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

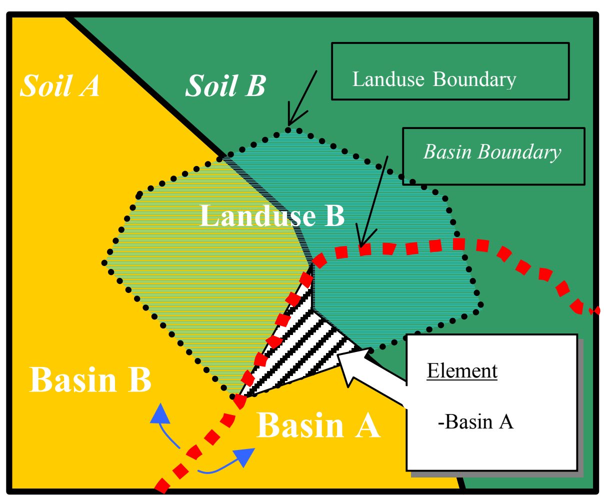

Figure 1. Elements of Calculation Element

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.

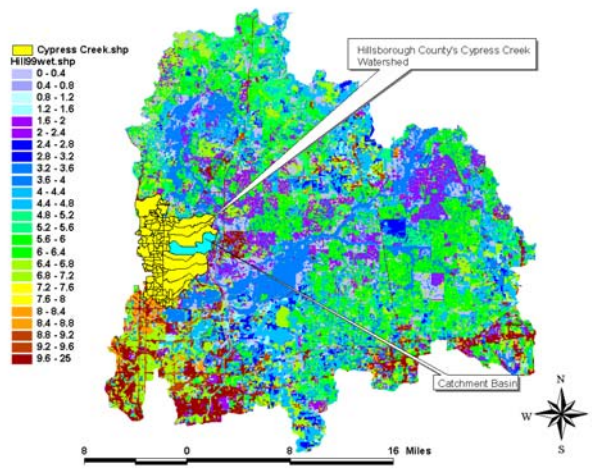

Figure 2. Hillsborough CWM 1995 Wet Season Potential Total Nitrogen Pollutant Load Layer

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.

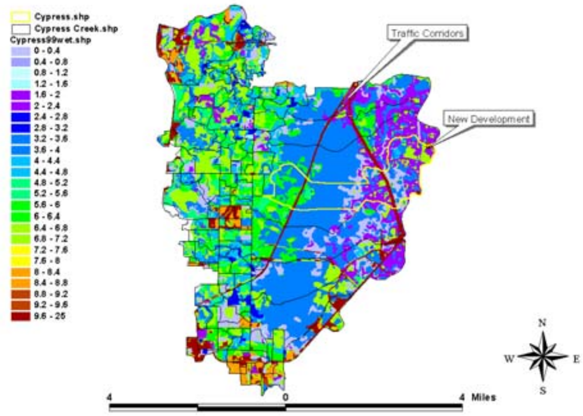

Figure 3. Cypress Creek PPLL (TN lbs/acre)

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.

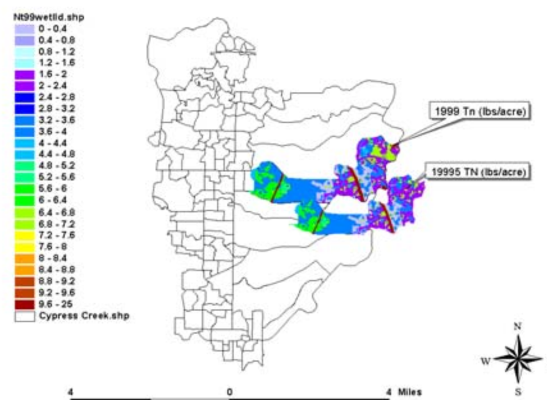

Figure 4. PPLL view for catchbasin (TN lbs/yr)

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

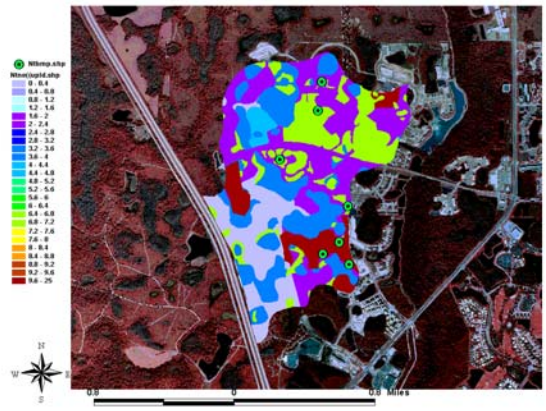

Figure 5. 1999 PPLL overlaid on 1999 aerial.

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.

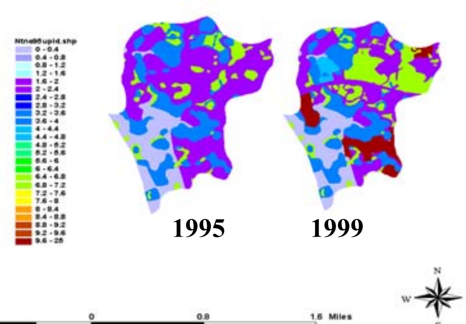

Figure 6. Comparison of two sub-catchbasins.

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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