Chapter 2

Literature Review

2.1 INTRODUCTION

The purpose of this literature review is to provide the reader with a general overview of environmental modeling as it pertains to GIS. Recently, this concept has become a popular subject in many science and engineering fields. Within the past five years, many conferences have been hosted which primarily discuss research in environmental modeling and engineering practices using GIS. The first part of this chapter gives a brief description of past and current work that integrates modeling into GIS. Next, examples of existing models which have been connected to or utilize GIS in some fashion is presented. Finally, a brief overview of connections between GIS and the WASP5 water quality model is given.

2.2 ENVIRONMENTAL MODELING USING GIS

When examining previous research, attention should be given to the type of connection established between the environmental model and the GIS software. In addition, the type of GIS software used is a concern. Tim and Jolly (1994) present a good overview of three types of model interfaces possible with GIS (Figure 2-1). Their paper describes the three levels of integration as 1) ad hoc integration, 2) partial integration, and 3) complete integration. In the first level, the GIS data structure and environmental model are developed independently. The data is extracted from GIS, the model run separately, and the output analyzed at the user's discretion. The second level results in GIS playing more of an integrated role in the modeling. GIS supplies the data and then accepts the modeling results for processing and presentation. The third level consists of complete model development within the GIS software. The user has a single operating environment, where the data stored in the GIS is structured to meet the demands of the model and vice versa (Tim and Jolly, 1994). It should also be noted that there are numerous types of GIS software with which a model link can be accomplished. Most literature reviewed for this project utilized

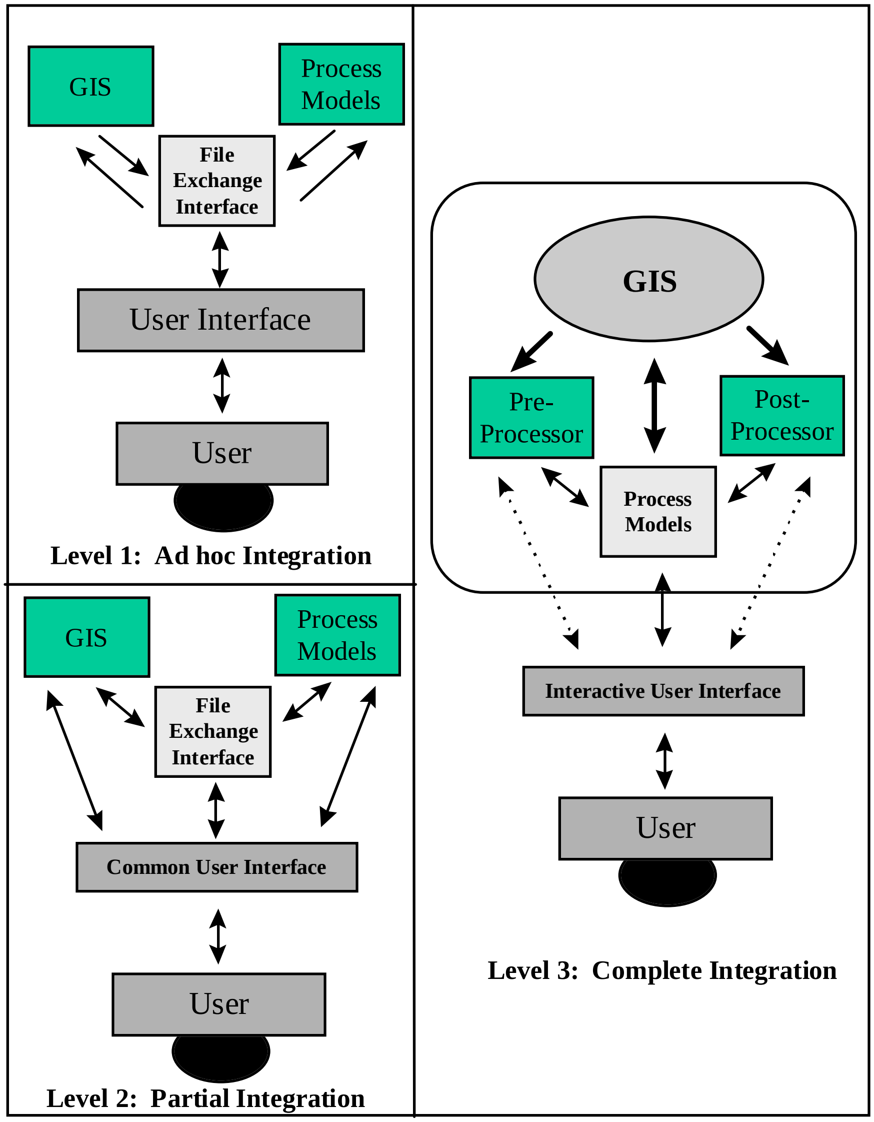

Figure 2-1 Levels of GIS/model integration.
Source: Tim and Jolly (1994)

the GIS software, Arc/Info and ArcView; although, some articles discussed below did accomplish links to other GIS software programs.

Environmental Modeling Within GIS -- Level 3: Complete Integration

For the past decade, the integration of GIS with environmental modeling has become an important research topic. The use of GIS for modeling provides ease and accuracy in the management and spatial representation of data. Recent projects which have conducted environmental modeling directly in the GIS have included studies in simulating hydrologic processes, water balancing a river basin, predicting chemical concentrations in rivers, and assessing non-point source loading over a watershed (Maidment, 1992; Stuart and Stocks, 1993; Olivera and Maidment, 1996; Ye, 1996; Maidment, *et al*., 1996; Mizgalewicz, 1996; Saunders, 1996; Newell, *et al.*, 1992).

The area of hydrologic processes is one of the primary areas of study in the literature reviewed for this project. One application of hydrologic modeling in GIS incorporated a set of generic modeling tools within an unspecified GIS software to implement a semi-distributed hydrological model (Stuart and Stocks, 1993). A set of pre-established hydrologic equations, which explain surface saturation, were integrated into GIS with the macro language of the GIS software utilized. Spatial information needed for the equations, such as land slope, rainfall intensity, and soil transmissivity, was stored in the form of GIS coverages. By using a GIS tool interface, which incorporated the needed equations, along with the data coverages, the spatial distribution of the surface saturation was calculated over a study area (Stuart and Stocks, 1993).

Besides hydrologic processes related to land saturation, numerous sources were found pertaining to the concept of flow and transport modeling over the land surface. Maidment (1992) investigated concepts in hydrologic modeling with GIS, using the Arc/Info software, such as grid based watershed delineation, geographic representation of the stream network, and dynamic segmentation for hydrologic feature locations on this stream network.

This research proposed a “hybrid grid network” which consisted of the delineated watershed grid and its connected stream network created from the delineation process. The modeling of the spatially distributed hydrologic processes over the grid was combined with a model of flow and transport processes in the stream network to result in a network of linearly connected flow systems. The overall model was developed in GIS, while using basic hydrologic concepts and equations to explain the flow and transport parameters.

In an ongoing study, an application of flow process modeling uses the concepts of spatially distributed land surface parameters to calculate runoff over a watershed area (Olivera and Maidment, 1996). This research applies the concept of spatially distributed unit hydrographs over an area of cells. These unit responses, which are each independent of the surrounding responses, are convoluted along a watershed flow path to produce a total runoff response at the watershed outlet. This entire process is executed within the GIS software, Arc/Info and Arc/Info’s subprogram, Grid (Olivera and Maidment, 1996). In contrast, a slightly different approach to GIS surface water flow simulation is being conducted by Ye (1996). This model, which utilizes the newer GIS programming language, Avenue through the software, ArcView, is designed to simulate surface flow runoff based on the precipitation or soil moisture contents defined on the subwatersheds of a river basin. This research is not only investigating time varying flow processes over a watershed, but is also incorporating a groundwater flow model with the surface water flow model. Both of these models interact with the user through tool buttons in ArcView which activate Avenue programs (Ye, 1996).

Another environmental concept which has recently been integrated into GIS is water balancing over a river basin. Specifically, a water balance model has been developed for the Niger Basin in North Africa (Maidment, *et al*., 1996). This model used a grid-based analysis to explain a relationship between flow, precipitation, evapotransporation, water demand, and water storage. Similar water balancing efforts using GIS have been performed on Texas and the Souss Basin in Morocco (Olivera and Maidment, 1996).

Besides hydrologic processes, GIS has been used to assess pollutant loadings entering a water body and to explain the transport of chemicals in surface water. Various studies have investigated the concept of non-point source (NPS) loadings from watershed areas. Two projects in particular used GIS to develop projected areal loadings of different chemical constituents. Saunders (1996) developed a grid-based model which assessed NPS loadings of nitrogen, phosphorous, cadmium, and fecal coliforms into a small coastal bay from the 6000 km^2 San Antonio-Nueces Basin in South Texas. The method used a grid of land use-based estimated mean concentrations (EMCs) multiplied by spatially distributed runoff volumes to obtain an annual areal loading over the watershed (Saunders, 1996). A similar study also utilized the concept of EMCs and runoff volumes to develop an assessment of NPS loads into Galveston Bay, Texas (Newell, *et al*., 1992). Newell, *et al.*(1992), also utilized GIS to spatially distribute runoff volumes, land use characteristics, EMCs, and final loading values. A slightly different pollutant study currently in progress is applying GIS to project chemical concentrations in the Upper Mississippi River Basin (Mizgalewicz, 1996). Using data collected in the United States Geological Survey (USGS) toxic chemical program throughout the Midwest, this GIS model is meant to explain the relationship between chemical concentrations in a stream and parameters such as chemical application, runoff, precipitation, season, and watershed characteristics. In addition, this research aims to describe chemical losses due to transport downstream using GIS as the ultimate modeling interface for these processes (Mizgalewicz, 1996).

Model Connections to GIS -- Level 1: Ad hoc Integration and Level 2: Partial Integration

As discussed in the previous section, various concepts have been developed within the GIS framework to assist in traditional environmental modeling. Of more concern for this research, though, is the establishment of a connection between an existing environmental model and the GIS software. Many research endeavors have investigated the feasibility of linking various models to GIS to assist in data management, manipulation, and output processing. Of particular interest for this project were those previous studies which concentrated on water quality and quantity model links. These projects have ranged from incorporating an entire model into the GIS software, to concentrating on a subprogram of the model to connect to the interface.

In the area of groundwater, literature reviewed included links to the USGS model, MODFLOW, and a European simulation program entitle MICRO-FEM (Biesheuvel and Hemker, 1993. Brown, *et al.*, 1996; Rindahl, 1996). Two studies included investigations with MODFLOW. Rindahl (1996) established an "easy to use interface" through GIS to display drawdowns, stream flow, and aquifer elevations simulated from the groundwater modeling program. The research, which developed the link primarily for ease in output presentation, utilized the GIS software, ArcView 2.1 and ArcView's programming language, Avenue. The study established a polygon coverage of the modeled grid, attributed with the information resulting from a typical MODFLOW model run. The attributes were in tabular format and joined to the polygon coverage through a model "identification number" termed a "Loc-Tag". Once joined to the corresponding coverage, the model results could be spatially displayed through ArcView. Avenue scripts were also compiled which assisted the user in output display. Another study investigating a GIS link to MODFLOW centered on the use of Arc/Info to provide an efficient means of data preparation and visualization of simulation results (Brown, *et al.*, 1996). ModelGIS, an interface using FORTRAN 77 and Arc Macro Language (aml), generated model grids, model layer elevations, aquifer properties, surface water data, and model output. The options in ModelGIS were executed from a customized menu developed in Arc/Info's subprogram, ArcTools. The different choices converted coverages to model based data, assembled the data into MODFLOW input, executed the MODFLOW program, and assisted in the evaluation of the modeling results. Throughout these processes, the user interacted with the interface in the creation of the model grid and data inputs. This link also has the capability of establishing a three dimensional modeling surface (Brown, *et al.*, 1996).

The final GIS/groundwater model connection reviewed utilized the GIS software, Integrated Land and Water Information System (ILWIS) (Biesheuvel and Hemker, 1993). This study was primarily concerned with investigating the pre- and post-processing ability of the GIS software with the European groundwater model, MICRO-FEM. The final product resulted in the establishment of a GIS/model link by allowing ILWIS to perform the following: 1) build a model network, 2) determine values for the model input, 3) combine results of the MICRO-FEM model run with other types of data, and 4) create background maps which can be used during the modeling process (Biesheuvel and Hemker, 1993).

More closely related to this current research are past studies which incorporated links to water quality models. Literature shows many different types of models and levels of connections being established, including a link for the widely used Hydrological Simulation Program (HSPF), as well as a connection with a number of selected equations, adapted from existing models (Al-Abed and Whiteley, 1995; Chen, *et al.*, 1995).

The HSPF model is used for simulation of watershed hydrology and water quality for a variety of pollutants. The model requires many parameters which describe watershed characteristics, including surface terrain, soils, land use, and vegetation. In addition, time series data for rainfall, temperature and other climatic attributes are needed to run HSPF. Al-Abed and Whiteley (1995) developed a loose connection to this watershed management model by using information stored in GIS coverages as the HSPF input. The research used the concept of look up tables and macros in Arc/Info to create spatial representations and tables of watershed characteristics. This spatial information was then entered into the HSPF model by the user (Al-Abed and Whiteley, 1995).

Two different articles relating to water quality modeling of agricultural chemicals were reviewed. One project discussed a GIS interface to four Agricultural Research Service (ARS) pollutant loading models: Agricultural Non-Point Source (AGNPS), A Basin Scale Simulation Model for Soil and Water Resources Management (SWRRBWQ), Erosion Productivity Impact Calculator (EPIC), Ground Water Loading Effects of Agricultural Management Systems (GLEAMS) (Geter, *et al.*, 1995). The goal of this research was to develop an interface which resulted in standardized and consistent input data to all of the water quality models, while providing a platform to interpret the model results through tables, graphs, and maps. The user first enters the necessary model data in the form of attributed coverages within the GIS software, Geographic Resource Analysis System (GRASS). The total connection requires five raster based maps linked to sixteen attribute tables. This base information is then interpreted by the GRASS interface and consistent model input is determined. The link established actually writes the derived input into the formatted file necessary for the models' input, and the connection did provide a means for the user to view the model output through charts, tables, and raster maps (Geter, *et al.*, 1995).

The second agricultural chemical pollutant article (Tim and Jolly, 1994) was interested in demonstrating the concept of integrating the aforementioned water quality model, AGNPS, with an Arc/Info interface. GIS provided the means to generate and spatially organize the data needed for the non-point source modeling effort, while AGNPS was used to predict water quality related parameters such as soil erosion and sedimentation. A partial integration link was established (see Figure 2-1), by developing computer programs which provided "access points" between the GIS database, the AGNPS model, and the user. The link read the model input from raster coverages imported into Arc/Info's subprogram, Grid. Once the grid-based data were converted to a readable format by AGNPS and the model executed, the output was re-imported into Grid and displayed through ArcPlot (Tim and Jolly, 1994).

2.3 PREVIOUS GIS/WASP MODEL CONNECTIONS

Research was conducted to review any connections with the WASP5 model which have been accomplished in the past. Findings indicated that one project utilized equations and concepts from WASP5 in a GIS connection, while another study connected WASP4's subprogram, EUTRO4, to the Arc/Info software (Chen, et al., 1995; DePinto, *et al.*, 1993; DePinto, *et al*., 1994).

The first study developed a model to evaluate the impact of land use and watershed management practices on the water quality of a Reservoir in Taiwan (Chen, *et al.*, 1995).

The article did not specify exactly which GIS software was utilized for the model development, but it did use equations and subprograms from the WASP5 program to model nutrient cycles. Geographic data was imported into the model from GIS and spatial attributes of some watershed and reservoir characteristics are entered through dialog boxes. Since the article discussed the use of the program in a Windows-based environment, ArcView with Avenue programming may have been used, but the accuracy of this assumption is unknown. The overall program, termed Integrated Watershed Management Model (IWMM), was run with menus. The menu choices activated object-oriented programs to execute the equations which modeled everything from reservoir hydraulics and hydrology, to water chemistry and nutrient cycles (Chen, *et al.*, 1995).

The second research project, conducted by the Great Lakes Program at the State University of New York at Buffalo and a water quality modeling firm, Limno-Tech, Inc, was the most developed connection to the WASP model found in this literature search (DePinto, *et al.*, 1993; DePinto, *et al.*, 1994). The result of this project was termed Geographically-based Watershed Analysis and Modeling System (GEO-WAMS). GEO-WAMS, which linked WASP4 (version 4 of the WASP model) to Arc/Info, performs the following functions: spatial and temporal exploratory analysis of system data; model scenario management; model input configuration; model input data editing; model input conversion to the proper file format; model output interpretation, reporting, and display; and model calibration, confirmation, and application. The interface also considered time variance in the system, along with possible three dimensional segmentation. In addition to the WASP4 connection, the system also performed a loading analysis with a spatial watershed model. All of these processes were conducted under a menu driven atmosphere created in Arc/Info and executed with Arc/Info's macro language (DePinto, *et al*., 1993; DePinto, *et al*., 1994). Although this connection could be termed a "partial integration" as discussed in Tim and Jolly (1994) (see Figure 2-1), the overall link from the model to Arc/Info was rather complex. The data necessary for the watershed loading model and WASP4 link included, but were not limited to, system geometry, morphometry, hydrology, soil properties, land-use, and point-source loadings, all in the form of GIS coverages, grids and tables. The research used a portion of the Buffalo River as the study area for the prototype link and connected just WASP4's subprogram, EUTRO4, in order to model dissolved oxygen in the reach (DePinto, *et al*., 1993; DePinto, *et al.*, 1994).