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USING A GIS FOR ESTIMATING INPUT PARAMETERS IN URBAN STORMWATER QUALITY MODELING[1]

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ABSTRACT: Geographic Information Systems (GIS) are being used increasingly as a method of preparing, analyzing, and displaying data for watershed analysis and modeling. Although GIS technology is a powerful tool for integrating and analyzing watershed characteristics, the initial preparation of the necessary database is often a time consuming and costly endeavor. This demonstration project assesses the viability of creating a cost-effective spatial database for urban stormwater modeling from existing digital and hard-copy data sources. The GIS was used to provide input parameters to the Source Loading and Management Model (SLAMM), an empirical urban stormwater quality model. Land use characteristics, drainage boundaries, and soils information were geocoded and referenced to a base data layer consisting of transportation features. GIS overlay and data manipulation capabilities were utilized to preprocess the input data for the model. Model output was analyzed through postprocessing by GIS, and results were compared to a similar recent modeling study of the same watershed. The project, undertaken for a small urban watershed located in Plymouth, Minnesota, successfully demonstrates that the use of GIS in stormwater management can allow even small communities to reap the benefits of stormwater quality modeling.
(KEY TERMS: modeling; geographic information systems; stormwater management; water quality;nonpoint source pollution; remote sensing; planning.)

INTRODUCTION

Surface water runoff from urban areas is a major contributor to water quality degradation, especially in urban lakes and waterways. Often referred to as urban nonpoint source pollution, polluted stormwater is a result of land use and urban activities throughout the urban environment. As such, it is often extremely difficult to characterize and effectively quantify nonpoint source pollution and its effects without a comprehensive and continuous runoff monitoring program. Extensive monitoring is impractical if not cost-prohibitive in most cases.

An assessment of the magnitude and nature of nonpoint source contamination is an integral component in establishing an effective pollution control strategy. In addition, knowledge of current conditions provides a benchmark with which to measure the effectiveness of current and proposed remediation strategies, programs, and policies. Computer-based stormwater quality models are one way to undertake such an assessment. Empirical models using rainfall-runoff relationships coupled with pollutant loading coefficients based upon land use are currently the primary method of evaluating source area runoff volumes and associated pollutant loadings (Ventura and Kim, 1993). These models require information on a number of areal watershed characteristics such as land use and cover, building density, soil properties, hydrologic connectivity, street width, and stormwater control practices.

Given the level of spatial heterogeneity and variability in a typical watershed, the acquisition and organization of the necessary hydrologic database required for modeling can be a formidable task for watersheds larger than a few hundred acres. The need to inventory and process large volumes of spatial data from various sources suggests that geographic information system (GIS) technology is a logical choice for support of this kind of modeling. With its ability to integrate and analyze properties related to geographic location, GIS can be used to easily prepare the data needed for modeling from spatially referenced input data (Bobba *et al.*, 1992). The development of the necessary geographic database, however, is usually the most costly (Aronoff, 1993) and time-consuming (Leipnik *et al.*, 1993) component in GIS implementation.

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GIS is increasingly being used from the local to national level for such varied purposes as land use planning, facility siting, wildlife management, resource development, infrastructure management, and emergency response. As such, many sources of currently available digital spatial data can be obtained for the purposes of water quality investigations. The use of GIS data from various government or private sources can reduce the cost and time associated with database development. One of the goals of this project is to demonstrate the development of a cost-effective digital database for urban hydrological modeling from existing GIS data as well as other hard copy and ancillary data sources.

Planning for flood control has traditionally been carried out at the regional or state level. However, planning for stormwater quality improvement has mostly been relegated to local units of government. Gathering the input data to run any urban stormwater management model through direct measurement and sampling is a task beyond the financial and time constraints of most smaller communities. The example study illustrates that creative use of frequently existing GIS data sources, plus the ability of GIS to transform disparate data sets into relevant input data streams, can augment hydrologic measures to create required input data for stormwater modeling. This approach opens a window of opportunity for a smaller community to conduct effective planning by directly comparing the benefits of alternative stormwater management strategies.

PROJECT BACKGROUND AND APPROACH

The goal of the project is to demonstrate the use of GIS in conjunction with a computer water quality model to assist in the assessment of stormwater pollution at the municipal level. Building upon the research efforts and demonstration projects undertaken by the Wisconsin Department of Natural Resources and the University of Wisconsin-Madison (Kim *et al.*, 1993), this project makes use of the Source Loading and Management Model (SLAMM). SLAMM is a computer-based model for estimating source area pollutant loadings for urban areas (Pitt and Voorhees, 1994). Based upon field observations, SLAMM utilizes rainfall-runoff predictions and particulate washoff coefficients to determine contaminant loads. SLAMM uses small storm hydrology algorithms and Monte Carlo simulation to estimate pollutant concentration values. The model also allows the user to estimate reductions in pollutant loadings due to the presence of stormwater quality control measures such as wet detention basins and street sweeping.

The project utilizes a GIS to manage and integrate various data sources. With the spatial analysis capabilities of a GIS, thematic data coverages of the watershed were used to provide the hydrologic input data to the SLAMM model. Both digital and ancillary data were obtained from a variety of sources and converted into the appropriate format. Minor field work was undertaken to obtain missing information, as well as to confirm existing data and statistics. A GIS was also used to process the model output data for interpretation and presentation of results. ESRI Arc/Info 6.1 running on the UNIX platform was selected as the GIS package for the project. ArcView 2.0 was used for the creation of hard copy maps and presentation graphics.

The overall objectives of the project are (1) to show the use of SLAMM and GIS as a combined functional tool for urban nonpoint source pollution characterization, (2) to demonstrate the development of a cost-effective digital database for urban hydrologic modeling, and (3) to compare results from the SLAMM model with other predictive models for nonpoint source pollution in the same watershed. Haubner (1995) provides an application for the project results in determining the effectiveness of both existing and planned best management practices for the watershed under study.

HYDROLOGIC MODELING WITH GIS

The use of computers in the field of hydrology has become so widespread that it provides the primary source of data for much of the decision making done by many hydrologic engineers (Bobba *et al.*, 1992; DeVantier and Feldman, 1993). Since much of hydrologic modeling is linked to processes and representations of the earth's surface, it is closely connected to the realm of geographic information systems, which deal with the analysis of spatial representations of our world.

Most hydrologic models fall into one of four categories: surface water hydrology, surface water quality, groundwater flow, and groundwater transport (Bobba *et al.*, 1992; Maidment, 1993; Booty and Wong, 1994). In each of these areas, applications for GIS have been found within the context of hydrologic modeling. Figure 1 is a taxonomy of hydrologic models based on their representations of space, time, and uncertainty of hydrologic systems. GIS is particularly suited for dealing with the treatment of spatial variation in hydrologic modeling.

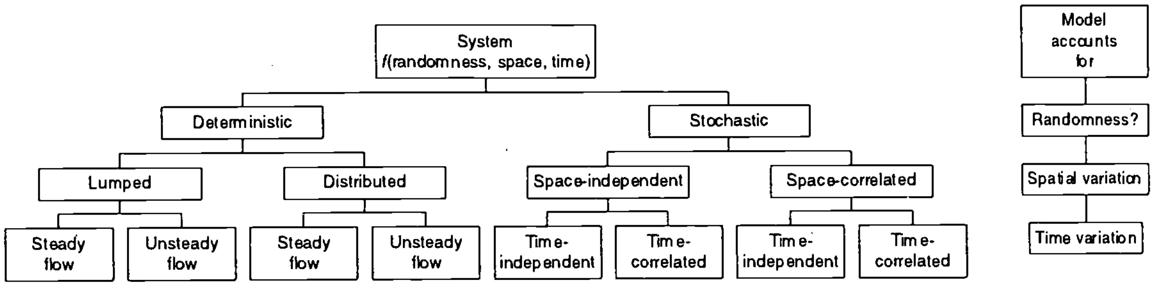

Figure 1. Taxonomy of Hydrologic Models.

Several associations between hydrologic modeling and GIS can be distinguished, each representing a different level of coupling and integration between the GIS and the model: hydrologic parameter determination, hydrologic conditions assessment, hydrologic modeling using native GIS functionality, and a GIS integrated with a hydrologic model with a common user interface. Of these, the determination of input parameters for an existing hydrologic model is the most common approach since it requires few if any software modifications (Fedra, 1993). This approach is easy to implement because it typically involves nothing more than the transfer of data or files between the GIS and the computer-based model (Figure 2). In addition, it is applicable to most currently existing empirical models, including many stormwater and runoff water quality models. Although a more automated and integrated GIS/modeling system is less cumbersome and less prone to error, manual or flat file data exchange between the GIS and model does not require a dedicated system or a specialized interface. This method is also more amenable to an already existing GIS system in place or under preparation at the local level. Hence, this study focused on using a GIS for estimating the input parameters for use with the SLAMM model.

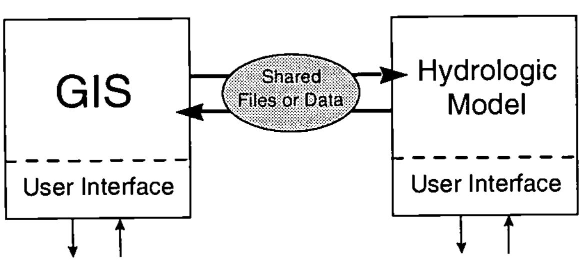

Figure 2. Loosely Coupled GIS and Model.

DESCRIPTION OF STUDY AREA

The study area chosen for the project was the Parkers Lake watershed, a suburban watershed located within Plymouth, Minnesota. Plymouth, a growing municipality with a population of over 55,000, is part of the greater Minneapolis/St. Paul metropolitan area (see Figure 3). The watershed drains approximately 384 hectares (950 acres), or 3.83 km^2 (1.48 sq mi), of mostly developed land into Parkers Lake, a small but important recreational lake with a surface area of 38 hectares (94 acres). The watershed contains a mix of land use and cover types, including light industrial, commercial, institutional, park and open space, and various residential classes (Figure 4).

Though historically a closed basin, an outlet from Parkers Lake was constructed in 1981 to deal with high water problems resulting from increased runoff due to urbanization. Parkers Lake and its drainage basin are now part of the larger Bassett Creek Watershed, which covers a land area of over 10,000 hectares (25,000 acres) and parts of nine communities in the northwestern metropolitan region (Bassett Creek Watershed Mgmt. Comm., 1990). Bassett Creek drains into the Mississippi River above St. Anthony Falls in downtown Minneapolis.

As with many urban water bodies in the Minneapolis/St. Paul region, water quality in Parkers Lake has decreased noticeably with increasing urban development. Reduced water clarity, increased weed growth, and algal blooms are some of the problems affecting the lake. These problems are due to additional nutrients and sediment entering the lake through stormwater runoff.

Water quality in the lake has been monitored by the Bassett Creek Watershed Management Commission (BCWMC) since 1972. Water quality parameters tested include total phosphorus concentration, mean summer chlorophyll a concentrations, and minimum Secchi disc transparency depth. Although lake conditions have improved since monitoring done in 1972 and 1977, water quality conditions continue to be

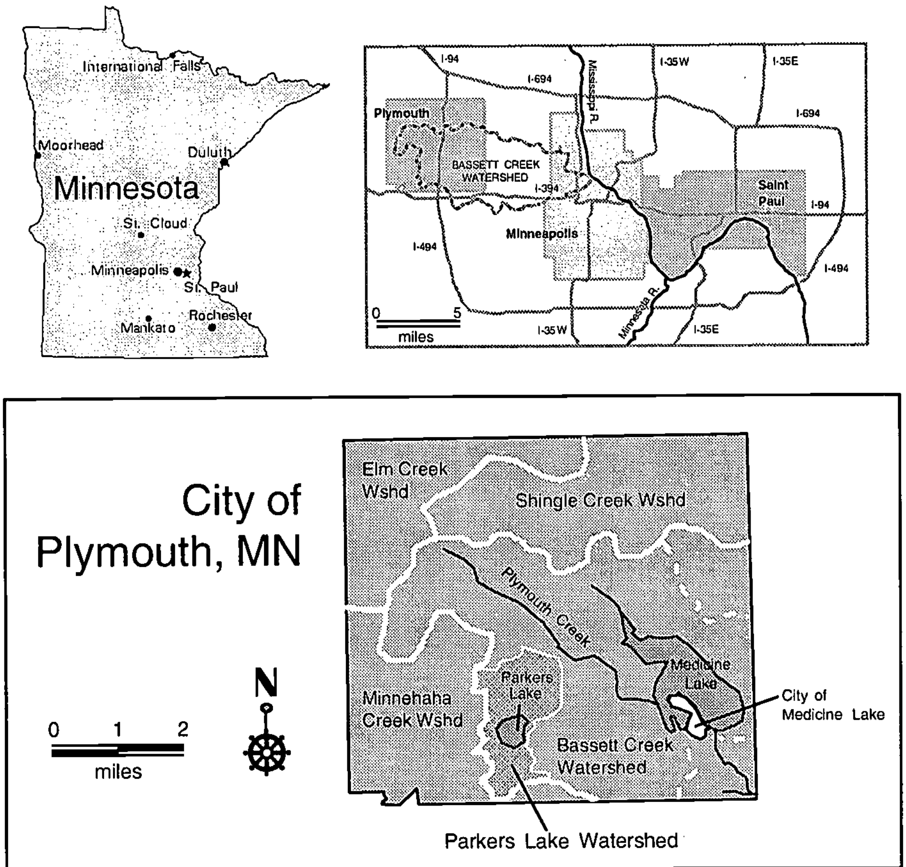

Figure 3. Study Area Location.

below the water quality goals set for the lake by the BCWMC (Barr Engineering, 1993). In fact, lake conditions appear to be worsening in recent years.

In 1992, Parkers Lake had a mean summer total phosphorus concentration of 38 mg/L, a mean summer chlorophyll *a* concentration of 22 mg/L, and a mean summer Secchi disc transparency of 1.8 m (5.9 ft). These values are below the water quality goals of a maximum phosphorus concentration of 30 mg/L, maximum chlorophyll *a* concentration of 10 mg/L, and a minimum Secchi depth of 2.1 m (7 ft). Using a trophic state index based upon phosphorus concentration, Parkers Lake is classified as a eutrophic water body.

The lake's impaired water quality conditions make it a good candidate for an evaluation of stormwater pollution inputs. The following sections outline the study:

1. Identification of data requirements and sources.
2. Acquisition of necessary digital, hard-copy, and ancillary data.
3. Development of GIS data layers and coverages.
4. Processing of the GIS data.
5. Outputting the resultant parameters to the stormwater quality model.
6. Running the model and evaluating the results.

INITIAL PROCEDURES

The first step of the study involved identifying the model input variables that could be effectively generated by GIS and determining the level of spatial resolution required for reasonable hydrologic modeling of the watershed. The SLAMM model uses a lumped parameter approach to deal with stormwater control devices. Therefore, the contributing drainage areas of individual control devices such as wet detention basins became the largest subbasins of the watershed that could be effectively modeled. SLAMM requires information on the developmental characteristics of a drainage area to be modeled. General land use classification, building density, source area fractions, rooftop pitch, hydrologic soil group, street width and lengths, stormwater control device specifications, and drainage system characteristics are all input

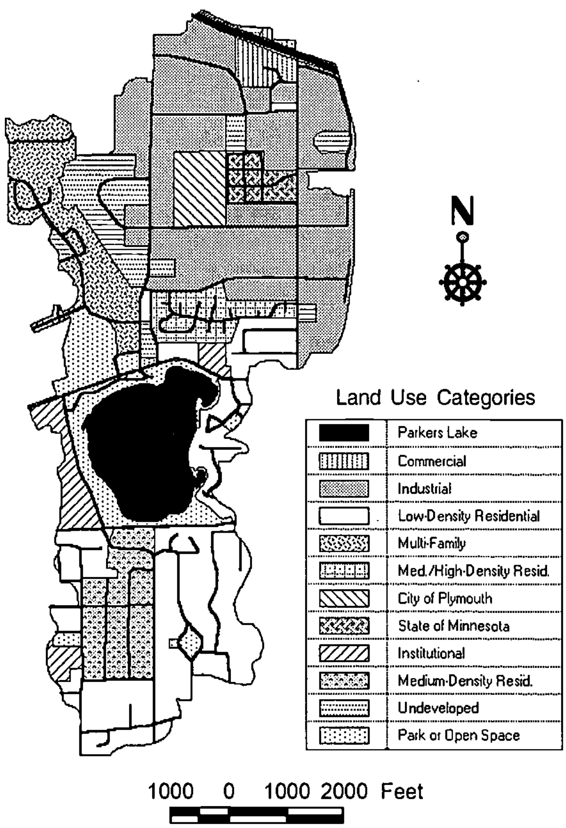

Figure 4. Parkers Lake Watershed: Land Use and Street Network.

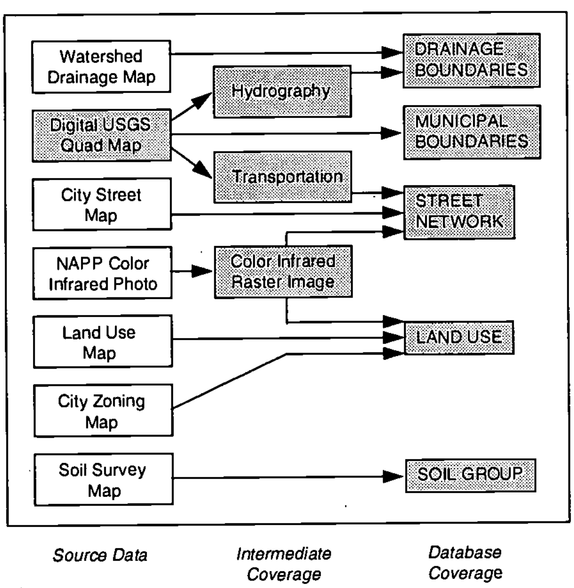

Figure 5. Original and Derived Data Sets.

parameters for the model. Ventura and Kim (1993) showed that a GIS database containing coverages of land use, soils, transportation, and stormwater drainage boundaries can provide most of the necessary information required by SLAMM. Figure 5 displays the original and derived spatial data sets used in the study.

The next task was to acquire and compile the necessary data from various sources (Table 1). Part of this investigation involved inventorying the sources of available spatial data, especially those in a digital format from existing GIS databases of the region. Every attempt was made to minimize cost and processing effort in obtaining the data. Digital maps of political, hydrographic, and transportation features were available from a state agency, which provided the data at no charge. Digital multispectral satellite images of the site can be purchased; however, their cost made scanning paper, color infrared aerial photographs of the watershed area an attractive alternative. Drainage boundaries of and within the watershed were on paper maps only and thus required manual digitizing or scanning to add to the GIS database. Finally, although a digital soils map of Hennepin County is in preparation, it was not available within the time frame of this project; therefore, paper maps of the county soil survey were utilized in this study.

GIS DATABASE DEVELOPMENT

Base Data Layers

Geographic base data are a representation of visible physical and cultural features and boundaries accurately referenced to a specific coordinate system. The base coverage in a GIS database is used to georeference other data layers to a common map projection and coordinate system. These coverages commonly include planimetric data such as roads, water bodies, political boundaries, and utilities.

The base geographic coverages for the GIS database were obtained from the Minnesota Department of Transportation (MnDOT). As part of its GIS activities, MnDOT has digitized all 1:24,000 scale USGS quadrangle maps for the entire state of Minnesota. These coverages contain all of the features of the USGS maps except structures, contours, and forest cover. These data files include quad and section lines, municipal boundaries, park areas, transportation, and hydrography.

The coordinate system for the MnDOT coverages is the Minnesota (state plane) coordinate system, south zone, which is based upon a Lambert conformal conic

TABLE 1. Data Sources for Parkers Lake Watershed.

Map / File / Data	Custodian	Contents
Digitized USGS Quadrangle Maps	MN Dept. of Transportation	Boundaries, Hydrography, Transportation
Parkers Lake Watershed Map	Barr Engineering	Watershed, Subwatershed, and Subbasin Boundaries
City of Plymouth Base Map	City of Plymouth	Parcel Boundaries and Transportation
Zoning Map	City of Plymouth	Land Use Information
1993 Land Use Map	Barr Engineering	Land Use Information
Hennepin County Soils Survey Map	Hennepin County Soil and Water Conservation District	Soil Classifications
Storm Sewer Map	City of Plymouth	Storm Sewer Drainage
NAPP Infrared Aerial Photograph	University of Minnesota	1992 Photographic Coverage
Precipitation Data	Wisconsin State Climatologist	Hourly Rainfall Totals
Stormwater Control Device Data	Barr Engineering	Wet Detention Pond Information
Transportation Data	MN Dept. of Transportation	ADT Values
Parkers Lake Watershed Study	Barr Engineering	P8 Modeling Results

projection. This coordinate system is referenced to the North American Datum of 1983 (NAD 83), and its units are in feet. The data were prepared in Intergraph format but were converted for use in Arc/Info into different base coverages: city boundaries, section lines, lakes, streams, and transportation. The City of Plymouth covers parts of four USGS quadrangles; thus, four quad coverages were edge-matched and joined to create each city-wide coverage.

The USGS source maps used to create the MnDOT GIS data were compiled in 1986. Newer developments in the city exist that do not appear in these files. Therefore, new streets and plats from a 1994 Plymouth base map were digitized to update the transportation coverage.

Color Infrared Imagery

The imagery used in the project are scanned aerial photographs from the National Aerial Photography Program (NAPP). NAPP is a federal multiagency program coordinated by the USGS to provide a complete photographic base of the 48 conterminous states of the U.S. (Lillesand and Kiefer, 1994). NAPP images, based on federal specifications, are 1:40,000 scale color-infrared photographs. The NAPP program completed a state-wide air photo flight in Minnesota in the springs of 1991 and 1992.

Digital (raster) color infrared images covering the city were created by scanning a set of four NAPP paper photographs at a resolution of 300 dots per inch. The images were subsequently enhanced by using image processing software to perform a histogram equalization on each image. This was done to improve image contrast, brightness, and apparent color saturation.

Using the interactive registration program with the Arc/Info system, a subset image of the Parkers Lake Watershed area was georeferenced to the base transportation coverage. Fifty different control points were selected on both the raster image and the vector transportation coverage. During the registration process, a number of these points were eliminated to achieve the desired root mean square (RMS) error in the residuals at the control points. The final registration of the two layers produced an RMS error of 10.6 feet. Given the "fuzzy" nature of drainage delineation and the spatial resolution required for nonpoint source pollution categorization, such error is well within acceptable accuracy for modeling purposes.

Drainage Boundaries

Basin boundaries for the Parkers Lake Watershed, as well as the major and minor drainage divides within the watershed, were taken from the 1993 Parkers Lake Watershed and Lake Management Plan (ref. Barr Engineering, 1993). The drainage boundaries were provided on a 1:500 scale map included with the document.

The watershed map was reduced and scanned at 300 dpi resolution to a raster image and subsequently converted to an Arc/Info GRID raster file. Using the vectorization capabilities of Arc/Info, the GRID image was then transformed into a vector (chain) coverage. A small amount of editing was necessary to remove topological errors in the resultant coverage. Tics were added at 15 control points where real world coordinates had been established at street intersections. The tics were used to register the drainage boundaries to the base coverages using a coordinate transformation routine. Other layers in the database were subsequently clipped to the watershed boundaries. Figure 6 shows the watershed along with its subbasins and major drainage districts.

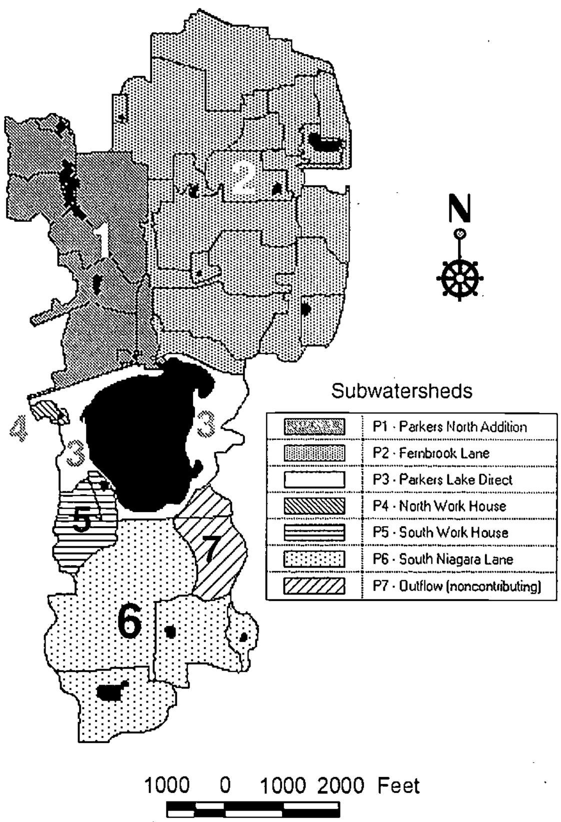

Figure 6. Parkers Lake Watershed: Drainage Boundaries.

Land Use

Land use characteristics within the watershed were derived from zoning maps, aerial imagery, and a map showing 1993 land use conditions from the Parkers Lake Watershed and Lake Management Plan. Additional information was obtained from city planning officials and field surveys of the watershed. Rather than digitize or scan one or both of the maps, on-screen (or "heads-up") digitizing using the color infrared image was performed to define current land use conditions within the watershed. City officials were consulted for discrepancies between the two maps, and several categories of land use were subdivided based upon lot size or special conditions.

Soils

In order to create a soils layer for the GIS database, soils maps covering the watershed area were taken from the Hennepin County Soil Survey and assembled to create a complete map of the watershed. Soils were divided into two categories: Soil Conservation Service (SCS) hydrologic soil group A or B, classified as "sandy" soils; and hydrologic soil group C or D, which falls into the "clayey" classification. The map was shaded to create polygons of sandy and clayey soil types. The outlines of these polygons were then traced onto onion skin paper, scanned to a coverage, and registered to the ground coordinate system with the same methodology as the drainage boundaries layer.

GIS DATA PROCESSING

One of the primary functions of many geographic information systems is the ability to intersect two polygon networks so that Boolean logic can be applied to the results (Burrough, 1993). Logical overlay of two or more data layers involves finding those areas where a specified set of conditions occur. In its most simple form, the spatial overlay of two maps involves the creation of a third map containing smaller, new polygons that result from intersecting the lines making up the original polygon boundaries. The spatial overlay process is demonstrated in Figure 7. The new, resultant polygons in Coverage 3 contain the attribute information from both Coverage 1 and Coverage 2. The number of polygons created is dependent on the number of polygons in the original maps as well as their locations, sizes, and shapes.

For the SLAMM model, we are interested in determining the areas of homogeneous land use and soil type that are used to define the source areas of stormwater contamination. In addition, we are also interested in knowing the drainage subbasin in which these areas are located. Using spatial overlay, the desired information from the data layers in our GIS database can be obtained. The first step involves overlaying the soils coverage with the land use layer. This creates polygons containing different land use and soil type combinations. Next, the subbasin boundaries coverage is overlaid on this new layer to create a set of polygons that contain an additional attribute code identifying the drainage subbasin of the land contained in each polygon.

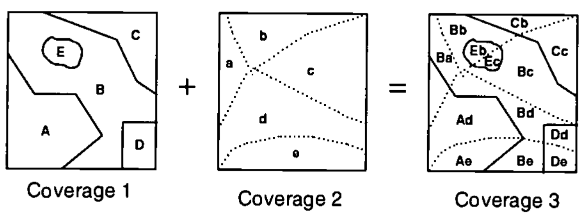

Figure 7. Spatial Overlay of Two Polygon Layers.

A similar process was used to determine the total length of streets within each subbasin. The subbasin boundaries were overlaid on the transportation layer, in essence "cutting" the streets at the drainage divides. Each of the resultant segments was automatically coded to the subbasin in which it was located. This process was repeated using the land use layer in order to add the land use category attribute to the street network.

GIS/MODEL LINKAGE

Because of the format of the SLAMM input files, it would have been extremely difficult to process and output data from the GIS in a digital file that could have been directly used by SLAMM. Therefore, all of the GIS data required some form of processing for eventual entry to the SLAMM model. After completing the spatial overlay, the next step was to prepare the information for each resultant polygon in a form that can be used for the SLAMM model input. Fortunately, Arc/Info attribute data files are in the common dBASE database format. Thus, the polygon attribute table is easily imported into most relational database processing programs such as Microsoft FoxPro.

Using FoxPro, polygon records were sorted by subbasin code. For each subbasin, records with identical attributes were aggregated to consolidate the database. This resulted in unique area records for each land use/soil type combination within a subbasin. For the street network created during the overlay process, individual lengths of street segments and their attributes were output to a database file. These were sorted and organized by subbasin location and land use category.

The SLAMM model was run for each subbasin using 1981 precipitation data, which is considered to reflect average climatic conditions for the area. Additional modeling runs were completed for 1976 and 1983, which are considered dry and wet years, respectively. The following stormwater contaminant loadings were modeled: suspended solids, particulate phosphorus, total phosphorus, chemical oxygen demand, lead, zinc, and fecal coliform count.

MODEL RESULTS AND DISCUSSION

A comparison of predicted contaminant concentrations for the three rainfall years under study is presented in Figure 8. These results show only the raw pollutant loadings before reductions due to stormwater controls. Table 2 shows the predicted annual areal pollutant loading for suspended solids, total phosphorus, and chemical oxygen demand (COD) for each subwatershed for the 1981 storm events. Predicted loadings are given with and without stormwater controls such as a drainage system capture and wet detention ponds. The percent reduction in pollution due to stormwater controls is also shown.

Figure 9 displays the predicted areal concentrations of suspended solids by subbasin on a map of the watershed. Notice the lower pollutant concentrations in the subbasins served by wet detention. Maps of this sort are easy to create using the available spatial data and are one of the primary advantages in using a GIS for the display of modeling results.

Finally, Table 3 shows a comparison between the SLAMM model total phosphorus predictions and model results from the Parkers Lake Watershed and Lake Management Plan. The model used in the PLWMP study is the *Program for Predicting Polluting Particle Passage through Pits, Ponds, and Puddles*, better known as P8. P8 is similar to SLAMM in that it predicts the generation and transport of stormwater runoff pollutants in urban watersheds by using continuous water balance and mass balance equations (Walker, 1990). The P8 model was developed for use by engineers and planners in designing and evaluating runoff treatment schemes for existing and proposed urban developments. The phosphorus loading estimates generated by both the P8 and SLAMM models are in good agreement with actual phosphorus monitoring data provided by water quality studies done in neighboring Ramsey County and on the Minneapolis lakes system (Barr Engineering, 1993).

It is interesting to note the effectiveness of wet detention ponds and other drainage controls in reducing particulate contamination. This is illustrated well

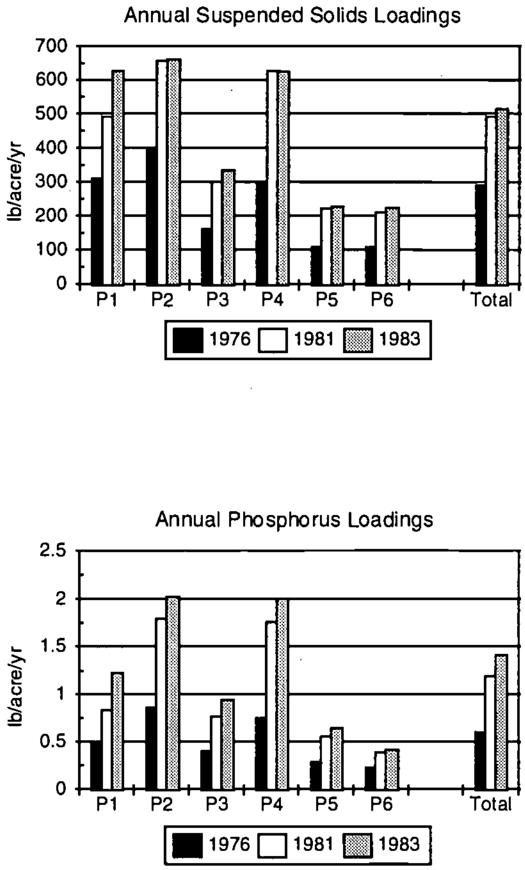

Figure 8. SLAMM Predictions for Dry, Average, and Wet Years.

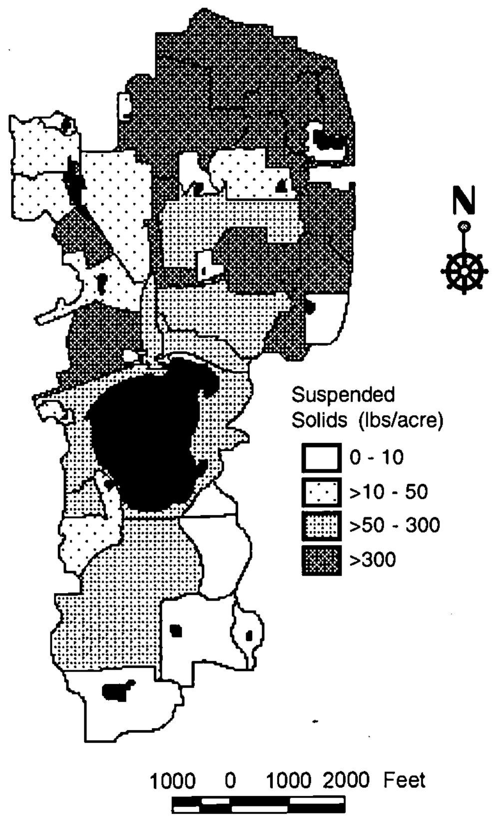

Figure 9. SLAMM Suspended Solids Loading by Subbasin.

TABLE 2. SLAMM Predicted Annual Areal Loadings for Suspended Solids, Particulate Phosphorus, and Total Phosphorus.

	Suspended Solids (lb/acre/yr)			Total Phosphorus (lb/acre/yr)			Chemical Oxygen Demand (lb/acre/yr)		
Subwatershed	Without Controls	With Controls	Percent Removal	Without Controls	With Controls	Percent Removal	Without Controls	With Controls	Percent Removal
Parkers North Addition (P1)	491	99	80%	0.83	0.52	38%	266	95	64%
Fernbrook Lane (P2)	656	283	57%	1.79	1.48	17%	423	260	39%
Parkers Lake Direct (P3)	299	161	46%	0.76	0.56	26%	238	158	34%
North Work House (P4)	625	98	84%	1.75	0.75	57%	452	128	72%
South Work House (P5)	221	29	87%	0.55	0.34	39%	127	45	64%
South Niagara Lane (P6)	211	36	83%	0.38	0.23	41%	106	36	66%
Entire Watershed	**490**	**178**	**64%**	**1.19**	**0.93**	**22%**	**303**	**166**	**45%**

in the case of Subwatershed P2, which contains the most land area served by wet detention. Subwatershed P5 and P6 also contain significant drainage to ponding areas, the effect of which can be seen in the output data.

It must be mentioned that the usefulness of these results is less in the actual values than in their ability to predict the nature and relative magnitude of the stormwater contamination that we can expect from the conditions under study. Runoff quality is highly

TABLE 3. Comparison of SLAMM Phosphorus Loadings to PS Modeling Results.

Subwatershed	Total Phosphorus Loading With Controls (lb/acre/yr)		Percent of Total Phosphorus Load to Parkers Lake		Ratio of SLAMM to P8 Results
	SLAMM	P8	SLAMM	P8	
Parkers North Addition (P1)	0.52	0.29	11%	7%	1.79
Fernbrook Lane (P2)	1.48	1.19	78%	77%	1.24
Parkers Lake Direct (P3)	0.56	0.39	4%	4%	1.44
North Work House (P4)	0.75	0.25	< 1%	< 1%	3.00
South Work House (P5)	0.34	0.12	1%	< 1%	2.83
South Niagara Lane (P6)	0.23	0.40	5%	11%	0.58
Entire Watershed	**0.93**	**0.75**	**100**	**100**	**1.24**

variable, both temporally and spatially. Therefore, one must remember that the model is primarily designed as a planning tool for estimating possible conditions and pollution reductions due to stormwater controls. The SLAMM model does not take into account point sources, nor does it provide a source area capability to handle construction site erosion. SLAMM can, however, provide a realistic prediction of the sorts of pollutant loadings that can be expected from the watershed under the given conditions.

The accuracy of the GIS database must also be discussed at this point, for it is used to define the extent of the source areas in the model. GIS coverages can only be as accurate as the original source data, both spatial and attribute, from which they are derived. The error in this data can be both positional and attribute error. In addition, digitizing/scanning and registration both introduce positional error to the data layers as they are converted into digital form. The mixing of spatial data of many different scales and qualities and from various sources is also an issue. In the context of SLAMM modeling, however, the limiting factor of accuracy is in the original definition of the drainage boundaries and land use classifications, which varied widely depending on the source map. Thus, it was assumed that the error propagation due to the creation of the database was insignificant compared to the uncertainty in the original data and the sensitivity of the SLAMM model.

CONCLUSION

Hydrologic modeling of stormwater runoff quality is one way to obtain an assessment of the need for runoff controls and nonstructural management practices. Because of their complexity and specificity, water quality models are often excellent candidates for use with geographic information systems. Empirical models can easily be linked to GIS databases since coefficients and input characteristics can be applied to GIS layers. As shown by this project, the use of GIS technology to integrate and process spatial information for hydrologic modeling is one way to simplify the task of defining source area characteristics for an urban watershed. When used correctly, GIS in combination with water quality models can be a powerful tool for water resources planning and management.

The time and effort needed to compile the necessary GIS layers for use in hydrologic modeling might preclude their widespread use. However, as geographic information systems become a more integral part of local and regional planning, engineering work, and public works maintenance, much of the spatial information required by these sorts of water quality models will already exist in digital form. As stormwater management is primarily a function of local communities, the efforts to bring GIS into the realm of stormwater planning are often tied to the abilities of municipalities to procure and implement the technology, as well as acquire the necessary spatial data. Even so, a number of agencies and levels of government can play a role in bringing the technology and data to the local and regional level. The coordination of spatial data sources by regional and state agencies and consortiums can be of enormous assistance to communities in their stormwater management endeavors. The presence of regional watershed commissions such as the Bassett Creek Watershed Management Commission, formed by legislative mandate in Minnesota in 1972, is another resource for communities. Such commissions can provide innovative leadership in the research of water quality problems that affect lakes and streams.

Overall, there is much work to be done in both the research of nonpoint source water pollution and in the implementation of management practices to address pollution effects in the urban environment. GIS and urban stormwater models such as SLAMM are two tools of many that can be utilized to these ends. The ideas put forward here are just a few of the many creative approaches that will hopefully be employed in the attainment of water quality goals in our communities.

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