sand at the site. Construction was scheduled during the summer when school was out.

A control structure was designed at the outfall pipe location to provide protection for a 25 year storm. The temporary connection to the existing downstream pipe had overloaded the downstream system in a heavy rain event, so a new outfall to the Indian River was designed through a park adjacent to the River. The park was owned by a Homeowners Association, which reluctantly gave a drainage easement through the park. The County agreed to make several improvements to the park and its boat ramp in exchange for the easement. The Corp of Engineers was concerned that the new outfall pipe discharges would impact the nearby seagrasses, so the new discharge pipe was not permitted to be constructed in the Indian River. A bubbleup box was designed ten feet back from the shoreline and rock riprap was placed between the bubbleup box and the mean high water line to prevent erosion. As mitigation for disturbing the shoreline, spartina and other plants were planted among the rocks to further buffer the shoreline from the stormwater discharges.

This first phase of improvements was finished in September 2000 at a cost of $124,000. The improvements implemented proved successful in preventing any flooding of adjacent homes in several large rainfalls in 2001.

The second phase of the project addressed stormwater quantity and quality concerns along 1650 meters of Oak Street, from A1A to Cherry Street. To provide further flood protection at Gemini Elementary School, retention swales were designed along both sides of Oak Street and 625 meters of storm drain pipe was designed to intercept runoff and prevent it from crossing the road onto school property. The piping also provided an outfall for the low spot in the road by the church.

This new pipe system discharged into a residential canal system, which was used by many of the adjacent residents for boating to the Indian River Lagoon (Bay). These canals were very politically sensitive since they were in need of dredging and the Town of Melbourne Beach does not dredge canals. The residents were concerned that the new stormwater system would lead to further sedimentation of the canals. The first alternative for treatment was to use land at the church site for a pond for the road runoff. The church was willing to donate the land where their septic tank fields were located if the County would provide a sewer connection. This scenario was designed, but when it came time for the church to give easements to the County, they balked and it was back to the drawing board.

St. Johns River Water Management District, (District), criteria requires stormwater treatment for improvements which a) increase discharge rates b) which increase pollutant loadings, or c) which increase impervious areas. With this project, no new increased impervious areas were proposed, but there would be additional water flowing to the residential canal from the extension of the pipe system to the flood prone areas. These new flows create the potential for increased pollutant loadings to the canal. Normal design methods would have used treatment ponds to offset these potential impacts. Due to lack of available land for ponds, alternative treatment methods were proposed for this project. The District will consider alternative treatment methods if it can be demonstrated that all other possible alternatives have been exhausted. It would not be possible politically to use more school or park area for treatment ponds. For this project, CEI showed that the only alternatives were to tear down houses for ponds, or use alternate treatment technologies.

The treatment strategy involved maximizing treatment methods within the project basin with alternative BMPs, as well as retrofitting two adjacent watersheds as additional mitigation. A total of 1.67 acre feet of retention storage was provided in Phase 2 in the roadside swales and small ponds. This was equivalent to 0.032 inches of retention from the drainage areas flowing to the retention areas.

A treatment train along Oak Street was designed by using 9 Grated Inlet Skimmer Boxes, from Suntree Technologies, Inc., in the new inlets to trap debris entering the inlets, constructing berms to slow runoff from the ball fields, and installing one baffle box at the downstream end of the new pipe system along Oak Street. Baffle Boxes are in-line stormwater treatment devices which trap sediment, trash, and debris. They have been used by Brevard County successfully for the last 9 years. In offsite Basin 4, which only had one existing baffle box to provide sediment removal, 16 Curb Inlet Skimmer Boxes were installed in all of the existing inlets to provide nutrient removal by trapping grass clippings, leaves, and yard debris. Nutrients were a concern in the canals since the nutrients promote algae blooms, which in turn increase muck build up in the canals. In offsite drainage Basin 5, there are 3 existing pipes which discharge directly to the canals. Three baffle boxes and 6 curb inlet skimmer boxes were designed to provide sediment and nutrient treatment for this drainage basin. Brevard County Stormwater Utility will implement this project and be responsible for all maintenance of the improvements. The baffle boxes will be inspected twice a year and cleaned as needed. The inlet traps will be cleaned twice a year. Brevard County has a vacuum truck dedicated to cleaning stormwater BMPs.

Using numerous BMPs on this project provided a high degree of treatment for the new piping system along Oak Street, and provided treatment for two offsite basins where little treatment existed. The retrofitting of the offsite areas was, in effect, mitigation for the new discharges to the canal. See Exhibit 1 for a map of the improvements. The estimated costs of the proposed improvements is $357,000.

CALCULATIONS

In Phase 1 of the project, the dry ponds and outfall pipes were modeled hydraulically using the Interconnected Pond Routing program. Since the dry ponds in the Phase 2 project area were too small to provide effective attenuation, the predevelopment and post development runoff calculations were made using Hydraflow and the rational method. The only available storm drain pipe for Phase 2 was a 36” pipe in offsite Basin 4. The new piping along Oak Street was connected to the existing 36” pipe, and the piping downstream of the connection was upgraded to a 42” pipe. The pipes were designed for a 25 year storm. Basins 1,2, and 3 were a much longer distance from the outfall than Basin 4. As a result of different times of concentration, the peak flows from Basin 4 passed sooner than Basins 1,2, and 3, giving only a slight increase in peak discharge, despite adding 12.25 hectares to the area flowing to the existing outfall.

The potential for increased pollutant loadings in the canal system was a concern of local residents. These canals had a history of dredging operations every 8-10 years, and the residents did not want to increase the frequency of costly dredging. The main pollutants of concern leading to muck deposition in the canals were Total Suspended Solids (TSS), Total Nitrogen (TN), and Total Phosphorus (TP). Sediment build up at the end of the pipes was common. Nutrient loadings from grass clippings, leaves, and fertilizers leads to algae blooms and low dissolved oxygen in the canals, which in turn leads to muck build up from the eutrophication process. Most of the material dredged from residential canals is typically muck.

To address this concern, a pollutant loading analysis of the existing and proposed stormwater discharges was performed. In the existing conditions, the only stormwater treatment for the canal system was a baffle box along Cherry Street for offsite Basin 4 of 24.24 hectares. There were a total of 7 outfall pipes discharging into the canal system.

In the first phase of this project stormwater treatment was provided for 8.02 hectares of the school grounds with 3 dry detention ponds. The discharge from these ponds was to the Indian River, rather than the canal system, so these pollutant loads were not included in the pollutant load analysis for the canal outfall.

The existing pollutant load to the canal only came from the drainage Basins 4 and 5, totaling 31.2 hectares. The runoff from Oak Street did not drain to the canal in existing conditions, only in the post development conditions.

The strategy for the pollutant analysis was to calculate the pollutant loads in the existing conditions, and then calculate the pollutant loads after the new pipes were added to the system and offsite areas retrofitted for stormwater treatment. The pollutants used in this analysis were TSS, TP, and TN.

Each drainage basin was categorized by land use. Areal, annual, mass loading rates from "Stormwater Loading Rate Parameters for Central and South Florida", Harper, 1994, were multiplied by each basin's area to give existing and potential annual pollutant loadings. See Table 1.

The next step was to calculate the pollutant removal rates for the different BMPs. Individual BMP removal efficiencies were take from "A Guide for BMP Selection in Urban Developed Areas", EWRI, 2000. What was challenging with this analysis was the use of multiple BMPs in series for the treatment train. Each BMP receives cleaner and cleaner water as the water moves down the train. At each BMP, the removal efficiency for each constituent was multiplied by the remaining percentage of the initial loading to give a weighted, cumulative, removal efficiency for each constituent. See Table 2. These calculated removal efficiencies were then multiplied by the total calculated pollutant loads to give the reduced pollutant loadings after the BMPs were installed. See Table 3. Table 4 shows that the total loads to the canal were reduced as a result of the retrofitting of onsite and offsite basins.

The pollutant loading analysis below demonstrates that as a result of the numerous BMPs proposed, the total pollutant loadings entering the canals after project completion will actually be significantly reduced from the existing pollutant loadings entering the canals. The key to overall pollutant reduction is to provide additional treatment in offsite drainage basins. This will result in a net benefit of reduced pollutants entering the canals and a reduction of the severe flooding often seen along Oak Street.

Table 1
Existing Pollutant Loading

			Loading Rate* (kg/ac - year)			Potential Pollutant Loading (kg - year)		
Basin	**Area (acres)**	**Land Use**	**TSS**	**Total Phosphorus**	**Total Nitrogen**	**TSS**	**Total Phosphorus**	**Total Nitrogen**
2A	9.23	Recreational	7.6	0.046	1.07	70.15	0.425	9.876
2B	1.15	Recreational	7.6	0.046	1.07	8.74	0.053	1.231
2C	0.77	Recreational	7.6	0.046	1.07	5.85	0.035	0.824
2D	1.45	Recreational	7.6	0.046	1.07	11.02	0.067	1.552
2E	2.63	Recreational	7.6	0.046	1.07	19.99	0.121	2.814
2F	1.97	Recreational	7.6	0.046	1.07	14.97	0.091	2.108
2G	0.75	Recreational	7.6	0.046	1.07	5.70	0.035	0.803
2H	1.29	Recreational	7.6	0.046	1.07	9.80	0.059	1.380
2I	0.08	Recreational	7.6	0.046	1.07	0.61	0.004	0.086
2J	0.8	Recreational	7.6	0.046	1.07	6.08	0.037	0.856
2K	0.57	Recreational	7.6	0.046	1.07	4.33	0.026	0.610
2L	0.34	Recreational	7.6	0.046	1.07	2.58	0.016	0.364
3A	2.19	Single Family	56.1	0.594	4.68	122.86	1.301	10.249
3B	3.02	Single Family	56.1	0.594	4.68	169.42	1.794	14.134
3C	4.02	Low Intensity						
		Commercial	343	0.65	5.18	1378.86	2.613	20.824
Subtotal	**30.26**					**1830.97**	**6.68**	**67.71**
4**	59.9	Single Family	56.1	0.594	4.68	672.00	24.910	280.332
5A	5.9	Single Family	56.1	0.594	4.68	330.99	3.505	27.612
5B	8.62	Single Family	56.1	0.594	4.68	483.58	5.120	40.342
5C	2.68	Single Family	56.1	0.594	4.68	150.35	1.592	12.542
Subtotal	**77.1**					**1636.92**	**35.13**	**360.83**
Totals	**107.36**					**3467.89**	**41.80**	**428.54**

* From "Stormwater Loading Rate Parameters for Central and South Florida", 1994. Harper
** Basin 4 has an existing baffle box providing treatment.
Basins 4 and 5 are the existing pollutant loadings to the canals.

Table 2
BMP Pollutant Removals

BMP POLLUTANT REMOVAL TABLE*			
BMP	**BMP Removal Efficiency**		
Type	**(%)**		
	TSS	**TP**	**TN**
Dry Pond	85	61	91
Swale	80	45	25
Baffle Box	80	30	0
Inlet Trap (grated)	73**	79**	79**
Inlet Trap (curb)	2***	11***	10***
Swale + Inlet Trap (g) + Baffle Box	98.9	91.9	84.2
Dry Pond + Inlet Trap (g) + Baffle Box	99.2	94.3	98.1
Inlet Trap (c)+ Baffle Box	84	37.7	10
Inlet Trap (g)+ Baffle Box	81.1	85.3	79

Multiple BMP Pollutant Removal Calculations

Swale + Inlet Trap (g) + Baffle Box

TSS – 100x0.8 + (100-80)x0.73 + (100-80-14.6)x0.8 = 98.9% Removal
TP - 100x0.45 + (100-45)x.79 + (100-45-43.45) = 91.9% Removal
TN - 100x.25 + (100-25)x.79 = 84.2% Removal

Dry Pond + Inlet Trap (g) + Baffle Box

TSS – 100x0.85 + (100-85)x0.73 + (100-85-10.95)x0.8 = 99.2% Removal
TP - 100x0.61 + (100-61)x0.79 + (100-61-30.8)x.3 = 94.3**% Removal**
TN - 100x.91 + (100-91)x.79 = 98.1% Removal

Inlet Trap (c) + Baffle Box

TSS - 100-x0.2 + (100-20)x0.8 = 84% Removal
TP - 100x0.11 + (100-11)x.3= 37.7% Removal
TN - 100x.10 = 10% Removal

Inlet Trap (g) + Baffle Box

TSS - 100x0.73 + (100-73)x0.30 = **81.1% Removal**
TP - 100x0.79 + (100-79)x0.3 = **85.3% Removal**
TN - 100x.79 = **79% Removal**

All removal values are from "Guide For Best Management Practice
** From Creech Engineers study "Pollutant Removal Testing For a Suntree Technologies Grate Inlet Skimmer Box", 2001
***From visual observation by Brevard County staff

Table 3
Proposed Pollutant Loading

Basin	BMP Type	BMP Removal Efficiency From New BMPs (%)			Pollutant Load Reduction From BMPs (kg/year)			Proposed Pollutant Loading (kg/year)		
		TSS	TP	TN	TSS	TP	TN	TSS	TP	TN
2A	swale + inlet trap (g) + baffle box	98.9	91.9	84.2	69.38	0.39	8.32	0.77	0.03	1.56
2B	swale+ inlet trap (g) + baffle box	98.9	91.9	84.2	8.64	0.05	1.04	0.10	0.00	0.19
2C	dry pond + inlet trap (g) + baffle box	99.2	94.3	98.1	5.81	0.03	0.81	0.05	0.00	0.02
2D	dry pond + inlet trap (g) + baffle box	99.2	94.3	98.1	10.93	0.06	1.52	0.09	0.00	0.03
2E	dry pond + inlet trap (g) + baffle box	99.2	94.3	98.1	19.83	0.11	2.76	0.16	0.01	0.05
2F	swale + inlet trap (g) + baffle box	98.9	91.9	84.2	14.81	0.08	1.77	0.16	0.01	0.33
2G	dry pond + inlet trap (g) + baffle box	99.2	94.3	98.1	5.65	0.03	0.79	0.05	0.00	0.02
2H	dry pond + inlet trap (g) + baffle box	99.2	94.3	98.1	9.73	0.06	1.35	0.08	0.00	0.03
2I	swale + inlet trap (g) + baffle box	98.9	91.9	84.2	0.60	0.00	0.07	0.01	0.00	0.01
2J	inlet trap (g) + baffle box	81.1	85.3	79	4.93	0.03	0.68	1.15	0.01	0.18
2K	inlet trap (g) + baffle box	81.1	85.3	79	3.51	0.02	0.48	0.82	0.00	0.13
2L	inlet trap (g) + baffle box	81.1	85.3	79	2.10	0.01	0.29	0.49	0.00	0.08
3A	inlet trap (g) + baffle box	81.1	85.3	79	99.64	1.11	8.10	23.22	0.19	2.15
3B	inlet trap (g) + baffle box	81.1	85.3	79	137.40	1.53	11.17	32.02	0.26	2.97
3C	dry pond + inlet trap (g) + baffle box	99.2	94.3	98.1	1367.83	2.46	20.43	11.03	0.15	0.40
4	inlet trap (g) + baffle box	81.1	85.3	79	544.99	21.25	221.46	127.01	3.66	58.87
5A	inlet trap (c) + baffle box	84	37	10	278.03	1.30	2.76	52.96	2.21	24.85
5B	inlet trap (c) + baffle box	84	37	10	406.21	1.89	4.03	77.37	3.23	36.31
5C	inlet trap (c) + baffle box	84	37	10	126.29	0.59	1.25	24.06	1.00	11.29
			Total		**2305.77**	**27.24**	**281.03**	**197.19**	**4.34**	**67.01**

Table 4
Net Pollutant Removals

	TSS (kg/yr)	TP (kg/yr)	TN(kg/yr)
Predevelopment	3015.78	35.13	380.83
Postdevelopment	630.97	21.95	289.15
Net Reduction	2384.81 (79%)	13.18 (37.52%)	91.68 (24.07%)

SUMMARY

The days of solving flooding problems in communities with simple ditch and pipe solutions have disappeared. Environmental concerns now dictate that stormwater treatment techniques be integrated into these flood relief projects. By adding water quality components to water quantity projects, communities can help achieve pollution remediation goals being established for NPDES, TMDL, and PLRG programs.

Retrofitting existing stormwater systems to provide water quality treatment is more complicated, expensive, and time consuming than traditional stormwater designs for new development. The scarcity of available land and numerous existing utilities in older built out areas will tax an engineer's imagination to provide innovative BMPs in these locations. A carefully planned treatment train was designed consisting of swales, ponds, berms, baffle boxes, and inlet traps to provide overall stormwater pollution reduction.

In order to address stormwater pollution concerns, treatment mitigation was designed in offsite drainage basins. The pollutant loadings and removals were calculated using a simple but effective spreadsheet analysis incorporating the latest in BMP efficiency studies. While complicated stormwater modeling software can be used for pollutant analysis, this type of modeling is more cost effective on large basin studies than small basins and individual projects. The pollutant removal calculations showed an annual net reduction of 79% for TSS, 37% for Total Phosphorus, and 24% for Total Nitrogen in the Oak Street basin despite the creation of a new stormdrain system for a landlocked area.

As this project demonstrates, there are typically numerous stakeholders that need to be brought into the project early in the process and kept in the process throughout the life of the project. Many meetings were held with city, county, and state officials, homeowners associations, schools, soccer clubs, churches, and utility companies. All it takes is one uncooperative stakeholder to set back or kill a project, as was demonstrated with the church backing out of the land acquisition process after many verbal indications of approval. Using creative partnerships with other entities and agencies allowed the development of a unique strategy to solve flooding at several locations in the project area.

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CHURCH
PLAY FIELD
PARKING
BALLFIELD
COURT
SOCCER
LEGEND:
PROPOSED CURB INLET TRAP LOCATIONS
BAFFLE BOX LOCATIONS
PROPOSED GRATE INLET TRAP LOCATIONS
PROPOSED SWALE
CREECH ENGINEERS, INC.
CIVILIZATION ENGINEERED
203 WEST 3rd STREET STUART, FLORIDA 34994 (561) 283-1413
4450 WEST EAU GALLIE BLVD. MELBOURNE, FL 32934 (321) 255-5434
707 EAST PARK AVENUE TALLAHASSEE, FL 32301 (850) 841-1705
OAK STREET
PROPOSED IMPROVEMENTS

Exhibit 1

LOW IMPACT DEVELOPMENT RETROFIT APPROACH FOR URBAN AREAS

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ABSTRACT

The use of Low Impact Development (LID) as a primary stormwater management strategy is gaining momentum throughout the United States as an alternative to conventional approaches. Communities and institutions are recognizing the inability of many traditional management strategies to meet new regulatory initiatives and community resource protection goals. They are also realizing the extensive costs of maintaining centralized end-of-pipe systems. LID is still a relatively new approach, but has been shown to have tremendous potential for use in the retrofit of urban areas for targeted management goals and objectives. This paper will explore some of the key management and implementation issues that many communities will face when applying the use of LID in perhaps the greatest challenge for watershed managers, urban retrofits. The findings and conclusions of this paper are based on the design, construction, and monitoring of pilot projects that the LID Center has been involved in during the last several years.

INTRODUCTION

Urban ecosystem restoration is a tremendously challenging and complex process. Local governments are not only faced with meeting regulatory requirements such as National Pollutant Discharge Elimination System (NPDES), Total Maximum Daily Load (TMDL), and Combined Sewer Overflow (CSO) programs but must focus on overall community water resource objectives, such as Environmental Justice or preservation and restoration of aquatic habitats. Traditional end-of-pipe solutions to urban retrofits have shown limitations due to the intensive capitalization of improvements, large-scale disruptions to communities, and area requirements that often compete with valuable and irreplaceable open space. Many of these "engineered" approaches are based only on peak flow control or reduction of chemical pollutants found in stormwater and are not designed to address the multi-functional approach that is required to protect the ecosystem functions of the receiving waters.

LID is a promising new approach to the management and restoration of urban ecosystems that utilizes a combination of conservation practices, precision engineering, and micro-scale distributed source control Integrated Management Practices (IMPs) (Prince Georges County, 1997). The objective of this approach is to use these design strategies and techniques to maintain or restore the hydrologic function of every development site in the watershed or to develop a "customized" design that addresses specific targeted watershed goals. The design foundation of IMPs is that they can be integrated into any part of the built environment and landscape. This includes buildings, roads, lawns, walks, parking areas, roofs, and gutters. The number, type, configuration, and appearance of practices are limitless. For example, a few years ago there were only a few manufacturers of permeable pavement systems. The demand for this product as a stormwater control has resulted in the development of many types of pavement systems such as plastic grids, concrete blocks, and even wire mesh. This approach presents an opportunity to move from large-scale centralized projects that can only be funded by Capital Improvement Programs because of cost considerations to controls that can be funded as part of private construction, infrastructure rehabilitation, or maintenance. This new paradigm in stormwater management presents opportunities as well as challenges for design and management of aquatic resource protection programs.

The use of microscale and decentralized controls as alternatives for end-of-pipe controls has been used successfully in other countries to meet a wide range of resource protection goals, including reduction of runoff volume and filtering of pollutants (Fujita, et.al., 1990). However. the study and use of distributed controls has been limited in this country, especially for urban retrofits. The potential and the foundation for the large scale use and funding of innovative controls in urban systems has been explored and in many cases justified (Heaney, et. Al. 1999). A number of communities, such as Portland, Oregon and Seattle, Washington, are conducting large-scale pilot projects for building roof design and street reconstruction. Institutions such as the federal facilities in the Chesapeake Bay have entered into an agreement to promote and incorporate LID into their stormwater programs. The success of these pilot projects has generated a tremendous amount of interest and support for the technologies. Water resource managers, planners and engineers, politicians, stakeholders, businesses, citizens, and property owners are demanding more information about the potential use of LID as an alternative to conventional approaches. Some of the key issues are:

Watershed Modeling: There are numerous methods and techniques to model rainfall and runoff relationships in urban watersheds. Many of these models, such as HEC-HMS, TR-20, or TR-55 are based on flood control technology and evaluate only peak flows from discrete events. Other models such as BASINS or HSPF are designed to model water quality. There are currently no widely available models that can evaluate the complex relationships of energy, nutrients, structure, and hydrology that are required to maintain or restore the delicate balance of biological integrity of urban streams and aquatic resources. There have been some successful studies that have used existing modeling tools to compare the costs and benefits of using targeted micro-scale controls instead of centralized improvements (Hoffman, 2000). EPA is also modifying SWMM to evaluate distributed micro-scale controls. This effort will include optimization routines to determine the most cost efficient and environmentally effective combination of controls (Heaney and Huber, 2002). The MUSIC model from Monash University also is designed to evaluate micro-scale controls (Wong, 2001). These are continuous models, which will give a much more comprehensive evaluation of the hydrologic and hydraulic response of the watershed. The modeling of micro-scale and distributed controls is, at the present time, a much more labor intensive effort than "lumped" approaches that aggregate individual sites or land uses into sub-basins. These sub-basins may be defined by convenience for modeling rather than hydrologic function. Advances in automation from technologies such as GIS and Remote Sensing will help reduce modeling time and give a much more accurate picture of the hydrologic and hydraulic response of the watershed. These are still first generation models for the evaluation of micro-scale practices and there is a tremendous amount of investment in time and resources that will be required for us to understand, as well as adequately and honestly predict the impacts of conventional and micro-scale management approaches.

Costs and Funding: Traditionally stormwater improvements are done as part of Capitol Improvement Projects or are required as part of development projects. LID offers tremendous new funding opportunities for stormwater management. For example, LID practices can be incorporated into streetscapes and tree planting areas. The District of Columbia has initiated some pilot projects using LID as part of several street reconstruction projects. Instead of using traditional water quality inlets, the landscape can be used to filter, detain and/or infiltrate runoff. The Bayscapes program that is run by the USFWS in the Chesapeake Bay region provides incentives and education for homeowners to privately construct bioretention cells, or rain gardens. Developers can utilize green roofs to filter airborne pollutants, absorb and filter rainfall, and detain stormwater as well as provide energy benefits and longer roof life. Permeable pavements can be used during repaving projects in parking lots. Soils amendments and aeration, designed to increase permeability and the filtering capacity of soils, could be done as part of routine landscape maintenance. This new approach presents many opportunities for construction but will require a shift in the way that we will approach the initial cost and funding of stormwater improvements. Because controls may be integrated into the streetscape, landscape, or building, the marginal cost of the controls may not be able to be directly separated for traditional cost analysis methods. Instead, LID leverages the basic funding and mobilization that is included in the other projects to construct water quality improvements.

Predictability of Implementation: The opportunity in LID to use multiple programs and methods to improve water quality and, in many instances, the dependence on individual property owners to construct improvements creates many more possibilities for the timing and implementation of watershed improvements to meet regulatory and resource protection goals. Because of the tremendous amount of reinvestment in urban infrastructure for street reconstruction, housing redevelopment, and urban revitalization, there exists the potential to integrate these controls into construction efforts. Many municipalities are moving towards user fees or taxing districts to pay for the reconstruction of drainage improvements and water resource restoration. When properties are slated for revitalization or rehabilitation, owners could incorporate LID controls into the building or landscape and receive credits or reduction in fees. This approach will allow for specific areas to be targeted or slated for improvements. The alternative of using one or two centralized systems, such as ponds or tunnels, is not feasible for many communities. For example, Reston, Virginia is an entirely developed community. The streams are extremely degraded, despite having well-established and extensive wooded buffers. The degradation, which includes entrenchment and high sediment loads that limit biodiversity, is a result of impervious areas directly connected to the channels through pipe outfalls and frequent discharges from the regional stormwater ponds. Because of limited funding and lack of space for large-scale end of pipe controls, the community is requiring LID to be used for redevelopment projects as part of its covenants and they are disconnecting and dissipating the energy from the storm drains as the budget permits (GKY, 2002). This is an excellent example of how a community can use a combination of private and public funds and still make significant progress towards meeting watershed restoration and protection goals.

Maintenance: The costs and effectiveness of maintenance programs for stormwater structures are potentially two of the most misunderstood and poorly implemented aspects of water resource management. The Office of Management and Budget has estimated that the cost of maintenance of stormwater structures is almost equal to that of the construction of new facilities. This relationship is not reflected in most urban stormwater management budgets. In many urban communities the costs of ponds, pipes, and other structures is borne by the general public and the structures are maintained by public works departments. Some communities have relied on homeowners associations to maintain the infrastructure in individual developments and then have had to take over the facilities because of the extensive costs for proper maintenance or due to poor maintenance performance by the citizens groups. Failures of centralized controls, such as ponds or tunnels, due to poor construction, poor predictions of effectiveness, or catastrophic events have also occurred. The large direct costs of maintaining centralized controls are rapidly becoming more apparent. On the other hand, the use of multiple and redundant decentralized controls offers several advantages. First, if some of the controls in the subbasin are not as effective or efficient as projected or are not properly maintained, there will still be substantial control and treatment from the remainder of the practices. Many of the practices, such as bioretention, are for the most part, landscape practices that are relatively simple to maintain. These are unlike many urban controls, such as sand filters, which require specialized safety and technical training to inspect and maintain. Although the data on the long-term effectiveness of these practices is limited, the prediction of pollutant treatment over the long-term is substantial (Davis, 2000). Communities such as Davis, California, have also had long-term success with the maintenance and upkeep of these practices (Corbett, 1999).

The LID Center has been involved in several studies and pilot projects in the Metropolitan Washington, D.C. area that can provide a more in-depth understanding of these issues. The Center conducted a study as part of a report for USEPA (LID Center, 2002) to determine the potential of using LID for urban retrofits for the control of CSOs. LID Retrofit designs were produced for several different land use types and then modeled using the actual hydrologic conditions for each study area and conventional models. Even with the limitations of the conventional models, the results showed the potential for dramatic improvements to the reduction of volume and treatment of non-point source pollutants.

The first substantial pilot construction project was at the Washington Navy Yard. The site is almost entirely impervious and there is an extensive network of underground utilities. Parking and open space at the facility is at a premium, with only one space per three employees. Replacement of parking spaces or open space was prohibited in the design. An in-depth analysis of utility records, interviews with maintenance personnel, and on-site investigations was conducted in order to understand the nuisances of the drainage network, pollutant loads, and potential utility conflicts. This additional effort was extremely valuable as field modifications were required for several of the projects due to utility conflicts. The construction of these facilities has been done as routine maintenance or as part of other construction project. Permeable pavers were installed as part of a pavement reconstruction project for a parking lot. Minor changes to the grade were required to direct the flow to the pavers, which then discharge to the existing drainage system. Mapping in many older urban areas is insufficient or incomplete. Therefore, flexibility in design and on-site observation were critical to this project. Figure One shows a Filterra ™ street tree filter that was installed to treat water quality for approximately 0.2 hectares (½ acre) of roadway. An unmapped gas line was discovered during construction and the structure had to be relocated and modified to avoid conflicts.

Figure One: Filterra™ Street Tree Filter

A second pilot project was that of The Southeast Federal Center, managed by the General Services Administration (GSA) and one of the last large major undeveloped tracts of land in Washington. As part of the reconstruction of the seawall along the Anacostia River, the GSA was required by the local regulatory agency to construct an extensive series of sand filters and storm drainage structures. The overall master plan for the property had not yet been completed, and GSA did not want to construct extensive infrastructure, which might dictate future land use decisions. However, they did want to provide water quality improvements for the property, which is approximately 24.3 hectares (60 acres) of highly impervious area. The Center designed an interim bioretention filter strip that runs parallel with the seawall and will treat a large percentage of the non-point source runoff. This allows for an inexpensive and effective treatment method that meets regulatory requirements and allows for future development flexibility. The cost savings for this approach were approximately $250,000.

The Center is also conducting a series of pilot projects with the University of Maryland for the Maryland State Highway Administration to determine the effectiveness of practices at improving water quality in urban areas. This includes extensive pre-construction monitoring, development of new standards and specifications, and reconstruction and rehabilitation of some existing facilities to determine life cycle costs of improvements. This program is focusing on the potential to improve water quality using linear construction programs in impaired watersheds that have regulatory restrictions for development. This year, Howard University will also begin an extensive monitoring program to determine the effectiveness of many of these practices.

All of these projects have been extremely successful at generating interest and activity in the development of LID approaches and technologies in the Anacostia Watershed. Citizens groups, government agencies, stakeholders, and private property owners under many different funding mechanisms are conducting these projects. LID is a new approach to stormwater management that is based on the oldest and soundest requirement to protect and restore the biological and habitat integrity of watersheds. LID has the very clear and straightforward objective of providing communities fiscally responsible and sustainable strategies and tools that can protect or restore natural watershed functions. Even though other countries and regions have used these approaches successfully, we must develop this approach to meet the specific requirements and objectives of our communities. Many communities are already adopting this approach because of its flexibility and the number of options to modify the built environment, infrastructure, and landscape, as well as the potential to involve all the stakeholders in improving water quality. One of the concerns that watershed managers may have is the complexity and amount of knowledge required to design and review LID projects. Several existing large urban programs, such as Prince George's County, Maryland, have shown leadership in modifying existing programs to incorporate this approach. The science of stormwater management is still very young and we are far from solving all the puzzles. There is still a tremendous amount of work that needs to be done, including basic research, pilot projects, and long-term evaluation of effectiveness, not only for LID but also for conventional approaches. The flexibility, adaptability, and number of choices makes LID the ideal tool to address the complex and changing requirements of ecosystem protection as we begin to better understand the relationship between urbanization and water resources.

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PINELLAS COUNTY'S TEAM APPROACH TO STORMWATER OUTREACH

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ABSTRACT

In the early 1990s Pinellas County started a Countywide Watershed Management Program, under which many educational components were required. In 1993, the National Pollutant Discharge Elimination System (NPDES) permit application process reinforced the need for non-point source pollution education. Since then, stormwater education has been a primary concern and is addressed by all parties involved with NPDES in our County. We are constantly working on improving existing programs and striving to create new ones. This has helped us maintain a good working relationship between all key players.

INTRODUCTION

Pinellas County forms a peninsula on the West Coast of Florida (Figure 1). It is bordered to the east by Tampa Bay and to the west by the Gulf of Mexico. Given that Pinellas County is almost entirely surrounded by marine waters, and numerous water bodies can be found within its limits, the State of Florida designated Pinellas County waters an Aquatic Preserve in 1972.

Pinellas County is heavily populated. There are 24 municipalities within its limits, and a population of 921,482 resides on only 280 square miles (density= 3291 avg. pop. per square mile). This is comparable in density to cities such as Houston, Dallas, or San Diego ("State and County Quick Facts," 2002). The highly urbanized nature of Pinellas County further heightens the importance of non-point source pollution education.

Regional and State agencies involved with stormwater issues that have been working closely with Pinellas County include: the Florida Department of Environmental Protection, which is the N.P.D.E.S. permitting authority; the Florida Department of Transportation District 7, one of our co-permittees; and the Southwest Florida Water Management District.

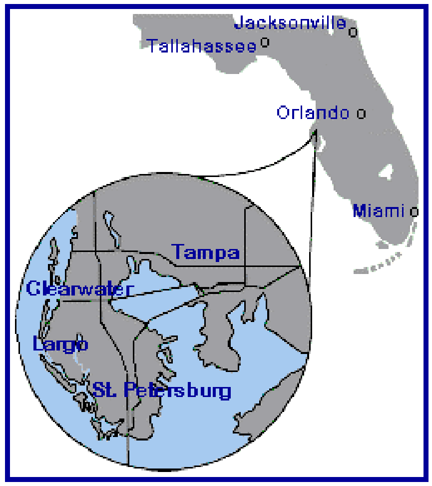

Figure 1. Florida Map – Location of Pinellas County

A chronology of how the County stormwater education program developed is summarized below:

- 1992-1993: Pinellas County and 23 of its municipalities join forces to apply for an NPDES permit.
- 1995: Beginning of stormdrain marking program
- 1995-1996: production of stormwater videos
- 1997: NPDES permit active Nov. 1st
- 1998: Stormwater mascot comes to life. Began distribution on brochures and coloring books
- 1999: Illicit discharge training is implemented

PINELLAS COUNTY STORMWATER EDUCATION PROGRAM COMPONENTS

1. **“Stormwater Run-off…A mixed blessing”:** This video was produced specifically to target citizens. It provides background information about stormwater run-off as well as a list of helpful tips to minimize impact on local water bodies. It is a 25-minute video featuring a local prominent news anchor and produced by a reputable Emmy-winning company. The Southwest Florida Water Management District provided partial funding for the project. The video was aired on NBC Broadcast Channel 8 and is currently broadcasted on our Government Access Channel at least three to four times a week, with a more frequent airing schedule during the rainy season.

2. **M. Phibian:** This is a cartoon character that was designed originally for the label on the video cover. He soon became our Stormwater mascot. A life-size M. Phibian costume was also purchased for public appearances at schools and fairs. He became so popular among staff that he was incorporated into our brochures and coloring books. These materials are simple and easy to read, with numerous pictures (Figure 2). The materials

highlight things to avoid and tell citizens what they can do to help keep stormwater runoff free of contaminants. They also provide useful contact information so citizens know who they should call for more information or to report an illicit discharge.

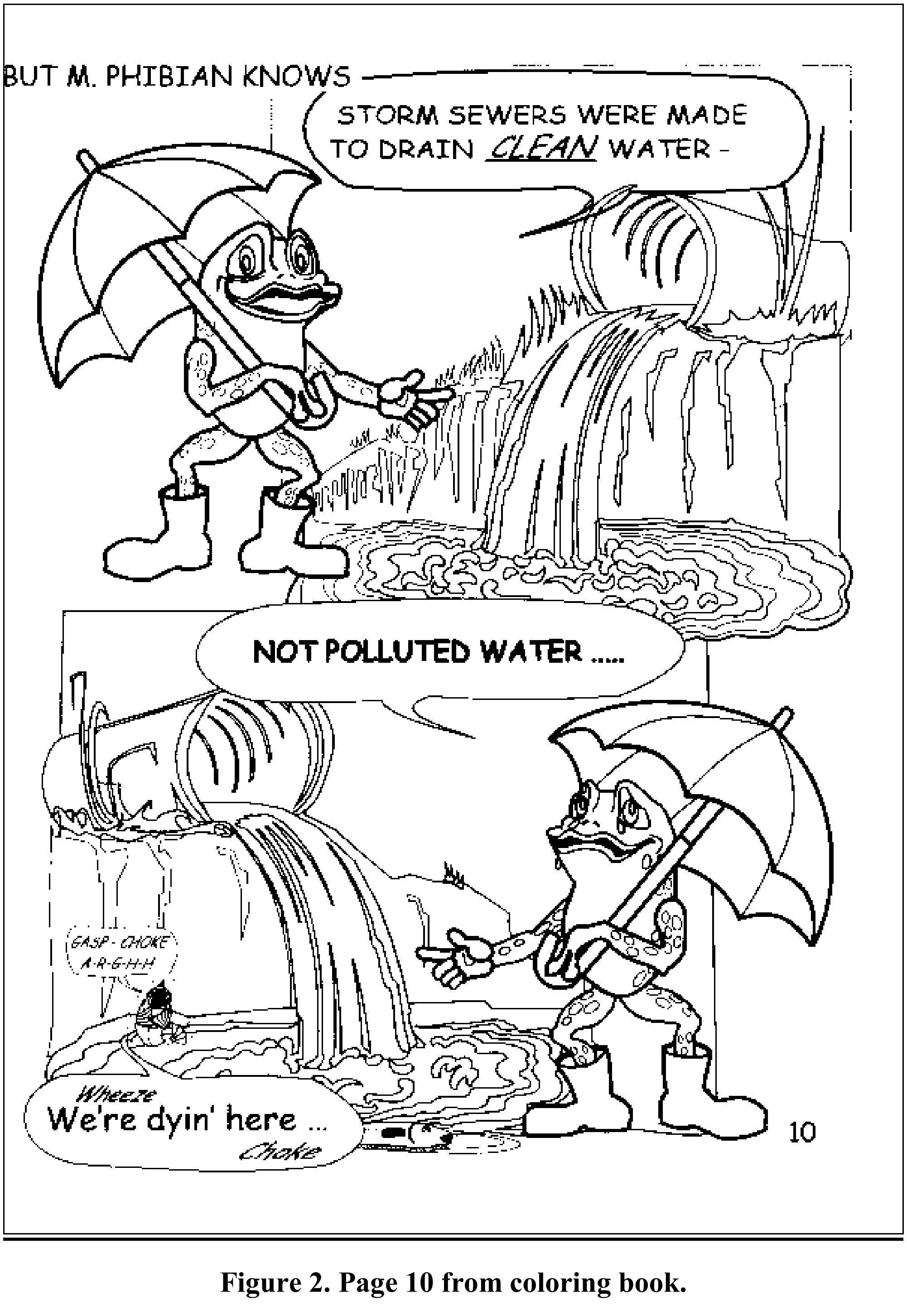

Figure 2. Page 10 from coloring book.

3. **Stormdrain Marking**: In 1995, Pinellas County Environmental Management initiated a stormdrain-stenciling program. After a couple of years, it was realized that the paint was not only washing off down the drains, but had faded greatly. In 1997, the painting of stormdrains was stopped. Since then, aluminum stormdrain plaques have been glued onto the stormdrain structures. Through state grants, a local committee of stormwater educators provides plaques to agencies within the entire Tampa Bay area. Stormdrain marking events are advertised in local newsletters as well as our own publications. Public response has been excellent. Each event not only serves to educate the volunteer participants, but also educates homeowners in the areas being marked. To date, over 200 volunteers have marked more than 2000 stormdrains in Pinellas County. A GIS map of all marked stormdrains in the County is being produced.

4. **Stormwater Watchline**: Pinellas County Department of Environmental Management set up a local voice-mail box designed to receive citizens' complaints on stormwater related issues. The number is published in the phone book, listed on all our publications, and advertised on our government access channel. About five calls per week pertain to potential illicit discharge violations. Each complaint is promptly investigated and documented.

5. **"On the Look-out"**: An Illicit Discharge Training course has been made available to city and County field employees. Along with the "Mixed Blessings" video for the general public, Pinellas County also created "On the Look-Out," a video designed specifically as a visual aid for that training course. The video is used in conjunction with a written manual to teach employees how to recognize illicit discharges to our storm sewer system. Like "Mixed Blessings," the "On the Lookout" video provides general background information, but also includes safety precautions, discharge reporting procedures, and contact phone numbers. To date, over 300 employees have been trained with future plans to periodically rotate staff through the training course. In the past few years, this training has proven to be effective; field staff can often spot violations in areas that would not normally be visible to the general public. The number of confirmed illicit discharges identified by field staff has increased significantly in the past two years.

EVALUATION

The stormwater education program has proven to be effective. The materials are widely distributed and positive feedback from many users across the state and beyond has been received. The videos are shown on a regular basis and the use of a celebrity narrator has also made a positive impact on viewers. Illicit Discharge Training for staff has almost become a requirement for new County and municipal field employees; supervisors are eager to get their staff trained. This has helped increase the number of illicit discharges identified with no workload increase to County environmental staff. Consequently, staff can devote more time to enforcement alternatives as opposed to time-consuming field screening excursions that have historically been ineffective in detecting such discharges.

Obstacles, however, have been encountered along the way. Some of the funding issues for the videos were tough. For example, funding was often tied to cooperative agency final product requirements that were not necessarily in agreement with the County's original intent. Furthermore, when stenciling was determined to be environmentally unfriendly, the switch was made to using aluminum stormdrain plaques. Another disappointment came when we realized that some of the original stormdrain plaques were too attractive and were subsequently stolen. Finally, it is hoped that the number of Stormwater Watchline calls continues to increase. The frequency of valid calls received has been low, and we are hoping that continued and expanded public outreach initiatives will result in improved public input through the Watchline.

CONCLUSION

Since issuance of our NPDES permit, Pinellas County and its municipalities have maintained excellent communication. A Lead Team composed of members of each involved department in the County (Public Works, Environmental Management, Planning, etc…) was assembled. The Lead Team meets regularly with the cities' representatives to ensure permit requirements are met, and to address ongoing stormwater issues. Recently, Illicit Discharge Training, Integrated Pest Management Training and Sediment and Erosion Control Training have been implemented and offered to selected staff. This has created a unique and positive working relationship between county, city and other agencies.

In conclusion, Pinellas County and its co-permittees have established an effective and well-rounded non-point source education program. A wide cross-section of the population has been targeted with plans to expand the geographical reach. Public service announcements to be aired over the entire Tampa Bay region are being developed in a joint effort by local governments to further spread the word about stormwater pollution prevention.

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IMPROVING PUBLIC PARTICIPATION IN WATER RESOURCE MANAGEMENT AND SERVING REAL-TIME DATA TO MANAGEMENT PROFESSIONALS: WATERATLAS.ORG

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ABSTRACT

A key component of improving public participation in the water resource management process in Florida is providing local stakeholders with user-friendly access to quality assured data. Unfortunately, water resource data are often dispersed between multiple agencies, in proprietary databases, incompatible formats, and almost never easily accessible or understandable by stakeholders. The net result is often a duplication of sampling effort among agencies and a lack of awareness and support from the local citizenry for restoration and watershed management related efforts. In an effort to solve this problem, the University of South Florida, in conjunction with several government agencies within Florida, have developed an online Watershed Atlas that provides timely data from many sources in a citizen-friendly web application. Three counties in Central Florida (Hillsborough, Polk, and Seminole) have implemented the system and development of the system is currently taking place in Lake County and a portion of the Southwest Florida Water Management District.

This paper serves to document the development and functionality of the Watershed Atlas and assess how well it is meeting the needs of its users. Preliminary results of this work indicate the Atlas is extremely effective and enhances communication between agencies and citizens, fosters use of quality assured data in decision-making, and increases interest in volunteer monitoring programs.

INTRODUCTION

According to the Florida Department of Environmental Protection, Florida has over 50,000 miles of rivers and streams, 7800 lakes, and 4000 square miles of estuaries (see http://www.dep.state.fl.us/water/surfacewater/index.htm). Under the federal Clean Water Act, state and local governments are responsible for establishing water quality standards and for monitoring water bodies to ensure compliance with these standards. Water quantity issues such as potable water supply, minimum flows and levels, and public safety related flooding concerns also require regulatory standards and extensive monitoring efforts. Unfortunately, the data concerning these resources are collected by widely disparate agencies at varying levels of federal, state, and local government. The result for an environmental professional working on these resources is often a costly data search and time intensive conversion process. For citizens and other less savvy stakeholders, access to quality-assured data along with interpretative educational materials are simply not available.

The need to establish a system that would bring together scientific data, educational information, and geographic information systems (GIS) maps related to water resources is not new to the environmental management community. Unfortunately, this need has gone largely unmet in Florida and throughout the United States. At the same time, the United States Environmental Protection Agency (US EPA) found through a telephone survey that, in general, people want more information about their community (Flynn 2000). While several attempts have been made to create tools to facilitate data sharing, these tools are often narrow in scope and not designed to provide information in an easily accessible and understandable format for citizens. For example, the EPA STORET website provides access to water quality data contained with the STORET database but interpretation of these data is left to users of the system (see http://www.epa.gov/storet/index.html). In an effort to solve this problem, the University of South Florida, in conjunction with several government agencies within Florida, have developed an online Watershed Atlas that serves timely data from many sources in a citizen-friendly application. Currently, the application is only available in three counties in Florida (Hillsborough, Polk, and Seminole). This paper will serve to document the development of the Atlas project, provide an overview of the functionality, and assess the benefits derived from the program.

Development Methods

Research on the Atlas began in 1998 with the development of the Hillsborough County Lake Atlas. The Hillsborough Lake Atlas was developed as a static html-based website populated with data from a simple MS Access database. With the availability of improved technology the Atlas was revised for Seminole County using entirely database-driven technology and ArcIMS mapping. Since that time, the same technology has been used to develop an Atlas for Polk County and additional projects are underway with the Southwest Florida Water Management District and Lake County. The Atlas projects were developed in four major phases following the typical systems development life cycle: analysis, design, implementation, and maintenance.

ANALYSIS

The analysis phase of Atlas development was research intensive and required significant stakeholder involvement. To facilitate intergovernmental coordination an advisory committee was formed. Each Advisory Committee consisted of citizens, environmental management professionals, data providers, and other stakeholders. The advisory committee helped to identify data providers, provide input on data presentation, and ensured cooperation with the agencies they represented. Data sources were catalogued, and prioritized for inclusion on the Atlas. Table 1 provides a partial listing of data providers, type, and frequency.

Once the data sets were prioritized, protocols and procedures were developed for data transfer between the host agencies and the University of South Florida. It was important to work with each data provider to determine the best method *for them* to provide timely quality assured data to the Atlas. Since much of the water resource information included on the Atlas is only valuable if provided on a timely basis, protocols for data transfer focused on methods to transform original data formats to a format compatible with the Atlas database.

Table 1. Partial list of organizations currently providing data for inclusion on the one of more Atlas projects, and a total number of samples and sample sites categorized by data type.

Data Provider	Update Frequency	Data Type			
		Water Quality	Levels and Flows	Rainfall	Ecology
City of Casselberry	Annually	YES	NO	NO	NO
Environmental Protection Commission of Hillsborough County	Quarterly	YES	NO	NO	NO
Florida Department of Environmental Protection	Annually	YES	NO	NO	YES
Florida Fish and Wildlife Conservation Commission	Annually	NO	NO	NO	YES
City of Lakeland	Monthly	YES	NO	NO	NO
LAKEWATCH	Semiannually	YES	NO	NO	NO
Legacy STORET	One-time	YES	NO	NO	NO
Pinellas County Department of Environmental Management	Quarterly	YES	NO	NO	NO
Polk County Natural Resource Department	Monthly	YES	NO	NO	NO
Seminole County Dept. of Public Works	Daily-Quarterly	YES	YES	NO	NO
Seminole County Watershed Action Volunteers	Quarterly	YES	NO	NO	NO
Southwest Florida Water Management District	Daily-Quarterly	YES	YES	YES	NO
St Johns River Water Management District	Quarterly	YES	YES	NO	NO
Stream WATERWATCH	Monthly	YES	NO	NO	NO
United States Geologic Society	Daily	YES	YES	YES	NO
Volusia County	Monthly	YES	NO	NO	NO
Total Samples		50,087	1,287,273	1,112,973	20,572
Total Sampling Sites		1,592	735	296	85

An important component of the Atlas was to spatially enable all of the data so that it could be tied to a specific geographic feature such as a watershed, lake, river, or even a particular river segment. To accomplish this, a comprehensive hydrographic GIS data layer was developed based on the National Hydrography Dataset (NHD). The NHD is a feature-based database that interconnects and uniquely identifies the stream segments and waterbodies that comprise the nation's surface water drainage system. It is based initially on the content of the USGS 1:100,000 scale Digital Line Graph (DLG) hydrography data, integrated with reach-related information from the EPA's Reach File Version 3.0 (RF3). While the NHD is the principal data source for hydrography, due to its scale limitation it is not the only source of hydrography data; local datasets are also used and integrated. Once the hydrographic layer is complete, a comprehensive sample location data layer was also created using location information provided by each data provider. Sample site locations from multiple agencies were compiled into a comprehensive layer, and tagged to identify the appropriate waterbody or river segment (from the hydrography layer) that is sampled by the station. Due to the variation in method used to collect geographic coordinates by source agencies, these locations are often found to be inaccurate when overlaid on the hydrography base map. A quality control procedure was developed to assign these wayward sample sites to the appropriate water resource. The end result of these GIS efforts was to create a sample location dataset that was linked to a hydrographic base layer.

To deliver these relatively complex data to both citizens and scientists, a web application was required that allowed browsing of spatial data such as aerial photographs, location of water resources, watershed delineations, and other important GIS datasets such as land use. In addition, key environmental and social data would need to be integrated with ample educational materials. From these parameters and from specific input from the various advisory committees on valid measures and benchmarks, the specifications for the web application were developed. The Atlas web interface would need to be fast, reliable, and widely available to users that might have access to the Internet using only a dialup modem. Therefore, the principles of "thin-client" design and browser independent technology were required.

System Design and Implementation

The overall system architecture of the Atlas is shown in Figure 1. Data providers and stakeholders provide both geographic and parametric datasets, as well as educational and other documents. These data are loaded into the Water Resources Atlas Database (W-RAD) using secure online data entry tools, via manual database load procedures, or using scheduled automated data load applications developed for the Atlas. The web application uses ESRI Internet Map Server (ArcIMS) technology and Microsoft's Active Server Page technology (ASP) to serve the quality-assured data to the citizens through a user-friendly interface.

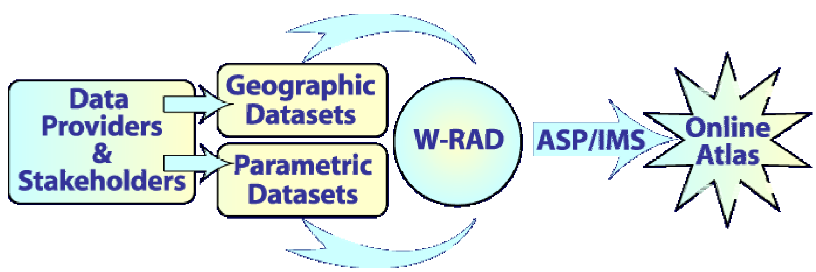

Figure 1. Illustration of overall system architecture.

The Water Resource Atlas Database (W-RAD) was designed as a data warehouse for sample data originating from many separate data providers and sampling programs. Because each data provider used different data management systems, the W-RAD was designed with data load tools customized for each source dataset. Each of these data load tools was programmed to automatically import source data, appropriately transform parameters to common units (e.g. milligrams per liter), perform quality control to remove inaccurate records, and store each dataset in a separate data table specific to the source. Equally important, the data load tools assigned the correct waterbody identifier to each record based upon the previously mentioned sample site GIS layer. In addition to parametric datasets stored in the W-RAD, a document catalog was developed to store all educational information according to subject, watershed, and waterbody where appropriate. All educational, management, and research oriented documents and resources (e.g., outside links) are stored within the database to eliminate the need to maintain static html-based web pages.

Microsoft's Active Server Page technology was chosen as the design platform because of the ability to support server-side scripting, the relative low software and hardware costs, and because of the availability of affordable skilled ASP programmers. In addition to using ASP programming for most of the Atlas website, WebCharts 3D was used as the server-side graphing tool to provide real-time graphs on the Atlas, and the ActiveX connector for ESRI ArcIMS was used to provide all online GIS services. To optimize performance of the application, server functionality was separated between GIS map services, web services, and database services. Optimal hardware required to support the application was based on staff experience and advice from ESRI staff as well as recommendations from existing ArcIMS users, and estimates of site usage. The Atlas is currently implemented on Microsoft Windows 2000 Servers using Internet Information Server, ArcIMS 3.1, Microsoft SQL Server 2000 and ArcSDE 8.1, all running on Dell Poweredge servers.

Maintenance

The system architecture of the Atlas was designed to minimize maintenance, however, since the project serves as a comprehensive data store for many diverse types of data and educational materials maintenance is required for the long-term success of the project. Maintenance of each Atlas website involves updates to data and educational materials, hosting the website and managing all servers and software, and upgrading the application when necessary. As part of our educational mission, the decision was made to maintain the Atlas at the University of South Florida. Data updates require periodic loading of files provided be each data provider as well as monitoring scheduled automated data load tools (e.g., hourly USGS data). For example, most water quality data updates has been provided quarterly by each data provider and require manual load and quality assurance procedures performed to complete each update. In addition, educational documents and other resources require continuous cataloging and management in order to ensure that the Atlas is as current as possible.

Atlas Functionality

The following section provides an overview of functionality available using the Atlas application. Since it is impossible to provide a true demonstration of Atlas functionality in this format, a visit to an Atlas website is encouraged. In order to provide a portal for users to access any Atlas website, the University has registered the domain www.WaterAtlas.org and has developed a preliminary website to serve this role. As additional Atlas projects are developed, access to each will be provided via the WaterAtlas.org website. The mapping interface is shown in Figure 2 and allows users to view multiple themes such as hydrography, wetlands, political boundaries, watershed boundaries, and aerial photography. The user can navigate to a water resource of interest through an address search or by browsing the map. Once a resource is in view, the user can select the resource with a select tool or choose to bring up a hyperlinked table of the water resources in the view. Either choice directs the user to a series of watershed or waterbody specific data pages.

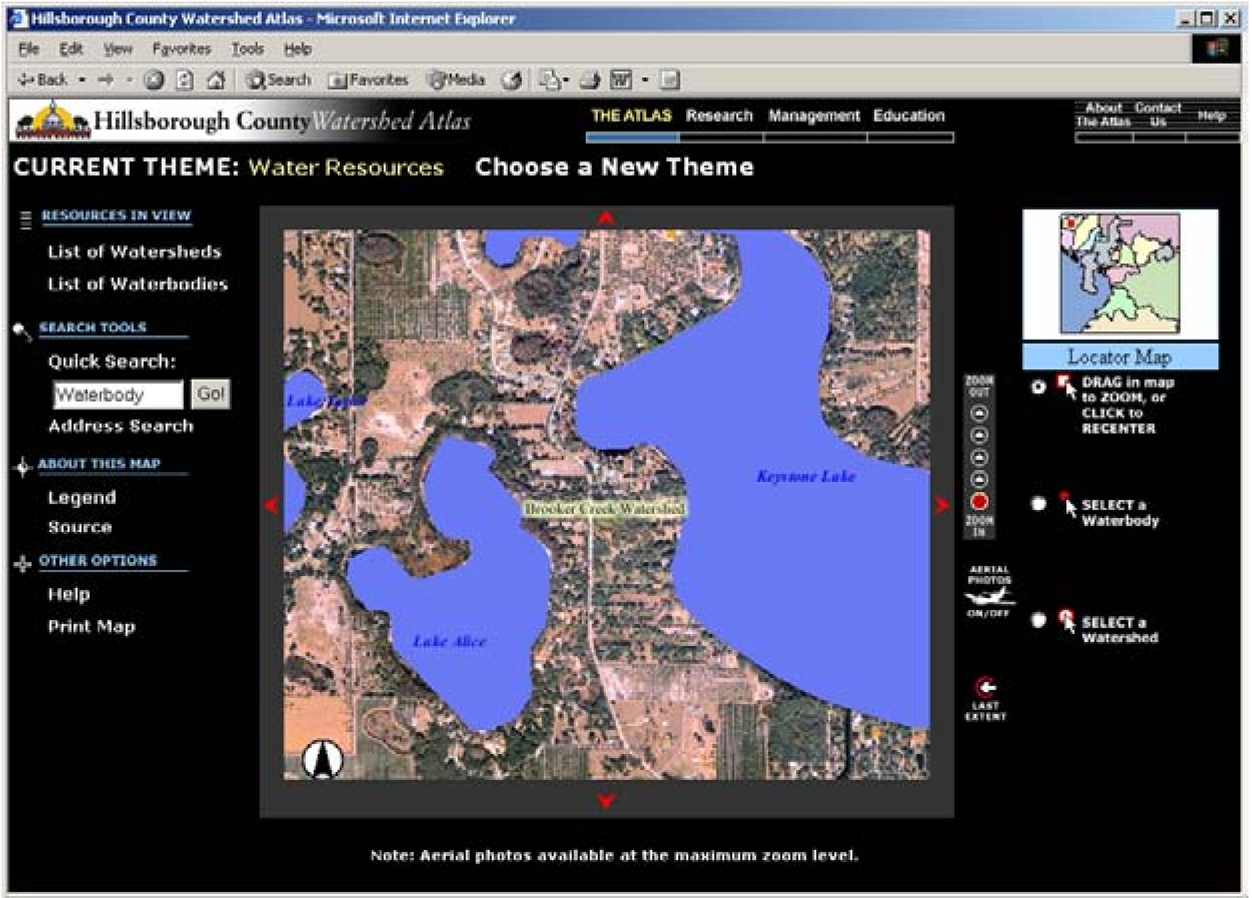

Figure 2. Example ArcIMS map interface as shown on the Hillsborough County Atlas.

The water resource data pages summarize data by topic and display key indices and parameters for determining the current conditions of a watershed, lake, river or stream. The data are organized by sections, including: general information, water quality, hydrology, people and recreation, and photographs. Figure 3 illustrates a typical general information view for a lake. The data are published in timely or near real-time intervals on the Atlas using automated protocols. In order to educate citizens and assist users in discerning meaning from the data presentation, each component of the Atlas is presented with a “What does this mean?” help page. For example, from the lake-specific general information page of the Atlas, Trophic State Index (TSI) is a parameter that is presented. As part of the TSI presentation, a “what does this mean” help page is linked which explains the difference between oligotrophic and eutrophic in terms designed to educate the average citizen. These educational help sections are included with each data component.

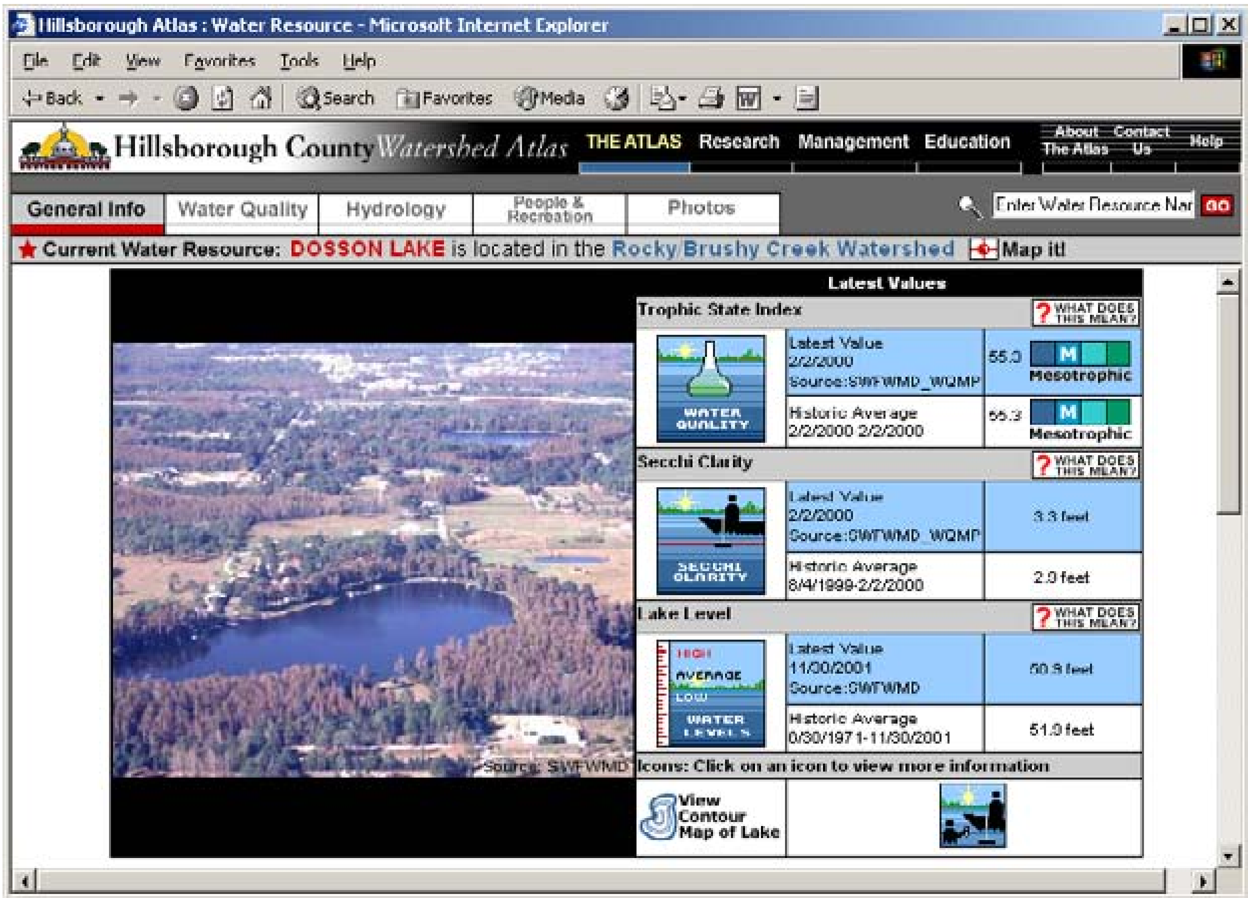

Figure 3. Lake-specific general Information page on the Hillsborough County Atlas.

Advanced Tools allow users to query, graph, and download data from any of the nearly twenty data sets in the Atlas. Figure 4 illustrates this functionality as implemented on the Hillsborough County Watershed Atlas. In order to access data related to a specific waterbody, users follow these steps:

1. The user chooses a waterbody and is then presented with the type of data available for that waterbody, such as water quality, hydrologic, and rainfall.
2. After selecting the type of data desired (e.g., water quality), the user is presented with a list of available sampling stations from all data providers where the chosen type of data are sampled or the chosen waterbody.
3. Once the user chooses the specific sampling station(s), the available period of record dates are presented.
4. The user then chooses the desired period of record and then chooses how to format the data. Data is formatted as either excel, delimited text, or as an online trend graph. If the desired format was a graph, the user would have chosen a specific parameter to graph, whereas the excel or text file is provided for download with all available parameters.

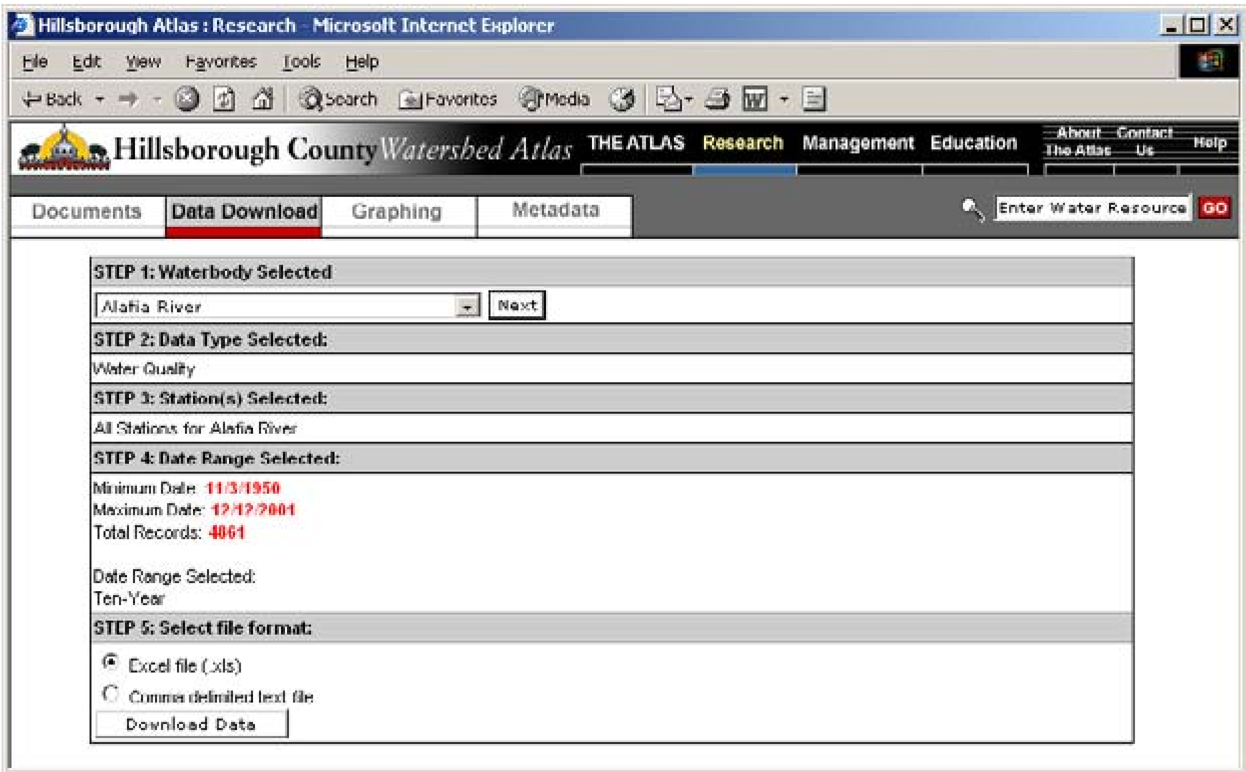

Figure 4. Example Data Download tool as implemented on the Hillsborough County Atlas.

In addition to providing data and GIS maps, educational and other documents have been cataloged and made available from various sections of the Atlas. A document catalog system was developed to allow secure web-based management of web links and adobe acrobat documents related to water resources issues. Once a document (or link) is added to the online catalog, it can be assigned a subject to specify the page(s) where the document will be displayed. In addition, if the document is related to a specific water resource, the document can be cataloged to display on the web page for that resource. Access to the administrative tool is provided via a secure interface so that designated staff from the University as well as the host agency can add or edit documents in the catalog.

Program Assessment

One measure of success of web-based projects is the number of users visiting the website. Currently, three counties in Florida (Hillsborough, Polk, and Seminole) are being served by the Watershed Atlas through WaterAtlas.org as of February 2002. To make a general comparison of the success of WaterAtlas.org, a ratio of the users per day to the total population served by the website was generated and compared to the number of user sessions for the Southwest Florida Water Management District's main website (see **Table 2**). While a statistical comparison is not feasible, it is reasonable to conclude that the Atlas websites are successful if measured by users alone. As a ratio to population served, the Atlas compares favorably with the main website for the Southwest Florida Water Management District. Another measure of the success of the Atlas program is the number of users requesting environmental information or expressing interest in becoming a volunteer. For the most recent quarter (December-March, 2002), 47 users filled out comment forms and 11 users expressed a desire to become volunteers.

While currently no data exist to compare citizen response prior to the Atlas, environmental professionals surveyed who were working with the Atlas have qualitatively expressed improved communication with the public and at the same time reduced staff time spent gathering data to answer questions from the public. Furthermore, the inclusion of quality-assured data from multiple agencies into one data source was cited as a benefit to both environmental professionals and citizens. Overwhelmingly, the survey respondents stated that the Atlas was meeting or exceeding their expectations.

Table 2. Analysis of the Atlas projects in terms of the ratio of users per day to total population served.

Website	Total Population Served	Average Users per Day	Ratio of Users/Day to Total Population Served
WaterAtlas.org	1,848,068*	665	1:2,779
Southwest Florida Water Management District	3,900,000 **	1,067	1 : 3,655
* Source: 2000 U.S. Census. ** Source: SWFWMD, 1995 population.			

CONCLUSIONS

The Watershed Atlas application is providing unprecedented access to water resources data and educational materials for the local citizenry and environmental professionals. The Atlas projects currently include data from 16 different agencies, contain a total of over 2700 active sampling locations, and over 2.4 million individual samples. Access to these data are provided via user-friendly water body specific web pages designed for citizen education as well as advanced data access tools designed for environmental professionals. Preliminary results indicate that the Atlas is being widely used by both citizens and environmental professionals and the amount of time spent by both user groups to access data has been reduced. Furthermore, in counties where the Atlas has been implemented, it has fostered communication between environmental professionals and the general public. Based on the current number of users per day, WaterAtlas.org will serve over 250,000 users in 2002. The number of users will continue to increase as additional geographic regions of the state are included and as the overall functionality is enhanced.

The University is committed to both improving the functionality of the Atlas and facilitating its development statewide. The Atlas program has been awarded funding from several additional agencies including an EMPACT grant from US EPA with Seminole County. Efforts underway to improve the Atlas include:

- Expansion into additional Florida Counties
- Development of K-12 curriculum for using the Atlas in the classroom
- Improved data transport between STORET and the Atlas

- Needs assessment involving environmental professionals conducting watershed management activities
- Needs assessment related to reporting and educational requirements of NPDES and TMDL requirements

Through these efforts and with the assistance of our agency partners we will continue to refine and assess the effectiveness of the Atlas to meet the needs of environmental professionals and the general public.

CITATIONS

Flynn, Mike. *Getting Information to People In Forms They Can Use and Understand*. Presented at the National Environmental Innovations Symposium: A Partnership Between the U.S. Environmental Protection Agency, the Environmental Council of the States, and the Council for Excellence in Government. Hyatt Regency Crown Center, Kansas City, Missouri: December 6, 2000.

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TMDL WATERBODY ASSESMENT USING LANDSAT 7 EMT+ AND IKONOS IMAGERY

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ABSTRACT

The use of remote sensing imagery to assess 303(d) listed water bodies and for use in tracking progress in TMDL implementation was tested on 14 waterbodies in the summer of 2001. Water bodies on the south shore of Massachusetts were surveyed to evaluate water quality and identify the presence of noxious aquatic plants. Four different overpasses of Landsat 7 ETM+ and one IKONOS 4-meter multispectral image were acquired through a data purchase grant offered by the NASA Affiliated Research Center Program at Brown University. A field crew consisting of remote sensing specialists and field geologists collected ground truth data concurrently with the image capture in a roughly 100-km^2 area equivalent to the IKONOS data set footprint. Field parameters collected during a four-hour window included water and plant visible and near-IR spectra as well as *in situ* water quality measurements such as turbidity, Secchi disk depth, and pH. Laboratory analysis of water samples yielded chlorophyll-*a* and phosphorous content. Vegetation mapping was typically performed in the afternoon or within two days of a flyover.

As a result of the field data collected, a predictive relationship between Secchi disk transparency and chlorophyll-*a* concentrations was established and could be used as a cost effective solution for future water quality assessments. A process was developed to detect the trophic state of the lakes and ponds in a subset of the study area. Remote sensing imagery analysis holds promise as a low cost technique in the monitoring the implementation of TMDLs. This methodology may also be applied in the future to tracking stormwater management control effectiveness.

INTRODUCTION

The state of Massachusetts as well as the EPA and other states, are stepping up efforts to identify, and adopt TMDLs for polluted/stressed water bodies. Within the United States over the next 11 years, State and the Federal Government will need to establish and implement in excess of 21,000 TMDLs representing over 300,000 river and shore miles and 5 million lake acres. This is a daunting task and an ambitious timetable even if sufficient funding was available to conduct this research. Due to the foreseeable problem with the current TMDL execution plan an attempt was made to develop a broad reaching but inexpensive management tool to assist in the TMDL assessment process. The major goals of this project were to 1) develop a method to qualitatively and quantitatively detect water quality from satellite imagery, 2) identify from the imagery the location and types of vegetation present in or surrounding the water body, 3) determine if the methodology developed is a cost effective solution for managing or prioritizing the TMDL process, and 4) determine if existing 303(d) listed water bodies are impaired and therefore accurately listed.

The majority of impairments of 303(d) listed water bodies in Massachusetts result from: noxious plants, exotic plant species, nutrients, organic matter/low DO, metals, pathogens, suspended solids, and turbidity. Some of the previous list are either undetectable from Earth orbit or do not exhibit properties that change the spectral signature of water. However, we believed that a method could be developed to detect some of the most common stressors. Factors that are the basis for establishing water quality indicators (quantifiable targets for a specific pollutant) shed light on the requirements for a successful alternative measure of impairment (i.e., remote sensing techniques). A successful surrogate indicator of impairment would exhibit a majority of the following attributes:

- Consistent with water quality standards
- Quantifiable
- Sensitive to local conditions
- Reproducible
- Discriminating at the scale of allocation and management evaluation
- Comparable to previously collected information
- Able to be referenced to baseline information
- Able to be used to evaluate future conditions and trends
- Able to be related to source and receiving water condition
- Affordable and cost-effective to measure
- Feasible to measure
- Minimally disruptive to beneficial use
- Understandable by the public

According to the MADEP's TMDL strategy, water bodies that have been identified as having an overabundance of noxious plants will be treated as a nutrient problem. That is, noxious plants will be considered an indication of over enrichment with nutrients (primarily phosphorus, P). Organic matter/low DO and turbidity caused by organics are also treated as nutrient problems. We believed that it was possible to spectrally detect biomass in lakes and coastal waters from low Earth orbit using currently available satellite imagery.

STUDY SITE

The study site for this project consisted of 14 ponds in the South Coastal Basin ranging in size from 30 Acres to over 200 Acres. The South Coastal Basin has a drainage area of approximately 220 square miles and is one of the eleven major basins in eastern Massachusetts discharging directly to the ocean (Figure 1). This basin is comprised of several independent coastal river basins as well as significant groundwater aquifer resources. The three primary hydrologic units are the North and South Rivers system, the Jones River, and part of the Plymouth aquifer. The Plymouth aquifer, which is located in the southern part of the South Coastal Basin, is characterized by an extensive groundwater system, which flows toward the ocean. Ponds and streams, which are fed by this groundwater system, are not significantly influenced by runoff. As a result, the flows in these streams do not fluctuate greatly over the year (South Coastal Watershed 1996 Resource Assessment Report, Commonwealth of Massachusetts, 1996).

Outwash plains make up most of the Massachusetts coastal landscape. They are made primarily of sand and gravel deposited by melt water during the last glacial maximum. This broad flat depositional surface slopes gently away from the former ice front. The deposits in the ice proximal part of the outwash plain were deposited atop the glacial terminus, and when the ice melted away, these deposits collapsed to form an irregular surface that sloped steeply in an up-ice direction. Outwash deposits also form a highly irregular and unorganized morphology called kame and kettle terrain. Kettles are hollows or undrained depressions that are steep sided and formed from the melting of a partially buried block of glacial ice. If the bottom of the kettle is at an elevation below the water table, a kettle pond will exist. The 14 waterbodies selected for analysis in this project were all of this type.

METHODS

To develop a valid approach to evaluate the accuracy of a remote sensing approach to waterbody assessment and determine the validity of the waterbodies 303(d) listing status 14 Ponds were chosen for study. Of those 14, 8 of the ponds were listed as impaired for noxious aquatic plants, nutrients, and turbidity. The other 6 were unlisted and 2 of those were actually reserve drinking water reservoirs.

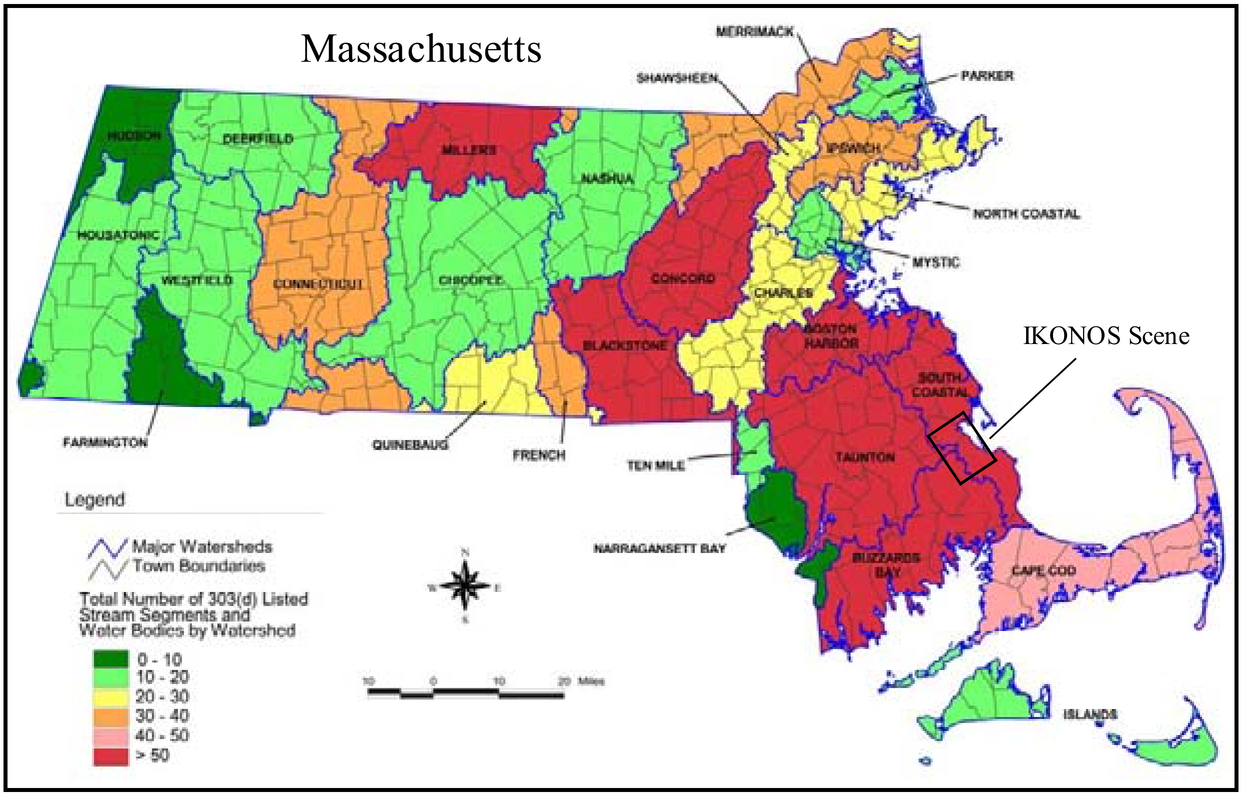

Figure 1: Massachusetts watersheds coded by number of 303(d) list waterbodies. The black rectangle labeled IKONOS scene represents the study area.

Data Collection

Spectral reflectance data was collected in the field using a portable spectrometer and included measurements of vegetation within and around the ponds, the pond water and clear portions of the sky. Water and sky measurements were taken in the field by canoeing near the center of each pond. These readings were made as close to the Landsat imagery acquisition time as possible, approximately 10:30 am EST. However due to the number of ponds sampled on a single day and the travel distance between ponds, measurements were often made between 9:30 am and 1:00 PM EST. Vegetation samples were also collected in the field and taken back to the lab where the spectral reflectance was acquired in a controlled environment with a reliable light source.

For each location investigated, a Global Positioning System (GPS) measurement with approximately 4 m accuracy was made wherever field data was collected. While one team member was measuring spectra the other was taking secchi disk transparency, actual depth, DO (dissolved oxygen), Conductivity, Turbidity, Temperature, pH, and ORP. Water samples were also collected at this location and sent on to the cooperating labs for analysis of Chlorophyll-*a*, Total Phosphorous, Dissolved Organic Carbon, and Turbidity. In-situ measurements and water samples were taken in the top foot of water column due to the assumption that the water present in this layer would most effect the readings obtained from the spectrometer and the satellite sensors. Vegetation for four of the ponds was investigated in the field following the sampling round. Detailed maps were created depicting not only the extent of vegetation but also the vegetation type. These maps were used to ground truth the satellite imagery during the analysis phase.

Imagery and GIS Data

Two remotely sensed imagery data types were used in this project. Four relatively clear Landsat-7 ETM+ images were acquired throughout the summer months at times corresponding to in-field data collections. This data type includes six bands of data in the visible to near infrared wavelength range (0.49-2.22nm), with a 30m spatial resolution. These images were from Path 12, Row 31, and acquired on June 26, July 12, July 28, and August 29 during 2001. All images were acquired around 10:30 am EST (Eastern Standard Time). The second imagery type included in this study was an IKONOS (www.spaceimaging.com) scene. The IKONOS imagery used has a four-meter spatial resolution for four spectral bands in the visible to near infrared wavelengths (0.45-0.9 nm). This image was acquired on July 30, 2001, at 10:45 am, EST. GIS data for the study area was obtained from MassGIS and included pond outlines, political boundaries, watersheds, and rivers.

RESULTS AND DISCUSSION

The primary goal of this project was to establish a relationship between the Landsat/IKONOS spectra and the measured water quality determined from laboratory and field measurements. The procedure developed involved four main steps; 1) atmospherically correct the imagery scenes; 2) extract the spectral signatures from the sampled ponds; 3) statistically determine the best-fit relationship for each day; and 4) apply the best fit to obtain the average pond value and relate it to measured chlorophyll content. A secondary goal was to determine the usefulness of /IKONOS imagery, mostly because of it's improved spatial resolution, for identifying vegetation properties.

There were several reasons for focusing on chlorophyll-*a* content as proxy for excessive nutrients. It was assumed that water bodies with excessive nutrients have correspondingly high chlorophyll content. Also, a positive correlation is often seen between high productivity algae/phytoplankton and high nutrient loads. Furthermore, lab measurements of chlorophyll-*a* are more accurate and less troublesome than a field determination of pond productivity. It has also been shown in prior research that chlorophyll-*a* measurements can be made using remotely sensed data. Therefore it was hoped that quantifiable measurements of chlorophyll-*a* concentrations could be made using the remotely sensed data. However due to the difficulties in image calibration of Landsat scenes for investigation of water features, only a qualitative measurements were achievable. Since quantitative measurements of chlorophyll-*a* results did not seem possible with the current datasets, a 3 fold qualitative approach was undertaken using a variation on Wetzel, 1982 (Figure 2 and Table 1).

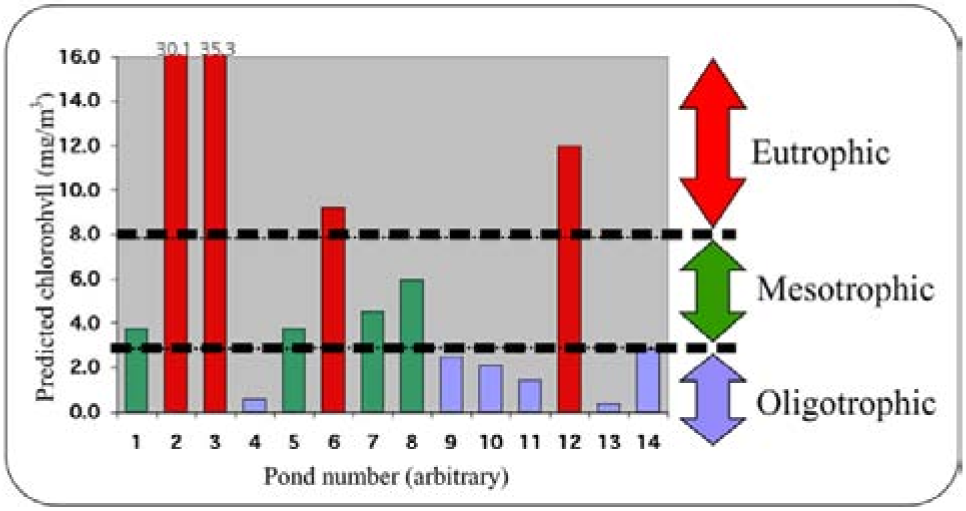

Figure 2: Graph of results using the 3 fold classification method. Results from ponds 6 and 12 were not valid because of their size and edge contamination.

Table 1. Chlorophyll Measurements used to Specify Trophic State.

Chlorophyll (mg/m^3)	Oligotrophic	Mesotrophic	Eutrophic
mean	1.7	4.7	14.3
mean +/-SD	0.8 – 3.4	3.0 – 7.4	6.7 – 31
Range	0.3 – 4.5	3.0 – 11	2.7 – 70
N	22	16	70

Table based on the general trophic classification of lakes and reservoirs in relation to Phosphorus and Nitrogen from Wetzel, 1982.

Based on 40 water quality samples taken over the course of the project several correlations were made that justified the above assumption. It was found that there was strong correlation between secchi disk measurements of water transparency and chlorophyll-*a* concentrations received from laboratory analysis. A power regression curve with an equation of $Y=12.756X^{-1.6722}$ fit the data set (Figure 3). Also, a direct relationship was observed between chlorophyll-*a* and Total Phosphorous concentrations, the limiting nutrient in these waterbodies (Figure 4).

Results from this project determined that for Landsat data sets, the minimum pond size needed to be at least 4 pixels across (120m) to extract water pixels untainted by edge effects caused by shoreline vegetation and overhanging trees. Two of the 14 ponds investigated did not meet these criteria and could not be accurately assessed using the developed method. Even after eliminating two of the smallest ponds, in general the smaller ponds often yielded the most erratic results. Also because of the nature of these waterbodies and many are ideal for floating leave and submergent aquatic plant growth making it difficult to find deep-water areas to extract clean, uncontaminated water spectra. Since vegetation typically encroaches upon pond edges, scattered light contributions to Landsat edge pixels is greatly enhanced especially in near infrared. It was found that using a Band 4 - Band 3 difference image permitted a better assessment of edge contamination.

Within the remaining ponds, truly eutrophic ponds were easily and consistently identified. However, it was difficult to identify a discrete boundary separating oligotrophic and mesotrophic ponds. This may be in part due to the seasonal variability of chlorophyll-*a* concentrations making fixed-value thresholds inappropriate. Consistent results were obtained for 3 out of the 4 dataset (7/28, 7/12, 6/26). Complete consistency between all data sets may be related to atmospheric differences being incompletely removed during the calibration step. As a result of this project it was determined that at least 1 or 2 of these waterbodies probably did not deserve an impaired status and should be considered for removal from the 303(d) list. This represents 7-14% of the total waterbodies assessed under this project. If this percent remained consistent throughout the entire 303(d) list, the total number of potential waterbody delisting could reach as many as 3000 waterbodies, which would represent an considerable cost saving measure to the parties responsible for funding TMDL studies.

Vegetation on these waterbodies was evaluated using both the Landsat and IKONOS imagery. As was expected, the higher resolution IKONOS scene produced superior results but the goal of identifying specific plant species was not obtained. Instead, a similar 3-fold classification of plant density (low, medium, high) was used to evaluate floating leave aquatic vegetation. This classification approach consistently identified ponds with vegetation problems in both the Landsat and IKONOS imagery (Figure 6). Also, because of the increased resolution, a fourth class of submergent vegetation was added to the IKONOS classification scheme. Although slightly less reliable than the floating leave classes, ponds with excessive submergent species such as Cabomba caroliniana (fanwort) were identified.

CONCLUSIONS

The following achievements and conclusions are a result of this study:

- Quantitative measurements of chlorophyll may not be possible but a qualitative 3-fold classification is still extremely useful.
- Oligotrophic—mesotrophic boundary gradational both in remote sensing and in directly sampled water chemistry.
- The majority of the time (3 out of 4 days) eutrophic ponds > 4 pixels across were correctly identified.
- Small ponds (< 4 pix across = 120m) are not adequate Landsat targets in most cases

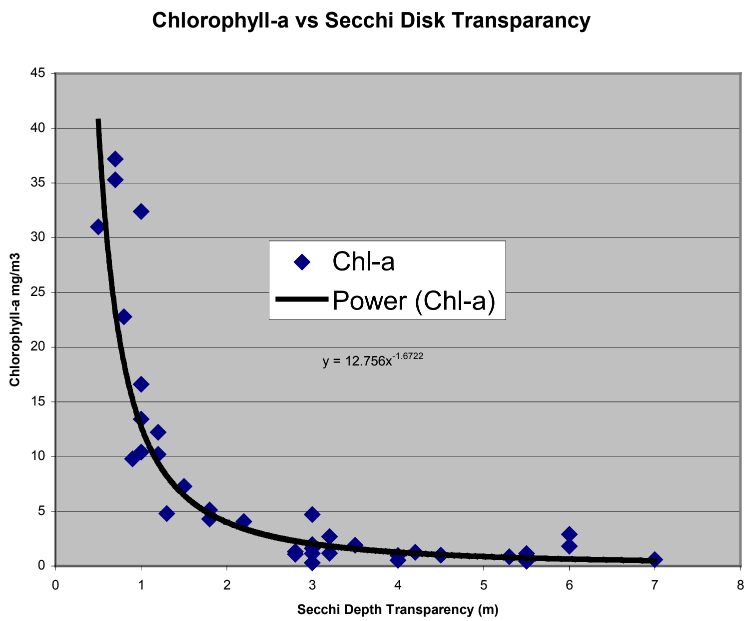

Figure 3: Graph of Chlorophyll-*a*(mg/m^3) concentration vs. secchi disk transparency in meters (40 data points). Notice the well-defined curve demonstrating this relationship.

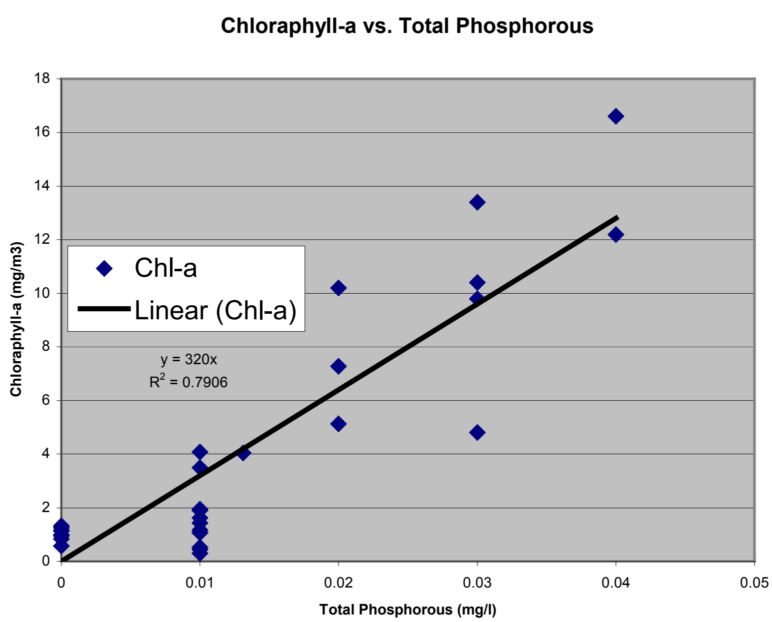

Figure 4: Graph of Chlorophyll-*a* (mg/m^3) concentration vs. Total Phosphorous (mg/kg) (40 data points).

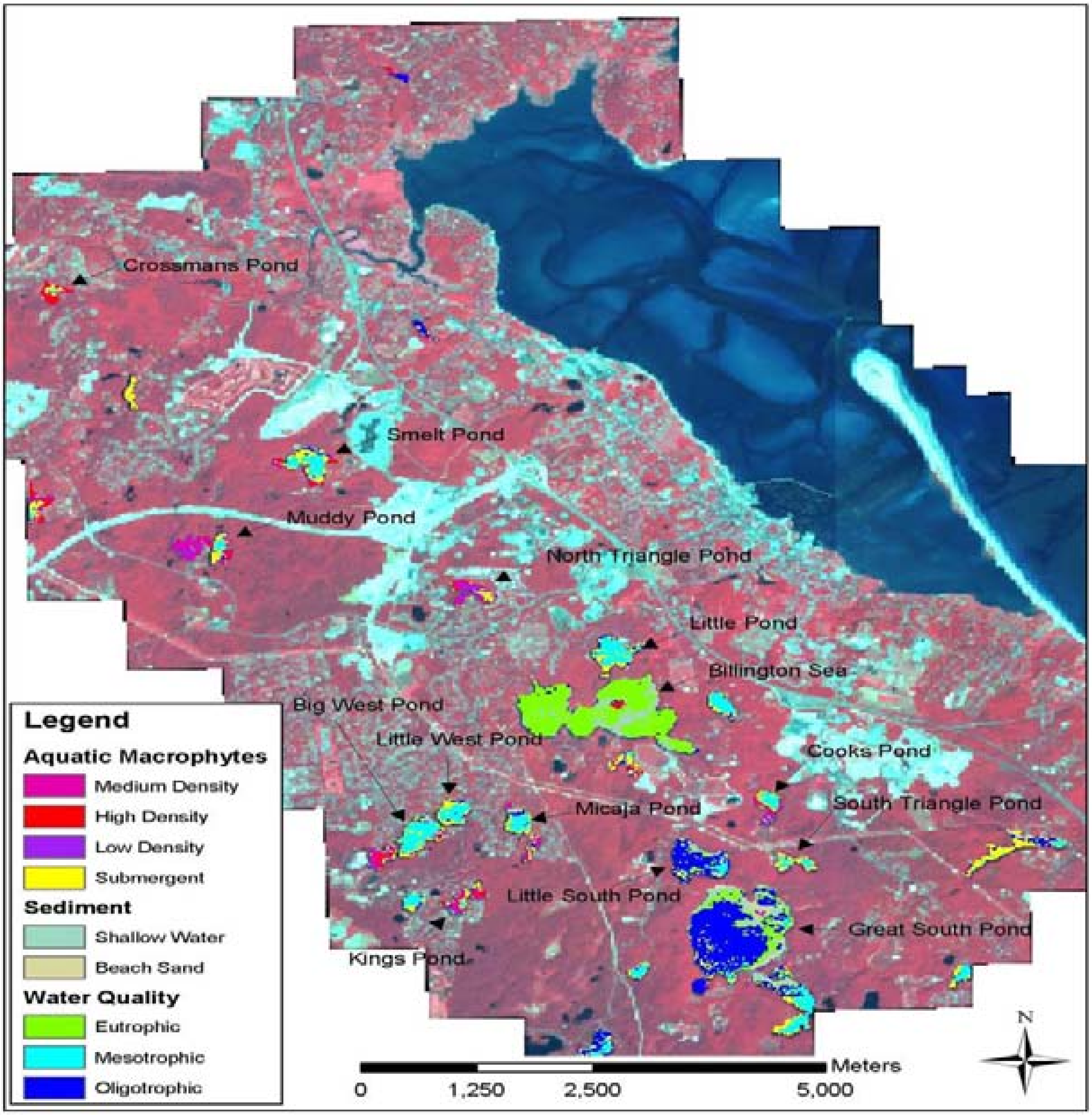

Figure 5: Three-fold classification of both water quality and vegetation from IKONOS imagery taken 7/30/01.

- Firm connection established in South Coastal watershed between chlorophyll-*a* and phosphorous. Validating the initial assumption.
- A 3-fold classification of aquatic plants is possible and useful for narrowing in on ponds with nuisance aquatic vegetation.
- Secchi disk depth may be used in lieu of time-critical lab chlorophyll-a sampling when funds are not available.
- Several water bodies examined in this study did not appear impaired, although they are present of 303(d) list

The results of this project have the potential to change the way TMDLs are assessed, monitored, and prioritized. The implications of the proposed project are significant for both the state of our environment and the efficient use of local, state, and federal fiscal resources. Due to the enormous workload and lack of budgetary requirements for federal and state officials, as well as their consultants to perform 21,000 waterbody assessments, methods developed in this project could assist regulators by facilitating efficient prioritization and clean up of regulated waters. It was determined that remote sensing was an efficient and cost effective means of prescreening waterbodies and potential providing recommendations for delisting prior to full scale TMDL studies. In summary, it appears that a properly ground-truthed remote sensing analysis could be used to supplement a field program and extend it spatially throughout an entire watershed or state.

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INTEGRATED WATER RESOURCE MANAGEMENT IN THE TUALATIN RIVER WATERSHED, OREGON

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ABSTRACT

The Tualatin River watershed encompasses approximately 710 square miles between the Coast Range Mountains and the Willamette River in northwestern Oregon west of the city of Portland. Discharges from two headwater tributary reservoirs supply drinking water to several major cities as well as providing a majority of irrigation needs for extensive agricultural operations in the Tualatin Basin and flow augmentation water for wastewater treatment facilities downstream. Two major wastewater treatment facilities discharge an average of 72 mgd of tertiary treated wastewater to the River and have been the subject of Total Maximum Daily Load (TMDL) requirements (Clean Water Act) for phosphorus, and ammonia since 1988 and temperature and bacteria most recently. Additionally, under the Endangered Species Act, winter steelhead trout and spring chinook salmon have been listed as threatened in the Tualatin River and its tributaries. The challenge facing our agency is to integrate the water quality, water quantity and habitat improvement activities for the Tualatin watershed in which we are involved as well as those of over a dozen local governments. This paper will discuss the major efforts our agency is undertaking to respond to these issues including our response to TMDLs through point and non-point source improvement, a water supply feasibility analysis for increased water supplies, and the Healthy Streams Plan as a response to the endangered species listing. Finally, our paper will describe how we propose to merge these various activities to ensure that we effectively meet the water resource needs of the Tualatin Basin.

INTRODUCTION

A consensus has been developing for some years now that the most effective way to engage issues of water quality, quantity as well as habitat protection and restoration is to use a watershed based approach (EPA 2001). By integrating and better coordinating all activities associated with water resources watershed-wide, the thinking goes, it should be possible to produce an overall better result in terms of protecting or improving these resources in a cost effective manner. The logic is impeccable. Since watersheds do not respect political boundaries, for example, a watershed approach to solving resource problems could result in fewer duplicative services and thus, ultimately, reduced costs for tax and/or rate payers. In practice, the theory of watershed management is very difficult to implement successfully. There are as many reasons for this as there are watersheds in the country; but in the end, where watershed management worked well communication between stakeholders within the watershed was good and where it failed stakeholder communication was poor or non-existent (Colorado School of Law 1996).

In the Tualatin River watershed a unique opportunity exists to develop and implement an effective watershed management strategy. Currently, new TMDLs are being instituted that will impact the point and non-point sources on the river. Also, a feasibility study has been initiated to evaluate alternatives for providing additional drinking and irrigation water supplies to meet future needs as well as for flow augmentation. Finally, Endangered Species listings for winter steelhead trout and spring chinook salmon have been established for the river and its tributaries. Water quality, quantity and habitat issues are thus in play simultaneously in the Tualatin watershed. The challenge now is to develop a mechanism(s) to implement a management strategy to take advantage of this opportunity.

DESCRIPTION OF WATERSHED

The Tualatin River emanates from two headwater reservoirs located in the Coastal Range Mountains west of Portland and flows nearly 80 miles east where it joins the Willamette River after passing over a low-head dam (Fig. 1). In addition to the two reservoirs, five major tributaries as well as numerous smaller ones feed the Tualatin River. The watershed comprises approximately 710 sq. miles of agricultural, forested and highly urbanized lands in northwestern Oregon in the most populous portion of the state. Forested lands constitute nearly 49% of the watershed while agriculture accounts for 38% and urban areas comprise the remaining 13%.

Among the most important physical features of the river is the low gradient nature of the last 60 river miles as it flows through the Tualatin Valley. Portions of the river in this area drop only 1 foot over 24 miles. This characteristic leads to periodic water quality problems during the low flow conditions of summer when the river becomes, essentially a poorly mixed reservoir. Algal blooms and the attendant swings in pH and dissolved oxygen were common during the summer months in this portion of the river prior to the 1988 TMDL that required phosphorus and ammonia reduction.

There are twelve small cities located within the watershed including portions of the City of Portland as well as Washington, Multnomah and Clackamas counties (Fig. 1). The major point sources on the river include two small wastewater treatment plants at Forest Grove and Hillsboro and two larger ones at Rock Creek and Durham, all of which are operated by Clean Water Services (CWS), the local public sewage and stormwater utility (Fig. 1). All together these plants discharge an average of 72 mgd of advanced tertiary treated wastewater to the river. During the low flow summer months, the discharge from these facilities can constitute as much as 25% of the daily flow of the Tualatin River.

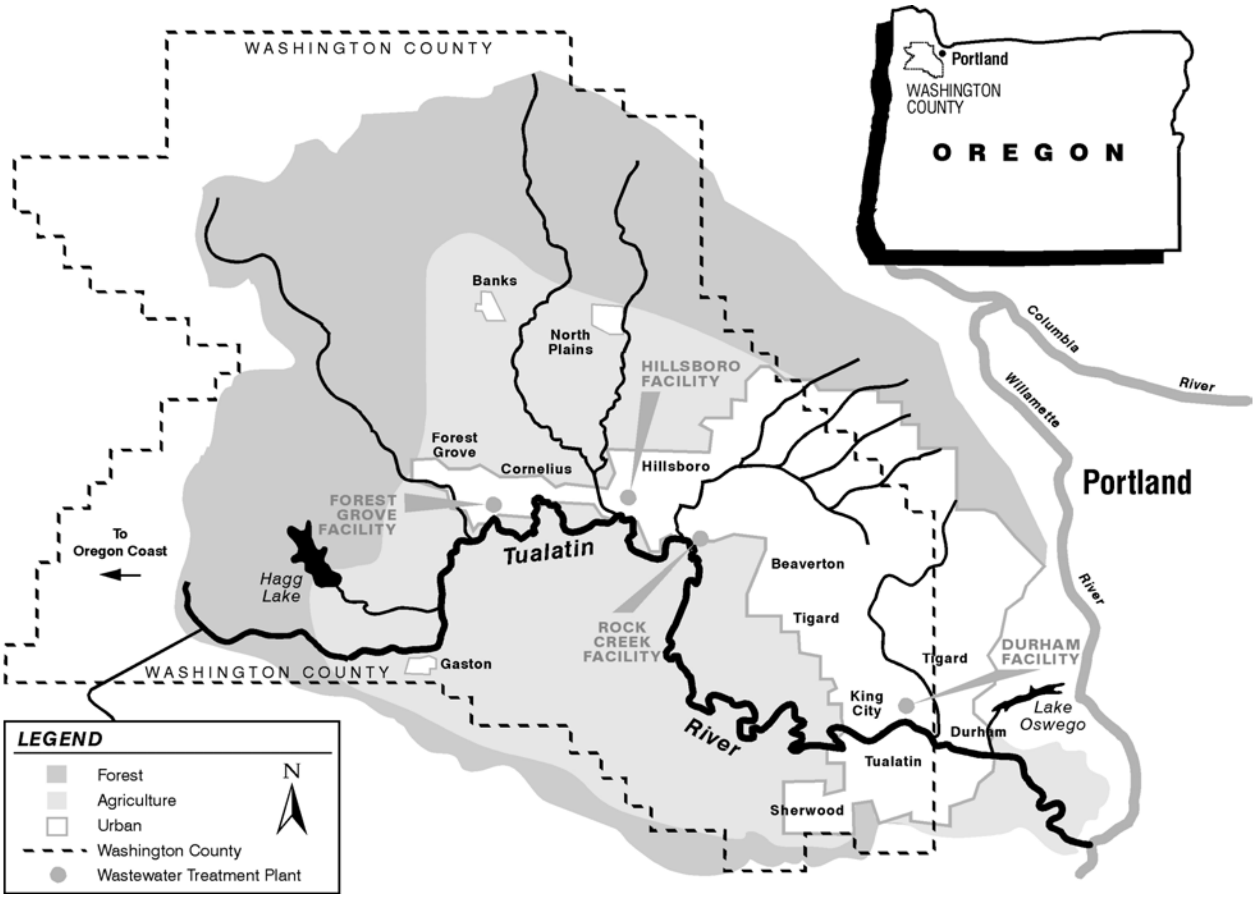

Figure 1. Tualatin River Watershed

WATER QUALITY

Up until the early 1970s, 28 poorly functioning wastewater treatment plants discharged their effluent to the Tualatin River resulting in high concentrations of phosphorus, ammonia, suspended solids, BOD and bacteria. In 1970 the Unified Sewerage Agency (now CWS) consolidated the existing facilities into two large regional plants and two smaller facilities (noted above). Although water quality in the river improved, problems with algal blooms, low dissolved oxygen concentrations, and toxic levels of ammonia continued periodically. In fact, concentrations of ammonia nitrogen and total phosphorus often exceeded 20 mg/l and 2 mg/l respectively in the discharges from the plants (Werblow 2000).

In 1984 the Tualatin was placed on the U.S. EPA's 303(d) list as a water quality limited river (USA 1999). At this point total phosphorus concentrations during the summer were averaging 1.0 mg/l while ammonia was over 5.0 mg/l (Jarrell 1999). Following a lawsuit by the Northwest Environmental Defense Center and a court decision in 1986-1988, the Oregon Department of Environmental Quality (DEQ) established TMDLs on the river for phosphorus (0.07 mg/l) and ammonia (1.0 mg/l) for the low flow period of May 1 through October 31. Thus, the Tualatin became among the first waterbodies in the nation for which TMDLs had been established.

Since most of the ammonia found in the river was discharged from the wastewater treatment facilities the solution was relatively straightforward: the construction of nitrification facilities at the treatment plants (Jarrell 1999). Additionally, since 1987, CWS has actively managed its flow augmentation water from the upstream reservoirs to increase the flow rate through the slow moving reaches of the river. This practice reduces the residence time for algal growth, which in turn reduces the frequency of blooms and high pH levels. It also reduces the impact of the sediment oxygen demand on the river in the late summer, which results in higher levels of dissolved oxygen when the algae are no longer photosynthesizing.

Phosphorus proved to be considerably more difficult to manage. DEQ set loads for total phosphorus of 0.02 mg/l for stream reaches in the forested headwater areas, 0.05 mg/l for stream reaches in agricultural lands, and 0.07 mg/l for the lower urbanized stream reaches (Jarrell 1999). Improved treatment of wastewater at the CWS plants resulted in a reduction in total phosphorus from 2.0 mg/l to 0.05 mg/l average concentration in the summertime discharges (Jarrell 1999, USA 1999). This led to significant improvement in phosphorus loading to the river but concentrations in the river were still nearly twice the DEQ objective. Continuous improvement in phosphorus reductions would depend, largely, on improvements in non-point source treatment in all three areas (forestry, agriculture, urban). The forested areas of the watershed were included in the state Forest Practices Act which prescribed certain best management practices (BMPs) to reduce erosion and runoff from forested areas. Similarly, agricultural water quality BMPs are regulated by Senate Bill 1010 which is administered by the state Department of Agriculture. Within the urban sectors of the watershed non-point source stormwater runoff was managed through CWS Surface Water Management Plans adopted in 1990, but has been regulated through the U.S. EPA MS4 permit which has been held by CWS and Washington County since 1995.

Although there has been a significant and on-going effort to improve stormwater treatment, particularly within the urban areas, progress has been incremental. CWS's Design and Construction standards require certain streamside setbacks and design specifications for stormwater treatment facilities. But there is still a significant amount of older urban development that falls outside these criteria.

In addition to the difficulty of controlling non-point source contributions from upland sources, a recent discovery has complicated the effort to reach the targeted TMDLs. In the early 1990s, analyses of total phosphorus in groundwater supplying the Tualatin River have been found in concentrations that would make it virtually impossible to reach the targets of 0.02 - 0.07 mg/l for the mainstem river (Jarrell 1999, Werblow 2000). However, the new TMDL (2001) has been adjusted to account for the impact of groundwater.

The 2001 TMDLs for the Tualatin include limits for bacteria, organic carbon (on the tributaries) and, more importantly, for temperature. All present unique challenges for control strategies, particularly temperature. Temperature is especially complex since it is important, not only as a water quality issue, but it is also influenced by decisions made to resolve quantity and habitat issues as well (see following sections).

WATER QUANTITY

Water supplies for agricultural irrigation as well as for municipal and industrial uses are derived primarily from two storage reservoirs (Barney and Hagg Lake) located in the Coast Range Mountains. Barney Reservoir, which is operated by the Joint Water Commission, stores approximately 20,000 ac. ft. of water while Hagg Lake holds 53,000 ac. ft. and is operated by the U.S. Bureau of Reclamation (BOR). Both facilities discharge to the Tualatin River from which withdrawals are made at the Joint Water Commission water treatment plant, several miles downstream, and by the Tualatin Valley Irrigation District (TVID). The water treatment facility provides potable supplies for 250,000 residents and commercial customers of Washington County while the TVID withdrawals supply irrigation water for approximately 17,000 acres of farmland.

There are region-wide efforts underway seeking additional sources of water to meet future demands. In the Tualatin Basin a Water Supply Feasibility Study has recently been commissioned by CWS, the BOR and nine other cities and water supply entities to evaluate several water supply alternatives to meet additional demands (approximately 50,000 ac. ft.) projected through 2050. These additional demands include not only those for municipal, industrial and agricultural uses, but also the instream flows needed to restore habitat for listed salmon and steelhead trout as well as to improve water quality conditions in the Tualatin River under the Clean Water Act.

Alternatives to be evaluated include additional tributary storage, transfer of Willamette River water for agricultural irrigation, conservation, increased use of reclaimed water for irrigation, and the expansion of Hagg Lake by raising the dam 20-40 feet. All the proposed alternatives have significant regulatory and/or public acceptance issues associated with them, as well as significant costs. Oregon water law, in which Water Rights are conferred on individual land owners on a "first in time, first in right" basis, adds a further layer of complexity in selecting the appropriate alternative or combination of alternatives.

HABITAT

In 1998 Upper Willamette River spring chinook salmon and winter steelhead trout were listed as threatened under the Endangered Species Act (ESA). This listing includes the Tualatin River and its tributaries and, because the fish are anadromous, is administered by the National Marine Fisheries Service (NMFS). In 1999 10 local governments in the Tualatin watershed, including CWS, agreed to prepare a "Healthy Streams Plan" (HSP). The HSP, led by CWS staff, responds to the listing of the fish by focusing on management strategies that will improve stream health for the benefit of aquatic species. The regulatory approval of the management strategies will be determined in the future and is likely to come in one or three forms: 1) a voluntary action plan; 2) developing limits as outlined in Section 4(d) of the ESA; or 3) by preparing a Habitat

Conservation Plan (HCP) under Section 10 of the ESA. One goal of the HSP is to minimize the "incidental take" of listed species through the planning and implementation of capital programs as well as by programmatic and regulatory changes at the local government level. An additional goal of the HSP is to meet water quality requirements of the CWA established through the TMDLs, particularly the one for temperature.

To date, Phase 1 of the HSP has been completed. This phase was dubbed "Watersheds 2000" and consisted of a sizable fieldwork component as well as a public outreach effort. The fieldwork, including hydrologic and hydraulic modeling, water quality and habitat measurements, was conducted at 471 sites on 483 miles of tributaries to the Tualatin River. At each site over 80 different physical, chemical and biological attributes were surveyed. These data, along with aerial photographs, have been developed into an extensive GIS database. Hydrologic and hydraulic models of the various stream reaches have also been prepared. Topographic data and stream cross sections were surveyed along 170 miles of stream, including over 400 hydraulic structures. The fieldwork was conducted throughout the subwatersheds contributing to the urban areas, with over one third of the sampled sites located outside the Urban Growth Boundary (UGB).

The public outreach program for Watersheds 2000 involved establishing three committees of interested citizens and other stakeholders from three different geographic regions of the watershed. The committees, assisted by CWS staff and consultants, developed priority lists of the types of projects and actions that were practical and economically feasible to implement for the various stream reaches within their geographic area. These priorities will be compared with the potential sites for habitat preservation or enhancement as well as potential programmatic changes that will be derived from analyzing the Watersheds 2000 data.

Additional project elements of the HSP that are currently in progress include: 1) a review of local government and utility stormwater facility/BMP operations and maintenance activities; 2) an evaluation of practical and economically feasible methods to reduce effective impervious areas; 3) development of an economic model that will help set priorities for capital projects; 4) a review of vegetated corridor regulations; 5) a public values/willingness-to-pay survey; and 6) an evaluation of the hydrology/hydraulics modeling developed from the Watersheds 2000 data. The results of these various efforts will form the basis of the programmatic changes that will support whatever strategy is developed to address ESA and CWA issues. Based on this information a decision will be made to prepare an HCP, seek 4(d) limits or perhaps simply submit the HSP to NMFS as the basin's ESA/CWA response.

INTEGRATED WATER RESOURCES MANAGEMENT

Internal - Since our agency has a lead role in all three management efforts it is essential that our internal activities are effectively coordinated to avoid duplications of actions or inadvertently working at cross purposes. To that end, an agency IWRM team has been established which consists of senior management and technical staff from all major functional areas. The primary goal of the team is to promote effective communication within and between all parts of the agency. Through this process agency staff will deliver a coordinated and consistent message on all watershed issues. The result is to be the development of a watershed management strategy that successfully integrates quality, habitat and quantity issues, i.e. TMDLs, the Healthy Streams Plan, and the Water Supply Feasibility project. This approach is presented in a simple diagram (Figure 2).

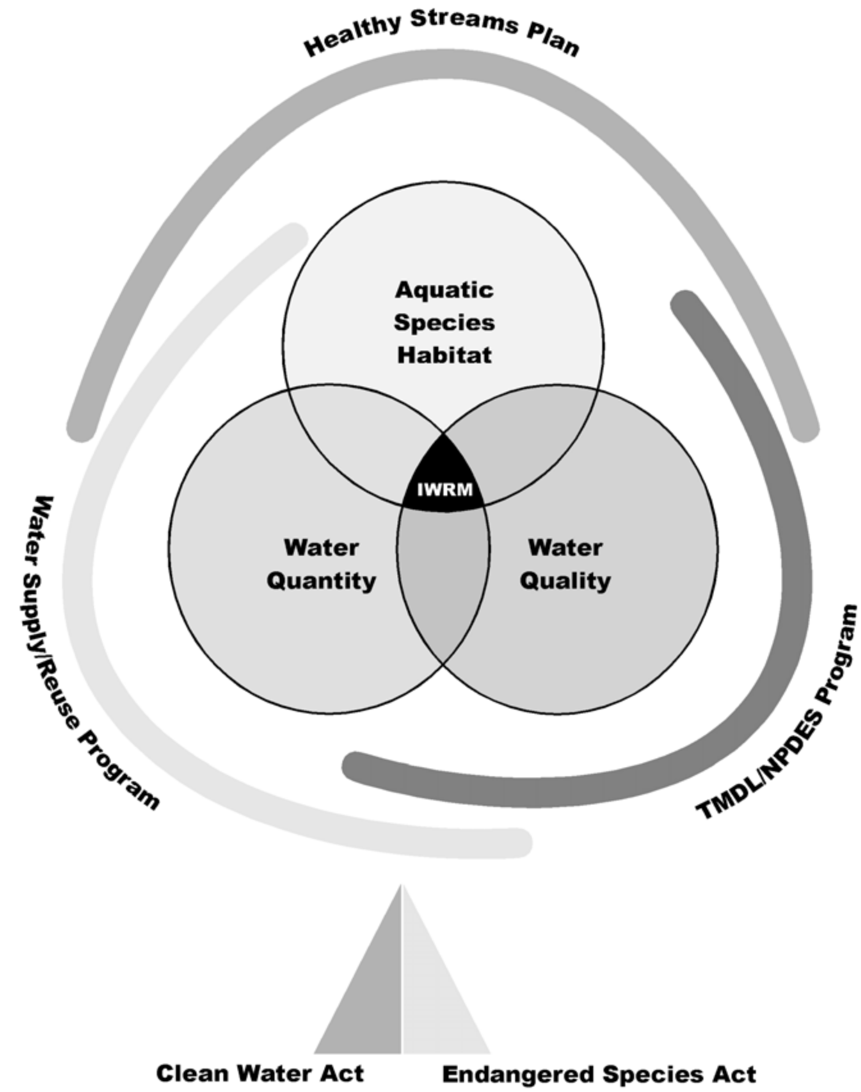

Figure 2. Integrated Water Resources Management

External - Stakeholders external to CWS, including the public, play significant roles in all three management efforts. For the non-point source portions of the TMDLs a Designated Management Agency group, or DMA (CWS plus affected cities, counties, agriculture and forestry), as well as the Tualatin Basin Public Awareness Committee, or TBPAC (DMA plus other non-government watershed groups and agencies) were established. These groups were given the responsibility of designing and implementing BMPs (DMA) and heightening public awareness of non-point source issues (TBPAC). The HSP, as noted earlier, has several subprojects that are each overseen by a stakeholder committee which, in many cases, also include members of the general public as well as state and federal regulators. Finally, although the Water Supply Feasibility Study is being managed by CWS staff, a stakeholder committee, the Water Supply Partnership, consisting of the major water suppliers and irrigation authorities, have oversight responsibility for the conduct of the project. As part of the initial phase of the study there has been a public outreach element that has focussed primarily on the residents whose property is located within the contours of the elevated water levels associated with raising the dam at Hagg Lake. Future public education and outreach programs will address other potential alternatives.

Regulatory - Of particular importance in developing an effective watershed management strategy is the need to consider revising the piecemeal, "command and control" regulatory mechanisms that currently govern all the activities noted above. In fact there has been recognition by the U.S. EPA that, often, a watershed-based NPDES permitting system could lead to an overall better outcome for the resource including: 1) better watershed-based decisions; 2) an emphasis on measurable improvements in water quality; 3) provisions for trading and other market based approaches; 4) reduced costs for water quality improvements nationwide; and 5) fostering more effective watershed implementation plans, including TMDLs (Bradley 2002). This approach could take several forms including General Permits for Common or Collective Sources, Integrated Municipal NPDES Permits, Single NPDES Permit to Multiple Sources (Co-Permittees) or even a Single NPDES Permit to a Watershed Entity (Bradley 2002). There are currently obstacles to implementing mechanisms such as these and a general lack of incentives to incorporate watershed permitting into the existing regulatory model. However, the potential for achieving significant improvements to the watershed as a whole through watershed permitting, suggests that it is time to consider this new approach. Finally, we suggest that, given the various water resource efforts taking place there, the Tualatin Basin would be a good candidate in which to test the concept of watershed permitting.

CONCLUSIONS

The Colorado School of Law (1996) outlined several features common to apparently successful watershed management efforts throughout the Western U. S. These included: a focus on resource management problems related to the allocation, use or quality of water; a geographic scope encompassing all or part of a watershed; an inclusive approach to public participation actively involving interested local community members as active decision makers or in an advisory capacity; a collaborative approach to decision making; and having a broader systems view of resource problems and potential solutions rather than resource by resource, agency by agency or political jurisdiction by political jurisdiction. We believe that all these elements for a successful watershed management effort are in place in the Tualatin River watershed. However, the continuing challenge for our agency is to foster effective coordination and communication among the numerous watershed interests to ensure an overall benefit to the Tualatin River basin.

ACKNOWLEDGEMENTS

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OUTSOURCING OF FLORIDA'S NPDES STORMWATER PROGRAM: IS IT WORKING?

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ABSTRACT

Florida's Department of Environmental Protection (DEP) assumed administration of the federal National Pollutant Discharge Elimination System (NPDES) stormwater program on October 23, 2000, ending a delegation process that began over six years ago. Florida is the last state in EPA's Region IV to accept delegation of the stormwater program. Governor Bush and the Florida Legislature have required the NPDES Stormwater program to be implemented largely by the private sector. How does this affect program implementation? Is there a loss of environmental protection? Governor Jeb Bush's privatization initiative is being tested at DEP by requiring "outsourcing" of several NPDES stormwater program functions. A contract was signed on January 11, 2001, marking the first time in DEP history, that a private firm will be carrying out all of the primary tasks associated with a regulatory program. The true impact of this privatization effort continues to unfold on a daily basis. Administration of the program is coordinated by DEP's Tallahassee office, under the Bureau of Submerged Lands and Environmental Resources. A core group of existing DEP staff are responsible for directing and managing the program. However, the contractor provides processing of NOIs, MS4 permitting, and inspections services.

INTRODUCTION

DEP assumed administration of the federal NPDES on October 22, 2000, ending a delegation process that began over six years ago. Florida became the last state in the Environmental Protection Agency's Region IV (EPA), to assume delegation of the NPDES stormwater program. Florida has also become the first state to outsource the bulk of its program activities on such a large scale. The outsourcing is provided by private contractors, who write and monitor permits, as well as provide inspections for construction, industrial and municipal permittees.

Although it is just one component of Governor Jeb Bush's privatization initiative that seeks to reduce the number of state employees by 25% in five years, the outsourcing of a state regulatory program such as this provides as unusual set of challenges, along with opportunities for benefit and growth.

Acquisition of the NPDES stormwater program from EPA should improve the State's ability to more effectively address urban programs and revisit longstanding issues. The transition will provide DEP with new tools to improve the State's stormwater infrastructure.

Delegation To Florida

As part of a phased approach, Florida accepted delegation of domestic and industrial wastewater point sources in 1995. However, a five-year transition period was imposed on the delegation process by the Florida legislature, as allowed by the federal Clean Water Act.

With an average of nearly 60 inches of rainfall per year across the State, and a varied topography that includes pine flatwoods, hardwood hammocks, wetlands, beaches and coastal plains, Florida recognized the need early-on to implement a comprehensive stormwater program. Approximately half of the State's water-quality impairment in surface waters is the result of nonpoint-source runoff.

To address surface water issues, Florida implemented one of the first statewide stormwater programs in the early 1980s, establishing new regulations to address construction of new development. The Environmental Resource Permitting program that Florida ultimately developed from this initiative, was designed with even more stringent requirements that those permits issued by EPA.

Outsourcing Administration

A contract was signed on January 11, 2001, marking the first time in DEP history, that a private firm will be carrying out all of the primary tasks associated with a regulatory program. The contract duration is 3 years, with 2 one-year extensions available.

As it now takes on the challenge of outsourcing, administration of the State's program is being coordinated by DEP's Tallahassee Office under the Bureau of Submerged Lands and Environmental Resources (BSLER). Not coincidentally, BLSER is also responsible for oversight of the Environmental Resource Permitting program. In preparation for the outsourcing efforts, Florida's DEP has consulted closely with the State of Texas, that received its own delegation of the NPDES stormwater program just over a year ago, and also carried out the transition process with the assistance of a private contractor.

In Florida, a core group of existing DEP staff are responsible for directing and managing the program. The state has also hired three more part-time employees to assist with administration of the program.

The consulting team consisting of Science Applications International Corporation (SAIC), Berryman & Henigar (BHI), Sheridan Spectrum Incorporated, and The Jaeger Group, was selected via a competitive bidding process. The contract was signed in January of 2001 and requires the contractor to provide processing of Notices of Intent (NOIs) for construction and industrial activities, processing of municipal separate storm sewer system (MS4) permits, and program-wide inspection services. The DEP retains signatory responsibility for "agency action" documents and therefore remains in primary charge regarding all permitting and enforcement decisions.

The contractor maintains the official administrative record for each permit, as well as permit files, supporting information, and related data and reports. All files are open to public inspection in full compliance with Florida Sunshine Law requirements.

Early on, it was recognized that effective communication between the DEP and the contractor are essential, and open communication is fostered by weekly teleconferences, as well as daily email and phone discussions. Data and document exchanges between the contractor and the Department occur very efficiently by use of the internet and web-based file transfer protocol (FTP). The FTP site allows Department staff as well as contractor staff immediate access to documents as well as providing an efficient means to update and post new information related to permit files. The FTP site eliminates cumbersome data transfer by e-mail and greatly reduces the Department's need for computer data storage.

Notice Processing Center

The contractor has set up a Notice Processing Center for accepting NOIs, Notices of Termination, and Discharge Monitoring Reports that are associated with General Permits for construction and industrial activities. At the time of the request for proposals by DEP, it was estimated that approximately 3,500 NOIs for construction projects will be submitted each year, along with approximately 3,000 NOIs for the industrial Multi-Sector General Permit each year. The DEP expects about 500 no-exposure certifications each year.

Upon receiving the notice-to-proceed from the DEP, the contractor established a Notices Processing Center in Tallahassee. SAIC developed standard operating procedures for handling and processing all NPDES stormwater-related notices, including establishing a toll-free help line for assisting permittees in completing notices.

The contractor also created form letters, and numerous discharge monitoring reports (DMRs) for various industrial sectors per DEP specifications. Accompanying materials, such as instructions, MSGP sector-specific DMR listings, and a web page for DMR distribution was also prepared early in the project.

To date, the Notice Processing Center has handled approximately 3,000 notices as follows:

- 1541 MSGP Notices of Intent
- 237 MSGP Notices of Termination
- 1031 CGP Notices of Intent
- 60 CGP Notices of Termination
- 124 MSGP No Exposure Notices

The Notice Processing Center help line has responded to over 400 individuals requesting information. Information requests include assistance with completing the notices, copies of their permits, and general program information. The contractor has also developed a stormwater reference library and an MSGP sector-specific permit library.

Municipal Program Permitting

Under the guidance of the DEP, the contractor is responsible for review of MS4 permit re-applications, modifications and annual reports. Duties include evaluation of stormwater management plans, review of water quality monitoring data, and assembling other information needed for permit re-issuance. The MS4 permit writer/reviewer team is composed of experienced regulatory and stormwater program personnel. There are 28 Phase 1 MS4 permits in Florida involving 220 co-applicants.

The contract calls for 28 annual report reviews and 28 compliance inspections per year (one each per permit). Each MS4 is permitted on a 5-year cycle. DEP inherited a backlog of 2 expired permits and 15 annual reports to be reviewed. In addition, 11 permits expired in the initial contract year (calendar 2001).

To promote statewide consistency, the contractor has developed and implemented permit and fact sheet templates to be used for drafting permits. For annual report reviews, the contractor developed a review checklist that was praised by EPA as "an excellent tool" to establish consistency in reviewing reports by multiple staff members. The following is a summary of MS4 permit activity to date:

Annual Report (AR) Reviews:

- 28 AR reviews completed.
- 7 AR reviews in process.

Permitting:

- 1 permit issued
- 3 permit out for public comment
- 1 permit undergoing internal DEP review
- 17 permits in process

Compliance Inspections and Enforcement

At the direction of the DEP, the contractor is also responsible for compliance inspections. Activities include review of records, observation of pollution prevention and best management practices, and interviews with maintenance personnel. For industrial and construction sites, the DEP periodically assigns a list of inspections to be conducted in the form of a task order. EPA expects annual compliance inspection rates of 30% for construction sites and 10% for industrial permittees. As of this writing, a total of 365 construction/industrial facility inspections have been conducted.

Regarding the 28 Phase 1 MS4 permits (involving 220 co-permittees), EPA expects that municipal permits will be inspected annually. All 28 MS4s were inspected in calendar 2001. Municipal inspections average approximately one to two days and may include records review, interviews, inspections of maintenance logs and activities, and review of public education materials. In addition, Standard Operating Procedures (SOPs) for conducting MS4 inspections were developed, including inspection report templates and database formats.

The contractor has also gone to great lengths in developing SOPs for conducting multi-sector generic permit and construction generic permit compliance inspections. All inspectors have been certified under DEP's Florida Stormwater, Erosion and Sediment Control Program, and therefore have a common basis for inspection observations. The contractor also developed inspection-reporting formats, and an Internet based inspection report database. This has greatly enhanced statewide consistency related to data management.

Compliance reports are prepared for each inspection and forwarded to the DEP. Staff at the DEP evaluate non-compliance findings and decide what action will be taken in response to violations. All enforcement activities are initiated by the DEP. The contractor may be required to provide testimony as a fact witness in subsequent legal proceedings. Compliance activities completed to date are summarized below:

Inspection Activities:

- Completed 28 MS4 inspections.
- Conducted 365 construction/industrial inspections.

Enforcement Activities:

- Issued 2 Notices of Violation
- Issued 67 Warning Letter
- Issued 170 Non-compliance letters
- Issued 105 Compliance letters

It should be noted that the number of compliance inspections and enforcement activities conducted under year one of the contract exceed EPA's cumulative efforts for the past 10 years.

Self-Supporting Program

A new aspect of Florida's NPDES permitting program regards its self-supporting fiscal status. The 2000 Florida legislature provided the DEP with $1.9 million of spending authority to implement the NPDES stormwater program. But the legislature, during the delegation process, required that all operating costs for the program be recovered by collection of permit fees. In the past, up to 70% of the cost for a regulatory program could be subsidized by trust funds or from general revenue. With these subsidies eliminated, fees associated with the NPDES program are necessarily be larger than what would have been required in the past, with or without outsourcing. However, with respect to NPDES permits, Florida law allows for collection of "annual" compliance and surveillance fees for larger facilities and MS4s.

During the delegation process, the DEP held several workshops and public meetings in order to determine an equitable fee structure, particularly for MS4s. In an effort to ensure equity, dozens of draft versions were considered before a reasonable fee formula was agreed upon. For MS4s, each permittee is required to pay a standard flat fee, plus an additional amount based on population. The population-based portion of the fee was based solely on the 1990 census, as

therefore it is "fixed in time." For these municipalities, the formula agreed to was an annual fee of $8,000 + $0.017 per capita. Under the formula, the largest permittee group, Dade County and co-permitees, is assessed a total of $32,410, to be shared among co-permittees according to population.
The fee for the industrial general permit (MSGP) is $500 for five years of permit coverage. The cost for a construction permit is a one-time $150 NOI processing fee.

Program Costs

The cost for outsourcing of much of the NPDES stormwater program's functions have been somewhat higher than originally anticipated. Annual costs to the Department for implementing the MS4 program, including all permitting and compliance activities is $446,000. Unit costs for processing NOIs, NOTs, and No-Exposure Exemptions are $59, $54 and $58, respectively.

Costs for inspections, compliance and enforcement for construction/industrial facilities are a little more difficult to assess on a unit basis. This should be obvious, when one considers the variable nature of these activities. For example, inspections for facilities that appear regulated, but have not filed an NOI, may require additional inspector efforts in order to establish that the activity is in fact regulated. Also, the inspector must establish the owner, find the proper contact person, and schedule an on-site meeting. Further, the follow-up required depends upon what is discovered during the inspection. It is safe to say at this point, however, that costs for inspections, inspection reports, follow-up letters and/or enforcement documents, and enforcement meetings have ranged between $500 and $800 per inspection. This work is accomplished at a contract rate of $64 per hour.

CONCLUSION

After years of anticipation and preparation, the DEP has begun administration of the NPDES stormwater program. The authorities provided by the Clean Water Act and federal regulations will provide the DEP with new tools for addressing water quality problems from stormwater run-off, one of the major sources of water quality impairment in the State. Both the regulated community and the DEP are waiting to see how effective the "outsourcing" of this program will be, especially as the private and public sectors form partnerships on an increasing basis. Recent advances in technology have assisted the new partnership, as both State and contractor have common access to records, and are able to share information instantly via electronic media. ***Successful implementation of this program may provide public agencies a new model for partnering with the private sector.*** By most accounts so far, the program is operating with relative efficiency and is providing an increased level of environmental protection.

EVALUATION OF EQUIVALENT ALTERNATIVE STORMWATER REGULATIONS FOR THE CITY OF ORLANDO

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ABSTRACT

Construction of a dual pond stormwater management system is currently required for all new development within the City of Orlando. The initial pond, constructed as an off-line system, is designed for pollution abatement and may consist of either a dry retention pond or a wet detention pond. The additional volume of runoff in excess of the capacity of the pollution abatement pond is directed into a second facility which is designed to control and release stormwater inputs at a rate which does not exceed the peak rate of discharge for the site in the pre-development condition. Alternatives to this requirement have been historically reviewed on a case-by-case basis by the City. However, to provide a higher degree of flexibility for future development, the City desires to establish a wide variety of equivalent stormwater management techniques which will exhibit the same performance efficiency achieved by current Orlando stormwater regulations, while maintaining flexibility in meeting the overall objectives of the stormwater management program.

During 2001, ERD completed an evaluation for the City of Orlando to determine the performance efficiencies of existing stormwater management systems designed under current regulations and to develop alternative stormwater treatment options which provide the same pollutant removal efficiencies. The alternative stormwater treatment options developed include on-line dry retention systems, on-line wet detention systems, off-line retention, liquid/solids separation technologies, and street sweeping. Specific design criteria were developed for each alternative treatment option.

This paper was not available at the time these Proceedings were compiled. Therefore, only the abstract has been printed. The paper will be provided at the conference and future printings will include the paper in the back of the Proceedings.

INFILTRATION OPPORTUNITIES IN PARKING LOT DESIGNS REDUCE RUNOFF AND POLLUTION

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ABSTRACT

A low impact (dispersed) design demonstrated how small alterations to parking lots can reduce runoff and pollutant loads. A whole basin approach utilized the entire watershed for stormwater management. Storm runoff was treated as soon as rain hit the ground by routing it through a network of swales, strands and finally into a small wet detention pond. When the volume of water from all the different elements of the treatment train (the swales, the strand and the pond) were compared, almost all the storm runoff was retained on site. Further, the size of the wet detention pond used for final treatment could be greatly reduced because of more pervious areas. Individual basins in the parking lot, the various elements in the treatment train, and rainfall usually had significantly different water quality concentrations. Most of the nitrate and ammonia entered the system directly in rainfall and concentrations in runoff were usually reduced as it traveled through the system. Ammonia-nitrogen was highest in the runoff from the basin without a swale and organic nitrogen and phosphorus highest in the strand and pond; metal concentrations were highest in basins paved in asphalt. Polycyclic aromatic hydrocarbons (PAHs) were detected in the soils at the site and some approached the significantly toxic levels. Chlordane was the pesticide most often detected in measurable quantities in soils. Dichlorodiphenyltrichloroethante (DDT) and its daughter products were detected in almost all soils tested and DDE was found in measurable quantities.

INTRODUCTION

Impervious surfaces, such as parking lots and roof tops, cause more stormwater runoff and pollutant loads than any other type of land use. These hard surfaces, which often replace natural vegetative cover, increase both the volume and peak rate of runoff and also provide a place for traffic-generated residues and airborne pollutants to accumulate and become available for wash off. An innovative parking lot at the Florida Aquarium in Tampa was used as a research site to determine whether small alterations to parking lot designs can decrease runoff and pollutant loads. During a two-year period over 50 storm events were sampled to measure water quality and quantity from eight small basins in the parking lot. In addition, once the berm between Ybor channel and the strand was repaired, data for one year included the strand and the pond. Sediment samples were analyzed to estimate long-term consequences and statistics were used to evaluate relationships. In this report, swales were defined as vegetated open channels that infiltrate and transport runoff water while strands were larger vegetated channels collecting runoff after treatment by swales.

METHODS

Site description - The parking lot design for the Florida Aquarium used the entire drainage basin for low-impact (dispersed) stormwater treatment. The study site is a 4.65 hectare (11.25 acre) parking lot serving 700,000 visitors annually. The amount of stormwater runoff was reduced by incorporating pervious vegetated areas into the overall design. Changing regulations by making parking spaces 0.62 meters (2 feet) shorter provided land for swales without reducing the number of parking spaces. It also did not compromise parking since the design had the front end of vehicles hanging over grass rather than impermeable paving. The research was designed to determine pollutant load reductions measured from three elements in the treatment train: different treatment types in the parking lot, a strand planted with native wetland trees, and a small pond used for final treatment (Figure 1a.). The final treatment pond discharges to Tampa Bay (HUC 03100206), an Estuary of National Significance included in the National Estuary Program and identified as a water body in need of attention (Section 19, Township 29, Range 19, Hillsborough County).

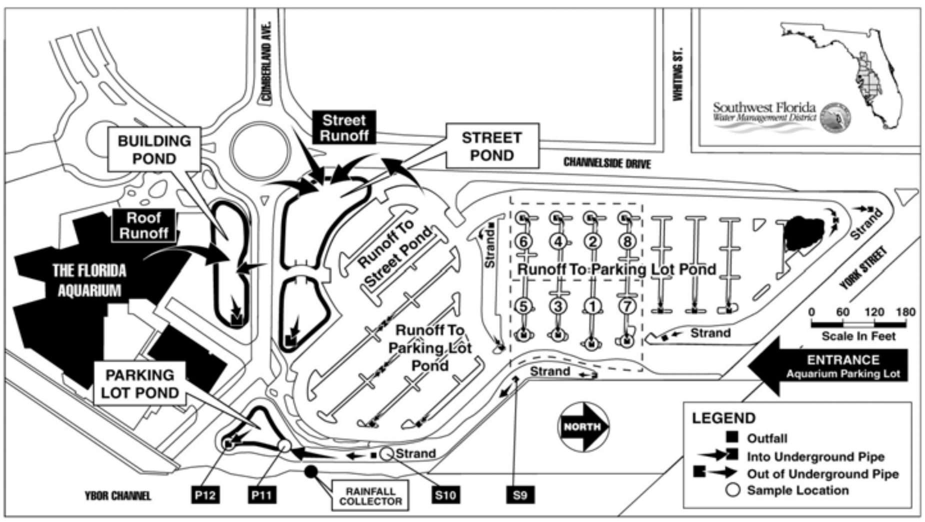

Figure 1a. Site Plan of the Parking Lot Demonstration Project showing sampling locations. The eight drainage basins evaluated in the parking lot are outlined by the dotted lines and are shown in more detail in Figure 1b. Numbered black boxes indicate sampling locations in the strand and the pond.

Experimental design - The experimental design in the parking lot allowed for the testing of three paving surfaces as well as basins with and without swales, creating four treatment types with two replicates of each type (Figure 1b.). The eight basins were instrumented to measure discharge volumes and take flow-weighted water quality samples during storm events. The four treatment types included: (1) asphalt paving with no swale (typical of most parking lots), (2) asphalt paving with a swale, (3) concrete (cement) paving with a swale, and (4) porous (permeable) paving with a swale. The swales are planted with native vegetation. The basins without swales still had depressions similar to the rest of the parking lot, but the depressions were covered over with asphalt. Three different breaches through the berm that was located between the strand and Ybor

Channel interfered with collecting data in the strand and pond as planned, but even so, over one year of data were collected and analyzed once the problem was corrected in July 1999.

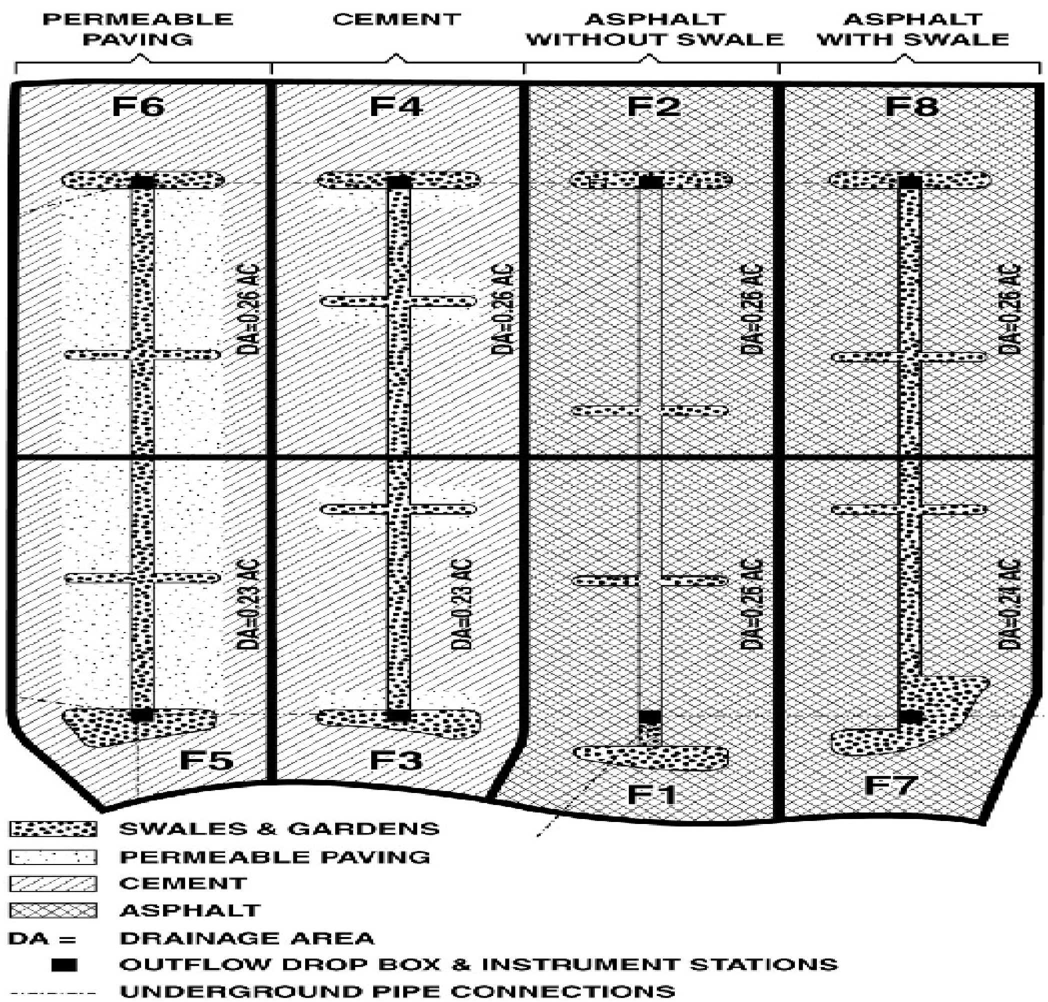

Figure 1b. Site plan of the parking lot swales delineated by the dotted lines in Fig 1a.

Flow out of each of the eight small parking lot drainage basins (0.09 to 0.105 ha) was measured using identical H-type flumes and shaft encoders (float and pulleys) connected to four Campbell Scientific CR10^{TM} data loggers. The major differences at the pond site compared to the parking lot were the primary measuring devices that were weirs instead of flumes. *Rainfall characteristics* were calculated using measurements from a tipping bucket rain gauge, summed over 15 minute intervals and stored in Campbell Scientific CR10^{TM} data loggers. Runoff coefficients (RC), LOADS, and LOAD EFFICIENCY were calculated using the following formulas:

RC = (volume discharged) / ((basin size)*(rainfall amount))
LOADS (kg/ha-yr) = ((concentrations)*(volume discharged))/(basin size)
LOAD EFFICIENCY (%) = ((Sum of Loads (SOL) in - SOL out)/SOL in)*100

Water quality samples were collected on a flow-weighted basis and stored in iced ISCO samplers until picked up, fixed with preservatives and transported to the Southwest Florida Water Management District (SWFWMD) laboratory. Samples were analyzed according to the guidelines published in their Quality Assurance Plan. Rainfall was collected using an Aerochem Metrics™ model 301 wet/dry precipitation collector. *Sediment samples* were collected in front of the outfall (drop box) in each of the swales, and also at one location in the strand and two locations in the pond during the fall of 1998 and again in the fall of 2000 (see Figure 1a.). Samples were extracted intact from the sediments using a two-inch diameter hand driven stainless steel corer. Cores were collected at two depths, representing sediments in the top 2.54 cm (1 in) layer and sediments 10 to 13 cm (5 to 6 in) below the surface. Residue in the drop boxes used to transport stormwater to the strand was also collected in 1998. Sediments were analyzed by the Department of Environmental Protection laboratory in Tallahassee using the methods outlined in their approved Comprehensive Quality Assurance plan. *Statistical computations* were performed using the SAS system (v 8.1) to determine significant differences and to analyze relationships among variables, and most test were run using non-parametic statistics such as Spearman correlations, Wilcoxon rank sum test and the Kruskal-Wallis chi-square test.

RESULTS AND DISCUSSION

Hydrology

Runoff – Drought conditions existed for both years but were much more severe the second year with only 77.22 cm (30.4 in) of rain instead of the average 132 cm (52in). This also reduced the runoff coefficient and storm flow that would have been expected in a normal year. The runoff coefficient (Table 1) accounts for the integrated effect of rainfall interception, infiltration, depression storage, evaporation and temporary storage in transit. If all the rain falling on a drainage basin ran off, the coefficient would be 1.0 or 100 percent. Except for basin F1, the odd numbered basins were slightly smaller and had larger recessed garden areas than the even numbered basins. The larger garden areas (less than the size of one parking space) in the odd numbered basins accounted for their 40 to 50 percent lower runoff coefficients. Another factor that may account for the good infiltration rate is the soil structure. The site is constructed on filled land and from soil analysis, the Florida Aquarium parking lot had a high gravel content (average 9.9% for soil particles > 2 mm) and it usually took a rain event of at least 0.84 cm (0.33 in) to produce enough flow to collect samples in the basins with planted swales. Also the data suggest that for large rain events, basin F2 overflowed its boundaries and some of its runoff was actually discharged from basin F1. This accounted for the smaller runoff coefficient for both years in basin 2 despite the similarity between the two basins.

Comparison of flow - One of the major advantages of low impact designs for parking lots is the reduction in the volume of water discharged from the site. When the volume of water discharged from the different elements of the treatment train at the Florida Aquarium site were compared, the results showed almost all runoff was retained on site. It was estimated that 6751 cubic meters (231,342 cubic feet) were discharged from the parking lot into the strand, while 1791 cubic meters (63,258 cubic feet) were discharged from the strand through the under drain pipe and into the pond. Only 20 cubic meters (706 cubic feet) were actually discharged from the pond into the receiving waters. Although the year sampled was during an extreme drought, which reduced flow considerably, it is still remarkable that stormwater was discharged for only one storm event and would probably have only discharged four or five times in a normal year. The data represented all major storms that produced significant flow for the one-year period.

Table 1. Summary of runoff coefficients for the eight basins calculated separately for the two years.

	RAIN AM'T cm	ASPHALT WO/SWALE F1	F2	ASPHALT W/SWALE F7	F8	CONCRETE W/SWALE F3	F4	POROUS W/SWALE F5	F6
YEAR ONE		**Total rain (cm)**		**87.71**					
Average	2.66	0.58	0.50	0.15	0.31	0.19	0.29	0.09	0.17
Median	2.08	0.57	0.48	0.12	0.30	0.13	0.25	0.02	0.14
max	6.60	0.97	0.86	0.43	0.78	0.67	0.75	0.51	0.59
Stddev	1.57	0.18	0.17	0.12	0.19	0.19	0.22	0.12	0.17
c.v.	0.59	0.31	0.33	0.83	0.60	1.01	0.76	1.44	0.98
YEAR TWO		**Total rain (cm)**		**77.22**					
Average	3.09	0.50	0.43	0.15	0.29	0.17	0.27	0.10	0.15
Median	2.72	0.53	0.46	0.08	0.29	0.06	0.26	0.04	0.13
max	7.49	0.78	0.67	0.53	0.74	0.65	0.72	0.56	0.72
Stddev	1.55	0.18	0.15	0.15	0.18	0.20	0.18	0.15	0.17
c.v.	0.50	0.36	0.34	1.00	0.63	1.18	0.66	1.49	1.09

Water Quality

Concentrations - The median concentrations of constituents measured in each of the basins for all storms sampled showed some differences between paving types as well as other variables. A comparison of constituents for all storms (Figure 2.) indicated some of the processes taking place in the parking lot, the strand, the under drain and the pond. For inorganic nitrogen, nitrate levels were highest in the parking lot and much lower once water collected in the strand and pond. High concentrations were also measured in rainfall. Ammonia was measured at lower concentrations than nitrate in the parking lot and about the same concentrations in the strand and pond. At least some of the higher than expected ammonia concentrations in the strand and pond can be attributed to stagnant conditions since storm water seldom flowed this far through the system. Ammonia had its highest concentrations in rainfall and the basins paved with asphalt. The lowest concentrations of organic nitrogen were measured in rainfall and also the basins without a planted swale while concentrations are highest in the strand and pond.

Phosphorus concentrations (Figure 2.) were much lower in rainfall and only somewhat higher than rainfall in the basins without planted swales (F1, F2). The highest concentrations of phosphorus were measured in basins where runoff had traveled through grassed areas (F3, F4, F5, F6, F7, F8) and in the vegetated strand. The higher concentrations measured in the under drain and in the pond may have been caused by added mulch. Some metals in runoff reflected the type of paving material over which it traveled as illustrated in Figure 2 with iron. Iron, manganese, lead, copper and zinc were measured at concentrations over twice as high in the basins paved with asphalt (F1, F2, F7, F8) compared to the basins paved with concrete products.

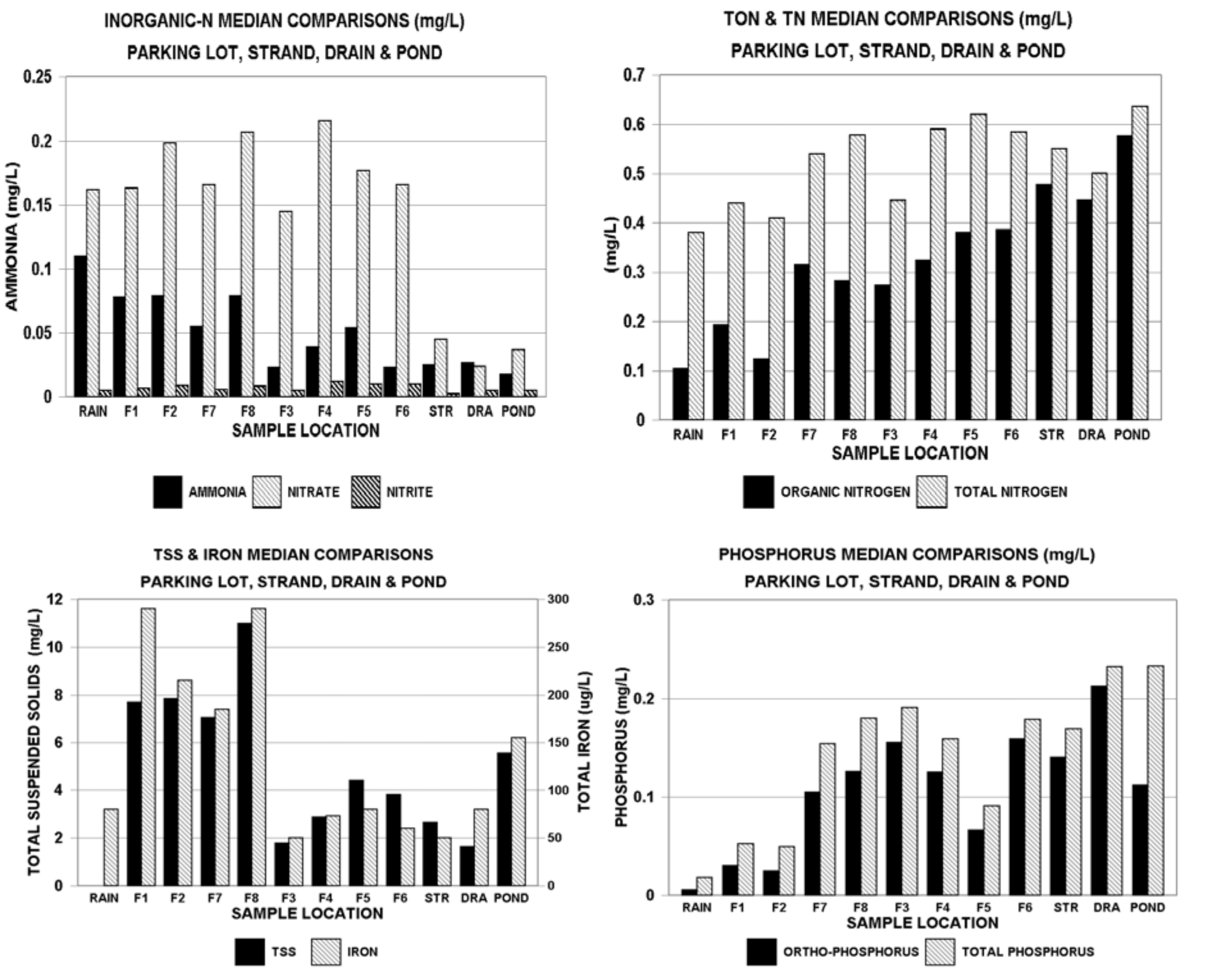

Figure 2. Comparison of median water quality concentrations at the outflows of the various elements of the stormwater system. See Figure 1 for sample locations. Abbreviations: STR=strand, DRA=under drain, POND=pond.

Load efficiencies, which include both runoff volume and water quality concentrations in the calculations, quantified how much pollution can be reduced by infiltration in vegetated depressions (Table 2). The basins paved with porous pavement had the best per cent removal, with most removal rates greater than 75%. Phosphorus was a notable exception and higher phosphorus loads were discharged from basins with vegetated swales than from the basins with no swales. This might be expected since there is not much phosphorus in rainfall, asphalt or automobile residues, but there is phosphorus in vegetation and especially in soils. Some of the poor reduction in phosphorus loads may also be attributed to landscaping practices since high concentrations, some greater than 1 mg/L, were sometimes measured in the basins with swales during the spring. Also total nitrogen was not removed as well as other pollutants. As almost all runoff was eventually retained on site, these were not serious problems. Additional infiltration capacity such as porous paving or larger garden areas (F5, F3, F7) improved efficiency, indicating both infiltration and more mature vegetation can improve total nitrogen efficiency (Table 2).

Table 2. Load efficiency (%reduction) of pollutants compared to basins with no swales. (F2 for even numbered basins and F1 for odd numbered basins).

Constituents Smaller gardens	**Asphalt with swale F8**		**Concrete w/ Swale F4**		**Porous w/swale F6**	
	YEAR 1	YEAR 2	YEAR 1	YEAR 2	YEAR 1	YEAR 2
Ammonia	46%	42%	73%	49%	85%	75%
Nitrate	44%	21%	41%	22%	66%	60%
Total Nitrogen	4%	12%	16%	8%	42%	55%
*Ortho Phosphorus	-180%	-230%	-180%	-337%	-74%	-153%
*Total Phosphorus	-94%	-157%	-62%	-216%	3%	-77%
Suspended Solids	46%	-11%	78%	78%	91%	71%
Copper	23%	14%	72%	60%	81%	82%
Iron	52%	-16%	84%	83%	92%	87%
Lead	59%	28%	78%	75%	85%	83%
Zinc	46%	15%	62%	50%	75%	41%
Constituents Larger gardens	**Asphalt with swale F7**		**Concrete w/ Swale F3**		**Porous w/swale F5**	
	YEAR 1	YEAR 2	YEAR 1	YEAR 2	YEAR 1	YEAR 2
Ammonia	80%	79%	86%	83%	80%	90%
Nitrate	73%	67%	64%	55%	79%	80%
Total Nitrogen	58%	66%	58%	54%	71%	81%
Ortho Phosphorus	-1%	-4%	-105%	-149%	-61%	55%
Total Phosphorus	-26%	16%	-32%	-69%	76%	66%
Suspended Solids	83%	56%	91%	91%	92%	89%
Copper	81%	75%	81%	79%	94%	94%
Iron	87%	79%	91%	94%	94%	94%
Lead	87%	73%	83%	85%	93%	94%
Zinc	79%	72%	76%	72%	89%	86%

* Notice that some efficiencies are negative, indicating an increase in loads in the basins with a swale.

Sediment Samples

Soil samples were collected in the swales, the strand and the pond in 1998 and again in 2000 (see Figure 1 for sampling locations). For 1998, samples were also collected in the drop boxes that received runoff from the swales. For the basins without swales, the sediments that had accumulated in the asphalt depressions were analyzed and there were no deeper soils to sample.

Metals - In 1998, metals were usually measured at higher concentrations in basins paved in asphalt (F1, F2, F7, F8) compared to basins paved with concrete (F3, F4) or porous paving (F7, F8), while inconsistent concentrations were measured in 2000 (Figure 3). Aluminum, iron and copper concentrations measured in the strand and pond only occasionally showed concentrations as high or higher than the asphalt basins in the parking lot even though most of the 10-acre parking lot is paved in asphalt. At least for 1998, results suggest that the swales and strand are effective for sequestering metals near the source. An example with zinc is shown in Figure 3.

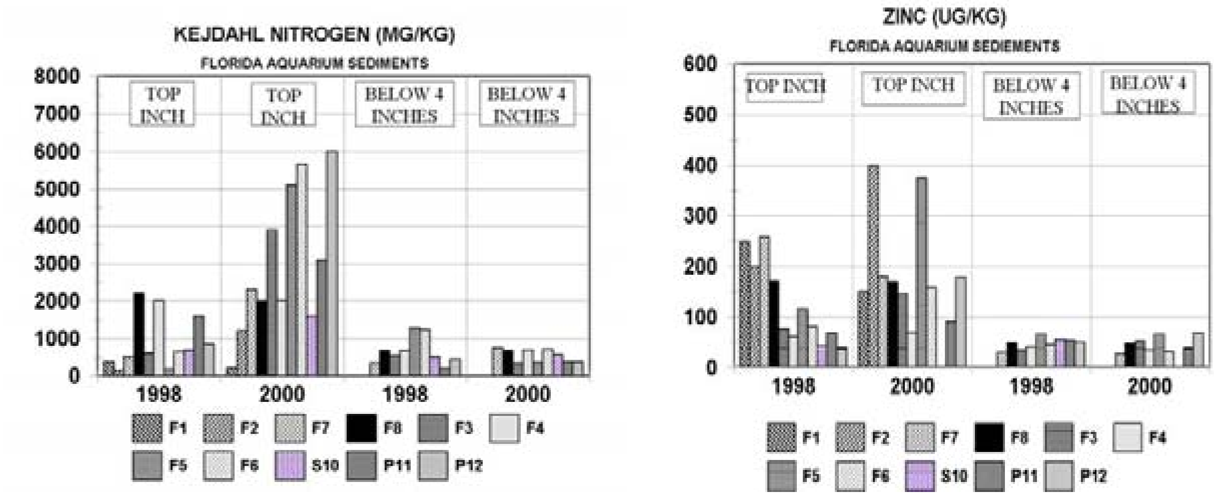

Figure 3. Sediment samples for zinc and total Kejdahl nitrogen collected in 1998 and again in 2000 at the outfall of each drainage basin as well as in the swale (S) and pond (P).

When the site in the strand in 1998 (S10) is compared to values in 2000, the year 2000 concentrations are usually significantly lower and can be explained by the berm repair that uncovered deeper cleaner soils. When the Pond data are compared between years, the concentrations are much higher in 2000, probably the result of Ybor channel water pumped into the pond during the repair and the subsequent inflow of stormwater from the channel into the pond through the under drain.

Nutrients - Total phosphorus and Kjeldahl nitrogen measured in the soils showed an increase in most basins from 1998 to 2000, especially for nitrogen (Figure 3). Usually nutrients are quite low for the basin without a swale that has no vegetation or deeper soils to cycle nutrients. Nitrogen, and to a certain extent phosphorus, increased in the swales from 1998 to 2000. The pond showed a considerable increase in both phosphorus and nitrogen from 1998 to 2000. Total phosphorus in the deeper sediments also increased by 2000, but a corresponding increase in nitrogen in the deeper sediments was not usually seen.

Polycyclic aromatic hydrocarbons (PAHs) – The most commonly measured PAHs are compared by percentages in Table 3. The highest percentages of detection were found at the deeper depths (12.7 cm) implicating previous hydrocarbon contamination. The lowest number of samples with hydrocarbon detection occurred in the surface soils in 2000, suggesting that hydrocarbon pollution is decreasing at the site. The most frequently measured hydrocarbon was fluoranthene, which was detected in at least 50 percent of the samples collected in each category. Chrysene and pyrene were also frequently detected, followed by the benzo-series (Table 3).

Table 3. Percentage of samples that detected pollutants in each of the soil strata for each of the eleven sampling sites.

PAH SEMI-VOLATILE ORGANIC		1998 TOP	1998 DEEP	1998 BOX	2000 TOP	2000 DEEP
Acenaphthene	ug/kg	0	20	25	0	17
Acenaphthylene	ug/kg	0	0	0	0	17
Anthracene	ug/kg	0	17	25	0	17
Benzo(a)anthracene	ug/kg	67	70	38	40	70
Benzo(a)pyrene	ug/kg	75	70	38	33	60
Benzo(b)fluoranthene	ug/kg	42	70	25	17	70
Benzo(k)fluoranthene	ug/kg	50	50	25	17	20
Benzo(g,h,i)perylene	ug/kg	17	30	13	17	20
Bis(2-ethylhexyl)phthalate	ug/kg	8	0	0	0	10
Butyl benzyl phthalate	ug/kg	0	0	50	0	10
Chrysene	ug/kg	67	70	38	50	70
Fluoranthene	ug/kg	75	100	63	50	80
Fluorene	ug/kg	17	0	13	0	10
Indeno(1,2,3-cd)pyrene	ug/kg	17	30	25	17	30
Phenanthrene	ug/kg	75	70	25	25	40
Pyrene	ug/kg	83	90	50	58	80
PESTICIDES						
Diazanon	ug/kg	10	0	50	0	0
Chlordane	ug/kg	75	40	63	25	10
DDD-p,p'	ug/kg	17	30	13	8	20
DDE-p,p'	ug/kg	83	60	50	66	30
DDT-p,p'	ug/kg	33	50	12	42	50
Dieldrin	ug/kg	0	20	63	0	8
Endosulfan Sulfate	ug/kg	0	0	8	42	10
Methoxychlor	ug/kg	0	0	0	17	8
PCB-1260	ug/kg	33	70	38	17	20

Pesticides & PCB's - At most sites pesticides and polychlorinated biphenyls (PCBs) were not detected but there were some exceptions (Table 3). Chlordane was the pesticide most often detected in measurable quantities and it was found at all locations but three. Dichloro-diphenyltrichloroethante (DDT) and its daughter products were measured at almost all locations, and DDE was found in measurable quantities. But the quantities were not considered toxic. Polychlorinated biphenyl (PCB-1260) was frequently detected in the soils and it was more often detected in the deeper sediments than in the surface soils.

Statistical Analysis

Differences among basins - Since there were few significant differences between years, all 59 storms sampled were combined for hypothesis testing. The basins exhibited at least one significant difference for all parameters except nitrate (Table 3). Some of the patterns can be explained by basin characteristics. For example, the basins paved in asphalt had significantly higher concentrations of metals and total suspended solids, which may be increased by the paving material itself. Higher phosphorus concentrations were measured in basins with planted swales, a result of vegetation, landscape practices, and soil particles.

Table 4. Significant differences between even numbered basins. Data from Duncan Multiple Range Test and significant differences calculated by the Kruskal-Wallis test.

Parameter	Pr>Chi-Square	Asphalt no swale	Asphalt with swale	Concrete with swale	Porous with swale
		F2	F8	F4	F6
Ammonia	0.0004	0.111 a	0.112 a	0.069 b	0.049 b
Nitrate	0.76 ns	0.264 a	0.263 a	0.242 a	0.221 a
Total Nitrogen	0.05	0.511 b	0.737 a	0.684 ab	0.639 ab
Ortho-Phosphorus	< 0.0001	0.047 b	0.192 a	0.203 a	0.195 a
Total Phosphorus	< 0.0001	0.082 b	0.267 a	0.253 a	0.237 a
Total Copper	< 0.0001	12.70 a	9.929 a	4.892 b	4.08 b
Total Iron	< 0.0001	431.67 a	328.93 a	85.40 b	87.73 b
Total Lead	< 0.0001	3.43 a	3.42 a	1.14 b	1.30 b
Total Zinc	< 0.0001	40.62 a	35.01 a	20.80 b	22.12 b
Total Suspended Solids	< 0.0001	16.02 a	11.48 a	4.70 b	5.53 b

MAJOR FINDINGS

- Basins with swales and paved in asphalt or concrete reduced runoff to 30 percent and porous paving, to about 16 percent; while basins without planted swales and only small garden areas reduced runoff to 55 percent. The basins with larger garden areas reduced runoff by an additional 40-50 percent (Table 1)
- Basins paved with porous pavement showed the best percent removal of pollutant loads with greater than 80 percent removal (except phosphorus) in basins with larger garden areas. (Table 2). When the entire system is evaluated pollution reduction is greater than 99 percent since almost all runoff was retained on site.
- Sediment samples implicated asphalt paving material as a source for metals (Figure 2). TKN and phosphorus in the sediments showed a considerable increase from 1998 to 2000 (Figure 2). Polycyclic aromatic hydrocarbons (PAHs) were detected in the soils at the site and some approached the significantly toxic levels (Table 3).

ACKNOWLEDGEMENTS

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Copies of the complete report are available from the author by request.

USE OF WETLANDS FOR TREATING FLORIDA'S AGRICULTURAL RUNOFF

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ABSTRACT

During the past decade, there has been increased interest in the use of wetlands as a technology for removing nutrients from agricultural wastewaters and runoff. Florida has been the site of some of the most innovative research on this topic, and is also the location of the world's largest operational wetlands used for agricultural runoff treatment. Such wetlands can be characterized as either passive systems, where little effort is made to control the type of vegetative community; moderately managed systems, whereby through water depth control a specific vegetative community is encouraged to thrive; or actively managed systems, where nutrients are directly removed from the system through vegetation harvest. This presentation addresses the current status of wetlands for treating agricultural runoff in Florida, as well as the opportunities and limitations related to operating treatment wetlands under these various management regimes.

INTRODUCTION

Agriculture has been a prominent industry in Florida for over a century, with citrus, beef cattle, dairy cattle, vegetable and sugarcane production contributing significantly to the state's economy. In recent decades, however, water managers have realized that non-point runoff resulting from many of these agricultural activities has adversely affected some of Florida's most prominent water bodies. For example, Lake Apopka water column TP concentrations increased from <60 μg/L to > 200 μg/L during the latter half of the 20^{th} Century, largely in response to agricultural drainage water (ADW) discharges from vegetable farms located in the lake's former floodplain marsh (Reddy et al, 1999).

Phosphorus (P) is the limiting nutrient for most of Florida's freshwater bodies, and it is this constituent of ADW that has caused adverse impacts to many of the state's lakes and streams. Key examples include the impacts of P in vegetable farm runoff to Lake Apopka, impacts of P in dairy farm runoff to Lake Okeechobee, and impacts of P in sugarcane, vegetable and sod farm runoff on the Water Conservation Areas north of Everglades National Park.

Wetlands are an effective, but land intensive technology for treating sources of non-point runoff. Agricultural settings often are more appropriate for deployment of wetlands for non-point source treatment than highly urbanized regions, due to the greater availability and lower cost of land.

Further, wetlands are an appropriate technology for treating non-point runoff because they can accommodate varying flows and are relatively inexpensive to operate.

A potential disadvantage of wetlands for ADW treatment in Florida is that these systems are not overly efficient at removing P on a mass per unit area basis. There are no gaseous losses of this element from the wetland, as there are for carbon and nitrogen, with sediments comprising the only sink for P removed from the water column. For example, in the Stormwater Treatment Area (STA) wetlands that are being built in Florida south of Lake Okeechobee, the projected P removal rate is 1 gP/m^2-yr, or 100 ha of land required to annually sequester 1000 kg of P. This large land requirement has led to research and pilot-scale testing of innovative design and management approaches to enhance wetland P removal.

In this paper, we describe some of the existing and planned full-scale efforts being conducted to deploy wetlands to mitigate adverse effects of ADW on downstream waters. We also describe some of the efforts, both full-scale and pilot-scale, to improve P removal performance of these systems.

Regional Wetlands for Agricultural Drainage Water Treatment

Everglades Agricultural Area Watershed STAs

Water managers in Florida are implementing an approach of constructing "regional" treatment wetlands to sequester P exported from agricultural operations in upstream portions of the watershed. In south Florida these regional treatment wetlands are called Stormwater Treatment Areas (STAs). Approximately 7,300 ha of STAs have been constructed to intercept runoff from the 296,000 ha of farms in the Everglades Agricultural Area (EAA) located south of Lake Okeechobee, and an additional 9,450 ha of STAs are slated for construction during the next five years. There ultimately will be a network of six STAs, reducing inflow ADW TP concentrations of 100 – 200 µg/L down to a target outflow of 50 µg/L.

Typical specifications of the "EAA" STAs are as follows (data obtained from unpublished South Florida Water Management District [SFWMD] reports):

- size range: 960 - 6674 ha
- hydraulic loading rate (HLR): 2.7 cm/day average; 30 cm/day peak
- average inflow [TP]: 145 µg/L
- average P loading rate: 1.43 gP/m^2-yr
- projected performance: 66% concentration reduction, to 50 µg/L TP
- average annual mass of P removed: 27.2 metric tons per STA
- average capital cost: $14,185/acre

The area requirement, or "footprint", of the EAA STAs originally was designed based on a target outflow TP concentration of 50 µg/L. Because recent research has shown that lower TP levels, potentially as low as 10-15 µg/L, will be needed to protect the pristine regions of the Everglades, there is considerable interest in "optimizing" the STAs so that they will provide additional P removal, and thereby achieve lower outflow TP concentrations. In an "unmanaged" state, the STA vegetation consists of a mixture of emergent, submerged and floating plant communities.

Vegetation management was not a component of the original STA design, because at the enormous scale of the STAs, it was widely held that it is prohibitively expensive to preferentially establish certain types of vegetation.

The SFWMD and Florida Department of Environmental Protection (FDEP) have funded a number of projects to enhance performance of the STAs. One of most promising is a project in which submerged aquatic vegetation (SAV) is encouraged to proliferate, rather than the typical mixture of vegetation found in the wetlands. SAV dominance is achieved by rapid flooding of the wetland upon hydration, which effectively kills most of the emergent macrophyte propagules. Long-term emergent plant control is achieved through periodic, spot herbiciding of any emergent plants that appear. Several large STA cells are now dominated by SAV, and one such wetland has provided mean outflow total P concentrations of 14 μg/L for as long as two years.

In hard waters, such as those found in the EAA watershed, SAV wetlands provide superior P removal to emergent plant communities because of an ancillary, biochemical P removal pathway. Photosynthesis by the SAV community results in an elevation in the water column pH, which in turn leads to precipitation of $CaCO_3$. Soluble reactive P (SRP) in the water column either adsorbs to, or is co-precipitated with, the $CaCO_3$, resulting in a reduction in water column P. This also results in high levels of $CaCO_3$ in the sediment, which facilitates retention of the sequestered P.

We consider the encouragement of SAV in wetlands used for ADW treatment to be a "moderate" level of management, where the extra expense associated with water depth control and spot herbiciding is justified by the superior P removal performance of the wetland biota.

Lake Okeechobee Watershed STAs

Stormwater Treatment Areas also are proposed for deployment in the drainage basin north of Lake Okeechobee, where P laden ADW from dairy farms and cattle ranches feeds into the lake. In the late 1980s, the P loads to Lake Okeechobee from the upstream agricultural watershed were estimated at 272 metric tons (Anderson and Flaig 1995).

Two such STAs are in an advanced stage of design (Stanley Consultants 2000). One small STA (68 ha) will be deployed adjacent to Taylor Creek, and a second, larger (715 ha) STA will be deployed adjacent to Nubbin Slough. The Taylor Creek STA is projected to reduce inflow total P concentrations of 620 μg/L to a mean of 69 μg/L. At the average proposed HLR of 6.2 cm/day, this is equivalent to a P removal rate of 4.6 gP/m^2-yr.

The Nubbin Slough STA will be designed to reduce inflow total P concentrations of 620 μg/L to between 10 and 50 μg/L. A mass P removal rate of as high as 2.59 gP/m^2-yr is projected for the STA. The proposed average HLR for this STA is 2.3 cm/day, which is similar to the HLRs projected for the EAA STAs. To date, no plans have been established to manipulate vegetation in the Lake Okeechobee STAs, so these systems can be considered to be "passive" with respect to vegetation management.

As noted above, because of massive scale of regional treatment wetlands, there is considerable interest in making STAs perform more efficiently. During 2002 and 2003, a private firm will be building and operating a pilot-scale project that is essentially an "actively" managed wetland for removing P from ADW. This system will be situated in the Lake Okeechobee watershed, and will consist of a water hyacinth pond, followed by a shallow raceway containing mats of attached algae (periphyton). Both the macrophytes and algae will require routine harvest, and the harvested biomass, rather than the sediments, will serve as the ultimate P sink. Clearly, for this approach to be successful, the P removal efficiency (on a mass per unit area basis) will need to be high, and some beneficial use of the harvested material must be found. These are the concepts that the private firm hopes to establish during conduct of the pilot study.

During 1999, we performed a small-scale investigation on the potential effectiveness of an actively-managed, sequential floating macrophyte – attached algae system for removing P from EAA runoff. The methods and results of this study are described in the following sections.

MATERIALS AND METHODS

In May 1999, we established an experimental facility adjacent to a large drainage canal that conveys EAA runoff from north to south, toward the northern reaches of the Florida Everglades. Water quantity and quality in the conveyance canals is dictated by rainfall and pumping at the farms, and the waters typically contain from 70 – 200 μg/L TP, at least half of which typically is in a bioavailable form (soluble reactive P [SRP]).

At the research facility, we fabricated a process train in duplicate, consisting of a 3.1 m L X 0.75m W X 0.09m D (area of 2.2m^2) shallow floating macrophyte (FM) raceway followed by 22 m L X 0.3m W X 0.02m D (area of 6.4m^2) attached algal (AA) raceway. The pair of systems was fed ADW at a HLR of 126 cm/day. Monitoring of the FMs and AAs (for inflow – outflow water P species and biomass and tissue P levels) was initiated in July 1999, and continued through April 2001. The FMs were stocked with two floating aquatic plants found in neighboring canals, water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*). Water sampling techniques, field measurements and laboratory techniques were performed using standard, EPA-approved methods.

RESULTS

During the July 1999 – April 2000 experimental period, the [TP] inflow to the treatment systems averaged 124 μg/L, and peaked as high as 275 μg/L. The FM reduced the inflow [TP] from an average of 124 μg/L to 83 μg/L, and the downstream AA further reduced [TP] to 45 μg/L (Figure 1). Average SRP inflow levels of 54 μg/L were reduced to 30 and 5 μg/L in the FM and AA unit processes, respectively (Figure 2).

On an areal basis, the inflow – outflow data demonstrate that the FMs removed an average of 51.5 mgP/m^2-day during the 9 month study. The mean P removal by the AA raceways was 16.4 mgP/m^2-day.

Plant weighing and harvesting (culling of biomass) was performed in the sequential systems at a frequency of 2 weeks (algae in AA) to 4 – 12 weeks (macrophytes in FM). Although both water hyacinth and water lettuce initially were stocked in the FMs, water hyacinths quickly out-competed the water lettuce and became the dominant species. Average water hyacinth productivity in the FM system during the study was 9.9 g dry wt./m^2-day, with a tissue P content averaging 2.6 mgP/g. Based on P in harvested biomass, P removal on an areal basis during the study averaged 25.0 mgP/m^2-day for the FMs. Note that these values represent about 50% of the TP removal estimated from inflow – outflow water flows and P concentrations, which suggests that some P removal mechanism(s) in addition to plant uptake (such as particulate P settling) was occurring in the FM systems.

The long, narrow AA systems were divided into three equal-sized sections for purposes of harvesting and quantifying periphyton growth and P uptake. This harvesting strategy revealed a strong influence of raceway location on periphyton performance. Algal productivity averaged 17.8 g dry wt/m^2-day in the front third of the raceway, and declined to 13.6 and 11.1 g/m^2-day in the middle and final thirds of the system. Raceway location had a similar effect on periphyton biomass [TP], with tissue P levels decreasing from 1.8 to 0.8 mgP/g from inflow to outflow regions of the raceway. On a biomass basis, P removal averaged 16.3 mgP/m^2-day in the AA raceways. Unlike for the FMs, this biomass P uptake value match almost exactly the calculated mass of P removed from the water during passage through the AA raceways.

DISCUSSION

On a mass removal per unit area basis, the "actively-managed" FM-AA system provided superior P removal to the STAs being designed and built for treating ADWs in south Florida. The inflow water we tested is identical to that being fed to STA-1W, a 2,700 ha STA located in western Palm Beach County. STA-1W originally was slated to receive ADW at an average TP concentration of 186 μg/L, and an average TP load of 1.39 gP/m^2-yr. The wetland is envisioned to remove 74% of the inflow TP (a mass removal rate of 1.03 gP/m^2-yr), and provide an outflow [TP] of 49 μg/L.

We can compare projected performance of STA-1W with that of our FM-AA system, which reduced a mean inflow [TP] of 124 to 45 μg/L, at a mean areal removal rate of 18.5 mgP/m^2-day (6.7 gP/m^2-yr). For this removal rate calculation, we used the more conservative biomass P uptake rates (rather than calculated water removal) for macrophytes and periphyton, and take into account that the FM comprised 25%, and the AA, 75% of the footprint of the experimental system. Even if the FM had received the higher mean inflow [TP] of 186 μg/L planned for STA-1W, the area requirement of the sequential FM-AA system would be markedly lower (about six-fold) than that of the treatment wetland.

Because of hydraulic considerations (periodic, high stormwater flows that require water storage), however, it is unrealistic that FM or AA systems would replace the EAA STAs, which are capable of some live storage of storm flows. It is possible that sequential FM-AA systems could be effective as a sidestream unit process for enhancing P removal from STAs. For this "active-management" approach to be cost effective, however, an economically viable use for the harvested biomass would need to be identified.

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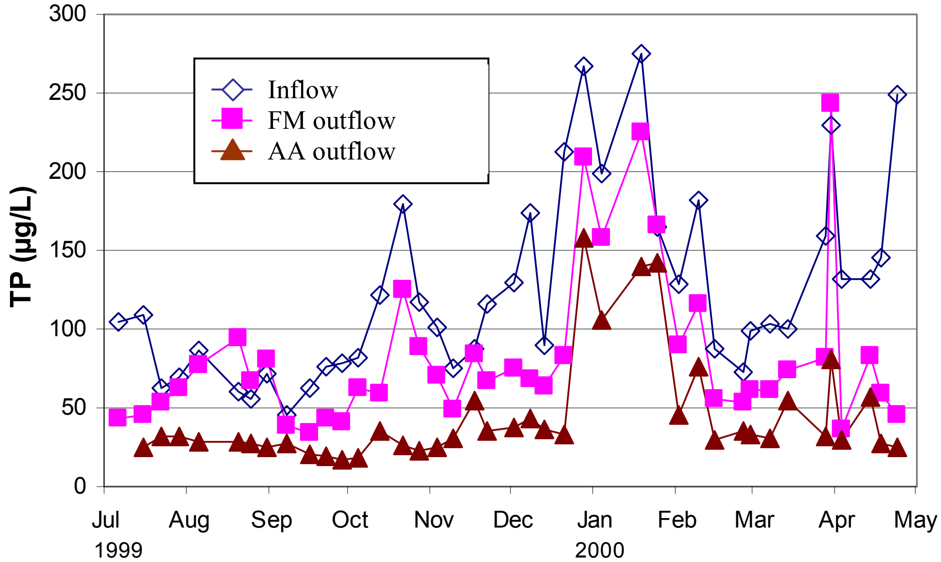

Figure 1. Total P removed by a sequential FM-AA system that received EAA runoff at a HLR of 126 cm/day. Values represent means from duplicate systems.

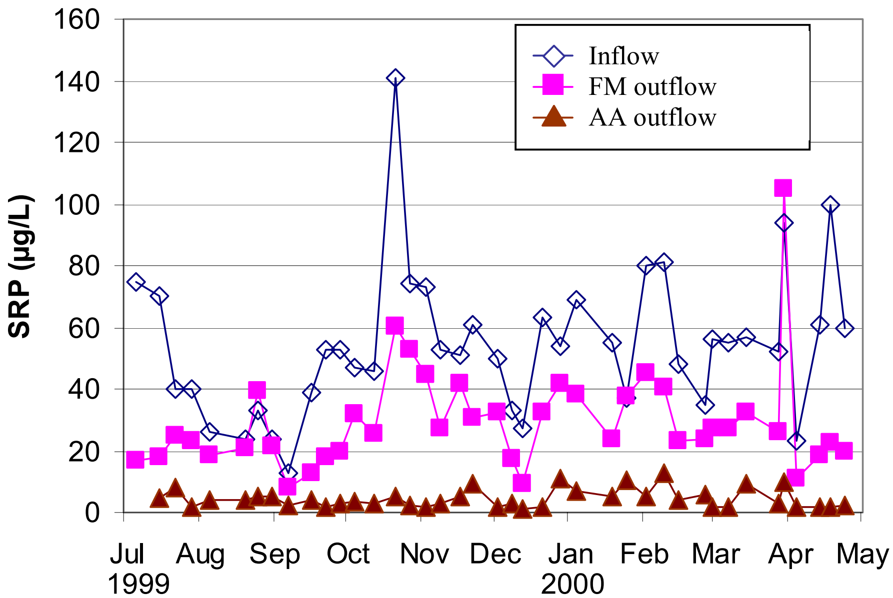

Figure 2. Soluble reactive P removed by a sequential FM-AA system that received EAA runoff at a HLR of 126 cm/day. Values represent means from duplicate systems.

STUDIES OF PARTICULATE PHOSPHORUS SOURCES AND POTENTIAL MANAGEMENT PRACTICES FOR CONTROL IN THE EVERGLADES AGRICULTURAL AREA

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ABSTRACT

Phosphorus in the drainage waters from the Florida Everglades Agricultural Area (EAA) can have a substantial impact on the receiving waters of the Water Conservation Areas (WCA's) and the Everglades National Park. Growers in the EAA are required by law to adopt a set of Agricultural Best Management Practices (BMPs) appropriate to their specific operation. The University of Florida Institute of Food and Agricultural Science (IFAS) has been involved in development and implementation of EAA BMPs for over ten years. The original BMP options, adopted in 1995, have resulted in significant reductions of phosphorus export from the EAA. Research subsequent to the issuance of the original set of BMP recommendations has shown that a large fraction of the phosphorus exported from individual farms is in the particulate form, which can account for 40-60% of the total phosphorus load.

The physicochemical characteristics of particulate phosphorus (PP) can differ greatly from the soluble inorganic and organic forms of phosphorus, consequently the identification of sources and the elaboration of transport mechanisms is essential for the development of effective control practices. The major sources of PP export have been found to be the biological growth within the farm canal and field ditch systems, rather than soil erosion, so traditional erosion control methods yield minimal benefit. Channel hydraulic conditions can have a major impact on the movement of PP. Growers may readily implement several control options. A number of others are currently under study for the development of economic practices.

INTRODUCTION

The South Florida Everglades, a natural resource unique in the United States, has been under ecological pressure for well over a century. The original Everglades watershed (Figure 1) was a broad, freshwater marsh that extended from what is now the Kissimmee River basin, through Lake Okeechobee, to the southern tip of the Florida peninsula. It included some 20,000 km^2 of upland and wetland territory. The historic flow, arising from a nearly flat land slope of five to 15 cm km^{-1}, was at very low velocity from north to south along a riverbed that was often 80 to 100 km wide. The ultimate discharge was into the waters surrounding the southern tip of Florida (Jones, 1948). Starting in the late 1800's large portions of the original Everglades were channelized and drained for development. Currently, there are over 2,500 km of major canals and levees supporting industry, municipalities, and agriculture. The Everglades Agricultural Area (EAA) is a part of this region.

The EAA (Figure 1.) is located south of Lake Okeechobee. The soils of this 280,000 ha tract are predominately Histosols underlain by marl and limestone. Approximately 200,000 ha are planted to sugarcane and about 40,000 ha are planted to vegetables, rice, and sod (Izuno et al., 1991). Farm water management is achieved using open field ditches to control water tables. Rainfall is highly seasonal and frequently intense. Virtually all drainage is by pumping with high volume pumps. Flows in the drainage/irrigation networks can undergo extreme variations, going from stagnation to maximum flow in short periods. Most drainage water from the EAA is ultimately discharged to the Water Conservation Areas (WCAs), Everglades National Park (ENP), or the South Florida coastal estuaries.

The agricultural drainage is nutrient-enriched compared to the original flows under which the Everglades evolved. This enrichment, specifically phosphorus (P), is cited as one of the causes of ecosystem changes in the WCAs and the ENP (LOTAC, 1990; Whalen et al., 1992). Current remediation plans require implementation of Best Management Practices (BMPs) by area growers, and the construction of numerous managed wetlands within the EAA (Whalen et al., 1992).

MATERIALS AND METHODS

From 1992 through the present, the UF/IFAS has undertaken a project to implement and assess the efficacy of BMPs at the farm level. To this end, 10 farms that are representative of EAA soils, geography, crop systems, and water management practices were chosen for inclusion (Figure 1.) in the study. An extensive array of monitoring instruments was installed at each farm site to track changes in P concentrations and drainage water discharge volumes.

In addition to the study concerning BMP development and efficacy, three related projects are also ongoing. The first project, initiated in 1996, is a demonstration of the short- and long-term effects of the BMPs on soils and crops. This work is being done in a state-of-the-art lysimeter field located on a grower's farm. The second project, initiated in 1997, monitors specific conductance and total dissolved phosphorus (TDP) at farm discharge structures, determines their characteristics in drainage water during different hydrologic events, and will develop control BMPs, if applicable. The third study, initiated in 2000, attempts to determine the relative importance of particulate matter in farm and EAA canal drainage streams. A major goal of the particulate study is to develop cost-effective BMPs that reduce the amount of PP leaving farms in the EAA.

RESULTS

Phosphorus is present in two forms, soluble (orthophosphate and soluble organics), and insoluble (minerals and particulate organics). Soluble phosphorus has received considerable attention. The primary sources for soluble phosphorus are soil mineralization and fertilizer application. Mineralization of the organic soils of the EAA is accelerated by over draining, which exposes the subsoil to aerobic conditions, causing oxidation and solubilization of organically bound phosphorus. A number of management practices have been implemented by the EAA growers to control water tables and reduce the opportunity for fertilizer-sourced phosphorus to reach the waterways (Bottcher, et al, 1995). These practices have been successful in reducing the movement of soluble phosphorus off the farms, but they do not, in all cases, address the discharge of phosphorus in the particulate form.

The magnitude of particulate phosphorus (PP) export was demonstrated by Izuno and Bottcher (1991). Further studies (Izuno and Rice, 1999) showed that PP accounted for 20% to 70% of the total phosphorus (TP) exported from EAA farms, and that PP export was frequently the cause of spikes in TP loads. Several EAA studies have evaluated the effectiveness of traditional runoff control and sediment trap technologies (Andreis, 1993; Hutcheon Engineers, 1995) to reduce PP loads. These studies were either inconclusive, or showed the traditional methods to be ineffective.

Stuck et al (2001) studied farm-scale PP transport, and proposed the "Biological Contribution Mechanism", claiming the majority of PP in the EAA originates from in-stream biological growth rather than from soil erosion. Under their hypothesis, much of the discharged PP is recently deposited biomass, e.g. plankton, algae, and plant detritus. Exported solids may also be contributed directly by floating or suspended plants when loosely bound material is detached by turbulent shear forces. At the farm scale, the biological contribution mechanism was strongly supported by the evidence that exported particulate matter had characteristics more representative of viable plant matter than of farm soils or underlying canal sediments.

Figure 2 shows the *typical* phosphorus content (mg P/kg dry mass) of a number of potential particulate phosphorus sources. Soil in the EAA typically has a phosphorus content in the range of 750-1000 mg/kg. The base sediments in the farm canals typically have phosphorus content in the range of 900-2500 mg/kg. Detritus from the ubiquitous floating waterweeds is in the range of 1500-3500 mg/kg, while the plants themselves may have phosphorus content in the range of 3000-7000 mg/kg. The phosphorus content of the planktonic and algal growth in the canals may be in the range of 9000-15000 mg/kg or higher. Figure 3 shows the cumulative distribution of the phosphorus content of samples of suspended solids discharged over a one-year span (Year 2000) from a typical EAA sugarcane farm.

Only about 5% or less of the samples had phosphorus content equal to, or less than that of soil. About 40% of the samples had phosphorus content that fell into the range of floating macrophyte and macrophyte detritus, and 40% of the samples had phosphorus content that fell into the range of planktonic and algal growth. It should be emphasized this illustration is ranked by sample, and is *not* flow weighted. The data should *not* be interpreted to imply that 40% of the mass load is sourced from planktonic growth. In fact the bulk of the mass loading appears to come from the macrophyte and macrophyte detritus population. This illustration does, however, serve to emphasize the biological nature of the particulate phosphorus that is discharged from EAA farms.

Particulate Phosphorus Transport

The biological pool is subject to growth, senescence, and internal transport by wind-driven currents. The pool tends to grow and accumulate in the inter-event times between discharge pumping cycles. Figure 4 shows the effect of the time between discharge pumping events and the discharged suspended solids concentration. Here suspended solids are being used as a surrogate for particulate phosphorus. The increasing trend of suspended solids concentration with increasing time between pump cycles is attributed to the biological growth and accumulation in stagnate canal waters between pumping events. This build-up/discharge cycle, coupled with the dynamics of pumping, tends to segregate the discharge of particulate phosphorus into several compartments.

Figure 5 shows a very illustrative event, where discharge particulate phosphorus is plotted as a function of canal velocity. The grower typically pumps either with one large or one small electrical pump, both of which are under on-off level control. Prior to this event, he had pumped relatively infrequently, using the small pump for a total of 82 hours and the large pump for less than 2 hours over the preceding 70 days, so there was ample opportunity for biological material to accumulate in the canals. During the event he switched from the large pump to the small one, and back, several times. There were also several instances of pump oscillation under the on-off control mechanism.

Large pump operation is indicated by flow rates that start at 2.5 m^3/s, small pump operation is indicated by flow rates that start at 0.5 m^3/s. The effect of the inter-event buildup is clearly illustrated by the initial particulate phosphorus surge, which rose to more than 0.85 mg/l (850 ppb). The figure clearly shows two subsequent waves of particulate phosphorus that are associated with high velocities from the operation of the large pump. This graphical illustration contains good examples of the primary motivating factors for the transport of particulate phosphorus. They are defined as follows:

<u>First Flush</u> – During the (relatively) quiescent period between pumping events biological material can grow and accumulate in the canals. This fresh material, along with solids that were suspended at the time of shutdown in the preceding event, can be readily suspended under the turbulent conditions that exist at pump start-up. This highly mobile material causes a high concentration of suspended solids during the early periods of pump events. Eventually this highly mobile material flushes out and the process of erosion proceeds on the less mobile particulate matter in the canals.

<u>Cumulative High Velocity</u> – The normal erosion process at constant velocity produces (in the idealized case) a steadily increasing discharge concentration of suspended solids. The reason for this is that water farther upstream has a longer time to accumulate eroded suspended solids as it moves downstream to the discharge point. There is, in theory, a critical velocity below which erosion is negligible. The erosion rate process is, in theory, proportional to the <u>square</u> of the

velocity that is in excess of the critical velocity, so if, for example, excess velocity increases to twice its original rate, the process of erosion will proceed four times as fast. If there is a substantial increase in velocity, there will not necessarily be an immediate increase in suspended solids concentration, because of the lag time (just described) for the flowing water to accumulate additional suspended solids. There are often circumstances during pumping events when velocity may change significantly, such as when a larger pump is started up or when canal depth becomes shallow, significantly reducing cross-sectional area available for flow. The effects of this velocity increase are not seen until sometime later, so changes in concentration may be affected by *cumulative high velocity*.

This process also proceeds after first flush, as long as velocity is sufficiently high. First flush mobilizes the material remaining close to the pump station from the previous event as well as the highly mobile new material that was produced in the inter-event period. After first flush, the sustained high velocity will continue to mobilize particulate phosphorus, the continued export of which will exhibit the lag just described.

Restart Flush – When pumping is terminated, suspended solids in the canal system settle out in place. If there had been a significant concentration of suspended solids in the downstream reaches of the canal system at shutdown, there will be a high initial concentration in the discharge when the pump is restarted. This is similar to First Flush, except that the time between pump shut down and restart is less than that for First Flush. In fact the break between First Flush and Restart Flush is somewhat arbitrary, in that an event is defined as the start of pumping after more than twenty-four hours of quiescence, so a pump start after twenty-three hours would give rise to a Restart Flush, whereas a pump start after twenty-five hours would give rise to First Flush. Because they are similar, both these phenomena are grouped into the category “Start-Up Flush”.

Particulate Phosphorus Spike – This is described by a somewhat arbitrary definition that if the particulate phosphorus concentration for a particular sample is more than twice that of either the preceding or succeeding samples, then a spike has occurred. The spike is assumed to originate from a random release of particulate material from upstream sources, such as a collection of floating macrophytes.

DISCUSSION

Statistical analysis of discrete sampling data taken from multiple farm locations has indicated that the bulk of the annual particulate phosphorus load is generated either during start-up flush or after times of continued high velocity. Figure 6 shows the distribution of hydraulic loads compared to the distribution of particulate phosphorus loads for a typical sugarcane farm over the wet season of 2000. In this figure, the various “packets of water”, typically the volume pumped over a one or two-hour period, was ranked by their particulate phosphorus load rate (kg particulate phosphorus discharged per hour). The cumulative hydraulic and particulate phosphorus loads were then calculated, in the ranked state. The resulting distribution curve shows the volumes of water sampled in their relative importance. Volumes of water that are adjacent to one another on the graph are there because they have similar particulate phosphorus load rates. They may not necessarily have been anywhere near to one another in time.

The important information to draw from Figure 6 is that 50% of the total annual particulate phosphorus load at this farm was generated by less than 20% of the hydraulic load. This pattern is seen consistently at all farms studied, and reinforces the contention that the majority of particulate phosphorus export takes place during concentrated times when specific conditions prevail. Focusing on these specific conditions when developing control strategies will yield the most productive return.

The picture of particulate phosphorus transport that has emerged is as follows. The primary source of exported particulate phosphorus is biological growth in the main canal system. The hydraulic conditions in field ditches are such that particulate matter that is formed there tends to stay there under most circumstances. High velocity is the single most important factor in particulate phosphorus transport. The velocities in main canals are highest in the most downstream reaches of the canals, so the greatest tendency toward particulate phosphorus mobilization will be in the lower reaches of the main farm canals.

The biomass that contributes to the particulate phosphorus load is typically light and flocculent, with specific gravities and settled bulk densities much lower than those of field soil particles or compacted base sediment. The suspended solids that contribute to any given pumping event represent a thin layer, at most a few centimeters thick, of this flocculent material, along with planktonic mass dispersed in the water column, and detachable detritus and epiphytic bacterial growth associated with the floating aquatic plants in the canal system. This biomass is heterogeneous, containing materials with a wide spectrum of densities, particle sizes, and phosphorus content. The heterogeneity of the population means that different fractions of the exportable particulate phosphorus will be mobilized at different rates.

The simplest description of the system is one of a tri-modal population. The first group of particles is very light and mobile and is readily re-suspended and transported under mild to moderate turbulence conditions. The second group is denser, and more strongly associated with either the underlying base sediment or the overlying aquatic weeds. This second fraction requires the continued application of shear stress to either erode it from the bottom, or dislodge it from the overlying plants. Continued application of shear stress, in the form of high velocity, can cause this second fraction to be mobilized in large amounts. These two fractions correspond roughly to what is exported during first flush and after continued high velocity, respectively. The third part of the tri-modal population is the particulate phosphorus that is randomly generated. The randomly generated matter can come from localized concentrations of biomass, atypical hydraulic conditions at some point in time or space, special rainfall, canal level, or pump operation circumstances, or other non-uniform events.

The majority of the particulate phosphorus load of interest is sourced either by first flush or by continued high velocity. Control efforts may thus be focused on reduction of first flush and minimization of continued high velocities. Reduction of first flush may be affected by preventing the formation and deposition of light biomass in the downstream reaches of the main farm canals. Continued high velocity may be addressed by both infrastructure changes and water management strategy modifications. Specific recommendations have been made to the EAA growers for immediate actions that might be taken to reduce particulate phosphorus export.

These recommendations are:

- Prevent the accumulation of floating aquatic plants in the vicinity of pump stations by the use of floating booms at least 300 meters upstream of the pump station.
- Regularly remove the biomass accumulated behind these booms, and transport it well away from the canal.
- Evaluate pumping strategies and revise them to reduce velocity spikes.
- Wherever consistent with crop drainage rate requirements, pump a give volume of water slower and over a longer period of time.
- Institute level controls to prevent low canal levels, which give rise to high velocities.
- Implement a regular canal cleaning program which focuses effort on the main farm canals, particularly the sections immediately upstream of the pump stations.

The preceding recommendations can be implemented with relatively little additional effort or infrastructure changes. Work is also proceeding on more innovative ways to prevent biomass accumulation, move the biomass to less vulnerable locations, and control the discharge patterns from the farms in ways that will reduce particulate phosphorus export.

These methods include in-channel sediment relocation to upstream locations by hydraulic dredging or reverse pumping, design of equipment for the continuous removal of floating macrophytes, and hydraulic delivery of macerated macrophytes or channel sediment directly to adjacent fields. Re-plumbing farms that have convenient channel networks is being examined as a means of diverting start-up flush back to the field ditches, which have low velocities and can act as sedimentation basins. Redesign of pump intakes is being evaluated to reduce locally high velocities that are generated at pump start-up. Temporary structures are being investigated that may be put in place during extreme events to alleviate the effects of necessarily high pumping rates associated with the intense storms that are frequently encountered in South Florida.

ACKNOWLEDGEMENTS

The Everglades Agricultural Area Environmental Protection District, the Florida Department of Environmental Protection, the Florida Sugar Cane Growers' Cooperative, the Florida Crystals Corporation, the United States Sugar Corporation, and Roth Farms, Incorporated, assisted in funding the studies cited in this paper.

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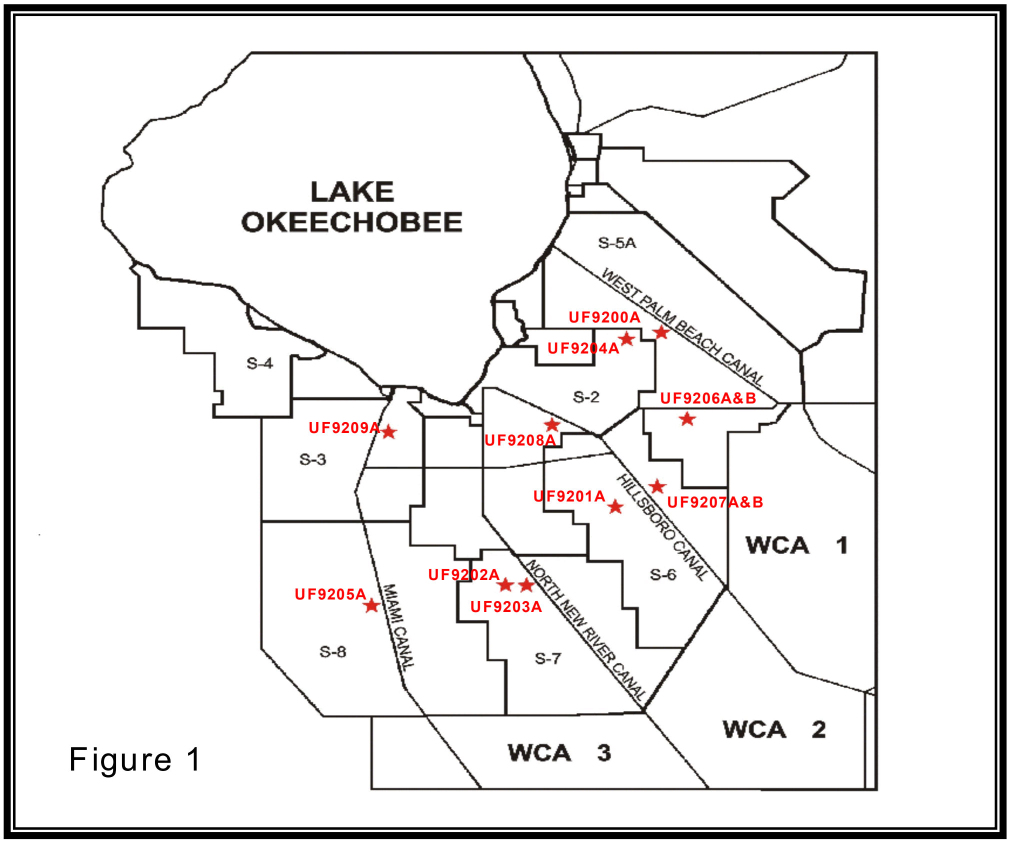

Figure 1. Map of the Everglades Agricultural Area including farm study sites.

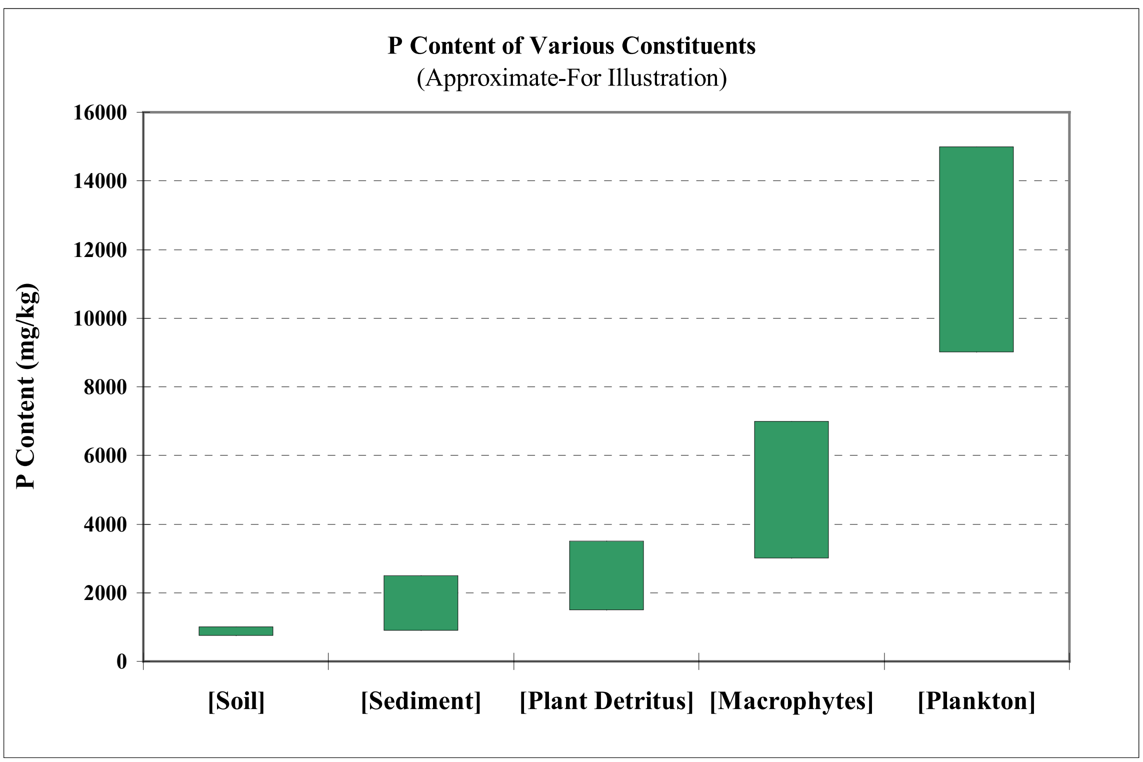

Figure 2. Phosphorus Content of Typical Particulate Phosphorus Sources

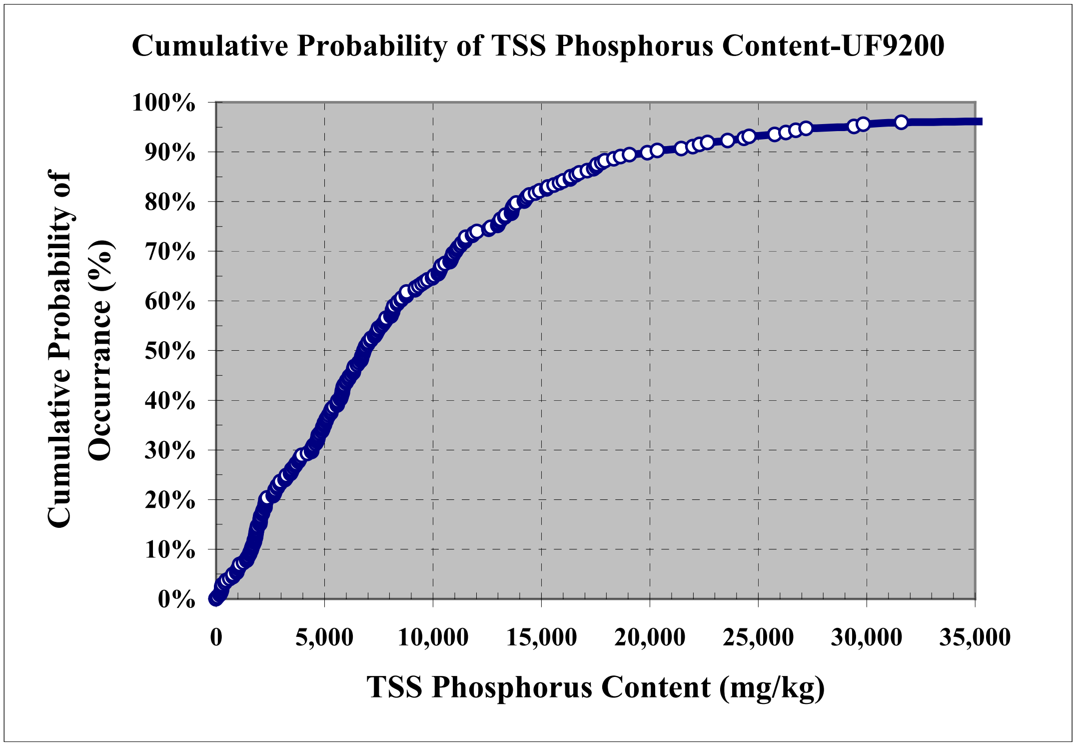

Figure 3. Suspended Solids Phosphorus Content Distribution of Discharge Samples from a Typical Farm (One Year Time Span)

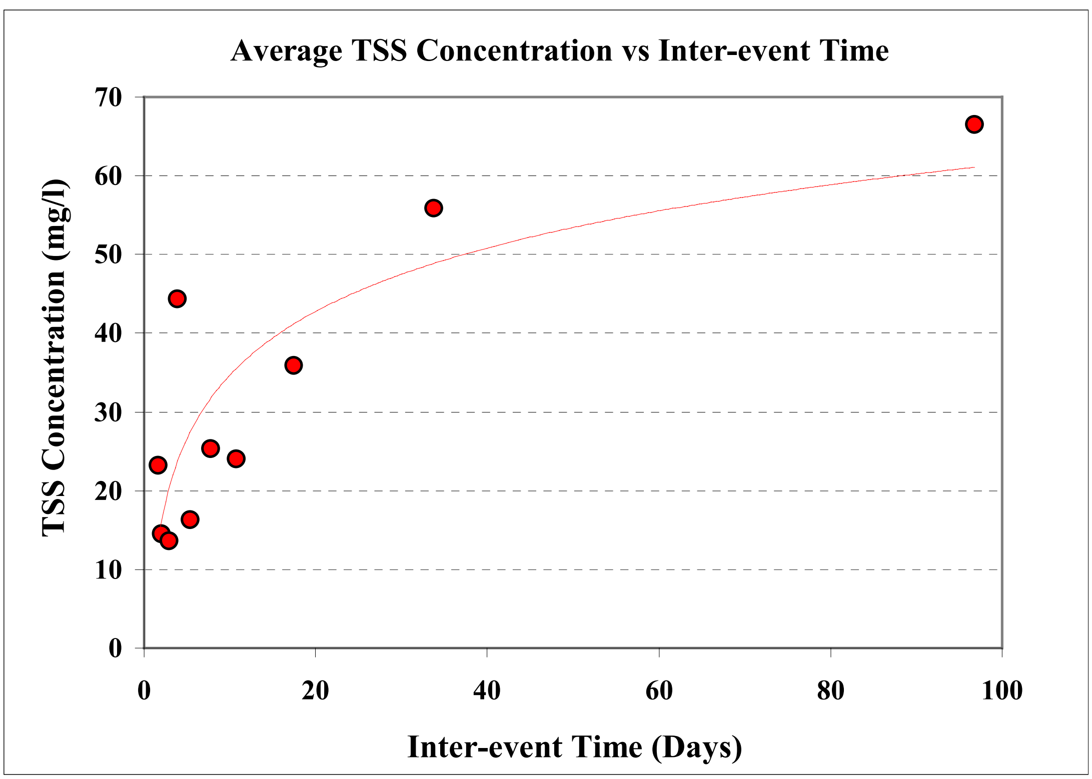

Figure 4. Canal Suspended Solids Concentration as a Function of Inter-event Time

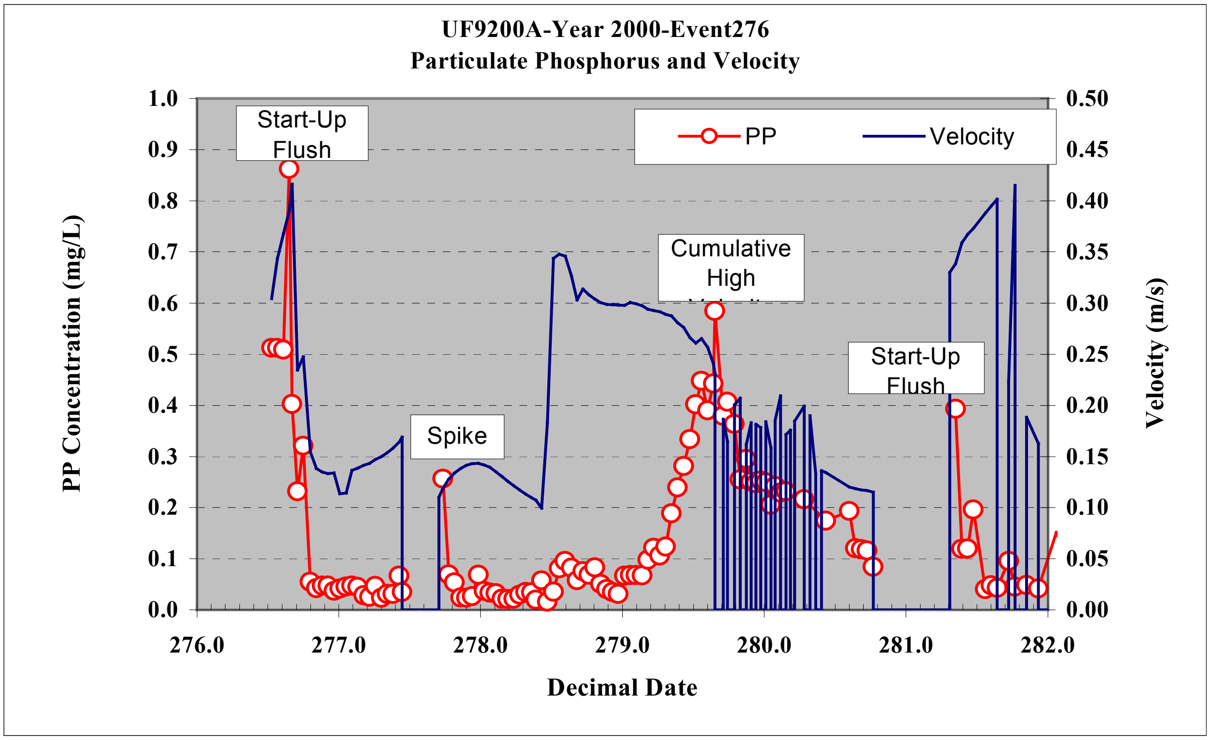

Figure 5. Discharge Particulate Phosphorus Concentrations for a Representative Pumping Event

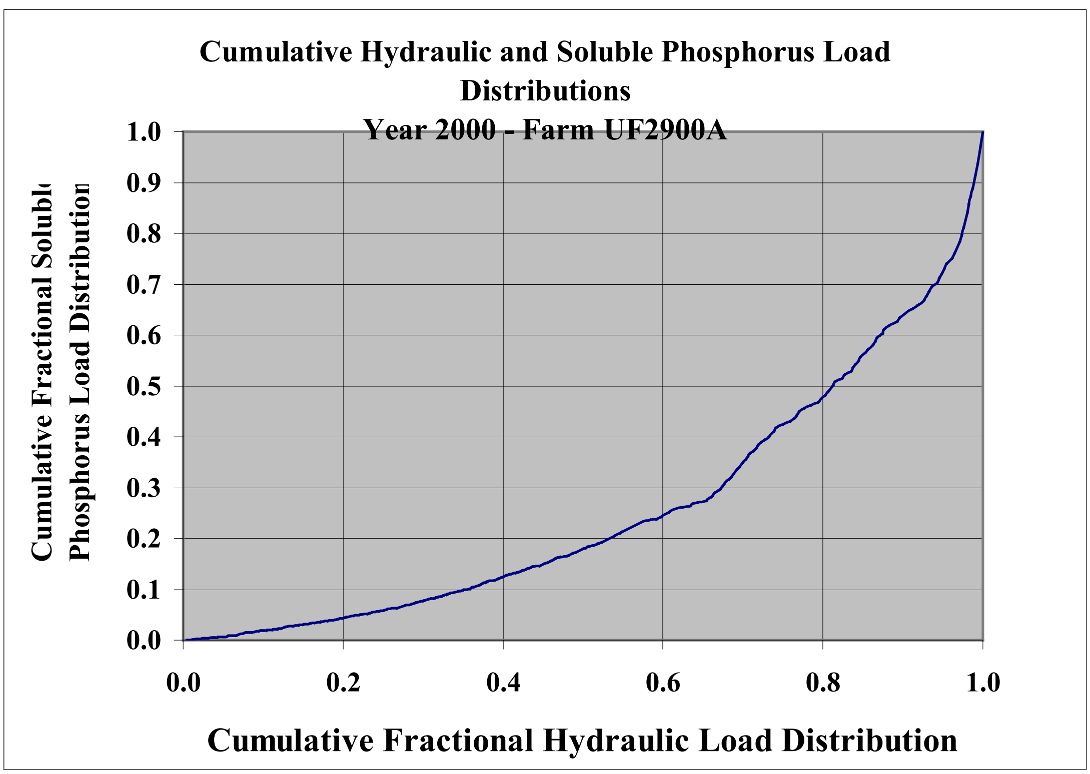

Figure 6. Hydraulic Load Distribution Compared with Particulate Phosphorus Load Distribution

DENITRIFICATION IN GROUNDWATER IN THE INDIAN RIVER LAGOON WATERSHED
REALITY OR SAMPLING ARTIFACT?

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ABSTRACT

The Indian River Lagoon, like most coastal estuaries, is threatened by inputs of nitrogen from stormwater runoff and groundwater discharge. The sources of nitrogen include wastewater, fertilizers, stormwater runoff and natural precipitation. In the Indian River Lagoon watershed a significant source of nitrogen is from dense residential development, primarily wastewater discharged from on-site disposal systems into groundwater.

The contribution of residential nitrogen to the lagoon was evaluated by comparing nitrogen concentration data from three sampling events at eight sites to modeled nitrogen concentrations, based on known land uses within the capture areas to the sampling wells. Wells were pumped for four to eight hours prior to sampling to collect samples representative of the nitrogen loading entering groundwater from a mapped capture zone to each well network.

Average measured nitrogen concentrations were significantly less than concentrations predicted by the nitrogen-loading model suggesting that nitrogen is attenuated by approximately 83%. Denitrification is a likely cause of attenuation given the reduced dissolved oxygen concentrations and the presence of dissolved organic carbon in groundwater.

The extent of attenuation suggests that on-site disposal systems are not as significant a nitrogen source to the Lagoon as expected. However, a question remains on the appropriateness of comparing measured and modeled nitrogen concentrations because the mapped capture zones may not be accurate given the lack of vertical groundwater flow data. With refined capture area mapping, it will be possible to confirm the extent of attenuation to properly evaluate the impacts of residential development on water quality within the lagoon.

INTRODUCTION

Excess nitrogen loading to the Indian River Lagoon watershed (Figure 1) has the potential to cause significant degradation and impairment of the Lagoon's ecosystem. Nitrogen has been identified as the most significant nutrient controlling the water quality of coastal ecosystems. Nitrogen loading leads to increased production of macroalgae and phytoplankton, reduced oxygen levels, poor habitat for fish and shellfish and reduced aesthetic appeal.

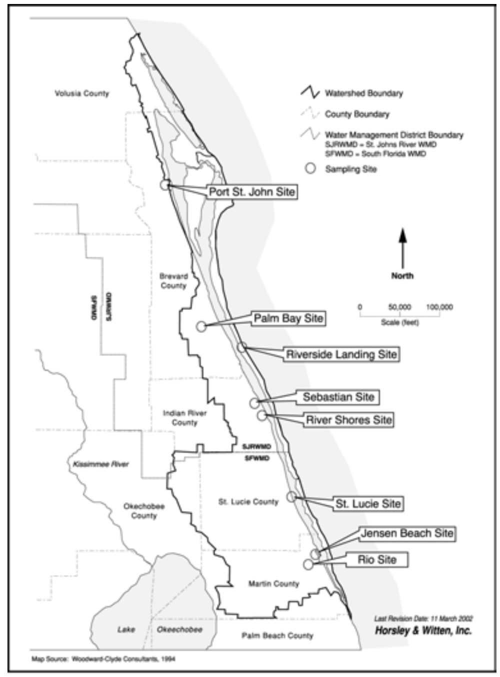


FIGURE 1. Indian River Lagoon Watershed with Sampling Sites

Sources of nitrogen from within the watershed include point source discharges of wastewater to the Lagoon and its tributaries, and non-point source discharges to groundwater, including on-site sewage disposal systems (OSDS), lawn and agricultural fertilizers and stormwater runoff. The impacts of these non-point sources can be modeled using a nitrogen loading model to predict the impacts of these sources on groundwater quality, and, ultimately on water quality within the Indian River Lagoon.

Such a model has been used to predict the nitrogen loading to groundwater from residential development at eight study sites within the Indian River Lagoon watershed. In order to adapt the model for use in the Indian River Lagoon watershed, it was determined that a calibration step was necessary to insure that the loadings from OSDS were accurately represented in the model. Previous analyses within the Lagoon watershed suggested that denitrification was attenuating nitrogen concentrations in groundwater (Ayers, 1993). More recently, denitrification has also been identified in a similar setting in the Florida Keys (Corbet et al, 2000). To accomplish the calibration, groundwater sampled from three monitoring wells at each study site was analyzed for nitrogen. The measured nitrogen concentrations were then compared to the modeled concentrations determined for the land area that lies within the capture area to the monitoring wells. In this way, adjustments to the model could be made to account for site-specific nitrogen attenuation issues.

STUDY SITE

The Indian River Lagoon extends approximately 225km (140 miles) along the central eastern shore of Florida, from Volusia County in the north to Martin County in the south. The watershed for the lagoon extends up to 45km (28 miles) to the west, and includes areas that provide both surface water runoff and groundwater discharge to the lagoon and its tributary rivers and canals (Figure 1).

The surficial aquifer within the watershed is comprised of unconsolidated sand, limestone, coquina and clay, and extends over most of the watershed to the lagoon except in the western portion of Volusia County, where the underlying Hawthorn Formation is exposed at land surface (Stewart and VanArman, 1987). This surficial aquifer varies in thickness from zero, in the far western parts of the counties, to 45m in the eastern parts (Woodward-Clyde, 1994, Stewart and VanArman, 1987). It is recharged by precipitation over its entire areal extent. In some instances in the western portions of the counties, water from the surficial aquifer may seep into the lower aquifer to recharge it in response to a greater hydraulic head in the surficial aquifer (Stewart and VanArman, 1987). In the southeastern parts of the watershed, where the confining unit is thick, groundwater in the surficial aquifer is prevented from migrating downward into the Floridan Aquifer and discharges into the Lagoon.

MATERIALS AND METHODS

A two-phased approach was used to calibrate the nitrogen loading model. First, field investigations were conducted at each of the eight sites to evaluate water quality and to determine groundwater flow directions and aquifer characteristics for use in the mapping of the capture zones to each of the monitoring well networks. Second, the capture areas to the wells were determined, and a land use analysis and literature evaluation was used to develop the inputs to the nitrogen loading model for each site. A representation of this process is provided for the Riverside Landing (Figure 2).

Field Investigations

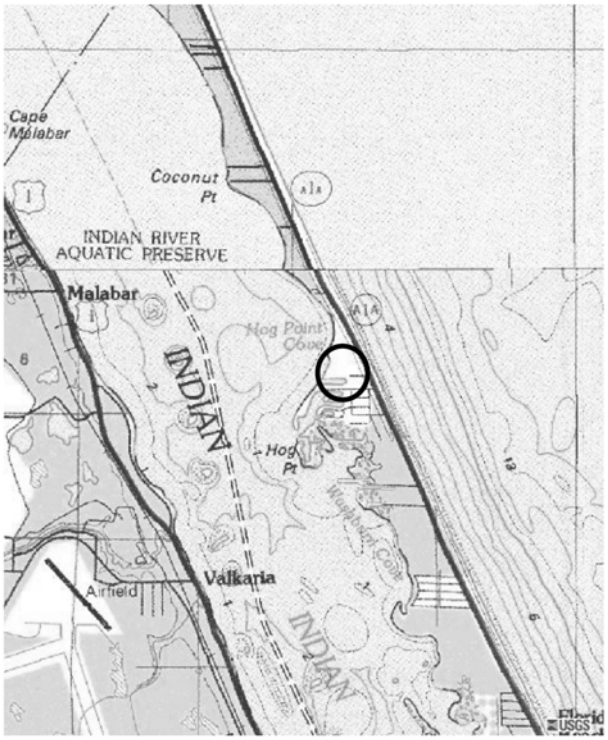
Well Installation

A total of four, 10-cm. (4 in.) diameter polyvinyl chloride (PVC) groundwater monitoring wells were installed using the hollow stem auger drilling method at each site location in January and February of 1999. Three of the wells were arranged as pumping wells in an orientation perpendicular to the estimated direction of groundwater flow. These wells were spaced evenly, with the distance between them determined by the well yields at each location. One well was located upgradient or downgradient from the pumping wells and used with the other three to determine the direction of groundwater flow. Each well was installed to a depth of approximately 7.6 m (25 ft) and was constructed with a 6.1m (20 ft) screen.

Groundwater Sampling

Groundwater was sampled on three separate occasions from March through October of 1999, to represent spring, summer and fall conditions. Pumping times for each site were consistent within each sampling round but varied between the spring, summer and fall rounds. Pumping times during the summer event were adjusted in the field based on the stabilization of field parameters.

Field parameters were monitored periodically during pumping using a Hydrolab™ Surveyor/MiniSonde multiparameter probe. Field parameters included dissolved oxygen, salinity, pH, specific conductance, and temperature. Groundwater was pumped out of the well and continuously discharged into a bucket where the parameters were measured. Measurements were taken every half hour until the parameters stabilized. Dissolved oxygen measurements were also taken within the well during sampling to avoid inaccuracies caused by flow turbulence and atmospheric exposure.



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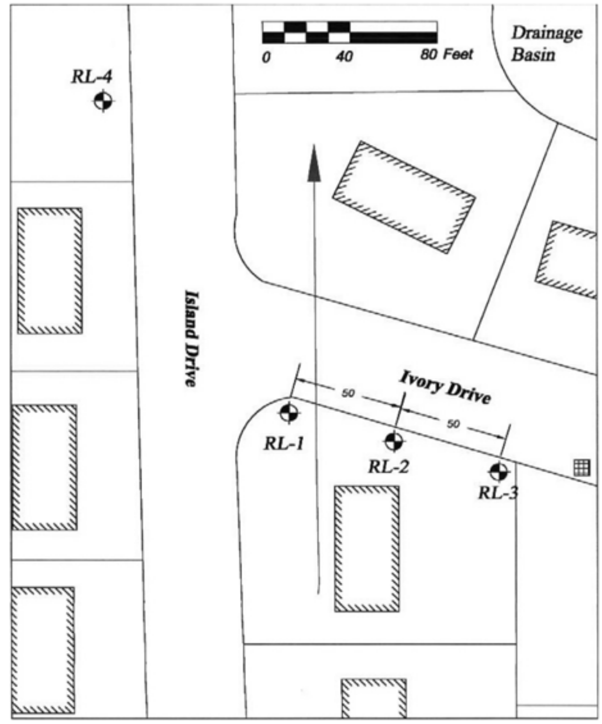
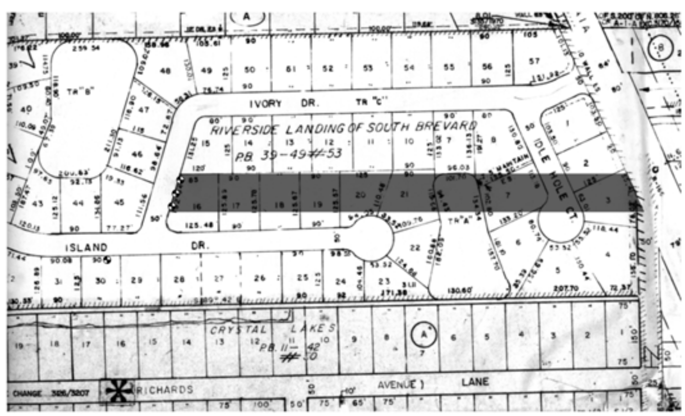


Monitoring Well Locations and Measured Groundwater Flow Direction



Modeled Capture Zone to Monitoring Wells

FIGURE 2. Representative Study Site, Riverside Landing

Groundwater samples were collected at the end of the pumping period from each of the three installed monitoring wells. Laboratory samples were submitted to the Brevard Teaching & Research Laboratory in Palm Bay, Florida (now Midwest Research Institute) for analysis. Water samples were analyzed for nitrate, nitrite, ammonia, total organic carbon, total Kjeldahl nitrogen (TKN), total phosphorus, chloride, and fecal coliform bacteria.

Capture Zone Mapping

The capture zones to each of the monitoring well networks were mapped by modeling the cone of depression caused by the pumping of the wells on the downgradient and lateral sides of the wells. This modeling was conducted using MODFLOW, and used measured field data for hydraulic conductivity and hydraulic gradient. The mean hydraulic conductivity values for each of the sites indicate that the sediments at each site are fairly homogeneous, with only minor variations in the conductivity values from well to well. However, a wide variety of sediment types are represented in these eight sites. The Riverside Landing site is highly conductive (180.9 ft/day), and the Sebastian site (3.9 ft/day) is highly constricted with respect to groundwater flow.

The upgradient distance from which water would flow under the wells instead of into the wells was used to define the upgradient boundary. This was based on an estimated recharge rate of 0.3 m/yr. (12 in./yr.) and a porosity of 33%. This corresponds to an annual contribution of 0.9 m (2.95 ft.) to the water table aquifer. In other words, groundwater flowing through the system is depressed 0.9 m (2.95 ft.) in elevation per year as it moves through the aquifer.

Nitrogen Loading Model

Horsley & Witten developed the nitrogen spreadsheet model used to estimate nitrogen loading and predict nitrogen concentrations in groundwater (Nelson et al, 1988, Horsley & Witten, Inc., 1996). The model quantifies the contribution of nitrogen loading from each nitrogen source within the capture zones, and calculates the total mass of nitrogen kg/year discharged annually and predicts the concentration of nitrogen (mg/L) in groundwater. This method has been used extensively for quantifying nitrogen loads to surface and groundwater.

The model has been utilized to estimate nitrogen loading in several estuarine embayments as part of the EPA-sponsored Buzzards Bay National Estuary Program (Horsley & Witten, Inc., 1991), the Casco Bay National Estuarine Program (Horsley & Witten, Inc., 1996), and the Delaware Inland Bays Program. It has also been applied to evaluate nitrogen concentrations in drinking water supplies across the country.

Nitrogen is present in groundwater as nitrate (NO_3), nitrite (NO_2), ammonia (NH_3) or organic nitrogen. The loading rates used in the model represent total nitrogen values. The model accounts for all sources of nitrogen in the analysis, including OSDS, lawn fertilizers and stormwater runoff from roads, sidewalks, and roofs.

Inputs to the nitrogen loading model consist of the area of the modeled capture zone, the number of homes within the capture zone, fertilized lawn areas, impervious surfaces (roofs, driveways, sidewalks and roads), the number of people per home generating wastewater, and the percentage of seasonal residences.

The numbers of homes, vacant lots, roof size and lawn size were measured through visual surveys of the neighborhoods using satellite imagery and assessor's maps of each area. Home lots that were bisected by the modeled capture zone were included based on the percentage of the lot within the capture area. If 25% or more of the lot was within the capture area, it was assumed that the OSDS fell within the capture area boundary.

Occupancy and population estimates for each site were obtained by examining 1990 U.S. Census data, which indicates that an average of 2.5 people reside in each dwelling. Approximately 13% of the population in the central region of Florida (which includes Brevard County) are "snowbirds" who reside in Florida an average of 5.2 months per year. In St. Lucie, Martin, and Indian River Counties, 35% of the population are "snowbirds", staying an average of 6.1 months of the year.

RESULTS

The sample averages of the three wells from each site were calculated for TKN, ammonia-N, nitrate-N and total nitrogen. Average concentrations of total nitrogen ranged from < 1 mg/l to >2 mg/l (Table 1). The widest ranges in total nitrogen concentrations were found at the Jensen Beach and Rio sites. Both sites had spring and summer concentrations of total nitrogen of less than 1.0 mg/l, while average September concentrations were approximately 4 mg/l. Dissolved oxygen concentrations measured in-situ during the final sampling round were less than 1 mg/l at all sites.

Total nitrogen concentrations from the field samples were compared with the model-predicted concentrations (Table 1.) Specifically, the average of the three sampling events was calculated and compared to predicted concentrations. The model-predicted concentrations of nitrogen in groundwater were significantly greater than measured nitrogen in groundwater samples in all cases, with the exception of the St. Lucie and River Shores sites. These two sites exhibited lower than predicted concentrations of nitrogen. For the five sites with lower measured groundwater concentrations, the percent difference ranged from -76% to -92% with an average of -83%.

These sites may be exhibiting nitrogen attenuation. An empirical nitrogen attenuation factor was derived from the predicted and measured total nitrogen concentration data for those sites exhibiting nitrogen attenuation. The percentage of nitrogen attenuated based on this data was equal to 83%.

Table 1. Comparison of Modeled Nitrogen Concentrations Results to Measured Nitrogen Concentrations.

Site	Modeled Nitrogen (mg/L)	Measured Nitrogen (Average) (mg/L)	Percent Difference*
Port St. John	7.53	1.35	-82%
Palm Bay Site	10.11	0.780	-92%
Riverside Landing Site	6.00	1.37	-77%
Sebastian Site	Not modeled	2.06	n/a
River Shores	0.08	1.45	+17%
St. Lucie	0.08	1.180	+14%
Jensen Beach	7.92	1.88	-76%
Rio	12.4	1.84	-85%

*Percent difference based on annual average.
n/a: not applicable

DISCUSSION

Two factors have the most significant effect on the predicted concentrations derived from the nitrogen loading model:

- A complete understanding of the hydrologic conditions, and
- The assumption that nitrogen acts conservatively in the aquifer, i.e., that nitrate is formed and does not transform to other nitrogen species.

UNDERSTANDING OF HYDROLOGIC CONDITIONS

The modeling of the capture areas was done as accurately as possible, given available information. However, there are three additional factors to consider that affect the area contributing water to the sampling wells: First, the hydraulic conductivity in the vicinity of the wells was assumed to be the same throughout the entire capture area. For the sites with low hydraulic conductivity, the use of this assumption results in a small capture area, whereas, if more permeable sediments are present upgradient, the capture area may actually be larger. The same argument could be made at the sites with permeable sediments. Less permeable sediments upgradient of the wells would make the actual capture areas smaller.

Second, the vertical component of groundwater flow is not fully considered in the capture area delineations. If a strong downward gradient exists upgradient of the sampling wells, the actual capture area would be smaller, and a portion of the nitrogen included in the modeling would flow underneath the wells and not be reflected in the water quality data. The water quality data from the Ayers Associates study (1993) suggests that septic system effluent plumes may have moved downward as they moved downgradient, thereby flowing underneath the well screens used for sampling in the Ayers study.

A strong upward gradient from the underlying Floridan aquifer into the upper aquifer could also be providing water to the sampling wells and affecting the measured nitrogen concentrations, possibly diluting the samples with water containing less nitrogen. The presence of this gradient along the western Indian River Lagoon shore has been described by Skipp (1988). If the sampling wells are collecting water discharging from the Floridian aquifer, nitrogen may be diluted.

Third, while the sampling wells have 6m (20 ft) screens, it is not possible to determine if the water samples represent average conditions throughout the depth of the well. While the soil samples indicated uniform materials throughout the well borings, a small zone could be providing a relatively high proportion of the pumped water. The nitrogen concentration of this zone would then have a significant influence on the concentration attributed to the entire twenty-foot section of the aquifer.

A series of clustered, multi-level monitoring wells could be used to confirm the accuracy of the capture area delineations. They would provide data on vertical hydraulic gradients, as well as more information about the hydraulic conductivity of the aquifer in areas away from the sampling wells. Well clusters could be installed at the sampling site with one well in the lower Floridian aquifer, and two wells in the upper aquifer. This would provide information about the contribution from the lower aquifer, as well as about the thickness of the shallow aquifer.

It should also be mentioned that the model is sensitive to the presence or absence of infiltrated stormwater. The majority of runoff at each of the sites is believed to be captured and discharged to a surface water body outside of the capture zones. However, if some infiltration is taking place, it would dilute other nitrogen sources and result in a slightly lower modeled nitrogen concentration.

Denitrification

Denitrification has been noted as an important process in aquifers given the appropriate conditions. Denitrification is a biological process performed primarily by facultative heterotrophic microorganisms. The transformation of nitrogen in OSDS effluent to nitrogen gas is a two step process, with each step requiring specific environmental conditions. First, the organic forms of nitrogen present in raw effluent (as well as ammonia) must be oxidized and transformed into nitrate-nitrogen. Oxygen must be present within an OSDS disposal facility, or within the unsaturated or saturated zone directly beneath the OSDS in order for this conversion to take place. Evidence to evaluate whether or not this nitrification process is taking place within the study areas was not collected as part of this investigation. However, the water quality data from a previous evaluation (Ayers Associates, 1993), suggests that at least some of the effluent is being converted to nitrate-nitrogen. The Ayers study found average nitrate concentrations were higher than average total Kjeldahl nitrogen concentrations in samples from wells directly adjacent to OSDS disposal facilities.

Once nitrogen is converted to nitrate, anoxic conditions must be present to allow for denitrification. Nitrate is first transformed to nitrite, and then nitrite is transformed to nitrogen gas, which volatilizes out of the aquifer and enters the atmosphere. Organic carbon is usually required for denitrification to occur. However, denitrification, based on oxidation of sulfide and ferrous iron (Starr and Gillham, 1993), instead of organic carbon, has also been observed.

The water quality data collected during this study suggests that environmental conditions exist to facilitate the denitrification of nitrate to nitrogen gas. Little to no oxygen was detected in the water quality samples, suggesting anoxic conditions exist in the vicinity of the sampling sites. Also, organic carbon was detected in concentrations that have been shown at other sites to be sufficiently low enough to allow for denitrification (Starr and Gillham, 1993).

Future studies to confirm the presence of denitrification in the surficial aquifer may include measurement of nitrogen gas and a biological assay of bacteria within the substrate to determine if denitrifying bacteria exist at these locations. In addition, other parameters to assist in confirming and quantifying the denitrification process include measurements of dissolved organic nitrogen, dissolved and particulate carbon, and dissolved sulfide.

CONCLUSIONS

- Measured total nitrogen concentrations in groundwater averaged 1.5 mg/L at the eight study sites over the study period. Estimated nitrogen loading from all 55 residential lots within the eight modeled capture areas is 279 kg (613 lbs) per year or 5 kg (11 lbs) per lot per year. Approximately 93% of this load is attributable to septic system effluent.

- Total nitrogen concentrations from the field samples were compared with the estimated nitrogen loading. The corresponding concentrations of nitrogen in groundwater associated with the estimated loading were significantly greater than those measured in the groundwater. An empirical nitrogen attenuation factor was derived from the estimated loading and measured total nitrogen concentration data for those sites exhibiting nitrogen attenuation. The percentage of nitrogen attenuated ranged from 45% to 98% with an average nitrogen attenuation factor for all sites equal to 83%.

- The calculated attenuation of nitrogen may be due to complexities in the hydrologic system that affects the capture zone delineations. On-site recharge, vertical groundwater flow gradients, and stormwater infiltration have been identified variables in the capture zone and nitrogen models that can significantly alter the modeled nitrogen concentrations.

- Denitrification in groundwater is also a likely contributor to the observed nitrogen attenuation. The conditions exist at the sampling sites to support denitrification, including shallow depths to groundwater, low dissolved oxygen concentrations and sufficient dissolved organic carbon.

- Two simple investigations could improve the findings of this study. Installing a series of cluster wells at one or two sites could refine the capture area delineations and therefore the model estimates. Measurements of denitrification rates and/or an evaluation of the presence of denitrifying bacteria in aquifer samples could be used confirm the extent of nitrogen loss through this process.

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STRUCTURAL AND NON-STRUCTURAL BMPS FOR PROTECTING STREAMS

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ABSTRACT

Stream ecosystems in three different locations in the United States were found to benefit in a similar fashion from retention of watershed forest and wetland cover and wide, continuous riparian buffers with mature, native vegetation. The findings can help guide comprehensive watershed management and application of these non-structural practices in low-impact urban design. Intensive study of structural best management practices (BMPs) in one location found that, even with a relatively high level of attention, a minority of the developed area is served by these BMPs. Those BMPs installed are capable of mitigating an even smaller share of urban impacts, primarily because of inadequacies in design standards. Even with these shortcomings, though, results showed that structural BMPs help to sustain aquatic biological communities, especially at moderately high urbanization levels, where space limits non-structural options.

INTRODUCTION

Urban Streams and Their Management

By the mid-point of the last decade the effects of watershed urbanization on streams around the United States were well documented. They include extensive changes in basin hydrologic regime, channel morphology, and physicochemical water quality associated with modified rainfall-runoff patterns and anthropogenic sources of water pollutants. The cumulative effects of these alterations produce an in-stream habitat considerably different from that in which native fauna evolved. In addition, development pressure has a negative impact on riparian forests and wetlands, which are intimately involved in stream ecosystem functioning.

What was missing at that point in time, though, was definition of the linkages tying together landscapes and aquatic habitats and their inhabitants strong enough to support management decision-making that avoids or minimizes resource losses. Lacking this systematic picture, urban watershed and stormwater management efforts have not been broadly successful in fulfilling the federal Clean Water Act's stipulation to protect the biological integrity of the nation's waters. Effective management needs well conceived goals of what biological organisms and communities are to be sustained and at what levels, and then the foundation for judging what habitat conditions they need for sustenance and, in turn, watershed attributes consistent and inconsistent with these conditions.

Management has usually centered on attempting to reduce stormwater runoff contaminants in passive structural BMPs like ponds with permanent pools or extended detention, vegetated drainage courses, infiltration basins, sand filters, and others. Some locations also focused management attention on amelioration of peak stream flow rate increases following development to reduce erosive shear stress and its damage to stream habitats. However, there has been little tie between these prescriptions and ecological considerations, or even how well they work to sustain biological communities that they ostensibly exist to protect. What little study had been done was far too limited to draw firm conclusions, but was not promising. Maxted and Shaver (1997) were not able to distinguish a biological advantage associated with the presence versus absence of structural BMPs along Delaware streams. Jones, Via-Norton, and Morgan (1997) concluded that appropriately sited and designed BMPs provided some mitigation of stormwater impacts on Virginia stream habitats and biota, but that the resulting communities were still greatly altered from those in undeveloped reference watersheds.

Toward a More Systematic View of Watersheds, Streams, and Management

With this background of insufficient understanding of relationships among watershed and aquatic ecosystem elements, and the capabilities of prevailing management strategies to influence these relationships, the U.S. Environmental Protection Agency (USEPA) commissioned the Watershed Management Institute (WMI) to investigate stream habitats and biology across gradients of urbanization and BMP application in four regions of the nation (Austin, TX; Montgomery County, MD; Puget Sound, WA; and Vail, CO). This study followed an earlier effort along similar lines in the Puget Sound region funded by the Washington Department of Ecology. Together these studies built a database representing more than 220 reaches on low-order streams in watersheds ranging from no urbanization and relatively little human influence (the reference state, representing "best attainable" conditions) to highly urban (>60 percent total impervious area, TIA).

Results from the initial Puget Sound research and a portion of the follow-up study have been extensively reported. Biological health was assessed according to benthic index of biotic integrity (B-IBI; Fore, Karr, and Wisseman 1996) and the ratio of young-of-the-year coho salmon (a relatively stress-intolerant fish) to cutthroat trout (a more stress-tolerant species). Both biological measures declined with TIA increase without exhibiting a threshold of effect; i.e., declines accompanied even small levels of urbanization (Horner et al. 1997; May et al. 1997). However, stream reaches with relatively intact, wide riparian zones in wetland or forest cover exhibited higher B-IBI values than reaches equivalent in TIA but with less riparian buffering. Until TIA exceeded 40 percent, biological decline was more strongly associated with hydrologic fluctuation than with chemical water and sediment quality decreases. Accompanying hydrologic alteration was loss of habitat features, like large woody debris and pool cover, and deposition of fine sediments that reduce dissolved oxygen in the bed substrata, where salmonid fish deposit their eggs. The research defined stream quality zones in relation to TIA and riparian corridor condition and identified sets of necessary, although by themselves not sufficient, conditions to maintain a high level of biological functioning or prevent decline to a low level. These findings provide a basis for managing watersheds in relation to biological goals.

Follow-up Puget Sound investigation turned to the question of BMP effectiveness. This investigation considered the density of structural BMP coverage and, as *de facto* non-structural BMPs, extent of watershed forest cover and riparian buffering (proportion of upstream corridor with riparian zone in forest or wetland cover at least 30 meters wide on each bank). In this comparison, riparian retention exhibited greater and more flexible potential than other options to uphold biological integrity when development increases, with upland forest retention also offering valuable benefits, especially low in the urbanization gradient (Horner and May 1999). Structural BMPs at the prevailing densities demonstrated less potential than the non-structural methods assessed to forestall resource decline as urbanization starts and progresses. There was a suggestion in the data, though, that more thorough coverage would offer substantive benefits in this situation. Moreover, structural BMPs were seen to help prevent further resource deterioration in moderately and highly developed watersheds. Analysis showed that none of the options is without limitations, and widespread landscape preservation must be incorporated to retain the most biologically productive aquatic resources.

Maxted (1999) gave a preliminary report on the overall results of the WMI study available at that time. Differences in expressions of macroinvertebrate community integrity appropriate for the various locations were reconciled by scoring each relative to the best attainable measure for the region. The patterns of association between these biological expressions and TIA were similar for the Maryland, Texas, and Washington sites, and also similar to the Delaware watersheds studied earlier (Maxted and Shaver 1997), in that none exhibited a threshold level of urbanization where biological decline began. As the Delaware results had indicated, WMI stream reaches with and without structural BMPs could not be distinguished in biological quality. This preliminary analysis points out two instances of general unity among differing ecoregions in landscape-aquatic ecosystem relationships.

Additional Research Needs

Observation in the Puget Sound study area of the role played by riparian and upland forest retention in maintaining stream ecology suggests that their benefits might be found in other regions having different aquatic ecosystems. If similarity were demonstrated, the finding would not only serve the pragmatic need for targeting management attention, but would also continue to develop the picture of general unity among ecoregions. The hypothesis was tested in the Montgomery County, Austin, and Vail study areas using the data collection and analysis methods developed in the Puget Sound study. The next section of this paper presents and discusses the results.

Following up the initial Puget Sound work on the role of structural BMPs in maintaining stream health, the analysis was supplemented by more detailed evaluation of BMP service levels and added assessment of implementation quality in several catchments relatively well and poorly served with structural BMPs. A later section of this paper reports the findings.

COMPARISON OF ECOLOGICAL BENEFITS OF RIPARIAN AND FOREST RETENTION IN FOUR ECOREGIONS

Study Sites and Methods

Table 1 indicates the general levels of coverage of the four regional programs. The regional programs developed multi-metric invertebrate community indices appropriate for prevailing ecological attributes but similar in complexity. Vail watershed configurations differ substantially from the others, because of topography and other physiographic factors and the development patterns prevalent there. Most Vail area streams originate in National Forest land and flow down steep slopes to form narrow valleys containing almost all development. Overall impervious coverage in these watersheds is low relative to other study areas, although the local degree of impervious ranges up to comparable levels. In further contrast to the other regions, runoff in Vail is mostly generated by snowmelt, and relatively coarse soils are more infiltrative there. Local municipalities do not use formal structural BMPs at all and manage mainly with the non-structural strategy of riparian buffer maintenance.

Table 1. Regional Program Characteristics

Characteristic	Austin	Mont. Co.	Puget Sound	Vail[a]
Number of stream reaches	45	60	74	50
Watershed area range (km^2)	0.13-10.5	0.12-6.9	0.65-60.0	0.28-37.3
Overall TIA range (%)[b]	1.5-53.2	4.7-58.0	1.2-60.6	0-3.5
Developed range (%)[b]	0-99.7	2.6-70.2	0-96.9	0-13.9
Forest and wetland range (%)[b]	0.3-100	2.4-43.2	3.1-87.0	86.1-100
Number of metrics in invertebrate community index	9	8	9	9

[a] Range statistics are given for 25 sites with full geographic information system coverage.
[b] Overall TIA (total impervious area), developed and forest and wetland ranges are percentages of the entire watershed. Developed signifies land converted from natural or agricultural cover by construction, including lawns and other pervious covers installed by humans. For Vail, forest and wetland includes mountain meadows that are an ecological climax condition.

An Index of Riparian Integrity (IRI) was developed in a manner similar to the B-IBI formulation (Fore, Karr, and Wisseman 1996) to express with one number the key attributes of riparian zones. Scores of 1 to 4, representing poor to excellent ratings or riparian buffering, were assigned to six attributes according to the criteria in Table 2. The six scores were summed and divided by the total possible score (24) and multiplied by 100 to express the IRI as a percentage of maximum value.

Table 2. Index of Riparian Integrity Metrics and Scoring Criteria

Index of Riparian Integrity Metric	Excellent (4)	Good (3)	Fair (2)	Poor (1)
Width (lateral extent >30 m, %)	>80%	70-80%	60-70%	< 60%
Width (lateral extent >100 m, %)	>50%	40-50%	30-40%	<30%
Encroachment (% <10 m wide)	<10%	10-20%	20-30%	>30%
Corridor continuity (crossings/km)	<1	1-2	2-3	>3
Natural cover (% forest or wetland)	>90%	75-90%	50-75%	<50%
Mature native vegetation or wetland (%)[a]	>90%	75-90%	50-75%	<50%

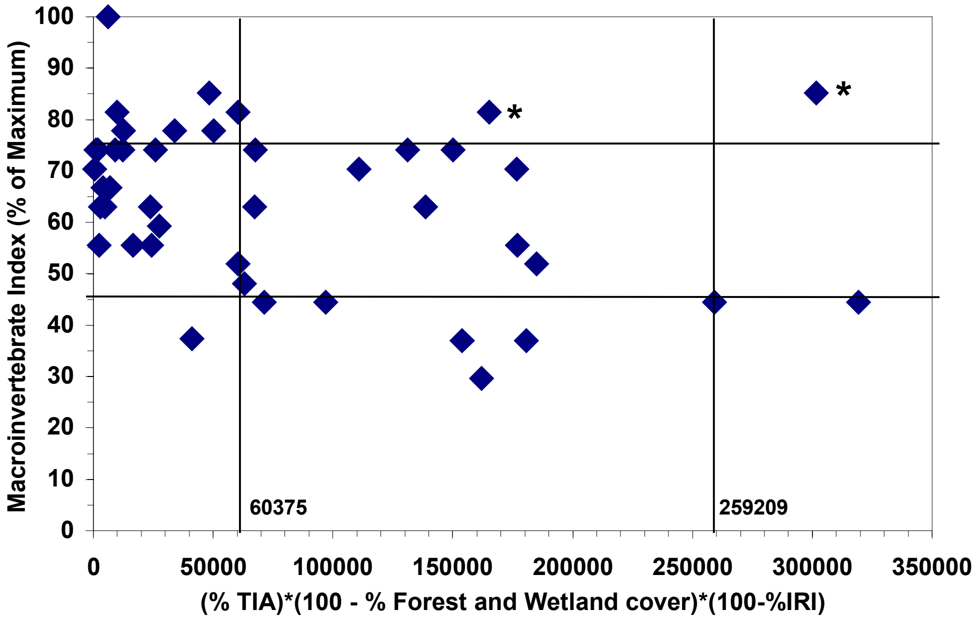
[a] "Mature" vegetation was considered to be the type, and in some cases average tree size (diameter at breast height, dbh), in the least disturbed reference sites, typical of natural riparian structure and functioning for the study location, even if not developed to the maximum extent that would be reached in more time. The definitions for each area are: Austin—ash-juniper or live oak forest; Montgomery County— >75 percent deciduous forest with dbh >23 cm (9 inches); Puget Sound— >70 percent coniferous forest with dbh >30 cm (12 inches) and native understory; Vail—patchy mosaic of aspen, spruce, fir, alder, willow, and native grasses with no clear dominant vegetation type.

The Puget Sound program quantified stream riparian characteristics during the period 1994-1997 using aerial photographs and field reconnaissance. The same exercise was performed in the other three regions with geographic information system (GIS) data that had become available by 2000-2001. These analyses involved defining bands of specified widths on both sides of stream channels and quantifying various kinds of natural and developed land cover in these bands, as well the number of anthropogenic riparian corridor breaks per unit stream length. The main product of interest from each analysis was a data set representing buffer continuity and the linear extent of riparian buffers of various widths in several vegetation cover types.

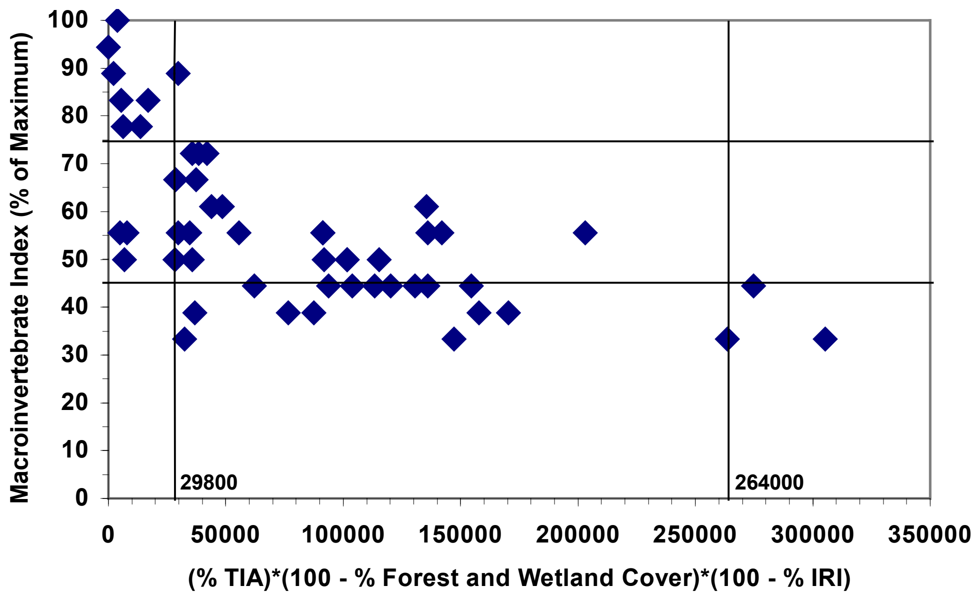
To permit comparison among study regions, invertebrate indices in each case were converted to percentage of the maximum possible score for the location. The coho salmon:cutthroat trout ratio (CS/CT) was an additional biological variable employed in Puget Sound data analysis. These dependent variables were examined relative to independent variables representing the effects of urbanization and loss of natural land cover: (1) % TIA, (2) 100-% watershed forest and wetland cover, and (3) 100-% index of riparian integrity. The independent variables were combined as products of two or all three to express multiple effects.

RESULTS AND DISCUSSION

Figures 1a to 1d present plots of biological measures versus the combined (% TIA)*(100 - % watershed forest and wetland cover)*(100 - % IRI) variable. Analogous graphs for paired combinations of % TIA with each of the land cover variables are not shown but, for the respective geographic areas, are highly similar to those given. This similarity suggests that each area has treated its riparian zones and overall watershed forests and wetlands in much the same way.



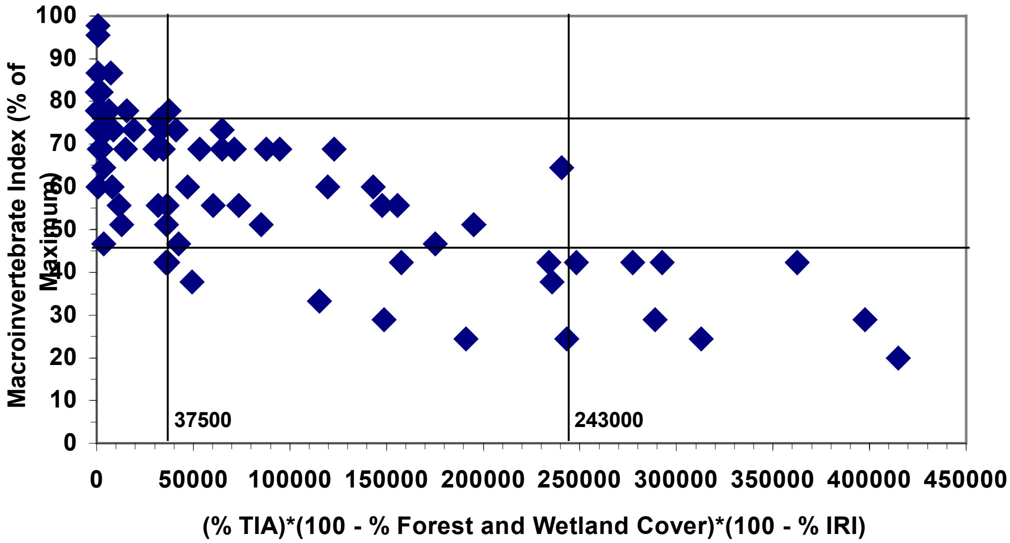
(a) Macroinvertebrate Indices for Austin



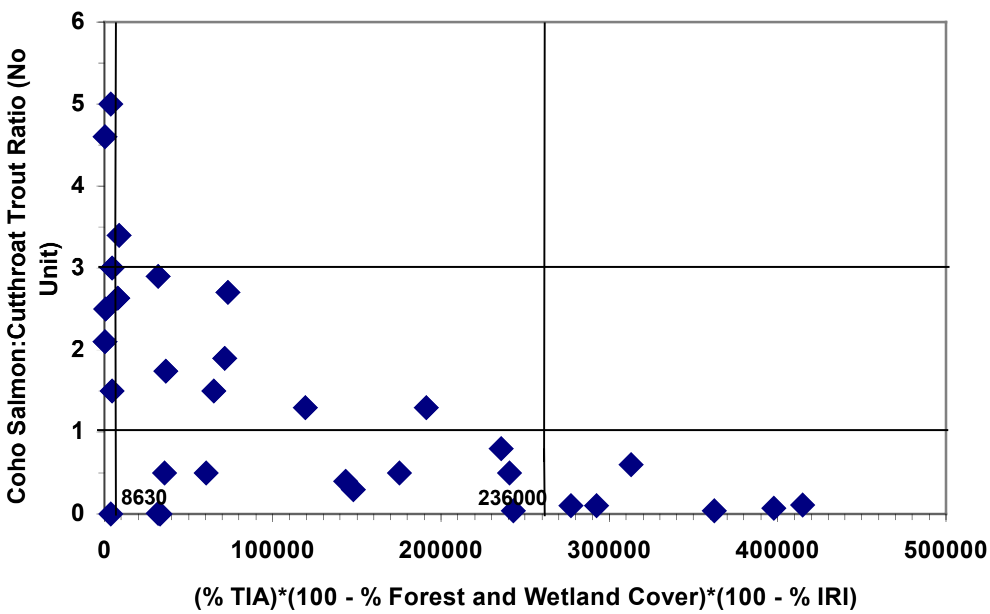
(b) Macroinvertebrate Indices for Montgomery County

Figure 1. Biological Community Indices Versus (% Total Impervious Area, TIA)*(100 - % Forest and Wetland Cover)*(100 - Index of Riparian Integrity, IRI)

[Note: Left and right vertical lines indicate maximum TIA associated with high biological integrity and minimum TIA associated with low biological integrity, respectively. Numbers near the vertical lines are horizontal axis-intercepts. Austin points marked * are from atypically nutrient-enriched sites and were omitted from this analysis.]



(c) Macroinvertebrate Indices for Puget Sound



(d) Coho Salmon:Cutthroat Trout (CS/CT) Ratio for Puget Sound

Figures 1a to 1c for macroinvertebrates exhibit some quite consistent trends among regions that are discussed below. Montgomery County and Puget Sound, both humid, temperate regions with primarily perennial streams, exhibit quite similar relationships. Austin's pattern differs somewhat. It has mostly intermittent streams and, compared to Montgomery County and Puget Sound, less frequent and higher intensity rainfall and much higher evaporation. Vail data do not exhibit the general trends in Figure 1, or other clear and consistent tendencies, and are not plotted. The differences in macroinvertebrate community responses in the Vail area compared to other locations, and the lack of clear relationships with urbanization, are likely due mainly to the small proportions of large watersheds that are developed there, as well as the unique physiography and terrestrial vegetation regime of the region. Analyses were performed using local measures of the independent variables, instead of watershed-scale measures, to see if aquatic biology associates more with nearby urbanization and natural land cover than overall watershed characteristics. These local measures represent land within 100 meters upstream and on each side of the stream measured from benthic macroinvertebrate sampling sites. Local TIA ranged as high as 26.0%, still substantially under maximum watershed TIA for other study locations. These analyses were not fruitful in discerning patterns helpful to understanding functioning of Vail area streams and managing them, and further attempts will be made.

Figures 1a to 1d, along with the graphs for other combination independent variables not shown, exhibit several trends consistent among regions and ways of viewing the data:

1. The very highest biological indices in all cases are at extremely low values of the combination independent variables, meaning that in three different regions of the nation the best biological health is impossible unless human presence is very low <u>and</u> the natural vegetation and soil systems are well preserved near streams and throughout watersheds. These most productive, "last best" places can only be kept by very broadly safeguarding them through mechanisms like outright purchase, conservation easements, transfer of development rights, etc.

2. Biological responses to urbanization in combination with loss of natural cover do not indicate thresholds of watershed change that can be absorbed with little decline in health, the same as seen in the plots of biological measures versus TIA alone in earlier reports on this work (Maxted 1999).

3. Regardless of location or variables considered, relatively high levels of biological integrity cannot occur without comparatively low urbanization and intact natural cover. However, these conditions do not guarantee fairly high integrity and should be regarded as necessary but not sufficient conditions for its occurrence.

4. In contrast, comparatively high urbanization and natural cover loss make relatively poor biological health inevitable.

5. In all cases the rates of change in biology are more rapid to about the points representing crossover to relatively low integrity (the intersections of the lower horizontal and right-hand vertical lines), and then further decline becomes somewhat less rapid. This pattern

is probably a reflection of communities with organisms reduced in variety but more tolerant of additional stress.

6. The points at which landscape condition takes away the opportunity for good biological health, or alternatively assures poor health, are similar among the study locations but deviate somewhat numerically. While these results might be put to general use in managing streams elsewhere, quantitative aspects should not be borrowed.

7. Comparing Puget Sound fish and macroinvertebrates, coho salmon exhibit more rapid rates of decline with landscape stress, lower TIA at which quite healthy communities can exist, and also lower TIA for poor health.

In viewing these data, a reasonable question is whether or not protecting more forest and wetland, riparian buffer, or both can confidently be expected to mitigate increased urbanization. This question has considerable significance for the ultimate success of clustering development within low-impact designs to sustain aquatic ecosystems. In beginning to think about this issue, it must first be reiterated that if the goal is to maintain an ecological system functioning at or very close to the maximum levels seen, the answer is no. If the goal is to keep some lower but still good level of health, or to prevent degradation to a poor condition, the findings suggest that there is probably some latitude.

In this case the answer to the question can be investigated by using the horizontal axis-intercepts in Figure 1 as bases for examining combinations of the landscape variables in relation to biological goals. For example, the left-hand intercept in Figure 1(d) represents the simple algebraic equation, 8630 = (% TIA)*(100 - % watershed forest and wetlands)*(100 - % IRI). That equation can be solved for any of the three landscape variables, which can then be numerically computed by substituting selected values of the other two. If, for example, the biological goal is to provide necessary conditions for a relatively healthy coho salmon population (CS/CT $\geq$3.0) with TIA = 10 percent and IRI = 65 percent, an estimate of the necessary forest and wetland retention is:

$$100-\frac{8630}{(\%TIA)*(100-\%IRI)} = 100-\frac{8630}{10*(100-65)} = 75\%$$

At least with the present level of understanding and confidence, analyses like this should be used in management only with caution and as advisory tools, and not as strict quantitative determinants. It must be kept in mind that, for high biological goals, the result only indicates the possibility, and not the certainty, of achieving the goal. Biological response depends on many circumstances not reflected in this simple analysis, such as where the developed area is relative to the stream and drainage pathways to it, what type of activity occurs there, and specific qualities of the natural landscape units. There are clearly limits to how much forest, wetlands, and riparian buffer can be preserved around development, particularly with the space constraints at moderate and higher urbanization levels. With all of these many factors unaccounted for, these data should be used only with care that conservatively protects resources.

If these cautions are recognized, though, watershed planners and managers can employ the findings from this multi-region study as approximate guides. The authors' hope is that their use will reduce instances of decision making without specific goals and consideration of the most crucial elements that determine their achievement. Decisions made in this way should reduce simplistic, overly optimistic approaches that very often lead to resource deterioration. Meanwhile, research should continue to represent more locations and to develop models encompassing more components of complex watershed systems.

The best and safest use of the results is probably to analyze how to prevent deterioration to lower biological integrity, or to improve health somewhat, at medium to high urbanization. For one reason, the stakes are lower in this situation, as losses have already been sustained and the relatively tolerant organisms remaining are more robust in resisting change than in more pristine areas. Also, the data show more certainty there than at lower urbanization, where favorable conditions are only necessary but not sufficient for predicting good health. Table 3 presents some cases from this part of the urbanization spectrum, computed as demonstrated in the example above. It considers only realistic forest and wetland cover and IRI values, as drawn from the regional data sets, which are quite consistent in the quantities of these variables actually present. Results for macroinvertebrates are similar between locations. For the most part, staying above what has been defined as poor aquatic health requires holding TIA under about 50 percent at usual levels of natural cover retention, or 60 percent with aggressive forest protection (about 5 percent lower in each case for Puget Sound salmon).

Table 3. Total Impervious Areas (TIA) Predicted to Be Sustainable with Specific Anti-degradation Goals and Hypothetical Natural Land Cover Cases

Location	Goal [a]	Forest and Wetland (%)	IRI (%)[a]	TIA (%)
Montgomery County	Index ≥45%	10	25	39
		20	35	51
		30[b]	40	63
Puget Sound	Index ≥45%	10	25	36
		20	35	47
		30[b]	40	58
	CS/CT ≥1.0	10	25	34
		20	35	44
		30[b]	40	55

[a] Index refers to the macroinvertebrate index for the location as percent of maximum value. Cs/CT—coho salmon:cutthroat trout ratio. IRI—index of riparian integrity.
[b] These forest and wetland cases represent an ambitious level of retention relative to the usual amount existing with fairly high urbanization.

DETAILED PUGET SOUND STRUCTURAL BMP ASSESSMENT

Introduction and Methods

Specific, direct evidence of the effectiveness of stormwater structural BMPs in protecting aquatic biota and receiving water beneficial uses is extremely sparse. As pointed out earlier, the few data do not give confidence in a clear biological payoff for the investments being made in these facilities, but are in no way adequate to warrant any solid conclusions in this regard. To add to this minimal information base, the Puget Sound component of the USEPA and WMI study conducted an intensive BMP assessment in the watersheds of four of its stream reaches, two in Big Bear Creek and one in its tributary Cottage Lake Creek (King County, WA), plus one in Little Bear Creek (Snohomish County, WA). Having received extensive management attention because of its rich salmonid fauna, the Big Bear Creek system has relatively large numbers of structural BMPs for its development level; while the Little Bear Creek reach has relatively few structural devices for the urbanization level. Sites were divided in this way because of the observation in earlier work that BMP service level (density of coverage) varied widely among the urban catchments in the study and, as seems logical, is a factor in effectiveness. These five catchments contain a total of 165 individual BMPs, about 6.5 percent of the more than 2500 found in the entire regional survey.

All BMPs were located and visited in the field, where, if above ground, their dimensions were measured and various observations were recorded. For BMPs intended to control runoff water quality (wet ponds and biofiltration swales and strips), observations included vegetation cover, erosion, and sediment deposition. Maintenance condition was noted in both quantity and quality control facilities. King and Snohomish County stormwater management agency files had information on almost all of the BMPs, which supplemented the field data collection and observations.

The assessment went beyond service level to encompass quality of implementation as well. Quantity control BMPs (mostly dry detention ponds and below-ground tanks and vaults, plus a few infiltration facilities) were rated in terms of their estimated replacement of natural soil and vegetation storage lost in development. Before development, mature, second-growth forests, almost entirely on till soils of glacial formation, covered the watersheds. For example, the Big Bear Creek site 4 catchment had >90 percent forest and wetland cover in 1985, when TIA was about 1 percent. Such conditions have been estimated to provide storage capacity for 15 to 30 cm of rainfall (Booth 1991; Booth, personal communication). Based on other local work on the till soils by Burges et al. (1989), 60 percent of this storage was estimated to be lost in the pervious portion of developed areas, and all would be lost in the impervious part. Storage replacement by infiltration devices was estimated as the volume that can be infiltrated in 24 hours as a function of the infiltration surface area provided and expected soil hydraulic conductivity. The volume detained in live storage for controlled release was taken as the replacement provided by ponds and under-ground facilities. It is recognized that, except for infiltration devices, the designs employed in these catchments are capable only of regulating peak rate discharge and not total volume ultimately released. Thus, they do not truly replace lost soil storage but only affect discharge patterns. An overall score of 100 percent for a catchment represents complete storage of all runoff from developed areas either via infiltration in 24 hours or in detention live storage.

For runoff treatment BMPs implementation quality was gauged according to recognized design and maintenance standards for maximizing performance, which were expressed as condition scores. For wet ponds the score was constructed according to wet pool volume relative to estimated design rainfall event runoff volume, ability to resist flow short-circuiting through flow path length and cellular configuration, emergent vegetation cover, and maintenance condition. For biofilters the score depended on size in relation to the estimated amount needed to provide sufficient hydraulic residence time to achieve known performance capabilities, favorable slope, energy dissipation, vegetation cover, and maintenance condition. Scores were proportioned based on the consensus capabilities of the devices to remove two pollutants (total suspended solids and total phosphorus) and the amount of developed area served by each facility. Individual BMP scores were then added to compute an overall score for the catchment. A score of 100 percent represents interdicting all pollutants expected to be in design storm runoff from developed catchments, performance that could realistically be achieved structurally only by complete runoff infiltration.

Profile of Catchments and BMPs

Table 4 summarizes the characteristics of the catchments and BMPs given detailed attention. Watersheds are as much as two-thirds developed but largely with medium-density single-family residences, producing TIA in or near the 5 to 10 percent range. The Big Bear and Cottage Lake Creek watersheds have the greatest coverage with structural BMPs among the 38 studied in the regional project, yet only about one-sixth to one-third of the developed area even has quantity control BMPs, the primary management concentration in these salmonid streams subject to habitat destruction by more frequent elevated flows after urbanization. The average facility was built before the mid-1980s in the Cottage Lake Creek watershed, where many are below ground. Those serving Big Bear Creek average 5 years younger and tend more to be surface ponds.

The quality control service levels are even lower, especially in the older Cottage Lake Creek developments (<5 percent of developed area). The much higher numbers in the Big Bear Creek catchments indicate the turn to quality control along with quantity control in the heavy development period there around 1990. The wet pond is the most prominent BMP type, somewhat exceeding biofilters in numbers. Most wet ponds perform double service as quantity control ponds with live storage too. Many installations are wet pond-biofiltration swale treatment trains, with ponds usually but not always draining into swales. Facilities expressly designed to be infiltration devices are relatively uncommon in these glacial till catchments.

The Little Bear Creek catchment has less service of developed areas by both quantity and quality control BMPs compared to the other watersheds. These cases thus provide a contrast in management under comparable urbanization.

ANALYSIS

Table 5 summarizes scoring of implementation quality for the two categories of BMPs. The analysis shows that <4 percent of soil and vegetation storage lost to development was recovered by BMPs in the Cottage Lake and Big Bear Creek catchments, and approximately 1 percent in the Little Bear Creek cases. These very low percentages are in strong contrast to the proportions of developed areas having quantity control BMP storage, which are about an order of magnitude greater, although still far from complete. This dichotomy signifies inadequate standards for designing these BMPs, a point discussed further below.

Achieving the full potential of water quality treatment was similarly low. The Cottage Lake Creek catchment scored near the Big Bear ones despite a much lower service level because of substantially more infiltration there, a factor also reflected in its quantity control score.

Table 4. Characteristics of Watersheds in Detailed Structural BMP Assessment

Characteristic[a]	Cott-2[b]	BiBe-1[b]	BiBe-4[b]	LiBe-2[b]
Catchment:				
Catchment area (km^2)	17.5	9.5	29.5	16.9
% developed	66.8	44.0	50.0	67.8
% impervious	11.1	6.6	8.3	9.9
Quantity Control (Qn) BMPs:				
No. Qn BMPs	56	22	59	17
% Qn BMPs below ground	41.1	9.1	32.2	11.8
% developed area with Qn BMPs	30.9	24.2	15.9	11.5
No. Qn BMPs/km^2 developed area	4.8	5.3	4.0	1.5
No. Qn BMPs/km^2 impervious area	28.8	35.1	24.1	10.2
Average age of Qn BMPs (y)	13	8	8	9
Quality Control (Ql) BMPs:				
No. Ql BMPs	11	22	49	5
No. infiltration devices	4	3	3	0
No. wet ponds	5	11	25	5
No. wet ponds that are also Qn BMPs	4	9	24	4
No. biofilters (swales, filter strips)	2	8	21	0
% developed area with Ql BMPs	4.6	15.4	13.5	3.4
No. Ql BMPs/km^2 developed area	0.9	5.3	3.3	0.4
No. Ql BMPs/km^2 impervious area	5.7	35.1	20.0	3.0
Average age of Ql BMPs (y)	11	8	7	9
Stream Biology:				
Benthic Index of Biotic Integrity	33	29	33	25
Coho Salmon:Cutthroat Trout Ratio	2.9	5.0	3.4	1.7

[a] Average ages are at time of stream ecology work; infiltration devices considered to be both quantity and quality controls.
[b] Cott-2—Cottage Lake Creek site 2; BiBe-1,4—Big Bear Creek sites 1 (upstream) and 4 (downstream); LiBe-2—Little Bear Creek site 2.

Table 5. Scoring of Quantity and Quality Control BMP Implementation

Score	Cott-2[a]	BiBe-1[a]	BiBe-4[a]	LiBe-2[a]
Quantity control score (%)[b]	2.0-3.9	1.5-3.0	1.2-2.4	0.8-1.6
Quality control score (%)	3.5	3.6	2.5	0.7

[a] See Table 4 note b.
[b] First number in range is score with assumption of maximum natural soil and vegetation storage (30 cm); second is with assumption of minimum natural soil and vegetation storage (15 cm).

This investigation started out to examine if the highest BMP service levels make a demonstrable difference in stream biological integrity. However, the mitigation potential provided by even these service levels proved to be so small that this question still cannot be conclusively answered. Biological measures are indeed lower in the relatively less served Little Bear Creek catchment, but factors other than structural BMPs could be responsible. Table 6 summarizes these potential factors for the four intensively studied catchments and two others with similar development but no structural BMPs at all. All of these streams are still producing salmon (generally, several species) and are thus resources to which strong management attention should be directed.

Table 6. Watershed and BMP Conditions and Stream Biological Integrity in Six Cases with Total Impervious Area in the Approximate Range of 5 to 10 Percent

Condition[a]	Cott-2[b]	BiBe-1[b]	BiBe-4[b]	LiBe-2[b]	GrCo-2[b]	LiSo-1[b]
Total Imperv. Area (%)	11.1	6.6	8.3	9.9	7.8	6.3
B-IBI	33	29	33	25	33	23
CS/CT						
% forest & wetlands	33.2	56.0	50.0	32.2	76.5	69.3
Index of Riparian Integrity	55.5	87.5	79.2	45.8	79.2	33.3
Quantity control score	2.0-3.9	1.5-3.0	1.2-2.4	0.8-1.6	0	0
Quality control score	4.1	5.4	4.2	0.7	0	0

[a] B-IBI—benthic index of biotic integrity; CS/CT—coho salmon:cutthroat trout ratio.
[b] See Table 4 note b; also, GrCo-2—Green Cove Creek site 2; LiSo-1—Little Soos Creek site 1.

The table does not present an entirely consistent picture. The Green Cove Creek reach equals the highest B-IBI among these sites without structural BMPs but high levels of forest, wetlands, and riparian buffer preservation. The LiBe-2 and LiSo-1 sites exhibit the lowest B-IBI values and also substantially lower riparian indices than the other locations. Still, Cott-2 equals the highest B-IBI with the highest and oldest development, nearly the least forest and wetlands, and only moderate IRI. It cannot be dismissed that this system is holding its level of health with the contribution of structural BMPs, even with their overall low service level and quality of implementation. Big Bear Creek has been the beneficiary of a King County program of fee-simple and conservation easement purchases that has encompassed 10.4 and 3.6 percent of the BiBe-1 and 4 catchments, respectively. These efforts are undoubtedly contributing to the thorough riparian buffering and moderate forest and wetlands retention seen there. Still, in biological measures these sites do not rise above the nearby Cottage Lake Creek catchment, which has very little (0.2 percent of the catchment) of these protected lands.

What is probably the safest observation is that many sources of natural variation in these ecosystems make clear-cut definition of cause and effect elusive. However, the general conclusion of the primacy of riparian buffering drawn in the preceding section appears to be upheld by these observations, and structural BMPs cannot be dismissed as contributing. Verification of that premise and delineation of how much protection they can actually afford requires their thorough and high quality implementation and then follow-up ecological study.

DISCUSSION

The analysis determined that, even in the watersheds around Puget Sound best served by structural BMPs, a distinct minority of the development has any coverage at all. The existing BMPs mitigate very small percentages of the hydrologic and water quality changes accompanying urbanization. To understand how this situation came about, it is worth reviewing some history of stormwater management in King County, which has jurisdiction over the relatively well served watersheds.

Agency records show the first detention ponds appearing in 1975. The first King County stormwater management regulation aimed at protection of aquatic ecosystems came in 1979. From the beginning of regulation, exemptions from compliance existed for relatively small developments (e.g., no requirement unless the development would create at least 5000 ft^2 of impervious surface). Many development projects are single dwellings or small short plats fitting in the exempted category. Exemptions largely explain why much of the developed area has no structural BMPs.

The 1979 regulation specified peak rate control ponds on the basis of a hydrologic estimation procedure based on the Rational Method. This rather crude procedure produced very inadequate pond sizes relative to vegetation and soil storage losses. These inadequacies resulted from the tendency of the method to underestimate pre-development discharges, which gave an artificially low target for post-development controls. Overall, detention ponds designed in this way recovered under 10 percent of the estimated lost vegetation and soil water storage (Booth, personal communication). These ponds thus gave very little water quantity control and, without any provisions for runoff treatment, no water quality mitigation.

A new King County regulation based on an improved method for hydrologic analysis (Santa Barbara Unit Hydrograph) took effect in 1990. This regulation also introduced water quality control requirements for the first time. Peak rate control ponds designed under it can replace perhaps two or three times as much lost storage as the preceding method (Booth, personal communication), an amount that still represents a small minority of the natural storage capacity. However, applicable law vests development applications filed before adoption of a new regulation at the standard prevailing at the time of application. In the rapid urbanization climate in the area *circa* 1990, many applications came under the old standard well into the 1990s. As a result, the large majority of the facilities in place when the stream ecology surveys were performed (1994-1997) were based on the very inadequate 1979 design criteria. Continuing deficiencies in design standards largely explain why, even where they are present, the facilities mitigate so little of the impact. These dual regulatory inadequacies of widespread exemption and insufficient implementation standards make inevitable the small beneficial effect of structural management, even where valued resources get a relatively high level of attention.

Relationship of Structural and Non-structural BMPs

Stormwater and urban water resources management first developed around the concept of structural BMPs but recently broadened to encompass principles often given names like conservation design and low-impact development. Most fundamentally, these principles guide where to place development and how to build it to minimize negative consequences for aquatic ecosystems. There are many specific tools to implement them, but they fit generally into the broad categories of separating development from water bodies (i.e., retaining riparian buffers); limiting impervious area in favor of natural vegetation and soil, especially forest cover; and strategic and opportunistic use of structural BMPs. The Puget Sound database offers some opportunity to examine how these structural and non-structural strategies might fit together and what they can accomplish in different urbanization scenarios.

Figure 2 encompasses the various general elements of conservation design and how they relate to stream biology in terms of macroinvertebrates and fish. Structural BMPs are expressed as the density of BMP coverage per unit area of impervious surface (sites with TIA <5 percent do not have structural BMPs and are excluded). Non-structural practices are represented as the product of watershed forest and wetland cover (percent) times index of riparian integrity (percent of maximum) and graphed for the highest, intermediate, and lowest one-third of the resulting numerical values.

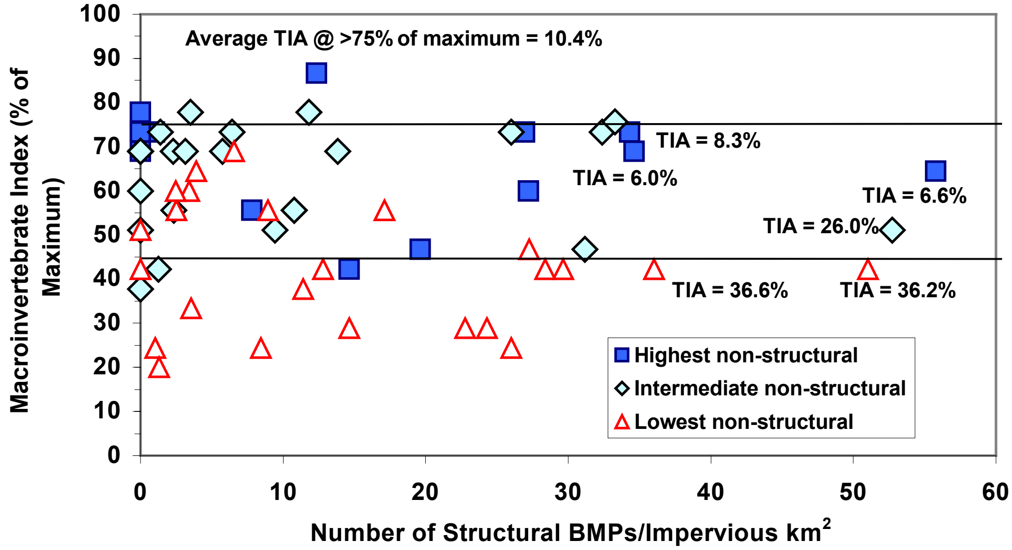
The first observation that should be made about Figure 2(a) is that the five highest macroinvertebrate indices are not represented, because they are from sites with <5 percent TIA. It is apparent that neither structural nor non-structural measures, at least at the levels represented in this database, can provide for the highest benthic macroinvertebrate integrity if any but the most minimal development occurs.

It can further be observed in Figure 2(a) that points at the left (relatively few BMPs) disperse widely over the macroinvertebrate index range. Some sites with little forest, wetland, and riparian retention rise into the intermediate biological integrity zone (45 to 75 percent of maximum index value), while a few locations with higher non-structural measures fall close to or into the region of relatively low ecological health. This observation is an expression of what is also apparent in Figures 1a to 1d, namely that a certain ecological status is not assured by any condition, or even combination of conditions, but is only more likely with those conditions.

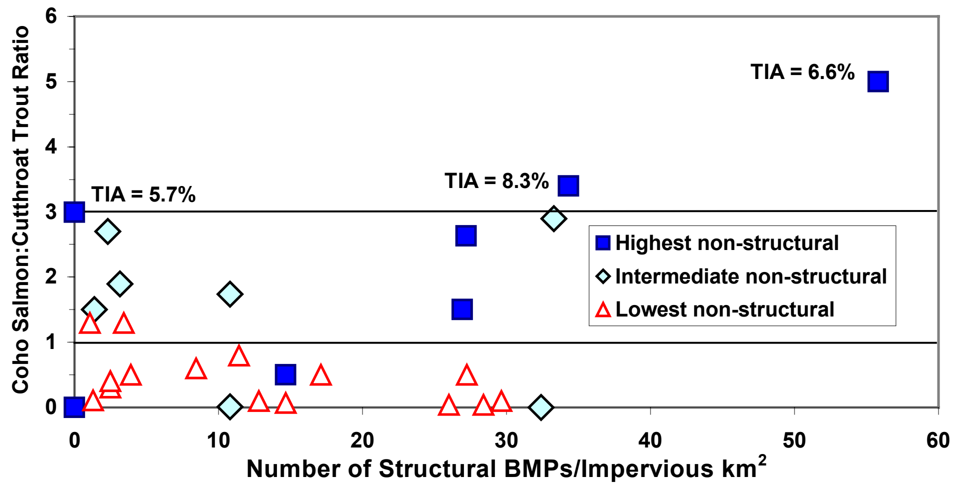
The Figure 2(a) points converge with increasing structural BMP density, overall and in each non-structural category. Sites with the lowest macroinvertebrate indices (and also highest urbanization and lowest non-structural measures) appear to benefit from structural BMP application; while those with higher biological and natural cover measures and lower urbanization do not, with the result that points tend toward the intermediate biological level. If ecological losses are to be stemmed at high urbanization, structural BMPs appear to have a substantial role. In this situation development has taken forests and wetlands and intruded into riparian zones, reducing the ability to apply non-structural options.

Given the dearth of data, Figure 2(b) gives a scantier picture for fish, but does suggest a few points. In contrast to macroinvertebrates, only the second-ranking among the five highest CS:CT ratios was in a watershed with <5 percent TIA and is missing from the graph. In further contrast, coho salmon appear to benefit from structural BMPs in relatively light urbanization, in combination with the highest natural cover retention, although the small amount of evidence cannot conclusively support this observation. These fish, therefore, seem to have some robustness in light and mitigated human presence. On the other hand, there is no evidence that

BMPs can lift the CS:CT ratio from very low levels in highly urbanized catchments low in forest, wetlands, and riparian cover, although data are inadequate to disregard this possibility.



(a) Macroinvertebrates



(b) Fish

Figure 2. Puget Sound Biological Community Indices Versus Structural BMP Density with the Highest, Intermediate, and Lowest One-Third of Natural Watershed and Riparian Cover

[Note: Upper and lower horizontal lines represent indices considered to define relatively high and low levels of biological integrity, respectively.]

Any conclusions from this analysis must be tempered according to the scope of the underlying data. Probably the leading factor giving caution is that no instances exist of structural BMPs being exceptionally widely applied and designed to mitigate a large share of the known impacts of urbanization. Therefore, the fullest potential of these practices has not been examined, and it is possible that extremely thorough applications would demonstrate additional benefits not suggested in these data.

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INTEGRATION OF THE FLORIDA YARDS AND NEIGHBORHOODS PROGRAM INTO STORMWATER PLANNING FOR NUTRIENT REMOVAL

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ABSTRACT

Stormwater from residential areas is estimated to contribute more than one-third (33%) of the total nitrogen load to Sarasota Bay. The Florida Yards and Neighborhoods Program (FYN) was developed in 1993 to promote environmentally friendly landscaping with plants suited to the Southwest Florida Climate, natural conditions, and wildlife. Using the FYN principles, homeowners can reduce fertilizer and pesticide use, possibly improving the quality of stormwater runoff. West-central Florida has been under severe drought conditions for over two years, and landscape irrigation can account for more than 40% of a homeowner’s water usage. Research being conducted by the University of Florida/IFAS will provide information that demonstrates the value of the Florida Yards and Neighborhoods Program as an aid in the improvement of water quality. Current research consists of two projects: 1) A set of replicated plots at the Ft. Lauderdale IFAS center, and 2) examination of the effects of Florida Yards and Neighborhoods in actual residential communities. The FYN program is presented directly to the general public as a tool that, if implemented at large enough scale, may help improve water quality in local streams and estuarine waters. To this end, the Sarasota County (Florida) Board of County Commissioners recently approved a bill requiring FYN-type landscapes be used in any new developments built within County limits.

INTRODUCTION

The SBNEP was initially responsible for characterizing the environmental condition of the Sarasota Bay region, and formulating and implementing a comprehensive restoration and protection plan for Sarasota Bay. The plan, formally called the Comprehensive Conservation and Management Plan (CCMP)(SBNEP 1995), was completed in November 1995. The CCMP presents resource management strategies derived from the many technical, early action, and public outreach projects conducted by the SBNEP since 1989.

As reported in the SBNEP's Framework for Action (SBNEP 1992) and CCMP, five major problem areas were identified: stormwater, wastewater, fisheries, recreation, and habitat loss. Other areas of interest included public education, Bay management, and additional technical studies. In brief, nutrient loads in Sarasota Bay in 1988 were approximately 400% of that expected from a pristine, undeveloped watershed; metals contamination was also identified as a significant issue in tributary areas. Approximately 39% of tidal wetlands and 30% of seagrass coverage has been lost throughout the Bay region.

The Florida Yards and Neighborhoods (FYN) Program is a statewide pollution prevention initiative in Florida that simultaneously addresses water conservation, stormwater runoff, wetland protection, preservation of groundwater and surface water supplies, neighborhood beautification, wildlife habitat, and watershed protection. To date, FYN programs have been established in 35 counties in Florida. Further expansion of these centers is anticipated as the FYN Program continues to evolve. This program is presented directly to the general public as a tool that, if implemented at large enough scale, they can use to improve water quality in the estuarine waters around their homes. Publications of the program include "The Florida Yardstick Workbook" and "Florida Yards and Neighborhoods Handbook – A Guide to Environmentally Friendly Landscaping." West-central Florida has been under severe drought conditions for over two years, and landscape irrigation can account for more than 40% of a homeowner's water usage.

In order to understand the impact that the Florida Yards initiative could have on the environment, it is necessary to document the results that can be achieved by adopting Florida Yards principles. This is yet to be accomplished. However, in southwest Florida, research and modeling has determined that a significant amount of nutrients and pesticides are being introduced to our coastal waters from residential and commercial areas. The FYN Program research results are incorporated into the well-established educational components of the Florida Yards and Neighborhoods Program within the State of Florida. Nitrogen has been identified as the principle pollutant of concern in Sarasota Bay, and it has been concluded that stormwater runoff contributes 55 percent of the nitrogen load to the Bay, 60 percent of which comes from residential neighborhoods. In addition, the Floridan Aquifer is also being depleted from over-pumpage. It is likely that Florida residents will need to adopt landscapes that help sustain growth and protect the environment. However, data from closely monitored, scientifically sound comparisons, as well as from "real-world" landscapes, are needed to justify and encourage such landscape adoption by the public.

This project provides data to incorporate measurable benefits into state-wide stormwater permits (in lieu of costly retrofit projects), to continue to solidify the strong cooperation among Cooperative Extension Agents statewide, and to continue to forge strong multi-jurisdictional partnerships through the NEP process. The FYN Program is truly comprehensive in that it simultaneously addresses water conservation, stormwater runoff, wetland protection, preservation of ground and surface water supplies, neighborhood beautification, wildlife habitat, and watershed protection.

In order to understand the impact that the FYN initiative could have on the environment, it is necessary to document the results that can be achieved by adopting FYN principles. Current research consists of two main projects: 1) A set of replicated plots at the Ft. Lauderdale IFAS center, and 2) examination of the effects of Florida Yards and Neighborhoods in actual residential communities. The program can have applicability Gulf- and nation- wide because it addresses the improvement of water quality through landscaping practices that may decrease fertilizer use and reduce water consumption for landscape irrigation.

STUDY SITES

The residential research sites are within the Sarasota Bay watershed, a designated SWIM program priority water body. University of Florida researchers established replicated plots at the Ft. Lauderdale IFAS research center comparing ornamental and traditional turf lawns with respect to runoff quality and quantity.

METHODS AND MATERIALS

Ornamental and Turfgrass Research Plots

The research at the Ft. Lauderdale site evaluated N losses from two landscape sites established in winter 1998-99. The sloped plots (10%) were established at the FLREC. The field plot design consisted of four replications of two yard types: 1) a turf lawn and 2) ornamental plots with plant species typically found within a Florida Yards landscape designed in cooperation with Mr. Alan Garner, Florida Cooperative Extension Service. The turfgrass is St. Augustine grass from sod. Plot size was 5 meters wide by 10 meters down the slope. Each turf plot has an in-set sprinkler head system to provide overhead irrigation at a rate of 5 cm hr^{-1}. The Florida Yards has a micro-irrigation designed by Michael Holsinger, Florida Cooperative Extension Service. Plots are hydrologically isolated to prevent cross surface flow. The site was instrumented to collect surface runoff and percolate water.

Data collection was initiated following the initial fertilizer application. The ornamental yards fertilized regimen varied between years due to management decisions and observed health of the plots. The fertilizer was applied to the Florida Yards as a granular material with an analysis of 8-4-12 (N-P_2O_5-K_2O). The material was 38% completely controlled/slow release during the first year, and 100% completely controlled/slow release after the first study year. The turfgrass plots were fertilized at 300 kg N ha^{-1} per year with a granular 26-3-11 material that contained 38% controlled release N as sulfur-coated urea. The fertilizer was applied approximately bi-monthly to the turfgrass at 50 kg N ha^{-1}. Turfgrass plots were lightly irrigated after fertilization. The FYN plots were not irrigated after fertilization. Maintenance irrigation was applied when necessary to avoid plant water stress (wilting) in turf. The FYN received irrigation when deemed necessary by Dr. Broschat. Irrigation was applied to the Florida Yards twice at approximately 5 cm during the experimental period. Although an evaluation of N in surface run-off and percolate waters was the main focus of the project, percolate samples were also analyzed for P and K.

The experimental design for the study was a completely randomized design with a single factor, landscape type. The design included two treatments and four replications per treatment. Daily nutrient loading (leaching) was calculated as the product of the concentration and the volume of percolate. Statistically significant treatment effects on nutrient leaching from percolate were identified using SAS analysis of variance procedures.

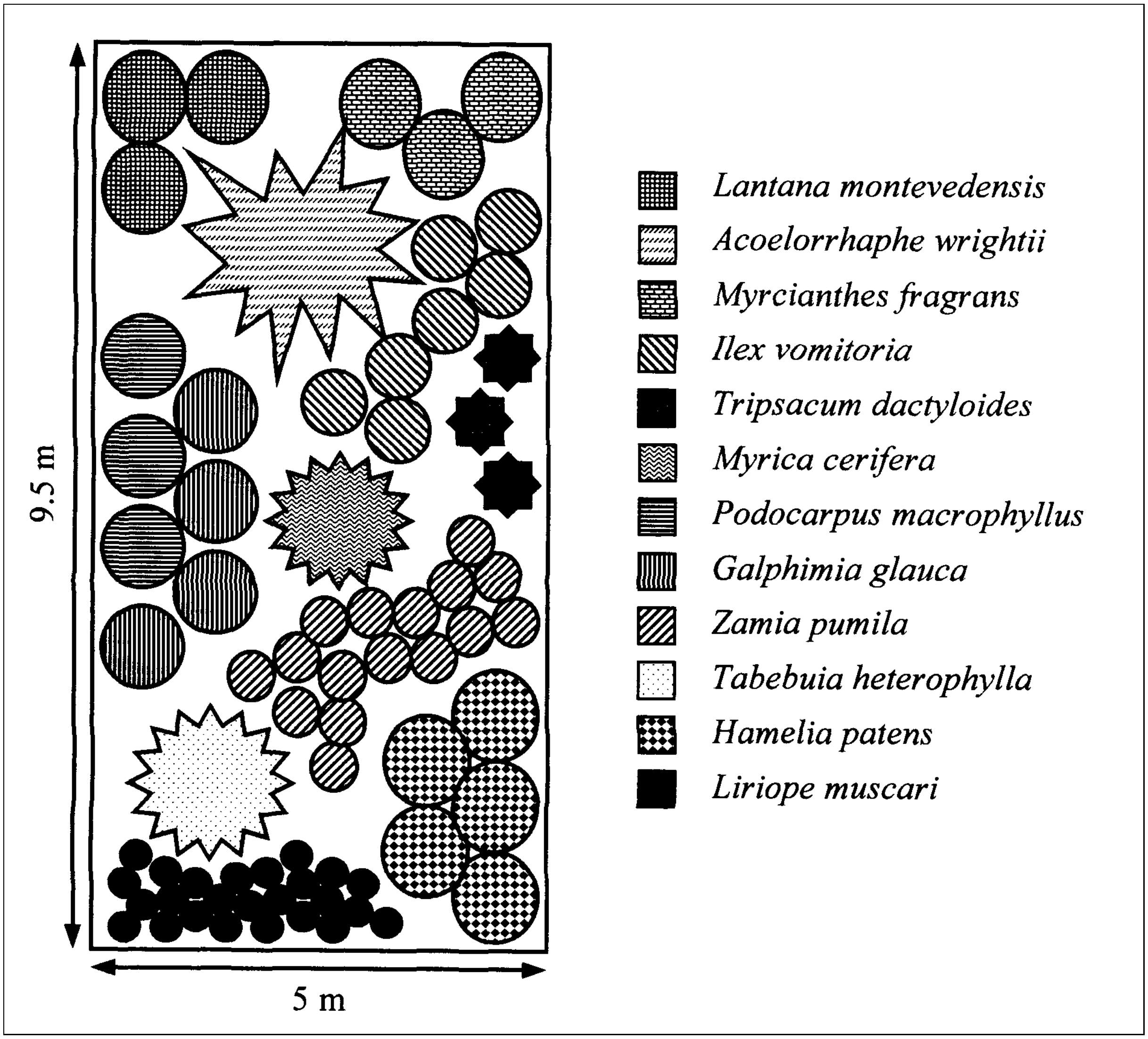

Figure 1. Layout of the ornamental species plots. The diagram shows the quantity and relative position of all species included within each 9.5x5m plot. The choice of plant materials and layout of the landscape were in accordance with principles espoused by the Florida Yards and Neighborhoods Program. The apex of the 10% slope coincides with the top of the diagram (from Cisar and Snyder 2000).

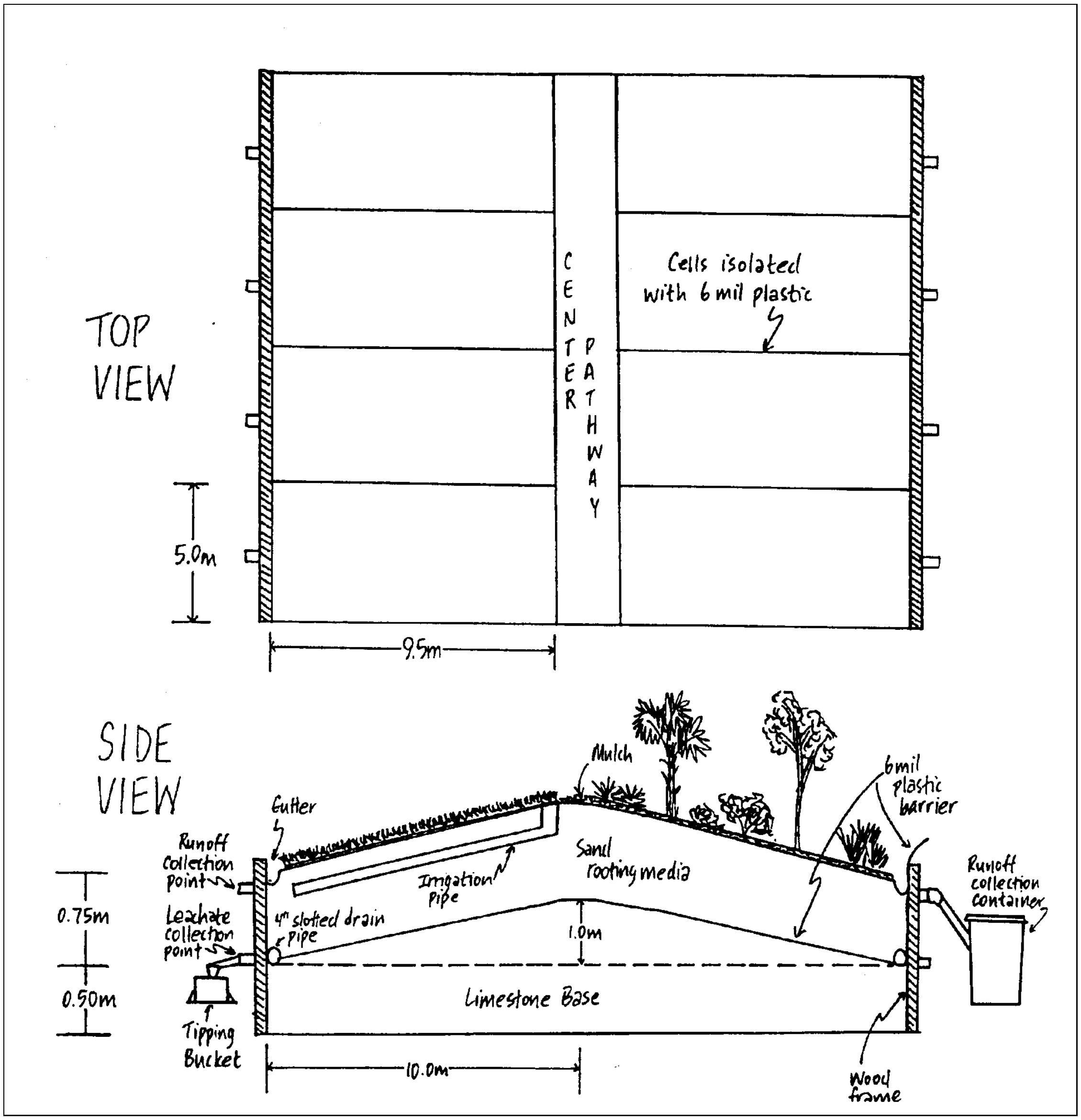

Figure 2. The 2Ox2Om facility constructed to assess surface runoff and leaching from two contrasting landscape types. Eight plots (9.5x5m) were created, which allowed for four replications of each treatment. A plastic barrier (6-mm) provided hydrological isolation for each plot. A gutter system collected any surface runoff, while 10.2-cm slotted pipes drained the percolate. Each landscape was established in 0.75 m of medium-fine sand at a 10% slope (from Cisar and Snyder 2000).

Sarasota Demonstration Yards

The second objective entailed setting up a nitrogen runoff demonstration site in Sarasota, which included a certified Florida Yards and a turfgrass lawn maintained by a lawn service. The purpose of this un-replicated demonstration study was to gain experience in the selection of appropriate study sites; in the installation and utilization of the proper sampling equipment; in collecting, storing and transporting water samples; in working with homeowners and cooperators who were the on-site personnel; in using the site as a template for additional sites for replicated studies; and in obtaining reliable data on N runoff under real world conditions.

The selected yards were adjacent waterfront property on Sarasota Bay. These sites were selected because of their location nearby a water body of concern, proximity to Sarasota County Cooperative Extension personnel and because we were able to obtain the services of a highly motivated individual homeowner. Despite a knowledgeable cooperator, precise management practices were not available for both landscapes. The owner of the Florida Yards concept landscape reported that no commercial fertilizers were applied to the yard and that no irrigation was applied; however a composting system existed that is a potential source for plant essential nutrients. A commercial lawn care company maintained the turfgrass lawn of the adjacent home, and was not able to provide information about exact quantities of fertilizer applied and application dates. These companies typically apply 300 kg ha^{-1} yr^{-1} (personal communication, Mrs. Erica Santella, Technical Manager, True Green, Inc.). Moreover, the turfgrass lawn was irrigated. Two runoff collection systems were designed and installed in each landscape. The gutter system allowed for the collection of any surface runoff. The potential for artifactual N entering the open system exists because the runoff collection system is placed within the landscape. In addition, two ceramic cup water samplers were installed in each landscape to collect percolate samples. The percolate samples provide a concentration of nutrients in the vadose-zone water. A water pump, instructions, and the sampling protocol (including storage procedures) were provided to one of the homeowners to initiate sample collection at the demonstration sites. Sampling was delayed until the site recovered from the disturbance related to the installation of the systems. Sampling from the demonstration site commenced during the dry season in February 2000. Samples were collected following rain events and subsequently analyzed for nitrogen. Samples from the Sarasota site were analyzed using electrodes to measure for NH_4-N and $N0_3$-N.

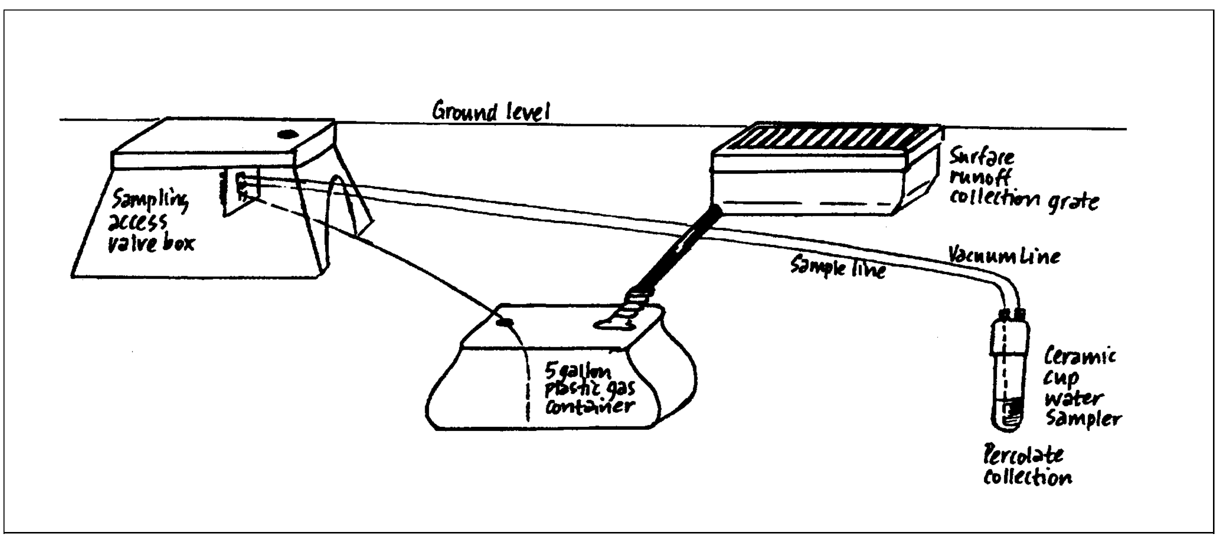

Figure 3. Design of the runoff and percolate collection equipment installed at the Sarasota demonstration site (from Cisar and Snyder 2000).

RESULTS AND DISCUSSION

Ornamental and Turfgrass Research Plots

The normal hydrology of southern Florida involves a wet season (June-November) with appreciable rainfall and a dry season (December-May) with little rainfall. In year 1, considered a "normal" rain year, rainfall totaled 205.4 cm during the study period. In year 2, one of the more severe dry season periods on record in south Florida, rainfall totaled 139.4 cm during the experimental period with the greatest quantity (over 100.0 cm) occurring as expected during the rainy season months. More irrigation was applied to the turf plots as compared to the ornamental plots during both Year 1 (establishment phase) and Year 2 (drought year)(Table 1). However, during Year 2, total water use decreased for both ornamental and turf plots (Table 2).

Table 1. Irrigation practices for ornamental and turfgrass research plots (cm).

	Year 1	Year 2
Ornamental Yard	88.5	10.4
Turfgrass Lawn	96.4	23.3

Table 2. Total water input for ornamental and turfgrass research plots (cm; Irrigation + Rainfall).

	Year 1	Year 2
Ornamental Yard	293.9	149.8
Turfgrass Lawn	301.8	162.7

The rapid infiltration rate of the sandy soil (59.9 cm hr^{-1}) was most likely the major factor influencing the amount of surface runoff observed. Despite the 10% slope used on each plot, runoff was collected only once during the study after an unusually intense rainfall event (22 cm) in June 2000.

Amount of percolate and nutrient concentrations determine the total nutrient leaching of a plot. Rainfall, irrigation, establishment phase, plot type, and fertilizer regime may influence the amount of total percolate seen within the research plots. Table 3 shows the amounts of nitrogen (as fertilizer and rainwater) applied to the 2 plot types.

Table 3. Nitrogen added as fertilizer (plus rainwater)(kg/ha) to ornamental and turfgrass research plots.

	Year 1	Year 2
Ornamental Yard	150 (+25)	240 (+17)
Turfgrass Lawn	300 (+25)	300 (+17)

During both study years, total inorganic-N leaching was significantly greater for the ornamental plots (Table 4). Total inorganic-N leaching was substantially less following the year 1 establishment study (Erickson et al., 2001). Compared to year 1, N leaching from turfgrass was reduced by approximately 60% and leaching from the ornamental plots was reduced approximately 88% (Table 4). This occurred at the same time the nitrogen (as fertilizer) had been increased for the ornamental plots (Table 3). Weather, plant maturity, and management factors could have played a role in reducing N leaching.

Table 4. Nitrogen leaching from ornamental and turfgrass research plots (kg/ha).

	Year 1	Year 2
Ornamental Yard	48.3	5.4
Turfgrass Lawn	4.1	1.2

Sarasota Demonstration Yards

Percolate and runoff nitrogen concentrations for the demonstration yards in Sarasota were similar for the Florida Yards and the Traditional Turf Lawn (Table 5). However, no estimate of total percolate volume was obtained during this portion of the study. If differences in volume of percolate occurred, perhaps due to irrigation practices, total impact to water quality would be different. To gain greater understanding of the value of the Florida Yards and Neighborhoods program, future data collected from the private sites will include, where possible, age of the landscape, rainfall amount and irrigation practices, and fertilizer regime along with water quality parameters such as total nitrogen content of the percolate.

Table 5. Nitrogen Concentrations (mg/L) in Sarasota Demonstration Yards

a. Percolate	Winter 2000 (n=6)	Fall 2000 (n=9)
Florida Yards	1.7	1.6
Traditional Lawn	1.4	1.6
b. Runoff (5 events in 2000)		
Florida Yards	6.7	
Traditional Lawn	4.1	

CONCLUSIONS

Important differences were noted between Year 1 and Year 2 for the Ft. Lauderdale study. The most notable differences were in the following areas: 1) the Florida Yards plots were more established, with a larger root system capable of harvesting more water and nutrients, thereby resulting in less percolate and leachate; 2) the methodology of irrigation management was redesigned in Year 2, allowing supplemental irrigation of ornamental plots only twice (under extreme drought conditions); and, 3) the methodology concerning fertilization of Florida Yards plots was also totally redesigned, requiring the use of lower rates of an 8-4-12 slow-release fertilizer in 6 bi-monthly applications. These changes most likely played an important role in the reduction of nitrogen within percolate from the ornamental plots.

This project provides insight on water quality effects of various landscape practices and presents alternatives for incorporation into various landscapes for water quality protection. Insight on the water conservation possibilities through incorporation of the Florida Yards and Neighborhoods Program principles were demonstrated. The study also showed that, in certain circumstances, turfgrass lawns are very capable of removing applied nitrogen. Ongoing research will compare the runoff from fully established turf and ornamental lawns to see if changes occur during maturation of the landscape.

In recognition of the value of the Florida Yards and Neighborhoods Program as a contributor to the improvement of water quality through the reduction of fertilizer and pesticide use, the Sarasota County (Florida) Board of County Commissioners recently approved a bill requiring FYN-type landscapes be used in any new developments built within County limits.

ACKNOWLEDGEMENTS

Funding for this project came from the Florida Department of Environmental Protection, the U.S. Environmental Protection Agency and the Sarasota Bay National Estuary Program.

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THE DEMONSTRATION PROJECT AND STORMWATER MANAGEMENT

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ABSTRACT

A monitoring project was designed to measure pollutant concentrations as well as the amount of water discharged from an effluent filtration (underdrain) system during storm events. The system was analyzed for water quality discharged from a stormwater pond that ultimately flows into the Tampa Bay estuary in Florida. The volume of stormwater runoff was also measured to estimate a water budget for the system. Also, the water quality and flow discharged through the underground filter system on a daily basis was quantified. The data in this report include nineteen rain events and concluded the first year of the study, which was designed to collect background data before making recommendations and improvements to the systems for phase II of the project.

INTRODUCTION

An important natural process known as rainfall saturates soils, replenishes aquifers and provides water for biological processes. While there are numerous benefits provided by rainfall, there is one important problem associated with rainfall that begins when the first drop contacts the ground, this is known as stormwater runoff. As rainwater mixes with pollutants that have collected on streets, parking lots, sidewalks, rooftops and other impervious surfaces, nonpoint source pollution is introduced into the watershed.

To deal with nonpoint source pollution, the Southwest Florida Water Management District (SWFWMD) issued permits for two stormwater ponds as part of the Florida Aquarium construction in downtown Tampa. The ponds provided an opportunity to study various aspects of stormwater management. Specifically to investigate some of the problems associated with pond maintenance, to educate the public about runoff pollution and to develop strategies to make stormwater systems an attractive landscape amenity. Two monitoring studies were actually conducted, however, for purposes of this paper only one study will be presented. This study evaluated an entire stormwater system using an effluent filtration system with the goal of constructing water and nutrient budgets and is designated "The Whole Pond Study." The pond on which this paper concentrates has been given the label the *Street Pond,* for the area of the watershed that it drains.

STUDY SITE

The site is located at the Florida Aquarium at 701 Channelside Drive, Tampa, Hillsborough County, FL (Section 19, Township 29, Range 19). The stormwater ponds are situated between the parking lot and the aquarium building. They discharge to Ybor Channel which leads directly to Tampa Bay, an estuary of national significance, included in the National Estuary program and identified as a water body in need of attention. The wet ponds in this study were quite different from one another and were named to designate the principal type of runoff each pond received (Figure 1). For purposes of this paper only the Street Pond (Pond 3 and Pond 4) will be discussed.

The Street Pond collects runoff from a well-traveled downtown thoroughfare and a large parking garage. The pond is designed to treat 10.4 acres of street and urban runoff. It is an effluent filtration system that uses artificial side drains packed in aggregate to treat stormwater. Filter systems direct low flows through this media to underdrain pipes which, in this case, discharges to the drop box at the outflow. High flows are discharged over the outfall weir.

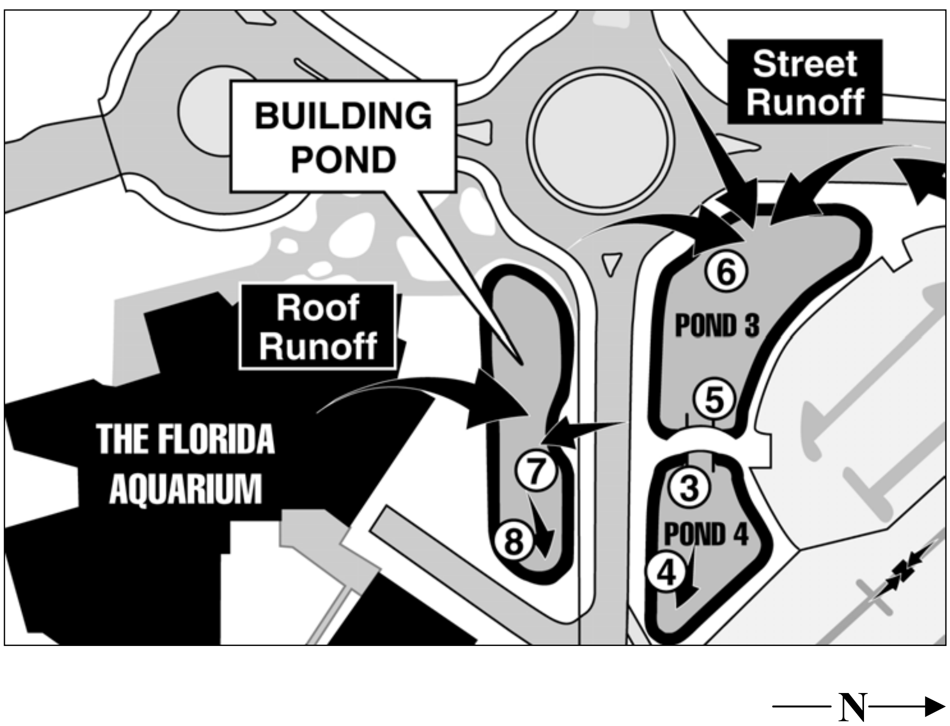

Figure 1. Site map showing the Street Pond (Pond 3 & 4) and the Building Pond (not included in this paper). Note the runoff to the inflow pipe (6) of Pond 3 (sedimentation basin). Notice the direction of flow towards the outfall (4) in Pond 4 (treatment basin) via (5) and (3), the equalizer pipe.

The Street Pond is actually two ponds connected in the middle with an equalizer pipe. The first pond was designed to act as a sedimentation basin and the second pond was the filtration system with side bank filters located on its south side. Maintenance of filter systems is an important component in keeping effluent filtration systems functional, but unfortunately this is rarely done. This pond was no exception and the drawdown pipes were clogged with debris and the screening material was in disrepair. The Whole Pond Study was conducted to evaluate the water quality and quantity for the inflow, outflow and underdrain system.

MATERIALS AND METHODS

The Street Pond was sampled at the inflow, outflow and underdrain structures, as well as for rainfall, to quantify the flow and water quality entering and exiting the system. The side bank filtration system and the outflow structure were taken into consideration when computing water and flow. Storm water was monitored from November 2000 through August 2001 by collecting flow-weighted composite samples and/or grab samples from the appropriate sampling stations after a rain event. Flow-weighted composite samples were collected at regular intervals in the underdrain pipe to compare with the pond water.

The chemistry laboratory of the Southwest Florida Water Management District (SWFWMD) analyzed water quality samples. Laboratory analyses were performed according to either Standard Methods (A.P.H.A. 1989) or Methods for Chemical Analysis of Water and Wastes (U.S. EPA 1983). Water quality samples were collected to analyze total nitrogen, organic nitrogen, total phosphorus, ortho-phosphorus, copper and lead. Acid was then added to the samples for preservation of metals and nutrients. The samples were placed on ice in coolers and transported to the SWFWMD laboratory for analysis using standard methods.

When analyzing the water quality data, there were a large number of measurements below the laboratory detection limit. When a value was listed below the limit of detection (LOD) then one-half the detection limit was substituted for calculating summary statistics.

To measure inflow hydrology a CR10™ data logger was connected to a Sontek™ velocity meter suspended into the inflow pipe about ten feet before the pipe discharged into the pond. The Sontek™ recorded velocity, which was later converted to flow using the area of the pipe, 1.2 m^2 (12.5 ft^2). An ISCO™ automatic portable sampler packed with ice was used to take flow weighted composite samples in the pipe.

Outflow Hydrology was measured using a CR500™ data logger connected to a float and pulley. The data logger recorded water level from the outflow, this data was used to estimate the amount of flow exiting the pond. The flow data for the weir structure at the outflow were estimated using the standard formula for a rectangular weir with end contractions. Each side of the outfall box was then treated as a separate rectangular weir. Here also an ISCO™ sampler was used to take flow weighted composite samples of the outflow. The underdrain hydrology was measured at the Street Pond using an ISCO™ bubbler flow meter and a Thel-Mar™ volumetric weir installed in the pipe.

RESULTS

Data from the Street Pond were collected and analyzed for water quality and flow for the period November 2000 to August 2001. During this period the site received 107cm (42 in) of rainfall compared to the normal 132cm (52 in). This amount was less than normal due to a severe drought.

Water Quality

When conducting this study there were several water quality parameters that were more important to the overall health of the ponds and ultimately the Tampa Bay estuary. The water quality parameters measured that were of significant value are shown in (Figure 2).

Nitrogen is an important nutrient for plants, but too much leads to noxious plant growth and blue-green algae blooms (Fox and Absher 2002). Nitrogen sources include fertilizers, atmospheric fallout, discharges from automobiles, mineralization of soil organic matter and decomposition of plant material (Rushton et al. 2002). A major pathway for both the ammonia and nitrate found in rainfall comes from the transformation of nitrogen oxides discharged from power plants and automobile exhausts.

All of the samples from the Street Pond were found to be over the established detection limit 0.01 mg/L of Nitrogen (Figure 2). This included the rainfall, inflow, outflow and the underdrain. It was found that the pond reduced the total nitrogen concentrations measured at the inflow by about 0.25mg/L when measured at the outflow weir.

Even though nitrogen levels at the outflow of the pond did not exceed levels thought to produce nuisance algae blooms, the Street Pond was highly eutrophic as measured by the amount of nuisance plant growth and by the response of dissolved oxygen and pH (to be discussed later). This indicates that the level of inorganic nitrogen needs to be kept much lower than 0.3 mg/L to maintain ecosystem integrity. Nitrogen levels are a major concern in the region because nitrogen has been identified as the limiting factor in Tampa Bay.

Phosphorus concentrations are a concern in stormwater ponds because algae require only small amounts of this nutrient to live, excess amounts can lead to extensive algal blooms. (Fox and Absher 2002). Phosphorus is not a significant constituent in rainfall and is usually introduced into stormwater through soil erosion, construction activities, fertilizers and vegetation cycling. The U. S. EPA recommended a limit for phosphorus in streams and rivers of 0.1 mg/L (U.S.EPA 1986) and the values in the Street Pond met this criterion in the treated outflow (Figure 2). The median values for the underdrain discharge exceeded this value both for ortho and total phosphorus. Other studies have also found higher levels of inorganic nitrogen and phosphorus in the underdrain pipes of effluent filtration systems. Harper and Herr (1993) observed that concentrations of both ammonia and nitrate increased substantially during migration through the filter media at the DeBary detention with filtrations site. They also found increases of over 200% for outflow concentrations of ortho-phosphorus through the filter media. Trapped organic particles of N and P on the filter media were listed as probable causes.

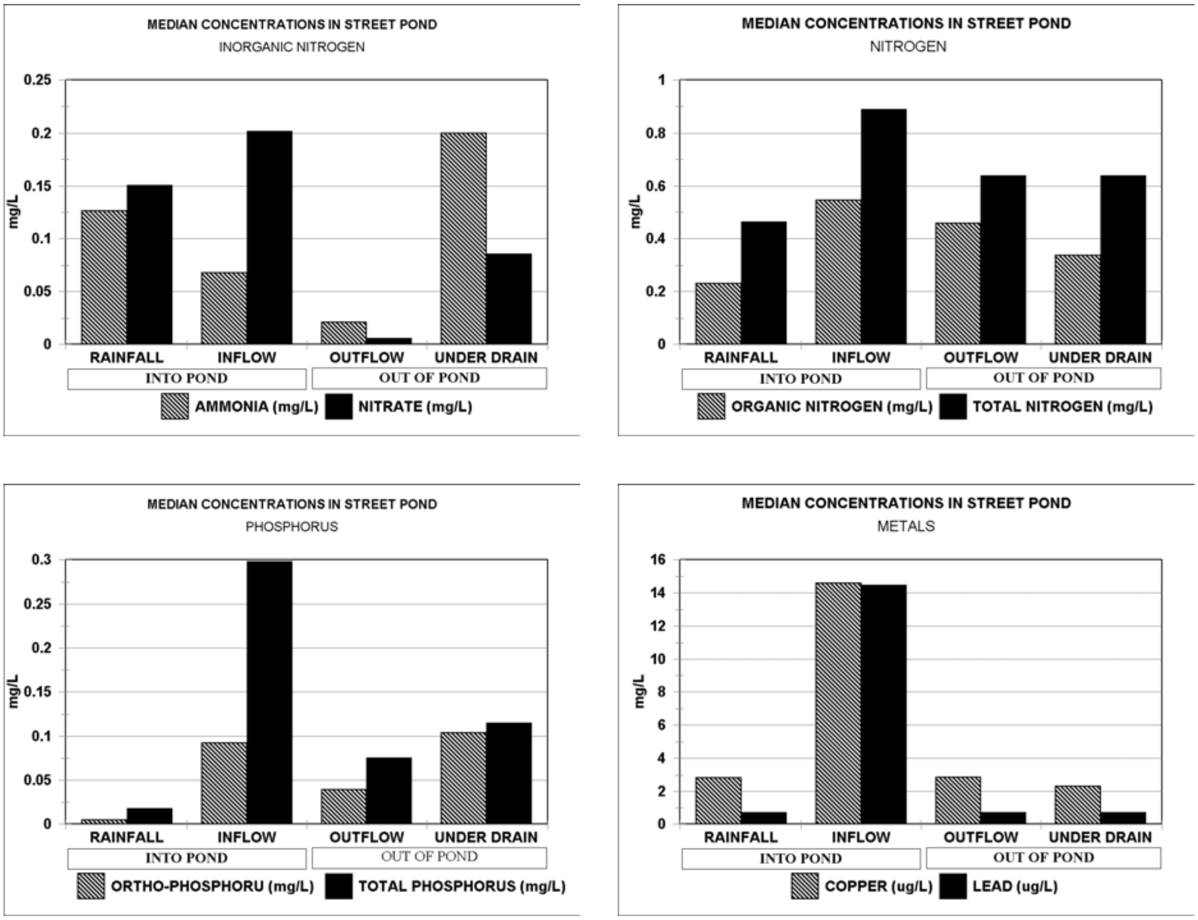

Figure 2. Water quality parameters collected in the Street Pond inflow and outflow. Data obtained by composite sampling methods.

Copper and Lead are a concern in urban runoff with loadings 10 to 100 times greater than the concentration of sanitary sewage (U.S.EPA 1983). Stormwater carries lead deposited on streets and parking lots from car exhaust, copper worn from metal plating and brake linings (Fox and Absher 2002). At the inflow, copper and lead were measured at higher concentrations than the outflow (Figure 2). The median concentrations for copper at the outflow were near the laboratory detection limit of 2.0 ug/L while the median values for lead were below the detection limit. This demonstrates that the ponds were effective in treating copper and lead before exiting the system. For this year of study, the pond discharge waters only exceeded the metal standards five times in the 180 samples collected.

Field Parameters

Physical water quality parameters are important in understanding the processes that influence constituent cycling in natural waters. During this study, conductivity, dissolved oxygen (DO), pH, and temperature were periodically measured at the inflow and outflow with a Hydrolab Datasonde® 3 (Figure 3).

Conductivity - The graph for conductivity demonstrates the response of the pond to rainfall. During dry periods conductivity rose as evaporation occurred and the process concentrated ions. Rainfall diluted the water in the pond during rain events, which could be seen by a drop in the curve. As evaporation occurred between rainstorms conductivity began to increase again until the next event. The outflow conductivity exhibits a relatively unchanging pattern, showing that the ponds were effective in keeping the discharge conductivity steady.

Dissolved oxygen – Dissolved Oxygen was at low levels as it was discharged from the urban street drain, a level that was increased with rainfall. Dissolved oxygen at the outflow exhibited the wide fluctuations typical of a highly productive (eutrophic) phytoplankton dominated system (Figure 3). The algal process raised values of dissolved oxygen during the day and lowered concentrations during the night as the outflow demonstrates. This created a diurnal cycle and was the result of photosynthesis, which utilizes carbon dioxide and produces oxygen during the day while during nighttime hours, photosynthesis was absent, and algal respiration dominates, using oxygen and expelling carbon dioxide. The measurements of dissolved oxygen at the inflow were accurate in showing that rainfall raises dissolved oxygen levels due to surface-air interface. The release of metals and phosphorus from the sediments when dissolved oxygen is low (reduced conditions) is one reason state standards require that dissolved oxygen shall not fall below 5.0 mg/L and that normal daily and seasonal fluctuations above these levels shall be maintained (Ch. 62-302 FAC).

pH – pH like dissolved oxygen, is the result of algal photosynthetic processes that peak during daylight hours and reaches a low at night when algal respiration dominates producing carbon dioxide and using oxygen. This explained not only the diurnal cycles but also the higher pH values in the Street Pond. Rain events changed this relationship slightly (Figure 3).

The pH is an important parameter since it affects the water chemistry and biology in stormwater ponds. For example, denitrifing bacteria operate best in the range $6.5 < pH < 7.5$, while nitrifiers prefer $pH > 7.2$ (Kadlec and Knight 1996). This target range for denitrification was seldom reached in the Street Pond. Some chemical reactions also require pH at lower levels than found in the Street Pond. For example, aluminum phosphate precipitates best at a theoretical pH of 6.3 and iron phosphate at pH 5.3 (Kadlec and Knight 1996). The state of Florida Class III water quality standards permit a pH range between 5 and 8 standard units. This range was sometimes exceeded during daylight hours during the summer.

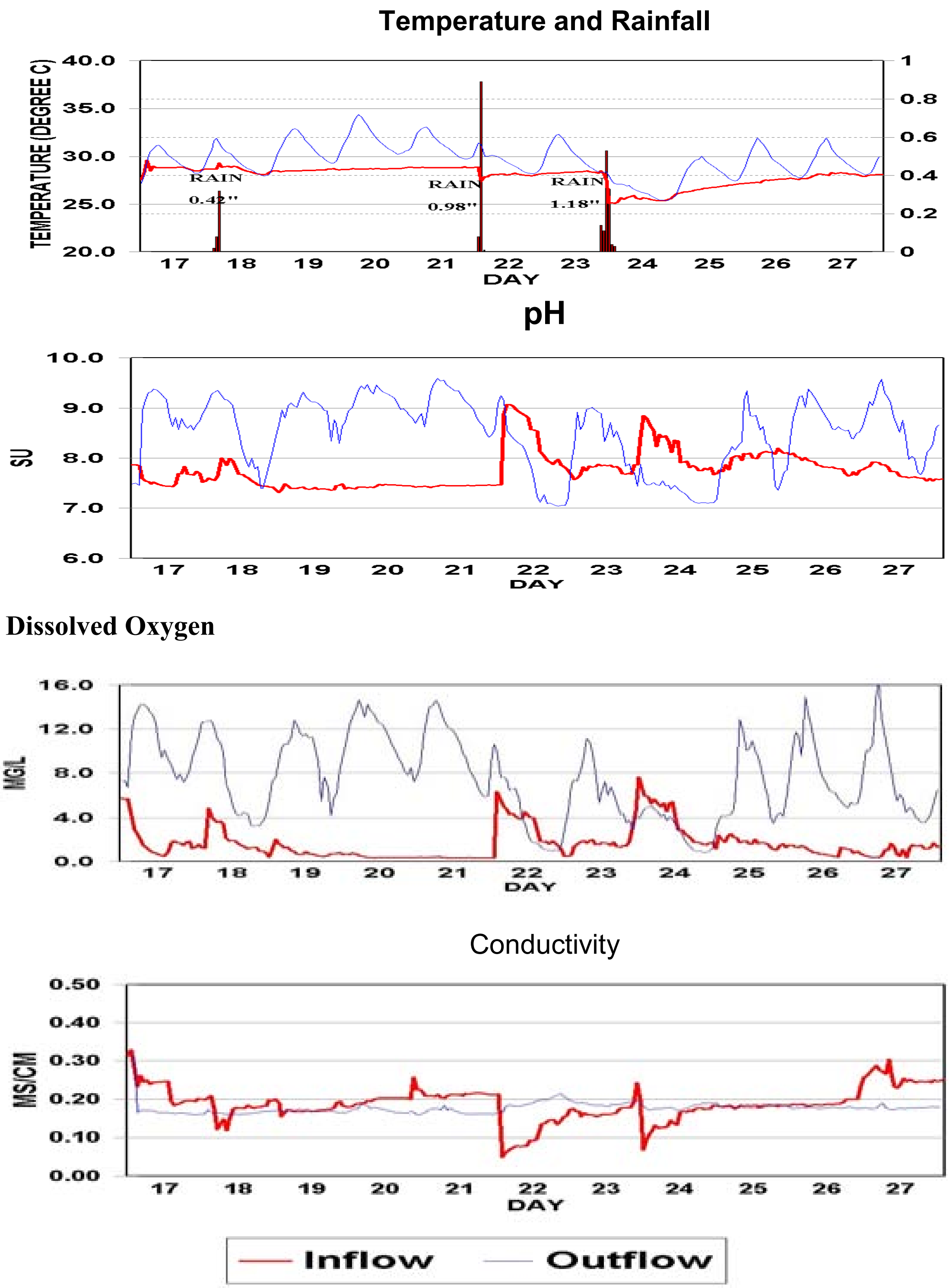

Figure 3. Inflow and outflow parameters measured in the Street Pond during 10 days in July 2001 with several rain events.

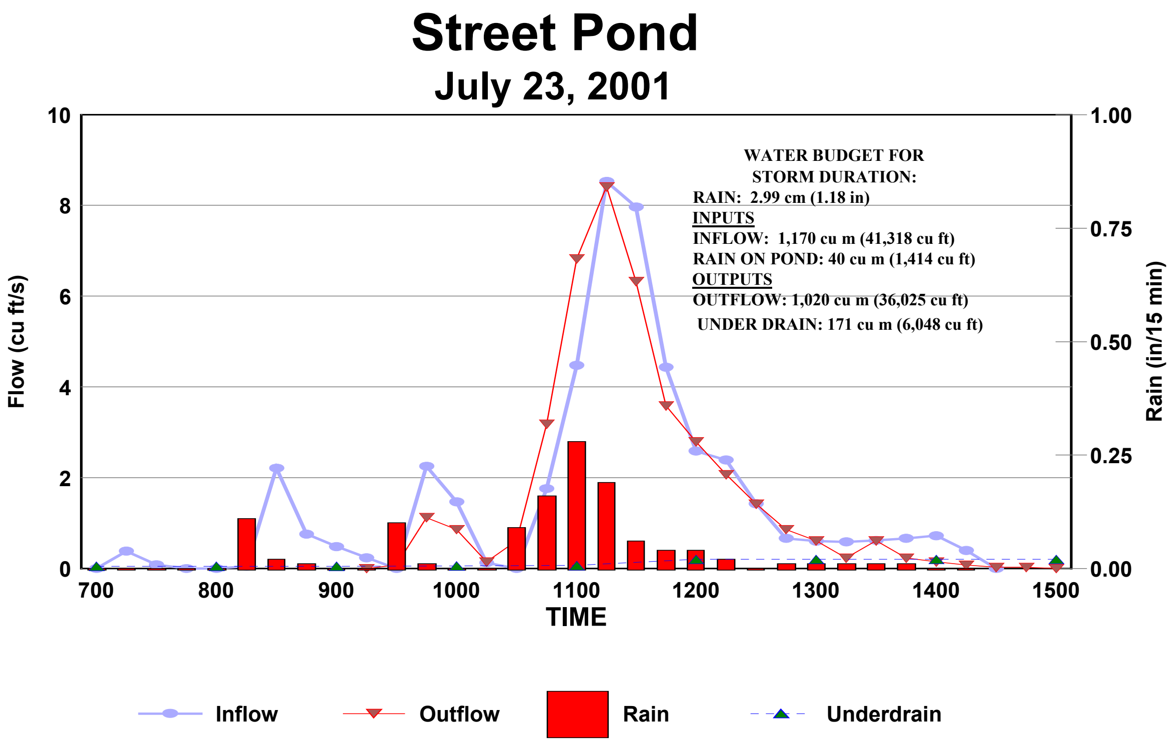

Figure 4. Inflow and outflow relative to the rain event. The underdrain data is displayed to show that the pond level had increased enough to flow into the effluent filtration system.

Flow

Flow data were analyzed to provide a better understanding of the how water quality loads affected the whole pond system. A complete water budget was estimated for one storm event that took place on July 23, 2001 (Figure 4). The inflow to the pond increased as the rainfall continued in intensity. The pond was then balanced by a volume of outflow that was close to the volume of inflow. The outflow was most likely due to pre-existing water in the pond, which was discharged as stormwater entered the system. The underdrain flowed continuously, which was possibly due to ground water but increases slightly during rain events. As the pond level increased and flowed into the underdrain, a small change could be seen as the water filled up volume in the pipe. One important note is that the underdrain flowed continuously and this data only represents an 8-hour storm. This discharge, although small on a daily basis, could be considerable when calculated as a monthly discharge. This is especially true for ammonia and nitrate, which were discharged at higher concentrations from the underdrain.

CONCLUSIONS

The effluent filtration system was effective in protecting the Tampa Bay estuary by acting as a "holding" pond allowing time for the pollutants to settle out of the water column and for biological processes to take place. The inflow to the Street Pond measured high levels of metals and soluble nutrients. The underdrain pipe showed considerably lower levels of metals, but like the inflow it also measured high concentrations of soluble nutrients. Concentrations of nutrients discharged over the weir were low in the Street Pond.

It was found that there was relatively no change in conductivity from the inflow to outflow in the Street Pond. There were improvements in dissolved oxygen at the outflow, which was accredited to algal processes.

It was concluded that the volume of inflow to the pond was nearly equal to the outflow of the system for most large rain events. From further study of smaller storms, it was shown that inflow volumes were greater than outflow volumes. According to the concentration levels during the July storm, it appears that the outflow volume measured was water that had been treated in the pond prior to the rain event.

Recommendations for pond improvements include:

- Plant the littoral zone with appropriate wetland plants.

- Clean out the side bank filter system and determine if this will solve the nutrient problem in the underdrains.

- Provide some pre-treatment to reduce metals and oils and greases.

- Clean out the initial sedimentation concrete lined basin on a regular basis to remove pollutants.

- Reuse the water in the pond to irrigate garden areas near the pond.

- Stock the pond with appropriate fish and other aquatic animals to determine if it can be maintained as a healthy aquatic habitat.

ACKNOWLEDGEMENTS

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Finance Department and especially Jan Smith tracked our budget, submitted invoices, and kept us informed about our expenditures.

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ASSESSING CITIZEN STORMWATER COMPLAINTS IN PINELLAS COUNTY, FLORIDA

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ABSTRACT

From January of 1999 through October of 2001, the Water Resources Management Section (WRMS) of the Pinellas County Department of Environmental Management fielded 435 citizen complaints. The complaints ranged from water quality issues and nuisance aquatic vegetation to information requests and drainage concerns. Of those, 135 (32%) fell under the stormwater/illicit discharge category. This paper discusses the categories of complaints, the types of responses to the complaints, public outreach and education, and ideas for the future.

The complaint responses broke down as follows: field inspections (37) were 27% of total, referrals (25) were 19%, field inspections coupled with referrals (51) were 38%, and complaints handled over the phone (22) were 16%. In 2001 the section began issuing NOVs (Notice of Violations) to individuals and industries found violating the county's NPDES (National Pollution Discharge Elimination System) rules. Public outreach included speaking to residents, school presentations, handing out information packets, and stormwater drain marking. Future developments include a County website that will make stormwater information available online.

INTRODUCTION

Pinellas County is located on the west central coast of Florida (Figure 1). It encompasses 23 cities, including St. Petersburg, Clearwater, and Largo. Pinellas is the most densely populated county in the state and is home to over 981,482 permanent residents (Pinellas County, 2002) as well as host to hundreds of thousands of tourists every year. With this growing population and resultant development, water quality issues are a top priority and the Water Resources Section devotes a great deal of time to citizen complaints as well as general concerns about the quality of water in Pinellas County. The unincorporated area of Pinellas County encompasses a little over 67,000 acres, constituting about 45% of total countywide net acreage (Pinellas County Planning Dept., 2002)

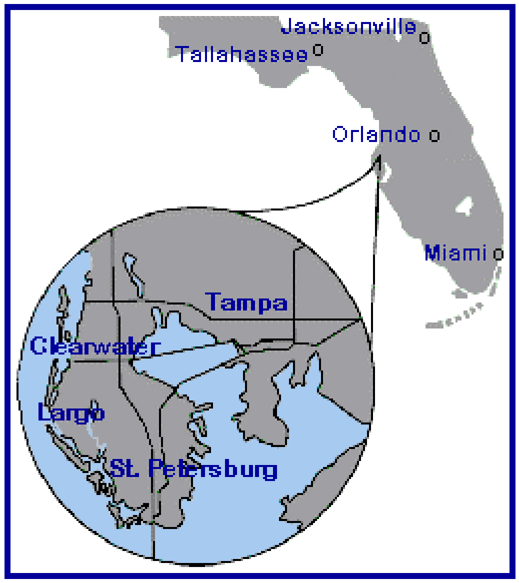

Figure1: Pinellas County, Florida

The Water Resources Management Section of the Pinellas County Department of Environmental Management monitors surface water quality in the various Pinellas County basins and watersheds. In addition the section is involved in: the development and implementation of watershed management plan, the County's NPDES permit, fish and seagrass monitoring programs, manatee protection and monitoring, public outreach and education, as well as a number of other water quality related projects.

COMPLAINT PROCEDURES

Complaints come into Water Resources section mainly through citizen phone calls. Other avenues include referrals from other agencies as well as through county commissioners. Additional complaints come from various departments in the County government including Utilities and Highway. Some county employees have gone through stormwater illicit discharge training enabling them to better identify a problem when they are in the field. Many of the stormwater ordinance violations come through the County's Stormwater Watchline, a local number for citizens to call in reports of illegal dumping or discharge. The number is listed in the phone book, appears on some of our publications and is advertised on a local government access channel.

After the complaint is received the inspector must decide whether it is a referral, field inspection, field inspection coupled with referral, or one that can be handled over the phone. Complaints are handled by whichever staff member is on hand and free to go out and investigate.

Upon returning to the office, a complaint report is typed up in an Access database. Complaints are entered based upon their parcel number, a unique ID used in the County's GIS programs. Pictures, if any, are downloaded to the server and added in a separate database. Apart from the

Access databases, there are other set protocols as to how a complaint should be handled. These include a comprehensive list of personnel and phone numbers for the referrals as well as a County-wide GIS system that is used to locate complaint areas, determine municipality or county jurisdiction and to identify the county stormwater system.

RESULTS

Citizen complaints constitute a large portion of the section's time and resources. From January of 1999 through October of 2001, WRMS received 435 citizen complaints.

Of those, the largest percentage was stormwater illicit discharge (135 complaints), comprising 32% of the total complaints. Water quality/fish kills (101) represented 23%. "Other" complaints (77) comprised 18% of the total. The remainder of categories: nuisance vegetation (69), algae blooms (32), odor (15), and erosion (6), represented 16%, 7%, 3%, and 1% respectively.

The responses for stormwater complaints broke down as follows: field inspections (37) were 27% of total, referrals (25) were 19%, field inspections coupled with referrals (51) were 38%.

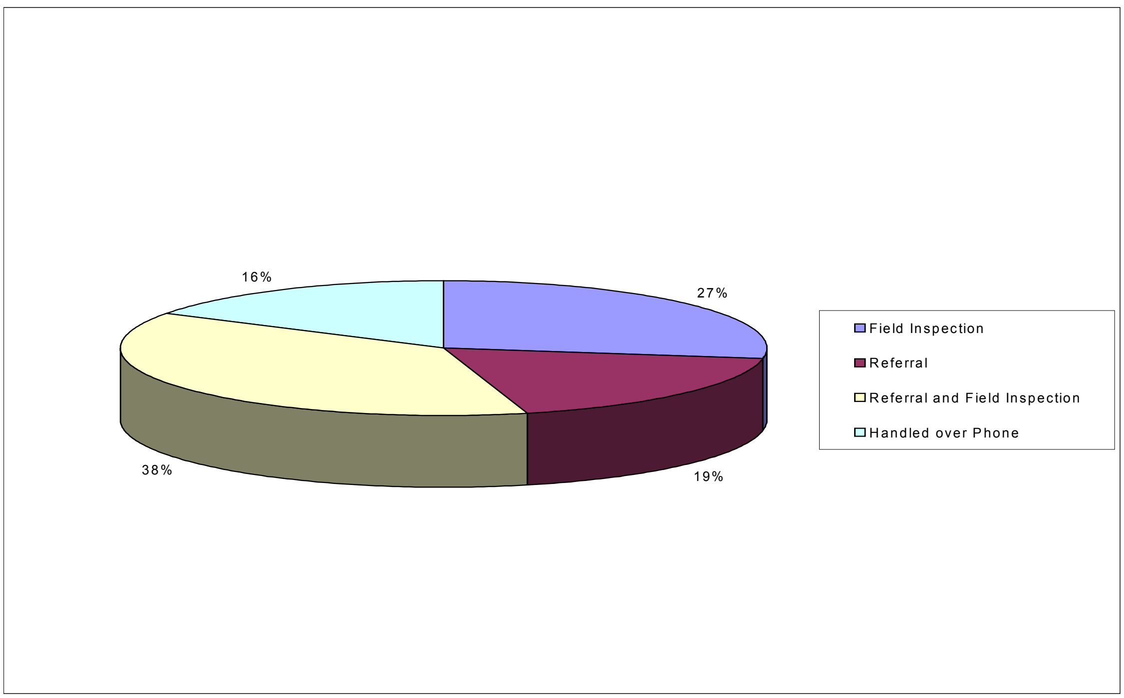

Figure 2: Stormwater Illicit Discharge Complaint Response

The wide and varied subjects of stormwater complaints can be best described by looking at some specific examples. Below are five complaints, ranging from the usual to the unique. The text is taken directly from field notes and the complaint sheets:

1. 3/18/99- (Referral) There was repeated flooding along 95th St in front of warehouses owned by complainant. Complainant says water came from Thunder Marine. The boat rinse water flows from the marina lot and accumulates in front of the warehouses. The complaint was referred to the Highway Department.

2. 9/27/00- (Handled by phone) Trademark Floors workers were pushing debris into storm drain system. Respondent spoke to _____ , owner of Trademark Floors and informed him of the stormwater ordinance and that any debris should be collected and disposed of as solid waste and not into the stormdrain. He indicated that the material was not hazardous and consisted of material that fell off the trucks. His crew was just trying to clean up the job site for the local residential neighborhood. He said he would clean up the mess.

3. 4/4/01- (Field inspection) Complainant said that the water in canal behind his condo is a deep blue green. PH and AY traced discharge to apartment complex north of canal retention pond had Aqua shade, a colorant used to treat algae and to make the pond have a Caribbean look. The inspector called the complainant and left a message that the colorant should not hurt the wildlife in the canal.

4. 1/27/01- (Field Inspection/referral) Red, rusty colored water from pipes discharging to Alligator Creek from long center retention pond. Also, a downed tree across creek some 500-1000' downstream of Long Center retention pond. Went to inspect site with Andy Squires. We found the outfall referred to in the complaint approx. 50 yards southeast of retention pond at the Long Center. The structure is a concrete outfall pipe with an overflow wall. The water level was nowhere near overflow, yet there was distinct flow, which might indicate seepage through the wall. The water was a rusty color with a heavy greasy film near the surface. Several dead fish were observed near the mouth of the outfall. The rusty color spread about 200-300 yards downstream into Alligator Creek where we did observe a downed tree severely impeding water flow. No distinct smell was noted.

Back to the stormwater pond, we could not observe any flow in any of the other storm water outfalls nearby. They all appeared to be dry. However, we could hear distinct heavy flow below a manhole just upstream from the outfall pipe the rusty colored water was coming out of. This might indicate wastewater intrusion into the stormwater system. Also we noted cracks in the wall around the pipe, which showed evidence of previous seepage. - There was a rust-red stain below each crack in the wall. Pictures were taken. Contacted Dave Stickel of Clearwater Wastewater Also E-mailed Brett Gardner of Clearwater's Public Works

1/30/01- Notified County Highway of downed tree.

1/30/01- I spoke with Dave Stickler who referred me to Clyde Howell. Claude seemed to think the structure we were looking at is part of an energy dissipater, meant to reduce the force of the stormwater flow coming down the pipe and into the creek. This would include a 6-8' drop just below the manhole by which we heard the water noise. Looking at Clearwater's Atlas Map of Stormwater sewers. This seems correct. According to Claude, that stormwater system is a roadway underdrain that goes back to Range St., just west of the Long Center. I also spoke to Bernard Kendrick of Pinellas County Public Works Engineering who confirmed the existence of the energy dissipater in that specific location.

1/30/01- I pulled up Clearwater's stormwater system map, which shows the outfall structure as well as the pipe leading to it. This drains from the range road area. I went back to the site with Kelli Levy and inspected Range Rd. We found evidence of rust wash all around and on Florida Power property. Drop inlets, road, dirt on side, were all covered with rust powder- According to Clearwater's map this drains directly under the railroad tracks to the Long Center outfall by Alligator Creek. I informed Brett Gardner of Clearwater who will follow up on this.

Per Brett Gardner, his crew did not find anything as the rain had cleared the system. We will keep an eye on the site anyway. I will inform the citizen who made the complaint.

5. 10/22/01- (Referral) Complainant observed a Pinellas County Public Works truck (orange and purple) discharging gray water into sewer at 6949 300th Ave Palm Harbor- he has witnessed this on several occasions. On the first occurrence he questioned the woman pumping the water into the drop inlet. He asked her if it was sanitary sewer water and her response was that it was filtered. He then saw the truck drive to a hydrant and fill up with water. This complaint was referred to Public Works.

DISCUSSION

In assessing the citizen water quality complaints handled by the Pinellas County Water Resources Section, the continued importance of addressing these problems is essential. With 435 complaints in a little under three years, it is apparent that these interactions with the public constitute a large portion of the county's water quality program. The reason we are continually changing and adapting our stormwater response is due to the fact that over 32% of all complaints are stormwater ordinance violations and there's no decrease in numbers coming in. There were 43 stormwater complaints in 1999, 37 in 2000, and 55 just through October of 2001.

A number of ideas are being discussed to help improve the complaint process. One idea, that some water resource departments already use, is a web-based complaint system where citizens can fill out a form online and send it in to the department. The web-based system allows users to supply specific information and even pictures of violations happening. Many times a violation has already occurred when an inspector gets to the site and the hope is the web system will enable the citizen reporting the event to give more details and perhaps even download digital pictures if applicable.

The Pinellas County Department of Environmental Management is currently working on a website. Water Resources will have their own section and it will serve as a place for concerned citizens to obtain information on water quality issues including stormwater discharge and NPDES-related material. The website would also be an ideal place to add an online complaint form.

Recently the Water Resources staff began issuing NOV's (notice of violations) for stormwater ordinance and NPDES violations. This will become an integral part of the overall water resources program and specifically the complaint component. Applicable training by the County

Codes Enforcement section has equipped WRMS staff with the necessary background to handle enforcement issues.

Public outreach is an integral part of the complaint process. Fish kill complaints that are handled over the phone require an in-depth discussion of the various factors that contribute to fish kills. We have a number of brochures on stormwater ponds, swales, and stormwater run-off, which are distributed to various citizens, civic organizations, neighborhood associations, and local governments. Public outreach increases awareness of the Department's programs and fosters a trust between the public and their county government.

As the population of Pinellas County continues to grow, stormwater issues will become even more of a priority. Through our complaint process citizens can take an active role in keeping the County free of major stormwater runoff problems. The Water Resources Management Section will continue to improve its response and assessment of stormwater complaints, ensuring that with the continued population growth there will not be a parallel growth in stormwater problems.

ACKNOWLEDGEMENTS

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CHARACTERIZATION OF THE POTENTIAL IMPACT OF STORMWATER RUNOFF FROM HIGHWAYS ON THE NEIGHBORING WATER BODIES CASE STUDY: TAMIAMI TRAIL PROJECT

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ABSTRACT

Florida's rapid growth and urbanization generated vast amounts of land clearing resulting in the creation of impervious surfaces which increased flooding and water quality degradation. Stormwater runoff contributed sediment, nutrients and heavy metals to these waters. Earlier research attributes 80 to 95% of heavy metal (mainly lead, zinc, and copper) contributions to our waters to be from highways and parking lots. In recent years, pollutant concentrations in stormwater runoff from highways have been significantly reduced due to the stricter environmental regulations implemented to protect the natural habitat and to enhance environmental conditions in rural/urban areas.

This paper presents a predictive model of heavy metal concentrations in stormwater runoff from highways based on the most recent available data in Florida. The model was then used to evaluate contaminant concentrations from the runoff of the Tamiami Trail / US 41 as a case study. Predicted results of pollutant concentrations from the Tamiami Trail are compared to a) existing trace metal levels in-situ and; b) Class III Fresh Water Criteria to evaluate the need of a water treatment facility for the project area. The results of the investigation suggest that pollutant levels in stormwater runoff from the Tamiami Trail will have little effect on the quality of the water and the surrounding aquatic habitat in the Tamiami Canal.

INTRODUCTION

This review provides a characterization of the potential impact of stormwater runoff from the subject project area of the Tamiami Trail on the neighboring water bodies. The first part of the paper demonstrates a general background and a description of the problem. The present status of water quality standards is then discussed to identify the water quality criteria for the water bodies adjacent to Tamiami Trail. Based on literature review of the pollutant concentrations in stormwater runoff from highways, a description of the pollutants and their expected levels from the Trail is provided. Next, the methodology adopted for this study is presented and followed by discussion of the results and biological aspects. The paper is then concluded by a summary of findings.

STUDY SITE

The study area for this investigation is the segment of Tamiami Trail / US 41 for an approximate 11 – mile segment beginning 1 mile west of Krome Avenue in western Miami, Dade County, Florida (Figure 1). The Tamiami Trail is the boundary between two classes of waters. North of the Trail is considered Class III waters; whereas, the south side of the Trail falls within Everglades National Park and is considered Class III Outstanding Florida Waters.

BACKGROUND

Florida's rapid growth and urbanization in the 1960's and 70's generated vast amounts of land clearing resulting in the creation of impervious surfaces. These activities resulted in increased flooding and water quality degradation. Stormwater runoff contributed sediment, nutrients and heavy metals to these waters. There was a realization that some of our rivers and streams, lakes, wetlands, and estuaries were being damaged.

Recognition of these problems led to the adoption in 1982 of *Chapter 17-25* (now 62-25), of the *Florida Administration Code, Regulations of Stormwater Discharge*. This regulation's primary objective is to minimize the pollution of Florida waters from new stormwater discharges that are constructed after February 1, 1982. The vast number of new stormwater discharges resulting from rapid growth preceded the determination of individual discharge limitations. It was agreed a performance standard be established providing a minimum treatment level such that a stormwater system would remove at least 80% of the annual pollutant load.

Extensive studies prior to 1982 determined that the "first flush" of stormwater carried 90% of the pollutant load from a storm event. Treatment of the first one inch of rainfall would help ensure that the water quality impacts of stormwater runoff were minimized. It also corresponds with the fact that over 90% of all storm events produce an inch or less of rainfall in a year.

Extensive research through the 70's and early 80's attributes 80 to 95% of heavy metal contributions to our waters to be from highways and parking lots. These metals include lead, zinc, copper, cadmium, and chromium. Other contaminants associated with highways and parking lots include oils and grease. These pollutants in highway runoff originate from the operation of motor vehicles, direct atmospheric fallout and the degradation of roadway materials. The most abundant metals have been lead, zinc and copper, which account for over 90% of the dissolved heavy metals.

POLLUTANT CONCENTRATIONS IN STORMWATER RUNOFF FROM HIGHWAYS

The concentration of pollutants in highway runoff is dependant on a number of factors including highway design, maintenance activity, surrounding land use, climate, and site specific traffic characteristics (Gupta et. al. 1981, Vol. I).

Highway stormwater runoff contains higher concentrations of trace metals, particularly lead and zinc, than the water samples from adjacent receiving water bodies (Yousef et al., 1986 and Harper, 1988). Soils adjacent to highways have higher concentrations of lead, chromium, and zinc than the background levels of these metals (Wanielista and Gennaro, 1977). Generally, lead, zinc, and copper are the major contributors to pollutant loading in highway runoff, with peak concentrations occurring within the first thirty minutes of rainfall.

Pollutant concentrations in stormwater runoff have been significantly reduced in the 1990's due to the stricter environmental regulations implemented to protect natural habitat and to enhance environmental conditions in rural/urban areas. One of the major milestones, in this regard, was the elimination of lead from gasoline and paint.

A recent study, conducted in 1996 by HDR Engineering, Inc. at the Howard Frankland Bridge (I-275) in Tampa, Florida shows a substantial decrease in the average pollutant concentrations, of lead, zinc, iron, copper, and cadmium in water samples collected at the edge of pavement (to collect the samples just as it flowed off the impervious roadbed) than the average values detected by Gupta et. al 1981 in samples collected from seven locations in the eastern U.S. during 1967-77. In addition, the HDR study assessed the capability of the grassed shoulders to reduce contaminant levels in stormwater runoff from the highway. For most metals, documented treatment efficiencies ranged from 10 to 74%.

Stoker (1996) indicates similar decreases in the concentrations of lead, zinc, iron, cadmium, chromium, and copper in stormwater runoff samples from the Bayside Bridge in Pinellas County, Florida. Stoker's study shows improvements over those previously reported by Yousef et al., (1986) and Harper, (1988) for samples collected near I-4 in the Orlando area.

By comparing the metal contents in stormwater runoff from highways for the 1996 studies and 1980's studies, one can observe a decreasing trend in metal concentrations in the stormwater runoff over time.

METHODOLOGY

The methodology adopted in this analysis included a comparison of predicted pollutant concentrations from the Tamiami Trail to a) existing trace metal levels insitu and; b) Class III Fresh Water Criteria. Existing trace metal concentrations were obtained from South Florida Water Management District (SFWMD, 2000) for the study area (Northwestern limit: Lat. 25° 50`, Long. 80° 45` – Southeastern limit: Lat. 25° 40`, Long. 80° 20`) for the 1980's and 1990's. There are a total of ten sampling stations along Tamiami Trail, starting at Station S12D and ending with Station S334 (Figure 1). S12D is located at a spillway on levee L-29 in Conservation Area 3A; S333 is located at the Tamiami canal below S-333; S12E, G69, and S334 are located at gated culverts; S333DS is located downstream of S333 on US41 at the south side of the canal; FROGCITY is located at a culvert under US41 6.0 miles west of S334; S355A and S355B are Cape Sable seaside sparrow sampling locations; and TAMBR6 is located at a culvert under US41, 3.3 miles west of S334. SFWMD classifies these sampling locations as canal/ambient waters.

Class III Fresh Water Criteria for cadmium, chromium, copper, lead, nickel, and zinc were calculated according to the governing equations using the corresponding hardness values at each sampling station. Predicted contaminant levels were estimated using the data obtained from the Howard Frankland Bridge (I-275), Tampa, Florida and the Bayside Bridge, Pinellas County, Florida, as these projects represent the most recent studies, similar climate conditions, and geographical locations.

Tamiami Trail traffic counts recorded approximately 5,200 vehicles per day (VPD) in 2000, and are projected to reach 9,200 (VPD) in 2020 according to the Florida Department of Transportation. Drapper et. al. (2000) reported correlation of median pollutant concentrations (lead and total suspended solids) in stormwater runoff from highways to the Average Daily Traffic. This approach was utilized to predict pollutants levels in Tamiami Trail stormwater runoff for the estimated traffic volumes (Tables 1, 2, and 3).

Based on the data recorded for the I-275 study, predicted levels of cadmium, chromium, copper, iron, lead, manganese, nickel, oil and grease, total solids, total suspended solids, and zinc for the Tamiami Trail are listed in Table 1. The Pinellas County study includes the analysis of these contaminants with the exception of manganese, oil and grease, and total solids. Predicted concentrations for Tamiami Trail based on the Pinellas County study are shown in Table 2. A summary of the predicted contaminant concentrations from both studies is presented in Table 3.

DISCUSSION OF RESULTS

The results of the analysis indicate that there will be no significant impact on the quality of the water in the vicinity of Tamiami Trail (Table 4).

It should be noted that Class III Fresh Water Criteria for some pollutants varies from one location to the other, as they are dependant on hardness. For any given metal (e.g. Cadmium, Chromium (trivalent), Copper, Lead, Nickel, and Zinc), Florida Administrative Code (FAC) provides a mathematical formula to calculate the criterion as a function of water hardness. Consequently, as the hardness changes, the criteria change accordingly.

Hardness also does change over time depending on many factors. One of the most influencing factors is water pH. As the pH decreases, water become more acidic and the concentration of hardness decreases and vice versa. Any environmental factor that affects the pH will have an impact on the water hardness.

The water environment in wetlands is generally, acidic. During the wet season, rainwater often increases the water pH, bringing it to neutral or slightly basic condition resulting in an increase in the concentrations of hardness. This concept may explain the higher hardness values during the summer (wet season). To follow the FAC equations for calculating the criteria for different metals at different sampling stations, the average hardness values measured over the sampling period (more than 20 years at some locations) at each sampling station were used.

Class III Criterion for cadmium ranges from 1.20 μg/l at Station S355A to 2.20 μg/l at Station S333DS. Existing concentrations of cadmium along Tamiami Trail range from 0.10 to 1.14 μg/l. Maximum predicted concentrations (maximum values of the concentrations predicted using the two studies: I-275 and Bayside Bridge) of the of cadmium are 0.06 μg/l in year 2000 and 0.11 μg/l in year 2020. Minimum predicted concentrations (minimum values of the concentrations predicted using the two studies: I-275 and Bayside Bridge) are 0.04 μg/l and 0.06 μg/l in year 2000 and 2020, respectively. The conclusion of this comparison shows that there will be no predictable impact from cadmium on the neighboring water body. Similar conclusions may be drawn for chromium, and nickel.

Total suspended solids, total solids and manganese are not regulated under *Florida Administrative Code Chapter: 62-302.530, Criteria for Surface Water Quality Classifications*. However, the predicted levels were calculated and documented for future reference.

For oil and grease, the predicted concentrations of 215.07 μg/l in year 2000 and 380.51 μg/l in year 2020 are much lower than the Class III Criteria of 5,000.00 μg/l. There are no records of the existing oil and grease concentrations at the sampling stations.

The analysis also predicts that there will be no significant impact from the primary polluting metals (copper, lead, and zinc) in the stormwater runoff. Predicted results from this study are consistent with the results reported by Driscoll et. al. (1990) for highways with less than 30,000 VPD. (Copper: 0.022 mg/l, Lead: 0.08 mg/l, Zinc: 0.08 mg/l).

Class III Criterion for copper ranges from 12.20 μg/l at Station S355A to 24.00 μg/l at Station S333DS. Existing concentrations of copper along Tamiami Trail range from 1.00 to 6.60 μg/l. Maximum predicted concentrations of copper are 1.48 μg/l in year 2000 and 2.62 μg/l in year 2020. Minimum predicted concentrations are 0.92 μg/l and 1.63 μg/l in year 2000 and 2020, respectively.

For iron, Class III Criterion is 1000 μg/l. Existing concentrations along Tamiami Trail range from 17.3 to 994 μg/l. Maximum predicted concentrations (in the runoff) of iron are 98.17 μg/l in year 2000 and 173.69 μg/l in year 2020. Minimum predicted concentrations are 30.49 μg/l and 53.95 μg/l in year 2000 and 2020, respectively.

For lead, Class III Criterion ranges from 3.30 μg/l at Station S355A to 9.10 μg/l at Station S333DS. Existing concentrations along Tamiami Trail ranged from 0.50 to 18.08 μg/l. Maximum predicted concentrations of lead are 2.51 μg/l in year 2000 and 4.43 μg/l in year 2020. Minimum predicted concentrations are 0.83 μg/l and 1.47 μg/l in year 2000 and 2020, respectively. It was noted that a single violation of Class III Fresh Water Criteria at Station S12D occurred in July 1992, where the existing lead concentration was 18.08 μg/l higher than the criterion (7.70 μg/l). The previous lead concentration measured at this station was 1.17 μg/l in June 1992, and the following measurement was 1.98 μg/l in September 1992. The next highest value recorded at this station was 2.65 μg/l, suggesting that the 18.08 μg/l record was a single incident or possibly an incorrect data notation in the record.

Class III Criterion for zinc ranges from 109.60 μg/l at station S355A to 213.90 μg/l at station S333DS. Existing concentrations of zinc along Tamiami Trail range from 4.00 to 329.01 μg/l. Maximum predicted concentrations of zinc are 10.02 μg/l in year 2000 and 17.73 μg/l in year 2020. Minimum predicted concentrations are 8.96 μg/l and 15.85 μg/l in year 2000 and 2020, respectively.

Predicted concentrations for some contaminants (e.g. zinc), although they did not violate Class III Fresh Water Criteria under any condition, can be found to be slightly higher than the existing minimum concentrations but well below the existing maximum concentrations. These observations are based on the data obtained from SFWMD and the results of the Howard Frankland Bridge and the Bayside Bridge studies. A detailed sampling and monitoring program for the Tamiami Trail is suggested to confirm these conclusions.

BIOLOGICAL ASPECTS

In general, highway runoff contains pollutants**:** that have a potential to adversely affect species dependent on wetland habitat for all or part of their life cycles**;** that can lead to the pollution of wetlands**;** and**,** that can cause a decline of wetlands values (Clairmont Graduate University and Rails-to-Trails Conservancy, 1998). However, documentation of adverse effects of highway runoff on aquatic organisms and their communities does not provide a clear relationship. Smith and Kaster (1983) reported that along a rural highway with relatively low vehicle counts (7,000 – 8,000 VPD) disruptions of benthic macroinvertebrate communities were negligible. However, other biological studies have documented changes in individual organisms and community structures at sites with low traffic volumes (Buckler and Granato, 1999). Generally, the ecological effects of highway runoff quality on receiving waters have been predicted using statistical models of contaminant concentrations and loadings. These predictive models indicate that there should be no measurable water quality effects at sites with annual daily traffic volumes supporting less than 30,000 VPD, (Driscoll et al., 1990).

CONCLUSIONS

The results of the investigation predict/confirm that pollutant levels in stormwater runoff from the Tamiami Trail, for an average daily traffic of 5,200 VPD in 2000, and 9,200 VPD in 2020, will have little effect on the quality of the water and the surrounding aquatic habitat in the Tamiami Canal. The predicted concentrations are expected to be less than the contaminant concentrations delivered to the site from other locations by the network of canals. Therefore, this paper suggests that there is no immediate, water quality driven need to provide stormwater treatment facility. It would not appear prudent to provide stormwater treatment for existing conditions which do not violate standards or future conditions which predictably meet standards, at the expense of measurable, physical impacts to wildlife and wetlands supported and protected by National Park covenants. Furthermore, the construction of stormwater treatment facilities would result in additional turbidity, the release of extant nutrients, and contribute to instability in vegetation and soils. Conclusions identified in this report could be evaluated and confirmed by designing and conducting a detailed sampling and monitoring program for the project area under normal operating conditions.

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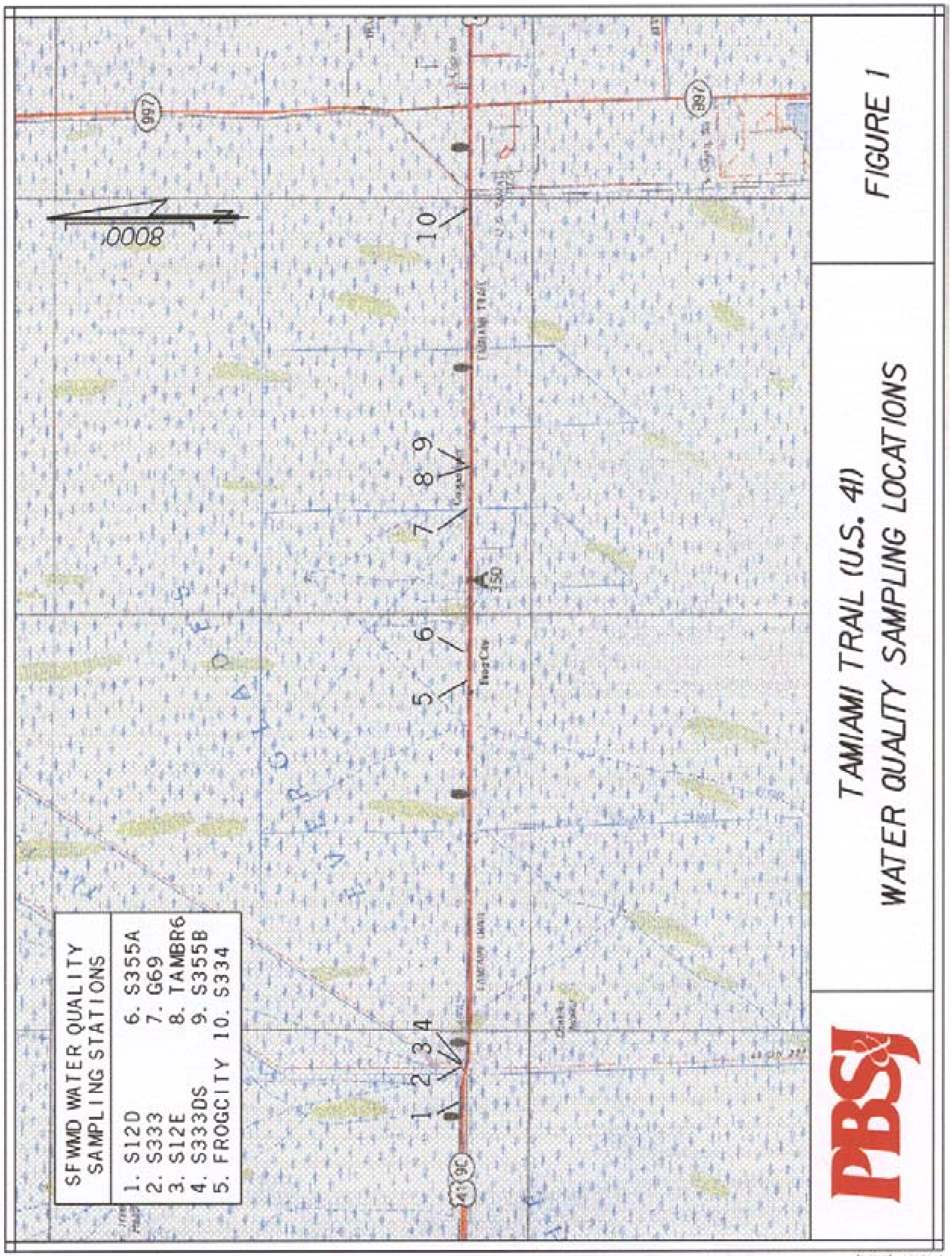

Bingham, Neal, and El-Agroudy

Table 1: Predicted Contaminant Levels for Tamiami Trail Based on I-275, Tampa, Florida Study (1996).
(Concentrations are in milligrams per liter.)

mg/l	Medians of 5 sampling locations (103000 VPD)	Prorated Values for Tamiami Trail (5200 VPD)	Prorated Values for Tamiami Trail (9200 VPD)
Cadmium	0.001	0.000	0.000
Chromium	0.015	0.001	0.001
Copper	0.018	0.001	0.002
Iron	0.604	0.030	0.054
Lead	0.017	0.001	0.001
Manganese	0.036	0.002	0.003
Nickel	0.007	0.000	0.001
Oil&Grease	4.260	0.215	0.381
TS	308.000	15.550	27.511
TSS	50.500	2.550	4.511
Zinc	0.178	0.009	0.016

Source: HDR, 1996

Table 2: Predicted Contaminant Levels for Tamiami Trail Based on Pinellas County Study (1996).
(Concentrations are in milligrams per liter.)

mg/l	Mean Values (43593 VPD)	Prorated Values for Tamiami Trail (5200 VPD)	Prorated Values for Tamiami Trail (9200 VPD)
Cadmium	0.000	0.000	0.000
Chromium	0.004	0.001	0.001
Copper	0.012	0.001	0.003
Iron	0.823	0.098	0.174
Lead	0.021	0.003	0.004
Nickel	0.004	0.000	0.001
TSS	20.000	2.386	4.221
Zinc	0.084	0.010	0.018

Source: Stoker, 1996

Table 3: Expected Pollutant Concentrations for Tamiami Trail Based on Previous Studies Performed in Florida in 1996.
(Concentrations are in micrograms per liter.)

	I-275 Study		Pinellas Study	
	Tamiami (5200 VPD)	Tamiami (9200 VPD)	Tamiami (5200 VPD)	Tamiami (9200 VPD)
Cadmium	0.062	0.110	0.035	0.061
Chromium	0.732	1.295	0.513	0.907
Copper	0.919	1.626	1.479	2.617
Iron	30.493	53.950	98.172	173.688
Lead	0.833	1.474	2.505	4.432
Manganese	1.797	3.180	N/A	N/A
Nickel	0.334	0.590	0.477	0.844
Oil&Grease	215.068	380.505	N/A	N/A
TS	15549.515	27510.680	N/A	N/A
TSS	2549.515	4510.680	2385.704	4220.861
Zinc	8.961	15.854	10.020	17.728

N/A : Data were not available.

Table 4: Comparison of Existing Pollutant Concentrations, Class III Fresh Water Criteria, and Predicted Concentrations from Tamiami Trail Runoff Based on a) I-275 Study, and b) Pinellas County Study.

		Station	1	2	3	4	5	6	7	8	9	10
		Code	**S12D**	**S333**	**S12E**	**S333DS**	**Frogcity**	**S355A**	**G69**	**TAMBR6**	**S355B**	**S334**
Cadmium	Existing		0.1-1.59	0.1-1.14	0.30	0.23-0.622	0.3-0.76	0.30	N/A	0.3-0.44	0.3-0.37	0.3-0.39
	Class III Criteria		2.00	2.00	1.80	2.20	1.80	1.20	1.60	1.90	1.60	1.90
	Predicted	I-275	0.06 - 0.11									
		Pinellas	0.04 - 0.06									
Chromium	Existing		1.03	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Class III Criteria		11.00									
	Predicted	I-275	0.73 - 1.30									
		Pinellas	0.51 - 0.91									
Copper	Existing		1-4.37	1-6.6	1.20	4.06-5.54	1.2-1.37	1.2-1.6	N/A	1.2-1.6	1.20	1.2-1.46
	Class III Criteria		21.40	22.30	20.10	24.00	20.10	12.20	17.70	20.40	16.80	20.60
	Predicted	I-275	0.92 - 1.63									
		Pinellas	1.48 - 2.62									
Iron	Existing		19.3-430	17.3-320	83.60	56.20	65.3-965.9	35.6-51.1	206.00	82.3-734	69.3-175.8	69-994
	Class III Criteria		1000.00									
	Predicted	I-275	30.49 - 53.95									
		Pinellas	98.17 - 173.69									
Lead	Existing		0.5-18.08	0.5-4.03	0.80	0.8-0.96	0.8-1.68	N/A	N/A	0.80	N/A	N/A
	Class III Criteria		7.70	8.20	7.00	9.10	7.00	3.30	5.80	7.20	5.40	7.30
	Predicted	I-275	0.83 - 1.47									
		Pinellas	2.51 - 4.43									
Manganese	Class III Criteria		None									
	Predicted	I-275	1.80 - 3.18									
		Pinellas	N/A									
Nickel	Existing		6.11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Class III Criteria		283.40	295.30	266.50	317.80	266.50	163.00	234.70	270.20	223.40	272.60
	Predicted	I-275	0.33 - 0.59									
		Pinellas	0.48 -0.84									
Oil&Grease	Class III Criteria		5000.00									
	Predicted	I-275	215.07 - 380.51									
		Pinellas	N/A									
Total Solids	Class III Criteria		None									
	Predicted	I-275	15549.52 - 27510.68									
		Pinellas	N/A									
Total Suspended Solids	Class III Criteria		None									
	Predicted	I-275	2549.52 - 4510.68									
		Pinellas	2385.70 - 4220.86									
Zinc	Existing		4-250.61	4-329.01	4.00	18-20	4-22.62	4-4.53	N/A	4-14.74	4.00	4.00
	Class III Criteria		190.70	198.70	179.30	213.90	179.30	109.60	157.80	181.80	150.30	183.40
	Predicted	I-275	8.96 - 15.85									
		Pinellas	10.02 - 17.73									

N/A : Data were not available.

1. Data analyzed are for the 1990's except for Nickel and Chromium as the most recent data for these two metals are from the 1980's.
2. Criteria reported for the chromium are those of hexavalent (trivalent concentrations have higher limits).
3. All concentrations reported are in micrograms/L (μg/l).
4. Cadmium predicted concentrations for Tamiami Trail based on I-275 study are 0.06 μg/l for 5200 VPD and 0.11 μg/l for 9200 VPD.

SALINITY SIMULATION MODELS FOR NORTH FLORIDA BAY

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ABSTRACT

This project will develop salinity simulation models for north Florida Bay using statistical methods and available time series data on rainfall, SFWMD C-111 canal flows and levels, groundwater levels, natural creek flows and levels, tides, and wind. Previous work by Marshall (2000) utilized a subset of the available data. This project uses a larger composite database, developed from the Everglades National Park Marine Monitoring Network, the SERC database, the SFWMD database, the USGS database, and other data. Salinity models are being developed for Joe Bay, Little Madeira Bay, Terrapin Bay, Garfield Bight, and North River Mouth in Florida Bay. The purpose of this project is to develop salinity simulation models for north Florida Bay using available data for use in evaluating modifications to water delivery schemes to Florida Bay. It is sponsored and funded by the Everglades National Park.

In a preliminary time series modeling effort for Florida Bay (Marshall, et al, draft document), "seasonal autoregressive integrated moving average" (SARIMA) models were able to handle the seasonal and correlated components of both the independent and dependent variable data. Because of the relatively coherent regional climate of the Everglades and Florida Bay, it is anticipated that the makeup of SARIMA salinity models for other embayments will include similar categories of independent variables. It is also expected that other local factors will play a role and that the influence of water management activities will weaken with distance from a particular set of structures.

USE OF A MICROSOFT ACCESS DATABASE PROGRAM TO TRACK POLLUTION LOAD REDUCTION GOALS TO TAMPA BAY

By
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ABSTRACT

The Tampa Bay Estuary Program (TBEP) working with its contractor, Janicki Environmental, Inc., has taken tracking implementation of pollutant load reduction initiatives a step further.

Realizing the need for a comprehensive tracking system to monitor pollutant load reduction projects, a Microsoft Access database was created. This database performs all calculations necessary to determine pollutant load reductions based on several key factors such as land use type and treatment method. To accurately calculate pollutant load reductions, the database incorporates a linked Microsoft Excel map of the Tampa Bay watershed and the corresponding land use type for each subbasin. Once information is entered into the database users may choose to print customized pollutant load reports for specific categories such as county jurisdiction and bay segment for total nitrogen (TN) and total suspended solids (TSS). The database also tracks habitat restoration and protection acreage, cost of project, start and end dates, and a text or image description of the project.

The database will be populated with current pollutant load reduction projects, and will serve as the clearinghouse for nitrogen reduction goals for Tampa Bay. It will also be used to provide the Department of Environmental Protection reasonable assurance that the innovative partnership of public and private entities participating in the Tampa Bay Estuary Program's Nitrogen Management Consortium is sufficient to attain applicable water quality standards.

CURIOSITY CREEK WATERSHED MANAGEMENT PLAN

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ABSTRACT

The Curiosity Creek Watershed Management project involved the development of a comprehensive watershed plan for an approximately 3 square mile urbanized drainage basin in Hillsborough County. Although the total study area was relatively small, an aggressive plan was developed to address a number of complex flooding and environmental issues. Problems in the watershed included repetitive flooding of several residential areas with extensive flooding during the El Niño rainfall events in 1997/1998; the closure of a sinkhole which historically drained Curiosity Creek and provided a positive outfall for the basin; significant losses of natural land cover from the development of over 80% of the basin; and poor water quality (excessive nutrients and fecal coliform bacteria) which has adversely affected a recreational spring and potential water supply source.

The project was funded by Hillsborough County's Stormwater Management Section and was implemented in concert with several other major basin studies within the county. The goals of this watershed management plan were to develop detailed evaluations of stormwater management, water quality, natural systems, and water supply issues within the basin. The evaluation also included performing water quality modeling to estimate pollutant loads from urban/suburban land uses and the development of alternatives to reduce loads to the downstream sinkhole area and a number of lakes in the basin. This presentation describes the watershed evaluation and planning process and descriptions of several alternatives which addressed major water resource issues to the County and local citizens. Several alternatives were recommended and are currently in the planning and implementation phase by Hillsborough County.

TRACKING CHLOROPHYLL-*a* AND LIGHT ATTENUATION IN TAMPA BAY

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ABSTRACT

The TBEP has developed a tracking process to determine if water quality targets are being achieved in Tampa Bay. The process tracks chlorophyll-*a* concentration and light attenuation. A decision framework is used to evaluate differences in mean annual ambient conditions from established targets. The results of the decision framework are placed in a decision matrix, which leads to various outcomes dependent upon the magnitude and duration of events in excess of the target. The outcomes of the decision matrix show that during the 1991-2000 period, mean annual chlorophyll-*a* concentrations and light attenuation depths were typically representative of conditions less severe than those requiring active management responses. This is in contrast to the preceding 15-year period, during which chlorophyll-*a* concentrations and light attenuation depths were typically indicative of large magnitude and long duration target exceedences.

INTRODUCTION

Water quality targets have been adopted by the TBNEP Management and Policy Committees for the four mainstem segments of Tampa Bay, shown in Figure 1. The Tampa Bay Estuary Program has developed a tracking process to determine if water quality targets are being achieved. The process to track the status of chlorophyll-*a* concentration and light attenuation involves two steps. The first step utilizes a decision framework to evaluate differences in mean annual ambient conditions from the established targets. The second step incorporates the results of the decision framework into a decision matrix leading to possible outcomes dependent upon the magnitude and duration of the events in excess of the target (Janicki et al., 2000). The tracking process is used not only to determine if there are differences between ambient conditions and targets, but also to determine the size of the differences and how long the conditions exist. The objective of this document is to compare the mean ambient chlorophyll-*a* concentrations and light attenuation measurements for 1975-2000 to the segment-specific targets using the tracking process.

METHODS

The first step of the tracking process is presented graphically in Figure 2. When mean ambient chlorophyll-*a* concentrations are less than the target, there is no cause for concern, as represented by Outcome 0 in Figure 2. When mean ambient chlorophyll-*a* concentrations are greater than target values, however, the size of the difference and the duration of the difference are considered. Small differences for short time periods result in Outcome 1, while large

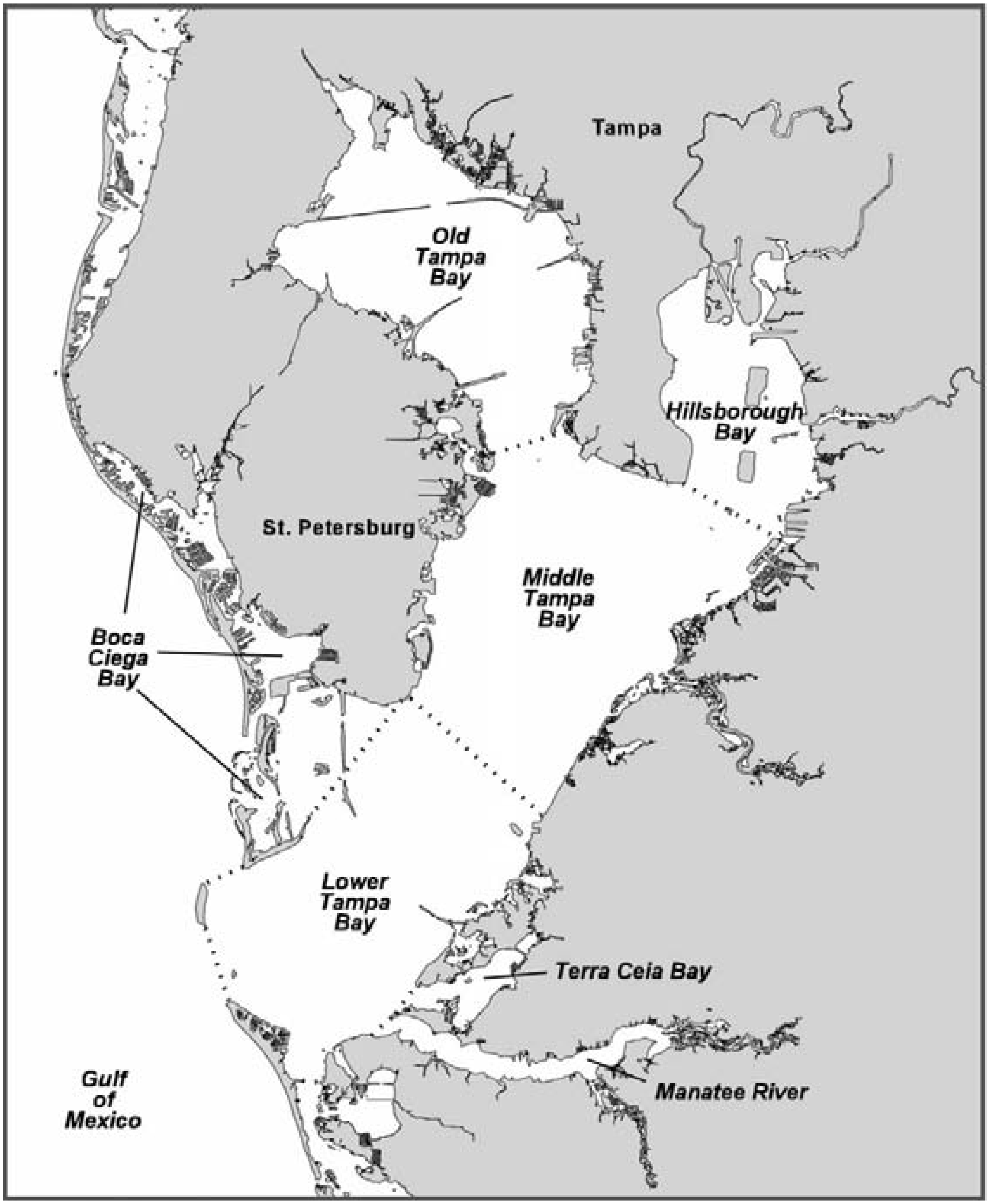

Figure 1. Bay segments of Tampa Bay.

differences for short time periods and small differences for long time periods result in Outcome 2. In the most severe condition, when large differences exist for long periods, the framework results in Outcome 3.

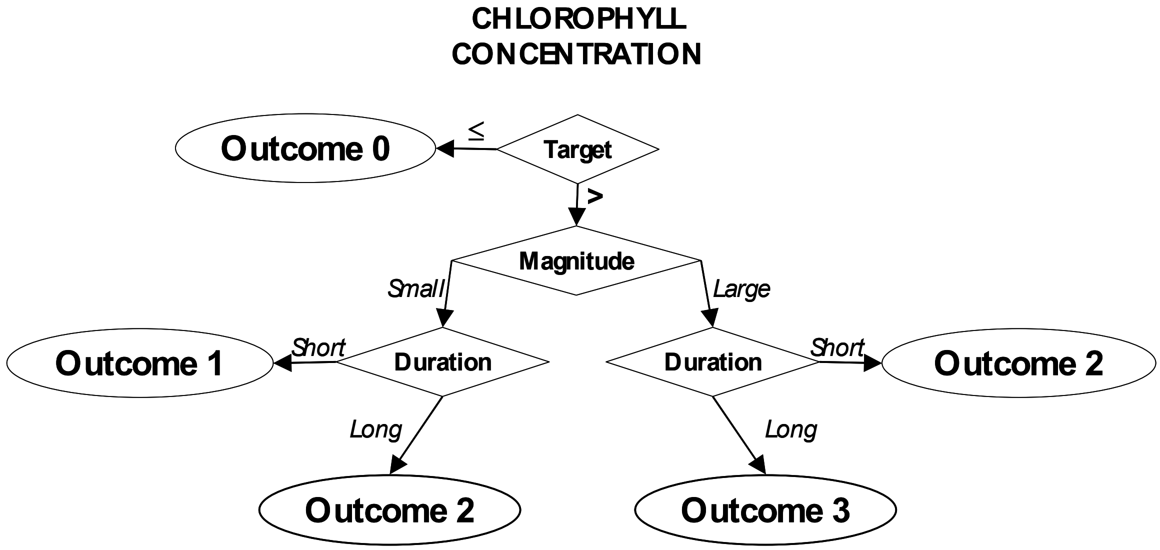

Figure 2. Monitoring and assessment decision framework for chlorophyll-*a* concentration (from Janicki et al., 2000).

A similar decision framework is employed to examine light attenuation, as shown in Figure 3. As for chlorophyll-*a* concentration, mean annual ambient light attenuation is compared to target levels, with various outcomes resulting depending upon the magnitude and duration of target exceedences.

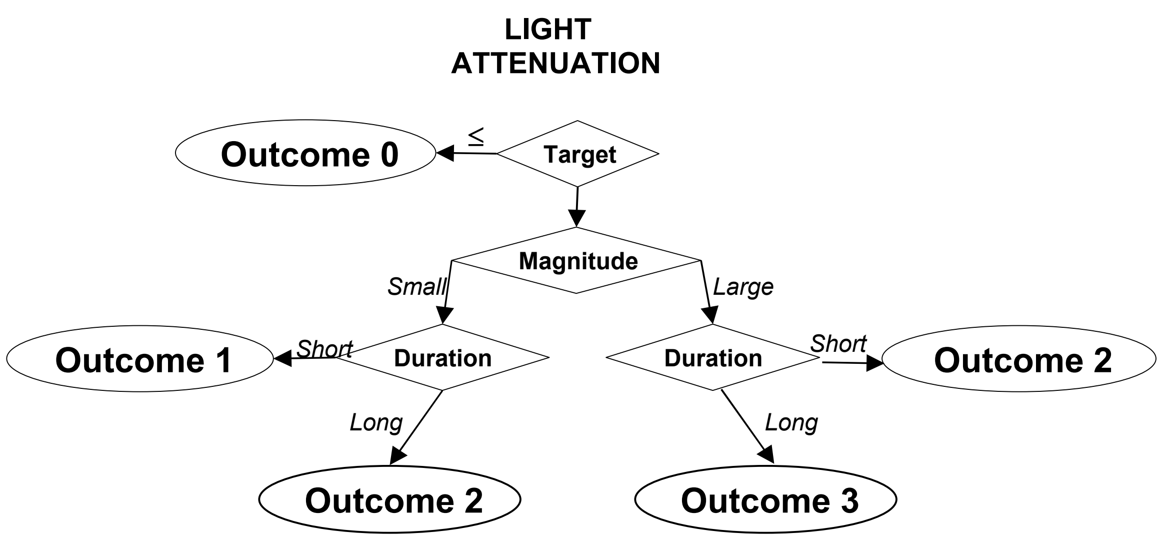

Figure 3. Monitoring and assessment decision framework for light attenuation (from Janicki et al., 2000).

The second step of the tracking process involves combining the outputs from the decision frameworks for chlorophyll-*a* concentration and light attenuation in a decision matrix to provide direction for management responses when targets are exceeded. The decision matrix incorporating the outcomes for chlorophyll-*a* concentration and light attenuation is shown in Table 1. When outcomes for both chlorophyll-*a* concentration and light attenuation are good, as represented by Outcome 0 for both, a condition exists in which targets are being met, and so no management response is required. This condition is signified by the green cell in Table 1. When conditions are intermediate, as signified by the yellow cells in Table 1, differences from the targets exist for either or both chlorophyll-a concentration and light attenuation. These conditions may result in some type of management response.

When conditions are problematic, such that the outcomes for the parameters fall within the red cells of Table 1, then stronger management responses may be warranted. The types of management actions resulting from the decision matrix are classified by color into three categories, shown following Table 1.

Table 1. Decision matrix identifying appropriate categories of management actions in response to various outcomes of the monitoring and assessment of chlorophyll-*a* and light attenuation data.

CHLOROPHYLL	**LIGHT ATTENUATION**			
↓	**Outcome 0**	**Outcome 1**	**Outcome 2**	**Outcome 3**
Outcome 0	*GREEN*	*YELLOW*	*YELLOW*	*YELLOW*
Outcome 1	*YELLOW*	*YELLOW*	*YELLOW*	*RED*
Outcome 2	*YELLOW*	*YELLOW*	*RED*	*RED*
Outcome 3	*YELLOW*	*RED*	*RED*	*RED*

- **GREEN** "Stay the course"; partners continue with planned projects to implement the CCMP. Data summary and reporting via the Baywide Environmental Monitoring Report and annual assessment and progress reports.
- **YELLOW** TAC and Management Board on caution alert; review monitoring data and loading estimates; attempt to identify causes of target exceedences; TAC report to Management Board on findings and recommended responses if needed.
- **RED** TAC, Management and Policy Boards on alert; review and report by TAC to Management Board on recommended types of responses. Management and Policy Boards take appropriate actions to get the program back on track.

The time series of annual chlorophyll-*a* concentrations and light attenuation for 1974-2000 in Hillsborough Bay are shown in Figures 4 and 5. As an example of the application of the process, the mean ambient chlorophyll-*a* concentration and light attenuation for 2000 for each segment are shown in Table 2, along with the segment-specific targets.

Table 2. Mean ambient chlorophyll-*a* concentrations and light attenuation for 2000.

Bay Segment	Chlorophyll-*a* (μg/L)		Light Attenuation (m^{-1})	
	2000	**Target**	**2000**	**Target**
Old Tampa Bay	7.2	8.5	0.73	0.83
Hillsborough Bay	8.8	13.2	1.20	1.58
Middle Tampa Bay	6.1	7.4	0.99	0.83
Lower Tampa Bay	4.5	4.6	0.87	0.63

Applying the decision frameworks for chlorophyll-*a* concentration and light attenuation as shown in Figures 2 and 3, the outcomes for the 2000 data were:

Bay Segment	Chlorophyll-*a* Concentration	Light Attenuation
Old Tampa Bay	0	0
Hillsborough Bay	0	0
Middle Tampa Bay	0	3
Lower Tampa Bay	0	3

Placing these outcomes in the decision matrix shown in Table 1 leads to the following results:

Old Tampa Bay: Green
Hillsborough Bay: Green
Middle Tampa Bay: Yellow
Lower Tampa Bay: Yellow

The "Yellow" results for both Middle Tampa Bay and Lower Tampa Bay are caused by the light attenuation in these segments being greater than the targets for long periods.

To place the 2000 decision matrix results in perspective with results from previous years, the decision matrix results for 1975-2000 are shown in Table 3.

Table 3. Decision matrix results.

Year	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay
1975	Red	Red	Red	Green
1976	Red	Red	Red	Yellow
1977	Red	Red	Red	Red
1978	Red	Red	Red	Yellow
1979	Red	Red	Red	Red
1980	Red	Red	Red	Red
1981	Red	Red	Red	Red
1982	Red	Red	Red	Red
1983	Red	Yellow	Red	Red
1984	Red	Green	Red	Yellow
1985	Red	Red	Red	Yellow
1986	Red	Yellow	Red	Green
1987	Red	Yellow	Red	Green
1988	Yellow	Green	Yellow	Green
1989	Red	Yellow	Red	Yellow
1990	Red	Green	Red	Yellow
1991	Green	Yellow	Yellow	Yellow
1992	Yellow	Green	Yellow	Yellow
1993	Yellow	Green	Yellow	Yellow
1994	Yellow	Yellow	Red	Red
1995	Red	Yellow	Red	Yellow
1996	Yellow	Green	Yellow	Green
1997	Yellow	Green	Red	Yellow
1998	Red	Red	Red	Red
1999	Yellow	Green	Yellow	Yellow
2000	Green	Green	Yellow	Yellow

Given the "Yellow" results for Middle Tampa Bay and Lower Tampa Bay, the recommended response is to review the data and attempt to identify the causes of the differences in light attenuation from the targets in these two segments. A review of the 2000 data has been completed. The next step is identification of the causes of the "Yellow" results. To this end, examination of other water quality components potentially affecting light attenuation is underway, focusing on the contributions of color and turbidity. As ambient chlorophyll-*a* concentrations have declined over the years, it is possible that color and turbidity may play more important roles in light attenuation than previously identified. Additionally, the unusual meteorological and estuarine conditions (low rainfall, high salinity) observed in 2000 and 1999 may have influenced those factors contributing to light attenuation.

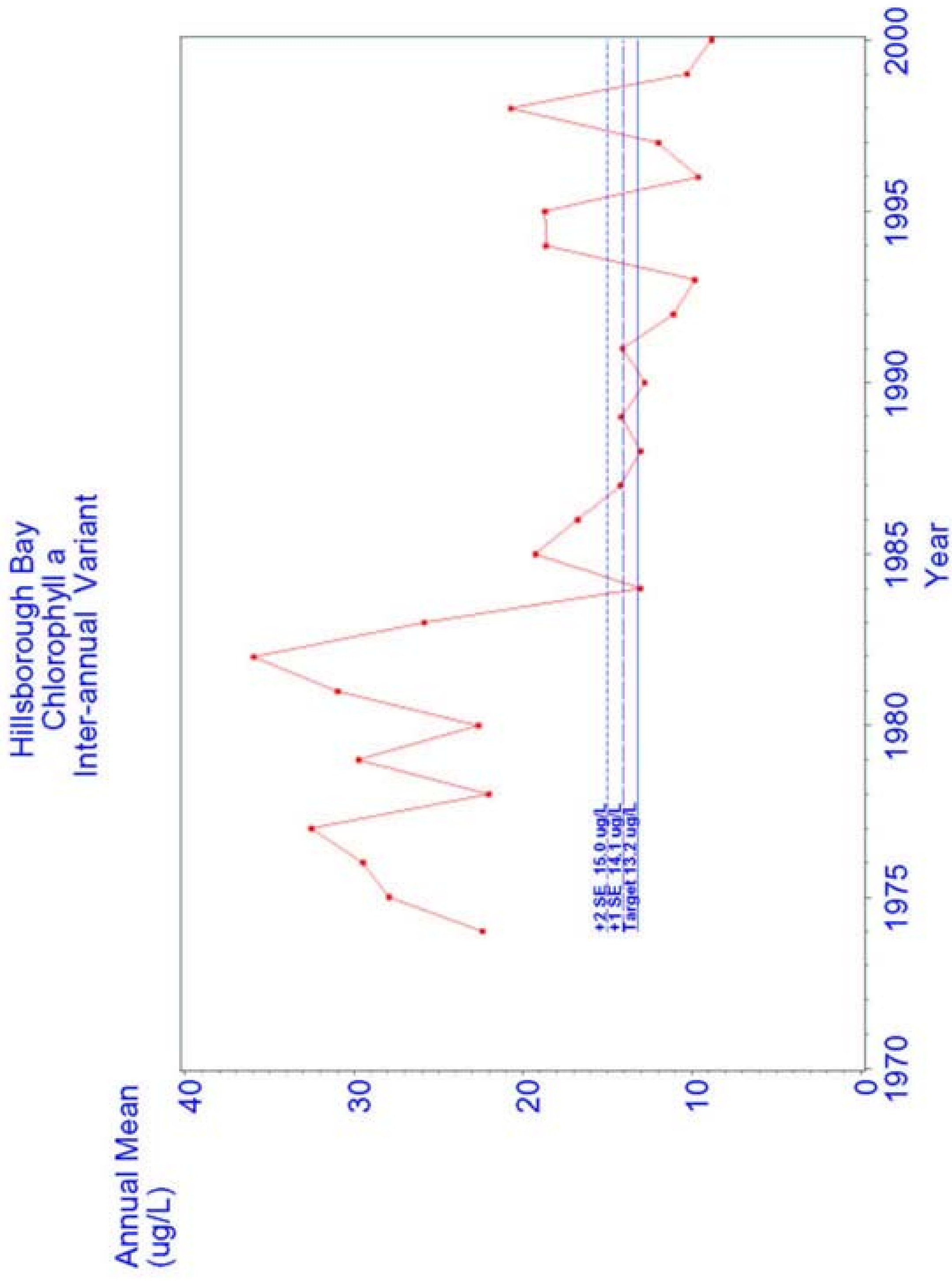

Figure 4. Hillsborough Bay average annual chlorophyll-*a* concentrations, with target and inter-annual variant-derived small and large magnitude differences.

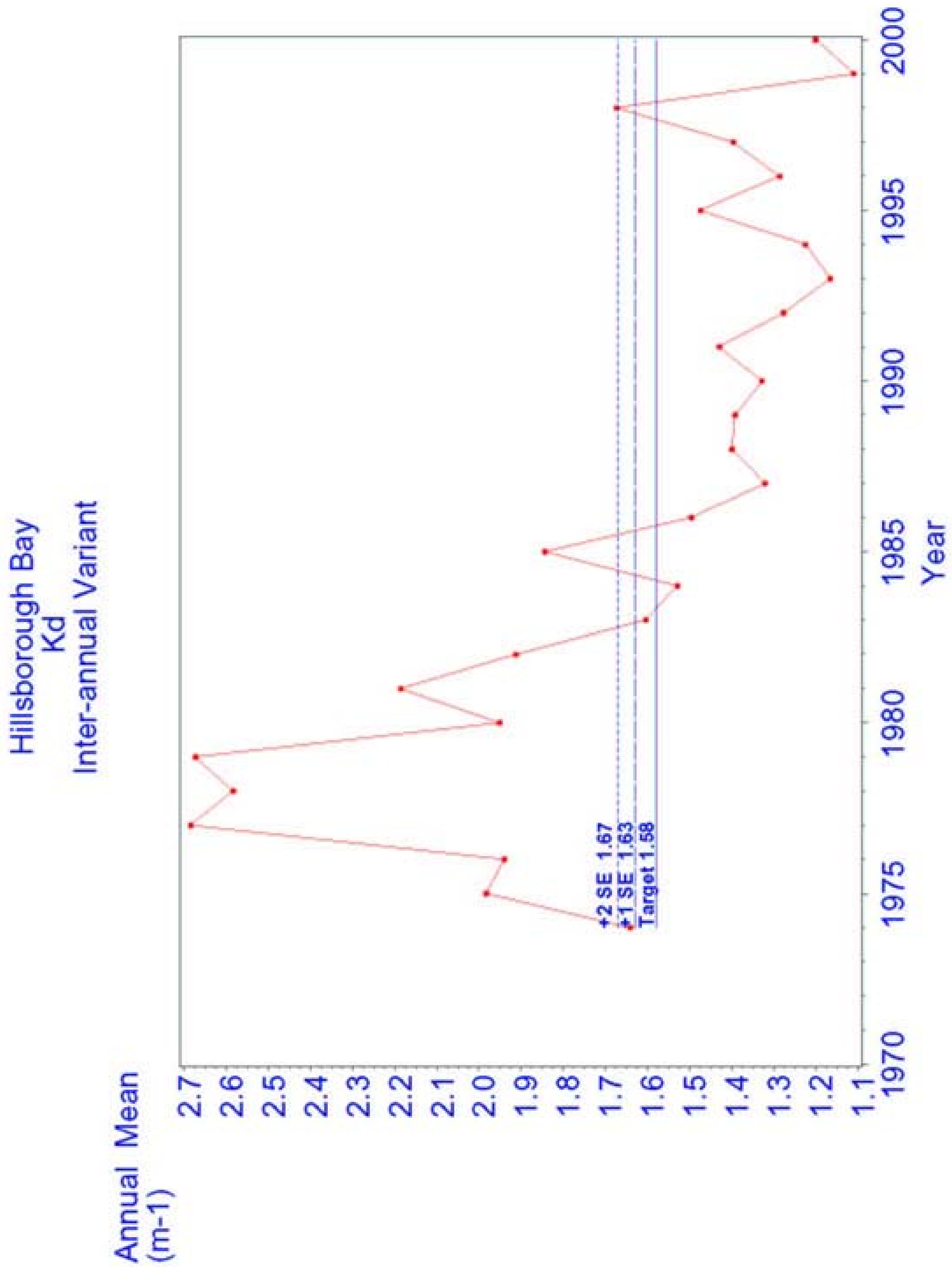

Figure 5. Hillsborough Bay average annual light attenuation, with target and inter-annual variant-derived small and large magnitude differences.

REFERENCES

Janicki, A.J., D. Wade, and J.R. Pribble. 2000. Establishing a process for tracking chlorophyll-*a* concentrations and light attenuation in Tampa Bay. Prepared for: Tampa Bay Estuary Program. Prepared by: Janicki Environmental, Inc.