1997

Development of a River Basin Management Framework Using GIS and Watershed Modeling: Application to the North Fork of the Kentucky River

L. Ormsbee
Kentucky Water Resources Research Institute

S. Yost
Kentucky Water Resources Research Institute

T. Stumbur
Kentucky Water Resources Research Institute

T. Bischoff
Kentucky Water Resources Research Institute

Development of a River Basin Management Framework Using GIS and Watershed Modeling: Application to the North Fork of the Kentucky River

Executive Summary

L. Ormsbee
S. Yost
T. Stumbur
T. Bischoff

Prepared for:
The Kentucky Division of Water

Prepared By:
The Kentucky Water Resources Research Institute
University of Kentucky
Lexington, Kentucky 40506

January 1997
KWRRI 9701

Development of a River Basin Management Framework Using GIS and Watershed Modeling: Application to the North Fork of the Kentucky River

---

Executive Summary

L. Ormsbee
S. Yost
T. Stumbur
T. Bischoff

Prepared for:
The Kentucky Division of Water

Prepared By:
The Kentucky Water Resources Research Institute
University of Kentucky
Lexington, Kentucky 40506

January 1997
KWRRI 9701

TABLE OF CONTENTS

INTRODUCTION

1.1 Background

As part of a national EPA initiative, the Kentucky Division of Water (DOW) has embarked on the development and coordination of a comprehensive watershed framework for use in managing and preserving the water resources of Kentucky. The purpose of the framework is to provide a means for coordinating and integrating the programs, tools, and resources of multiple stakeholder groups to better protect, maintain, and restore the ecological structure and function of watersheds as well as support the sustainable uses of watersheds. In contrast to a strict regulatory approach, the proposed framework employs a resource-centered approach. Success is measured in terms of maintaining and improving environmental quality and protecting public health by fostering the protection and restoration of specific resource uses, such as drinking water supply, aquatic and wild life habitat and propagation, and recreation, while sustaining economic activities that depend on natural resources (DOW, 1997).

The term watershed refers to "the delineation of a water body system and the land that drains into it. Watersheds can therefore be viewed as landscape units that integrate land, groundwater, surface water, and atmospheric processes over time. The topological ridge lines that define the boundaries of watersheds provide a natural basis for organizing stakeholders (i.e. agencies, organizations, businesses, and the general public involved in or affected by natural resource management decisions), tying the people to the resource, and sustaining the means for focusing on common problems. As a result, watersheds serve as a convenient tool for integrating water resource protection and restoration activities." (DOW, 1997)

1.2 Framework Components

The proposed framework includes five basic components: 1) basin management units, 2) a basin management cycle, 3) a statewide basin management schedule, 4) a partner network and public participation, and 5) basin and watershed management plans.

1.2.1 Basin Management Units

In order to facilitate the application of the watershed management approach across the Commonwealth, the state of Kentucky has been subdivided into 5 basin management units. The basin management units represent large geographic areas that combine one or more of the major 6-digit river basins that lie within Kentucky. A listing of the five basic units and their associated statistics is provided in Table 1. A map of the five basic units is provided in Figure 1.

1.2.2 Basin Management Schedule

In applying a watershed management approach across the state, each basin management unit will be processed through a five-part basin management cycle. In order to provide for the strategic utilization of program resources, the basin management cycle

Basin Management Units and Major Drainage Areas

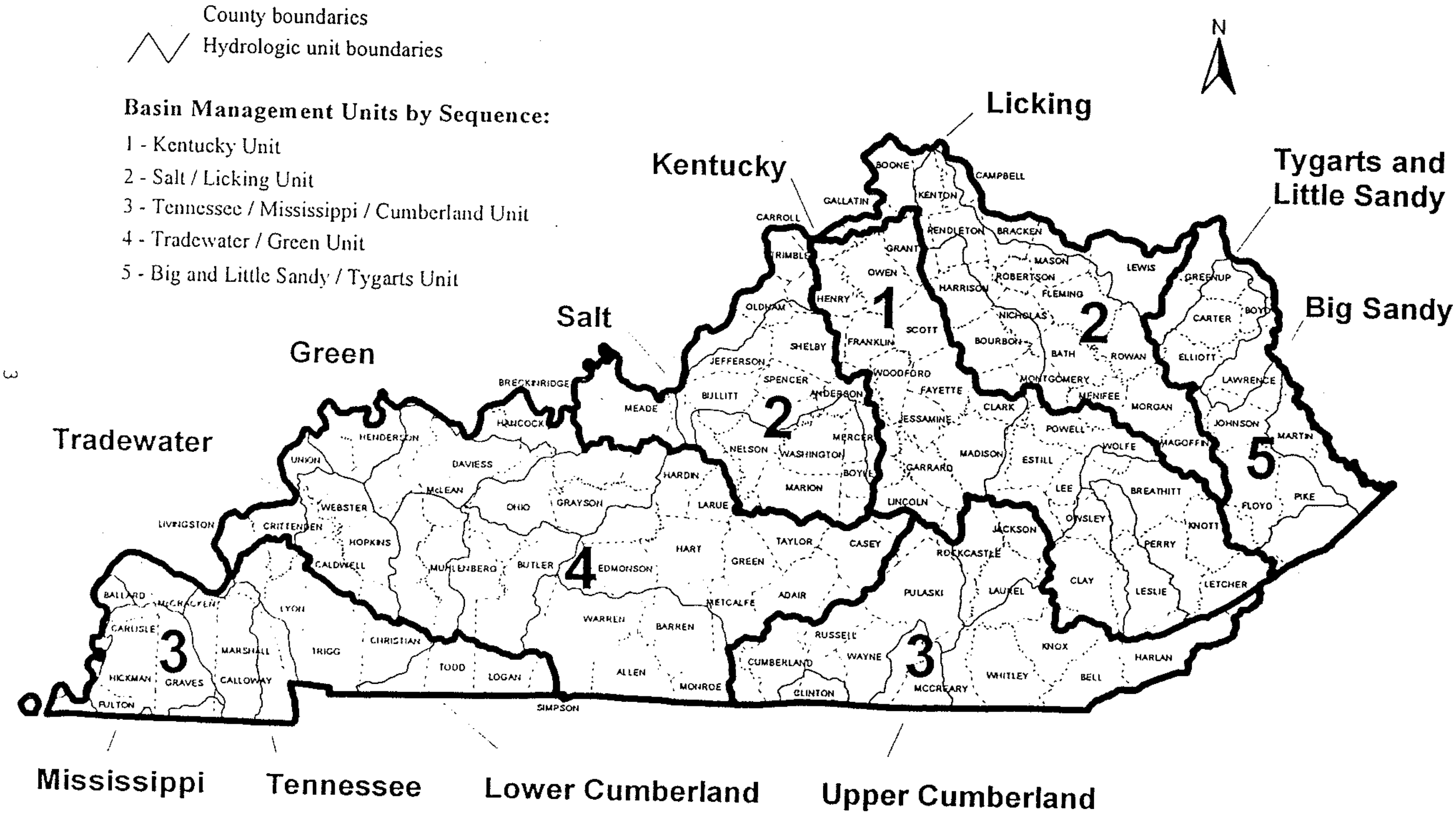

Figure 1

for each basin management unit will be staggered by one year, and sequenced over a five year period.

Table 1. Basin Management Units for the Kentucky Watershed Framework.

Basin Management Unit Number and Description	No. of USGS 6-digit HUCs	Area (mi2)	Percent of Total Area
1. Kentucky River	5	6,966	17.2
2. Salt and Licking Rivers	8	9,037	22.4
3. Upper and Lower Cumberland, Tennessee, and Mississippi Rivers	15	9,853	24.4
4. Green and Tradewater Rivers	12	11,109	27.5
5. Big Sandy, Little Sandy, and Tygarts River	6	3,424	8.5

1.2.3 Basin Management Cycle

Kentucky's basin management cycle has five activity phases that are sequenced and repeated for each basin management unit at fixed 5-year intervals to ensure that management goals, priorities, and implementation strategies are routinely updated and progressively implemented (Figure 2). A brief discussion of each activity is provided in the following sections:

1.2.3.1 Scoping and Data Gathering

This phase involves the development of a "Basin Status Report" for the purpose of documenting the baseline conditions of the basin. Interested partners will then develop and implement a strategic data collection plan that clarifies the purposes for collecting

Basin Management Cycle

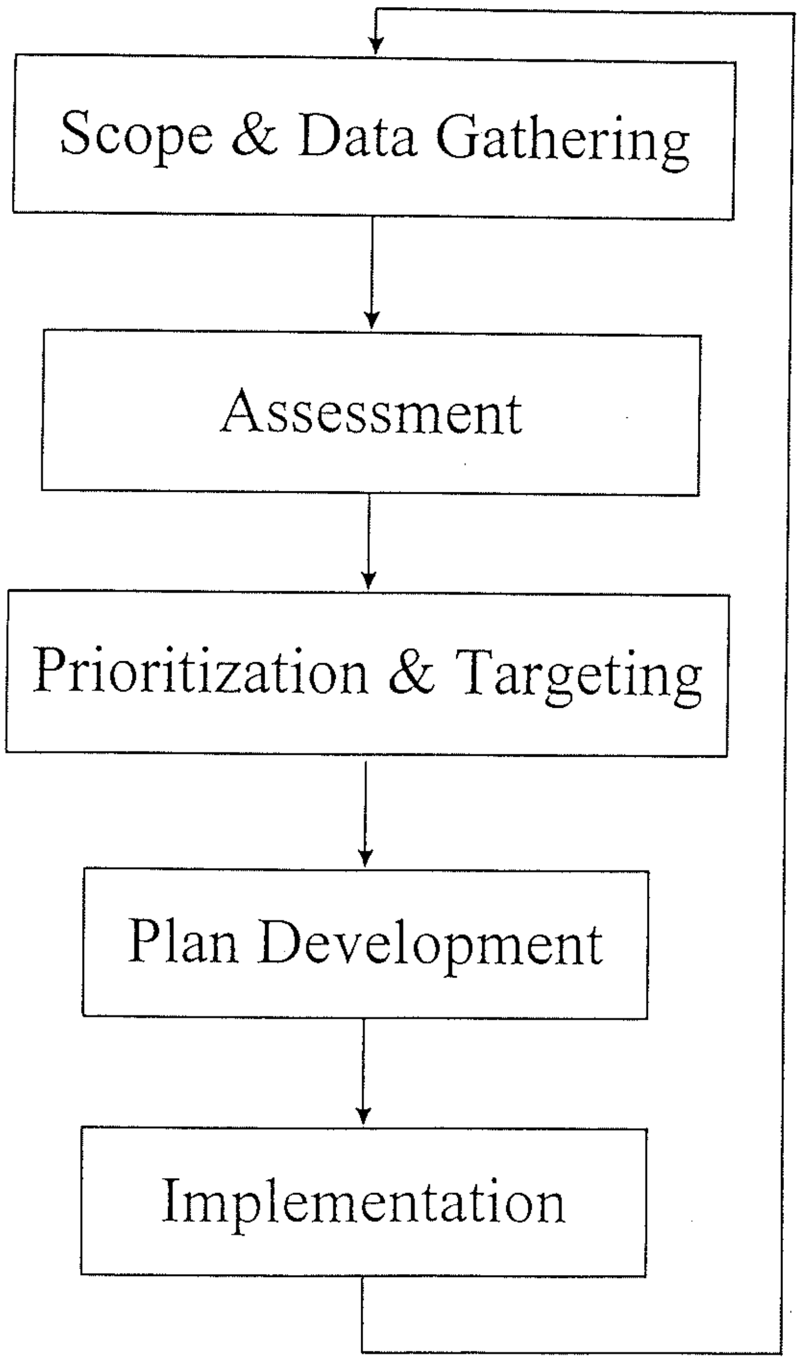

Figure 2.

information, identifies what can be accomplished with the resources available and outlines the complementary roles and responsibilities (DOW, 1997)

1.2.3.2 Assessment

During the second phase, quantitative and qualitative analyses will be performed to evaluate and document the severity, causes, and sources of stress to watershed resources. The 11-digit scale watershed has been selected as the basic unit for assessment. Key summaries of partners' assessments are then complied to update the "Basin Status Report" and provide the basis for ranking management priorities and targeting stakeholder resources for management strategy development.

1.2.3.3 Prioritization and Targeting

In the third phase, framework partners and other interested stakeholders work together to establish a priority ranking for 11-digit watersheds within the basin. Priorities will be determined based primarily on technical factors related to resource impairment (i.e. severity of impact plus spatial scale or extent of impact) and threat to watershed resources (considering scale and immediacy of threats, and special protection status of certain resources).

1.2.3.4 Plan Development

In this phase, technical experts from partner agencies will work with other stakeholders to identify, evaluate, and select management strategies to address targeted priority issues. Implementation strategies will be documented in draft basin and watershed plans that outline specific actions and funding sources to serve as a guide for framework partners.

1.2.3.5 Implementation

During phase five, framework partners will carry out and guide management actions in accordance with agreed-upon actions plans.

1.3 Study Objectives

Implementation of the previously described watershed framework will require the coordination of many stakeholder agencies and related partners. It will also require the management and analysis of significant amounts of data and related technical information. In the current study, the potential use and integration of GIS technology along with mathematical watershed models is investigated. The specific objectives of the study may be summarized as follows:

1) Identify potential watershed models for use in the proposed framework.
2) Identify existing/potential GIS data linkages.
3) Identify data needs/problems.

1.4 Watershed Modeling

The first part of this study involved an investigation of possible watershed models for use in the proposed framework. Three separate phases of the proposed watershed management framework were examined for possible integration and application of both GIS and watershed modeling. These include: 1) the assessment phase, 2) the prioritization and targeting phase, and 3) the plan development phase. Because of the nature of the associated activities, different classes of mathematical models were considered for each phase. In general, assessment models are normally restricted to a large time scale (i.e. annual loads) with either small (subbasin) or large (watershed) spatial coverage. Conversely, prioritization and targeting models are normally restricted to a large (watershed) spatial coverage with either a small (days) or large (years) time coverage. Finally, plan development models are normally restricted to both small (subbasin) spatial coverage and small (days - minutes) time coverage (see Figure 3). The relationship between the recommended models and the different management cycle steps is shown in Figure 4. This figure also illustrates the relationship between the models and the associated hydrologic data as linked through a GIS environment.

1.4.1 Assessment Models

In the context of the watershed management framework, assessment models will be used to provide a general assessment of each 11-digit watershed within a basin management unit. For the purpose of this study, the ArcInfo raster analysis module

Modeling Matrix

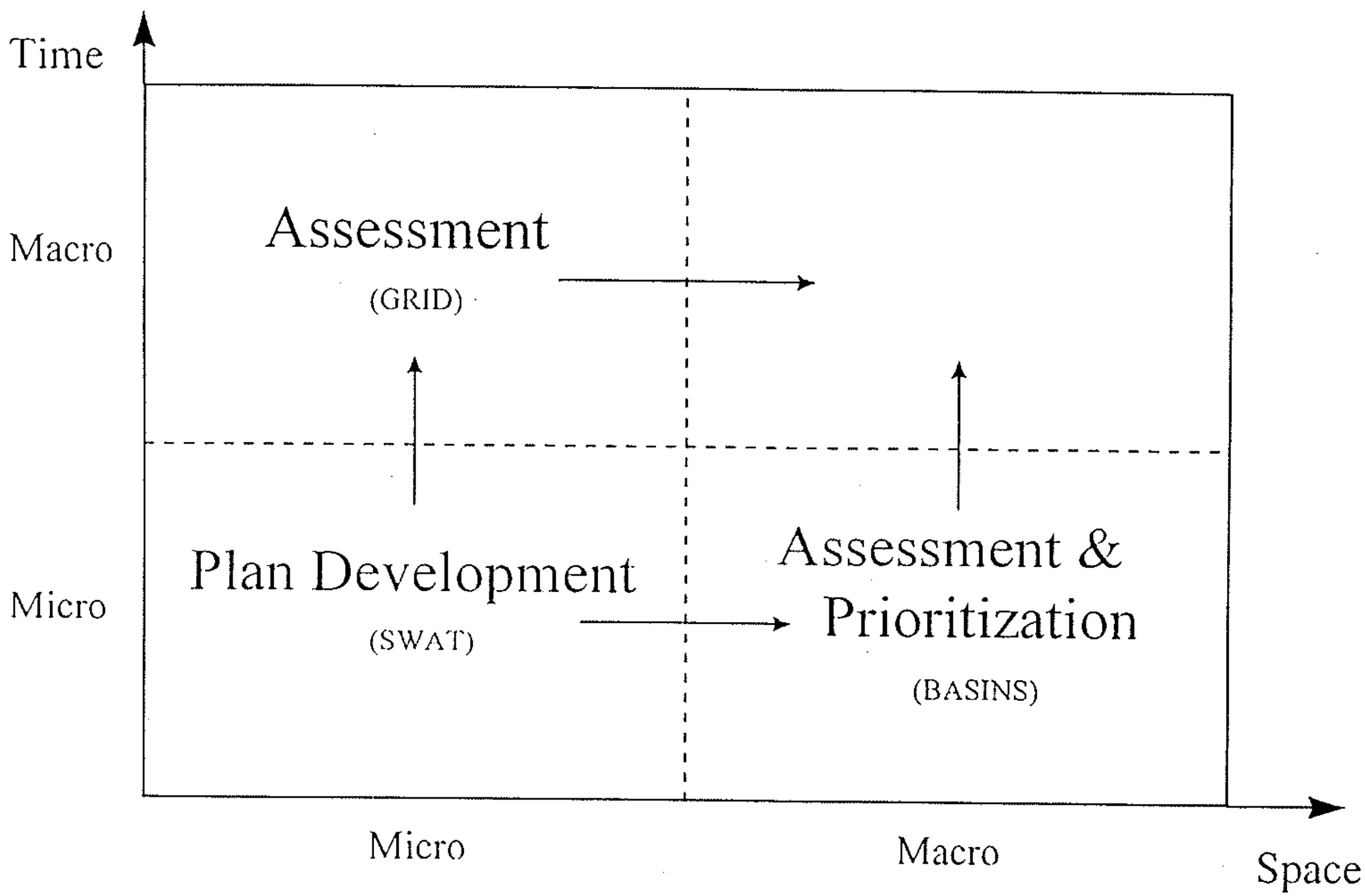

Figure 3.

Integrating 5 year Basin Management Cycle with Modeling

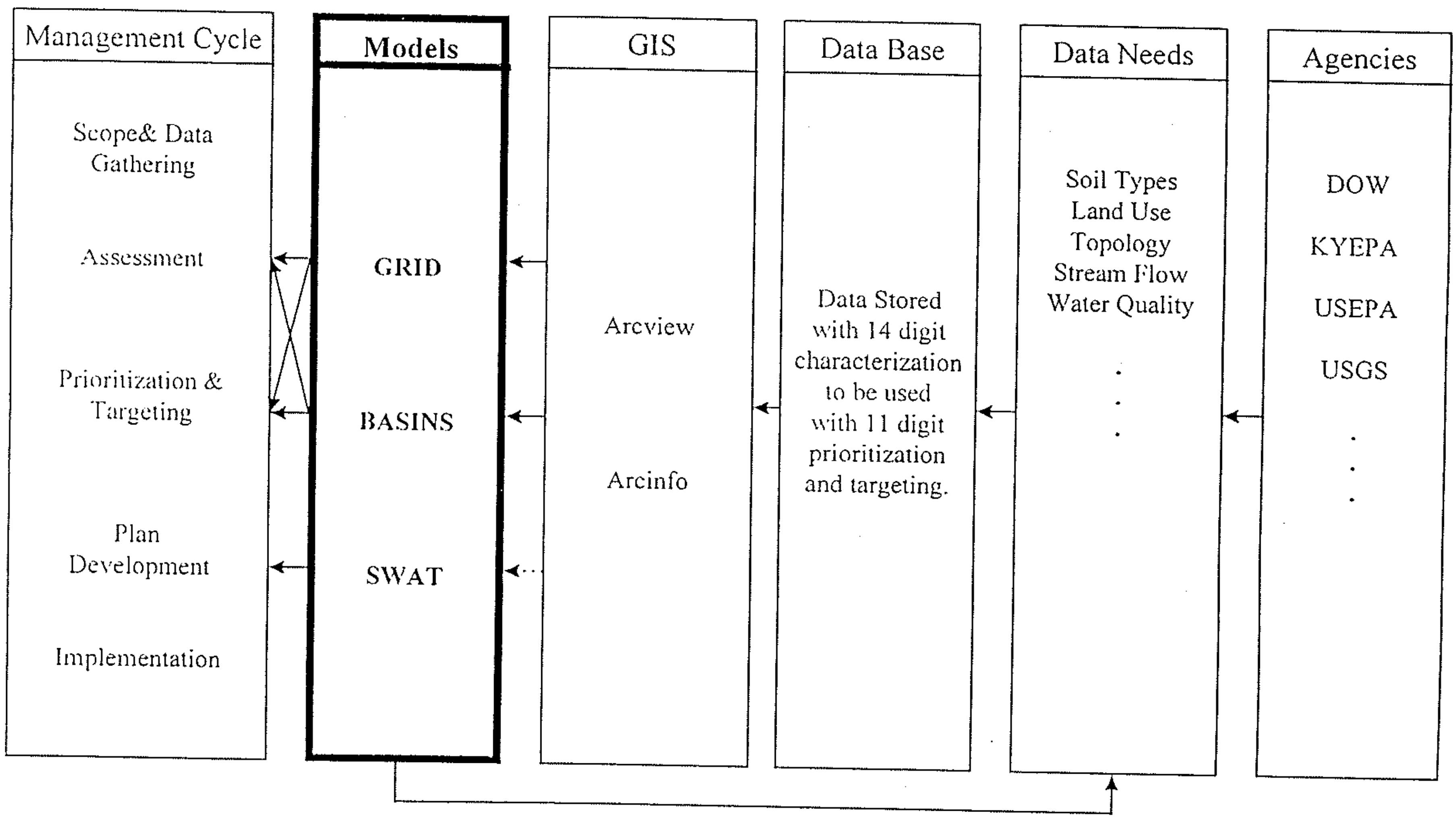

Figure 4.

GRID was selected for use as an assessment tool. With GRID's linkage between spatial maps and its layered database, it has the capability to store spatial data as uniform cells and assign each cell a numeric value. Then it can manipulate cell values in single or multiple layers arithmetically or logically for analysis. It also has several built-in capabilities for macro-level hydrologic modeling that make it especially attractive for use as an assessment tool.

1.4.2 Prioritization and Targeting Models

In considering the needs for watershed prioritization and targeting, both GRID (discussed previously) and BASINS were considered. BASINS (Lahlou, et al., 1996) stands for the "Better Assessment Science Integrating Point and Nonpoint Sources". The program has been developed to execute directly within the GIS module ArcView. In addition to containing three general assessment tools (i.e. TARGET, ASSESS, and DATA MINING) the program also has linkages with three separate modeling tools (i.e. NPSM - a non-point source model, TOXIROUTE - a conservative transport model, and QUAL2E - a waste-load allocation model). The main limitations of the BASINS program is that it is currently restricted to applications at the 8-digit watersheds and uses built-in data sets only.

1.4.3 Plan Development Models

In examining plan development models, several different models were considered. In the end, SWAT: Soil and Water Assessment Tool (Arnold, et al., 1996) was selected for a detailed evaluation. SWAT is a continuous simulation watershed model the allows for the prediction of both short-term and long-term effects of various land use practices.

1.5 Watershed Modeling Report

The results of the watershed modeling investigation are provided in a companion report entitled: **Computer Modeling of the North Fork of the Kentucky River Using SWAT and BASINS** (Bischoff, et al, 1997). This report documents that advantages and disadvantages of several available watershed models and provides a pilot application of the selected models to the North Forth of the Kentucky River.

While the original plan for this work was to show how hydrologic modeling could be integrated into the basin management cycle, it became more clear that much work needed to be done just to implement a modeling strategy. In selecting a watershed model for use in the proposed watershed framework, a brief review of several of the more well known hydrologic models and how they would fit into the scope of the basin management cycle. A listing of important considerations was developed, which included, but was not limited to: event-based versus continuous simulation, flexibility in both large and small watershed applications, water quality modeling, including point and non-point source pollution, sediments, nutrients, pesticides, dissolved oxygen, vector versus raster based, and, probably most importantly, ease of use and technical assistance. Dozens of models were investigated and five were picked due to there overall strength. Of these five, two were finally chosen for detailed investigation and implementation. These two models are the Soil and Water Assessment Tool (SWAT) and Better Assessment Science Integrating Point and Non-Point Sources (BASINS). Despite their benefits, each has certain shortcomings. SWAT, while relatively easy to use, is limited as to the water quality modeling capabilities. It can simulate some pesticides, phosphate and nitrogen, but other species and dissolved oxygen must be simulated with alternative means. The BASINS model on the other hand is very extensive and takes advantage of a GIS linkage between its databases and simulation engines. The main draw back to BASINS, as mentioned above, is that the resolution of the simulations is currently limited to 8-digit watersheds and the data is supplied from built-in databases. Thus, BASINS simulates the entire North Fork as one basin. Another draw-back is that there is no routing component in the hydrologic engine. Included in the report is a detailed comparison between both models. Much like the companion GIS report, the report includes a detailed listing of the data needs as well as source and price information.

In investigating the capabilities of SWAT, the model was applied to the North Fork for several different scenarios. The hydrologic results include an application to the Troublesome Creek watershed at both an 11-digit (four sub-watershed) and a pseudo 14-digit scale (the actual 14-digit watersheds were not used but rather generated using GRID in Arc/Info because the USGS 14-digits delineation was not available at the time). A five year period between 1970 and 1975 was used for calibration purposes due to the availability of reliable rainfall and stream flow data for that period. Next a comparison of the simulations with actual stream flow data is presented for the years 1980-1990. These comparisons are in the form of both monthly and daily histographs and water balance charts. Using the Troublesome Creek basin, a protocol was developed for implementation to the entire North Fork.

The outlet of the North Fork did not contain a stream flow station, thus a comparison of simulations between BASINS and SWAT was made. For the entire North Fork there were a few internal gage stations which allowed intermediate comparisons of SWAT to actual data. Overall, the SWAT model performed fairly well, although it generally underestimated peak discharges on a monthly time scale. This discrepancy is mainly attributable to the under-prediction of basin interflow.

The most interesting result of the study was a comparison between SWAT and BASINS for the entire North Fork. The BASINS model seemed to be very inconsistent, even in the mass balance analysis. Much of this may be attributed to the lack of routing in the hydrologic simulation

Other results of the study include a qualitative section on sensitivity analysis of the SWAT model as a function of the predominant model parameters. This information should be very valuable for future applications and subsequent calibration of the model. It should be noted that when performing parameter calibration, the literature suggests that calibration may be performed using monthly averaged data. However, we have found that the filtering process of monthly averaging can leave large discrepancies in daily comparisons.

While the SWAT model shows real potential in its usefulness in basin modeling, there are still some significant drawbacks that would require future work. Since SWAT is limited in its water quality modeling, an appropriate water quality model (e.g., QUAL2E) should be linked. Presently, work at the University of Kentucky and University of Illinois is ongoing to develop such a linkage. Lastly, while SWAT was one of the simpler model to use (besides BASINS which does not allow any flexibility) it required considerable effort in post-processing the data into a user friendly format. Several output modules needed to be written in EXCEL to take the data, convert it and organize it, then present it in graphical form. Once these MACROS are created however, repetitive simulations and post-processing is almost automatic.

Unfortunately, a GIS interface, like the one found in BASINS, is not presently available for SWAT (however, a least two such linkages are currently under development at different universities). This make a strong argument for use of BASINS, however, because of its fixed 8-digit scale, the detail needed to identify local areas of concern is not possible with BASINS. Furthermore, BASINS currently employs a very rigid data structure that precludes the use of user-specified data sets. This greatly limits the use of the model for plan development applications.

1.6 GIS/Data Needs Report

The second part of this study involved an investigation of the possible use of GIS in the proposed watershed framework along with an identification of related data needs.

The results of this investigation are provided in a companion report entitled: **GIS Linkage with Hydrologic Models: Application to the North Fork of the Kentucky River** (Stumbur, et al, 1997).

Geographical Information Systems (i.e. GIS) bring together three main components: computer technology, people and data. Applications of GIS in comprehensive watershed management can be problematic for several reasons, not the least of which are the significant data requirements. Data for use in a GIS can be characterized as either raster based data or vector based data. In a raster based system, a map is divided into individual cells or rasters which are then associated with different data attributes. In a vector based system, attributes are associated with points, lines, or user defined polygons. Raster based data has several advantages: it can be used to pinpoint information in space and can be used to generate time averaged statistics (i.e., annual, monthly), directly within a GIS environment. Conversely, vector based data can be used to directly characterize individual events or continuous processes within watersheds through direct linkage with an off-line watershed model.

GIS data is organized by data layers. For instance, one layer could include the delineation of the watersheds, a second the predominant soil type, another the land use, still others the location of permitted discharges, and so on. The number of layers, and hence data, is almost unlimited. From this information, a user could then analyze which basins have the most concentrated agricultural (fertilizer) usage coupled with point discharges to quantify potential environmental risks. This is where some modeling capabilities could be useful within GIS. While GIS can not perform physically based numerical simulations, it certainly can do basic conservative mass balance to locate troubled basins. This would be a great starting point in the assessment phase of the basin management cycle. Later, detailed hydrologic models could pinpoint trouble spots when trying to targeting resources to strengthen/change regulation and monitoring.

A significant portion of the GIS report looks at the source and accessibility of data necessary for performing a range of hydrologic analyses. Much of the basemap data (land use, watershed delineation, stream networks, topology, roads, etc.) can be acquired (in the future) from the Kentucky Office of GIS (OGIS) with coordinated efforts between the US Geological Survey (USGS) and other federal agencies (EPA, NRSC, etc.). Currently most of the US is digitally mapped on a 1:250,000 and 1:100,000 source scale with a concerted effort to have all spatial data on a 1:24,000 scale. Presently, the eastern half of Kentucky has been mapped 1:24,000 where the hydrologic data is delineated on a 14-digit scale (the North Fork basin is an 8-digit basin, the entire Kentucky River basin is 5-digit). An important question does arise as to what level of resolution is needed for the analysis. Since the 14-digit is not currently available throughout the state, a coarser coverage may be necessary. It was found that while the 11-digit coverage is presently recommend by the Division of Water, there exist significant limitations with the existing database. The most important limitation is that some 11-digit watersheds contain several stream outlets or inlets.

One way to overcome this problem is to use GIS software to build hydrologic units from stream networks. For example, the GRID routine in Arc/Info provides built in commands for delineating watersheds. While this may require more up-front work in the overall management cycle, the added flexibility is advantageous. A detail description of using GRID is provided, as well as alternatives to evaluate how well the Arc/Info generated watershed compare to USGS or similar watershed delineations.

Data sources for soil coverage and land use are also provided, but the coverages are currently limited. General soil and land use coverages have been digitized but the detail is very coarse at best. Detailed coverages are presently being digitized but will not be available for several more years. Using 11-digit or coarser watersheds would be consistent with the general maps, however 14-digit coverage could take advantage of the added detail to provide a good estimate of soil characteristics for hydrologic modeling. Other data requirements and sources are detailed within the report.

There is no shortage of problems when trying to acquire and use geo-referenced data. While much data exists, some of it is hard to find. Hopefully, a major benefit of this study includes a listing of the data sources, how to access it, contact numbers, and associated cost, if any. Some data is inaccessible due to authorization barriers (i.e., classified for what ever reason), or unavailable documentation relating to how to use the host database. Finally, there is always a question as to the reliability of the data both in terms of missing data and data that has been entered into the data base incorrectly.

1.7 Summary and Conclusions

This study has been concerned with identifying potential watershed models for use in the proposed Kentucky Watershed Management framework as well as potential GIS linkages with the selected models. In addition, the study has attempted to identify the data needs necessary for hydrologic modeling as well as the existing problems and limitations associated with such data. In the context of the watershed management framework, three of the five phases were identified where hydrologic watershed models could be applied. For each case, at least one recommended model was identified. The identified models include: 1) GRID, 2) BASINS, and 3) SWAT. Each model has certain advantages and disadvantages which are discussed in detail in an accompanying report. At the present time, it would appear that GRID has sufficient capabilities for use as a general assessment tool and possible prioritization tool. In this context it is envisioned that the proposed watershed prioritization formula may be directly integrated and processed within GRID. Implementation of this tool will require the development of the necessary data layers as well as the development of the protocol for use in processing the data and the associated formulas. BASINS holds the potential for both a general assessment tool and a prioritization tool in addition to a potential planning tool. However, as currently configured, BASINS is limited to applications of 8-digit scale watersheds. It is anticipated that this limitation will be removed in the next release of the model. However, at the present time no date has been set for this release. In the interim, it is recommended that GRID be used for assessment and prioritization. At the present time, it is proposed that SWAT be used for the development of individual watershed plans. The main limitation of SWAT is the lack of a sophisticated water quality model and the lack of a direct GIS interface. At the present time, research is currently underway to remove both of these limitations. It is anticipated that updated versions of SWAT will be released during the later part of 1997.

Hydrologic modeling requires significant amounts of spatial data that may be managed and processed through the use of a GIS. Such data includes watershed data, stream data, soil data, land-use data, stream-flow data, precipitation data and water quality data. In order to successfully link the previously discussed watershed models with GIS it is important that the existing data be in a form compatible with such an application. An index of the available data layers (along with their sources) for use in such hydrologic modeling has been included in the accompanying GIS report.

At the present time the 11-digit scale watershed has been selected as the basic unit of management for the proposed watershed management framework. Unfortunately, some of the 11-digit watershed units are inconsistent with a hydrologically defined watershed (i.e. they contain multiple stream inputs). It appears that the 14-digit scale watershed do not have this problem, at least at the level of the 4th order stream network. As a consequence, it is recommend that all watershed data be processed and stored at the 14-digit scale with the option of aggregating the data sets to the 11-digit scale through the use of GIS. At the present time it is felt that such aggregation should be adequate for both assessment and prioritization purposes. For the subsequent development of watershed management plans, it will be possible to generate watershed units through the aggregation of selected 14-digit scale subbasins that may or may not be totally consistent with the current 11-digit scale maps. This latter option provides a way to accommodate the majority of 11-digit scale units while leaving the flexibility to accommodate those instances when the 11-digit scale delineation is inconsistent with the watershed resolution necessary for detailed watershed modeling.

REFERENCES

Arnold, J.G., Williams, J.R., Srinivasan, R., and King, K., *Soil and Water Assessment Tool User's Manual*, USDA-ARS Grassland Soil and Water Research Lab, Temple, TX, 1996.

Bishoff, T., and Yost, S.A ., Ormsbee, L ., Stumbur, T., *Computer Modeling of the North Fork of the Kentucky River Using SWAT and BASINS*, Kentucky Water Resources Research Institute Technical Report to the Kentucky Division of Water, Lexington, KY,1997.

Lahlou, M., Shoemaker, L., Paquette, M., Bo, J., Choudhury, S., Elmer, R., and Xia, F., *Better Assessment Sciences Integrating Point and Non-Point Sources User's Manual*, Version 1, Tetra Tech, Inc., Fairfax, VA, 1994.

Stumbur, T., Ormsbee, L., Bishoff, T., and Yost, S.A., *GIS Linkage with Hydrologic Models: Application to the North Fork of the Kentucky River*, Kentucky Water Resources Research Institute Technical Report to the Kentucky Division of Water, Lexington, KY,1997.

Kentucky Watershed Management Framework (draft), Kentucky Division of Water, Frankfort, KY, January, 1997.