The Watershed Characterization and Modeling System (WCMS): Support Tools for Large Watershed CHIA and NPDES Analyses[1]

Jerald J. Fletcher[2], Robert N. Eli, Michael P. Strager, Qingyun Sun, John B. Churchill, Samuel J. Lamont, Thomas A. Galya, and Andrew N. Schaer

Abstract. The Natural Resource Analysis Center (NRAC) at West Virginia University (WVU) has developed the Watershed Characterization and Modeling System (WCMS) application to add advanced GIS tools and the necessary data to support watershed analysis to the ESRI ArcGIS software. The development of WCMS has been influenced by the primary issue affecting West Virginia (WV) watersheds – the cumulative impacts of coal mining. Support for development of WCMS has included WVU resources and grants and contracts with state and federal agencies, consulting companies, and non-profit organizations.

WCMS was initially developed as an ESRI ArcInfo AML application in the early 1990's but was later rewritten in ArcView 3.x. By 1999, WCMS was the basic tool used by permit writers in the WV Department of Environmental Protection (WVDEP) Divisions of Water and Waste Management (DWWM) and Mining and Reclamation (DMR). Interactions with WVDEP staff led to modifications and enhancements and was then packaged as an ArcView project with all data for WV included (about 7 GB). WVDEP, through the Program Enhancement Cooperative Agreement (PECA) with the U.S. Dept. of Interior, Office of Surface Mining (OSM), has supported advances in the software tool selection. WCMS is now an ArcGIS extension that appears as a toolbar in ArcMap. Additional tools supporting hydrologic and water quality modeling through links to the Hydrological Simulation Program – FORTRAN (HSPF) model are being added and tested.

This paper provides an overview of WCMS, outlines steps in development, and discusses the application of WCMS to understanding the hydrology of relatively large watersheds. WVDEP staff currently use the ArcView version and the ArcMap toolbar for all anti-degradation related NPDES work in both DWWM and DMR. CHIA writers use the software extensively to delineate watersheds and acquire basic flow, loading, and area information. Links to digitized mine maps, water quality data, and a variety of other information maintained by WVDEP in GIS, Oracle, and other formats make realistic CHIA related modeling and analysis possible for WV watersheds.

Additional Key Words: GIS, ArcGIS, CHIA, AMD, WCMS, HSPF, Watershed Modeling

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[2] Jerald J. Fletcher is Prof and Director, NRAC, WVU, Morgantown, WV, 26506-6108; Robert N. Eli is Assoc Prof of Civil & Environmental Engineering (CEE), WVU, Morgantown, WV, 26506-6103; Michael P. Strager and Qingyun Sun are Research Asst Profs and John B. Churchill is GIS Analyst, NRAC, WVU, Samuel J. Lamont is Research Assistant, CEE, WVU; Thomas A. Galya is Hydrologist, OSM, Charleston, WV 25301; and Andrew N. Schaer is Geologist, WVDEP/DMR, 601 57th Street SE, Charleston, WV 25301-2345.

Introduction

The Watershed Characterization and Modeling System (WCMS) is a combination of software and data. The software application adds advanced geographic information systems (GIS) tools to the ESRI ArcGIS software. The data includes all the information, spatial and non-spatial, necessary to support the analysis of water quality issues at a watershed scale throughout West Virginia (WV). The current version of WCMS is the culmination of fifteen years of research and development into the use of GIS to analyze environmental and management problems from a watershed perspective at the Natural Resource Analysis Center (NRAC) at West Virginia University (WVU). The primary strength of WCMS has been the integration of sophisticated GIS tools made available to users that have some, but not extensive, training in GIS with appropriate data for specialized analyses. Data development has actually required and received the greater proportion of the total effort. Much of the development work has been supported by the WV Department of Environmental Protection (WVDEP).

The initial development of WCMS was guided by a vision that GIS and innovations in computer technology can provide relatively non-technical users with the tools necessary to analyze complex water related issues over a broad scale. This vision continues to guide the development of WCMS. Making this vision a reality has required the development of a framework to guide the analysis, appropriate GIS tools to implement the analysis, and the data necessary to support the calculations required for the analysis. As originally envisioned, when complete, WCMS will support analysis at a variety of scales from the local watershed to statewide assessments. If based on consistent methodological approaches and data, local analyses should be comparable spatially on a scale that is statewide or, potentially, broader. Such analyses provide the fundamental building blocks necessary to develop and evaluate a variety of policy options, develop management plans, and guide regulatory activities.

WCMS development was initially limited to those issues where statewide data was either currently available or could be reasonably developed. It became evident that tools that could effectively utilize newly developed, detailed spatial data provided additional impetus to data development and centralized database activities – tools foster support for data development which supports further analysis and tool development – a circle that leads to continual development and improvement in our ability to manage water resources.

Background

The Problem

WCMS was originally developed to support the management of the water resources of West Virgina (WV). In West Virginia, as in other states, resource managers consistently ask similar questions when examining water quality problems at the watershed level. What is the extent of the water quality problem? Where are the problems occurring in the watershed? Where should sampling or monitoring locations be established to assess the problem more accurately? Where should we focus best management practices or reclamation plans to address the problems that have been identified? How will specified development activities (mining, highways, housing, industrial, etc.) affect the water resources of the watershed? Advances in GIS tools and the availability of spatially explicit data combined to make development of tools such as WCMS feasible. The result is a powerful force for information and technology transfer.

History of WCMS Development

The initial attempt to develop water quality models that met the needs of WVDEP started in 1991 using SPANS; an early GIS system then under consideration for broader adoption by the Technical Applications and Geographic Information Systems (TAGIS) group. Data and functional limitations became apparent and, in 1993, development was transferred to the ESRI Arc/INFO environment.

Support from the National Mine Land Reclamation Center (Skousen et al., 1992), the West Virginia Water Research Institute, and other projects provided a problem oriented basis for further development (Phipps et al., 1994; Zucker et al., 1992a; Zucker et al., 1992b). The initial development in the Arc/INFO environment resulted in the development of useful tools but the data limitations remained (Dai et al., 1995). In addition, the software required relatively expensive Unix workstations and associated software; the cost per user ($30-50,000/yr) was felt to be higher than the agency could justify.

Initial development activities occurred in a period when the functionality of both computer hardware and software was improving rapidly. In the mid 1990's, ESRI introduced the ArcView software package that, in combination with the Spatial Analyst Extension, could support the analysis required by the WCMS application on a personal computer (IBM compatible PC). Microsoft introduced a usable version of the Windows operating system. Capabilities of

personal computers were increasing at a dramatic rate and costs continued to decline. This combination of breakthroughs in the software and the computing platform dramatically reduced the cost per user by over 75% – $7-12,000 per user initially with annual costs of $2-5,000.

Agreements with the Division of Mining and Reclamation (DMR) (1996-98) and the Division of Water and Waste Management (DWWM) (1999-2000) resulted in the development of usable GIS tools that were rapidly adopted by most permit writers in West Virginia. By 2000, this ArcView project version of WCMS consisted of over 7 GB of software and data (mostly data) that provided a stable platform that supported many of the analyses required by WVDEP staff responsible for water quality permits on a daily basis (Strager and Fletcher, 2001).

The current WCMS development project was initiated in 2001 with support from WVDEP/DMR primarily funded by the Program Enhancement Cooperative Agreement (PECA) with the U.S. Dept. of Interior, Office of Surface Mining (OSM). This project represents the most intensive, focused effort to develop additional functionality since development of WCMS began. This project includes six major components: (1) migration from the ArcView environment to the ArcGIS environment, (2) development of a significantly enhanced hydrology component with links to the Hydrological Simulation Program—Fortran (HSPF) model, (3) completion of the 1:24,000 National Hydrography Dataset (NHD) data for West Virginia, (4) development of a new mine drainage water quality modeling component for the ACIDPH routine in HSPF, (5) links to the Environmental Quality Information System (EQuIS) database under development at WVDEP, and (6) training and support for WVDEP staff on the software and modeling capabilities. WCMS development was further supported by a separate NRAC project with WVDEP/DMR, also support by PECA funds, initiated in 1998 and finished in 2003, that provided detailed, spatially explicit information on coal mines in WV derived from scanning, digitizing, and attributing over 6,000 permit maps for active mine permits in West Virginia.

WCMS is now an ArcGIS extension that appears as a toolbar in ArcMap. The current hardware and software requirements for WCMS are outlined in Table 1. Additional tools to support hydrologic and water quality modeling through links to the Hydrological Simulation Program – FORTRAN (HSPF) model are being added and tested.

Table 1. Hardware, Operating System, and Other Requirements for WCMS 8.x Deployment

ArcGIS 8.3 and the Spatial Analyst extension from ESRI
PC platform – any PC capable of running the ESRI ArcGIS software with Spatial Analyst
Operating System: Windows 2000/XP or Server 2000/2003
WCMS currently runs in a Citrix environment at WVDEP
User Requirements: Basic GIS and ArcMAP skills
Available GIS data imported into WCMS

Source: Natural Resource Analysis Center, 2004, *Watershed Characterization and Modeling System Version 8.0 Users Manual*, West Virginia University, Morgantown, WV 26506-6108, May, 36 pgs.

GIS Tools

While GIS software packages such as those provided by ESRI include the technical tools that can help provide answers to these questions, the specific analyses needed to address water quality issues are not standard fare. Easy pull down menu choices for watershed analysis are not included in the standard graphical user interface of the GIS but require extensive customization. The WCMS toolbar provides a set of tools for watershed characterization and management to aid in analysis, modeling, and decision making related to evaluating water quality problems. The tools provide hydrological modeling functions and decision support capabilities, and the graphical user interface (GUI) supported by the ArcGIS software make the tools available to non-GIS specialists. Integral components of WCMS include: an overland flow model that provides insight into optimum water quality sampling locations, a flow estimation technique for all streams, an instream water quality and loading model for pollutant levels, a watershed ranking model to prioritize where to focus remediation programs or make other water resource decisions, and the ability to generate low flow estimates (7Q10) for any point on any stream in the state.

As designed, WCMS provides consistent technical information on natural processes through a visual, graphical representation of the complex, spatial nature of watershed issues and facilitates "what if" analyses for discussion and the development of alternative strategies. WCMS can help in the development of practical solutions and guide decisions for addressing watershed and water quality problems. The analyses supported by WCMS provide critical input into the development of estimates of the benefits and costs of alternative actions.

Data Development

The availability of appropriate spatial data is the key to make systems such as WCMS an effective tool. It is imperative to understand the data that drive the process, current limitations in available data, and the steps in the current approach that support the modeling process. While some of the discussion in this section includes technical GIS terminology, the underlying structure of the analysis should be clear. The basic data developed for WCMS for West Virginia is outlined in Table 2.

Table 2. GIS Data Used by WCMS Tools (Provided for West Virginia)

Raster stream network
Flow direction grid
Flow accumulation grid
Runoff grid
Cumulative runoff grid
Hydro-corrected DEM with burned in streams
30m DEM (the standard DEM that is not hydro-corrected)
Landcover from the WV GAP analysis project
Landcover made from MRLC data
Table of expected mean concentration values
Layer of critical low flow values
Layer of USGS gauged watersheds
Regional stream flow variability curve
Stream flow variability index

Source: Natural Resource Analysis Center, 2004, *Watershed Characterization and Modeling System Version 8.0 Users Manual*, West Virginia University, Morgantown, WV 26506-6108, May, 36 pgs.

Models such as WCMS require consistent, accurate data. To support the hydrologic modeling capabilities, it is necessary to have or produce a hydrologically consistent stream coverage and digital elevation model. Currently available data are inconsistent and must be modified or corrected to support analysis over a large area. The following section describes this process. The input data initially used in WCMS development consisted of 30m DEMs from

USGS, 1:24k hydrology, monthly 30-year average precipitation grids at 90m resolution, and historical streamflow for USGS gauging stations. The background work required to prepare the data, a hydrologically correct DEM, and a runoff grid for hydrologic modeling was performed using the Grid module of ARC/INFO. The analysis incorporates many of the techniques described by Saunders and Maidment (1996), Reed and Maidment (1995), and Olivera et al. (1996). The approach presented is based on 20 m DEMs to support a consistent grid size and to improve the visual appearance of the final output.

The first step is based on the 30m USGS DEMs. The DEMs were downloaded and merged for West Virginia to create a complete mosaic for the state. The statewide coverage was then resampled from 30m to 20m to provide the resolution desired. The Grid Fill command was then run to remove all sinks from the DEM (ESRI 1992). This step finds all sinks in the continuous grids and removes inconsistencies in the USGS DEM data primarily due to the grid approximation to a continuous surface.

The second step involved working with the 1:24k-stream coverage. All rivers which were originally digitized with left and right banks were bisected with a single arc and tributaries connected. Next, all lakes, resulting from inflowing rivers and streams, were bisected with a single arc. Any braided, stray or unconnected streams, ponds or lakes were removed from the study area coverage. The goal was to make sure water flow is represented with a single arc for the surface flow direction and flow accumulation Grid functions. When all streams were hydrologically "corrected," the coverage was then converted to a grid with a resolution of 20m. The rasterized stream network was then thinned to ensure single cell stream width.

The third step applies a "burn in" process by merging the raster stream network with the off-stream DEM cells raised 50 meters. It is important to keep the original DEM values for the stream grid so flow direction and slope within the stream can be calculated. After the streams have been "burned" into the DEM, the DEM is then filled again with flow direction and accumulation grids calculated. This process is necessary to produce what is termed a hydrologically corrected DEM with flow direction and accumulation grids.

The fourth and last step is to create a runoff grid built on the relationship between precipitation and stream flow based on a regression relationship between historical stream flow and 30-year average annual precipitation grid values. The precipitation grids are 90m in cell size and were extrapolated to grid format from the observation collection points. The historical

stream flow is recorded for the same time that the precipitation grids were recorded. For each gauging station location, the watershed is delineated and the average precipitation for the watershed area determined. The next step is to divide the flow volume (m^3/year) by the watershed drainage area in m^2 to calculate an equivalent depth of recorded stream flow in mm/year. Regressing the value of the equivalent depth of recorded stream flow versus the average annual precipitation provides a regression equation to apply to the precipitation grid to estimate runoff (Saunders and Maidment, 1996). The runoff grid represents the relationship between precipitation and stream flow. A cumulative runoff grid is developed by running a weighted flow accumulation with the runoff grid. The runoff grids are used with flow accumulation and flow direction grids to model the flow estimation, pollutant concentrations, and potential maximum yearly loadings.

As the accuracy and spatial scale of available data improves, the models that rely on these data will improve as well. The development of 1:24,000 NHD data also provides improved support for modeling activities.

Application of WCMS Tools

Identifying Potentially Affected Streams

Given that spatially explicit, accurate data are available for hydrologic modeling, it is possible to proceed through an analysis of a variety of common water quality and watershed management questions. It is possible to track the surface runoff from potential pollution sources across the landscape. The sources for pollution may come from a variety of sources including abandoned mine lands, row crops or other agricultural land use, or permit discharge locations. Based on the assumption that each source can be a pollution contributor during a precipitation event, it is possible to identify all stream segments that could be affected by the runoff from these sites. This information helps to determine stream locations for sampling and to determine the effect of such runoff. To develop this tool, a value of 100 was assigned to each of the pollution source cells that were then used as the weight grid in the flow accumulation function. Assigning a threshold value to the flow accumulation function resulted in a synthetic raster stream network that was converted to vector format. The final vector stream coverage contained an item called “grid-code” which indicated the presence or absence of runoff from the pollution sources. The individual grid cell values can be used to determine on-screen stream colors for

presentation to the user through on-screen maps. The technical detail is suppressed and the qualitative results clearly conveyed.

Multiple Watershed Delineation

If a water quality sampling plan that approximates an equal area scheme is desired, it is possible to delineate watersheds based on specified drainage areas (size), then locate the pour points for each watershed. The pour points define the sampling locations for an equal area weighted sampling scheme. This requires a threshold cutoff value. Suppose the goal is to develop the most comprehensive sampling scheme possible with limited resources. For example, if a watershed is 10,000,000 m^2 (1000 Ha, ≈2500 ac) and if time, costs, and manpower limitations restrict the number of feasible sampling locations to 50, then each sampling point should cover approximately 200,000 m^2. The value to select out of the flow accumulation grid should be 200,000 divided by the grid cell size squared. For example, using a 30m flow accumulation grid cell size would mean dividing 200,000 by 900 to get a flow accumulation value of 222 (the actual watershed size for 222 cells is 199,800 m^2). Selecting values that are integer multiples of 222 from the flow accumulation grid provides cutoff locations to automatically delineate watersheds with approximately equal areas of the selected size.

Representative Average Streamflow Estimates

In watershed characterization, it is important to determine loadings in mass/unit time (e.g., kg/hr, lb/day, or tons/year) for the amount of pollution entering a stream. Estimates of stream flow for all streams in a watershed provide scenarios that simulate conditions that may occur during the year. For example, by estimating and modeling the likely high, low, and average flow conditions on a monthly basis, reclamation strategies and systems can be effectively designed to match the various conditions expected to occur over an extended time period. Fundamentally, this approximates stream flow at a point with the area weighted proportion of the flow at the gauge with some correction for precipitation patterns.

As this technique is based on creating a runoff grid by examining the relationship between rainfall and stream flow, other landscape or site-specific variables could be combined to improve the accuracy. For more information on estimating stream flow see Andersson and Lepisto

(1998), Astatkie and Watt (1998), Gabriele and Perkins (1997), Garren (1992), and Sharma and Lall (1997).

Representative Instream Concentrations and Loadings

Other relevant data for characterizing watershed problems centers on the in-stream concentrations and loadings from nitrogen (N), phosphorous (P), and total suspended solids (TSS). The approach applied assumes that the streams have the same hydro-geometric properties (stream slope, roughness, width, and depth) and that the streams have the same ecological rate constants (re-aeration rates, pollution decay rates and sediment oxygen demand rate). The concentrations modeled can be thought of as the maximum potential concentrations with the available data and under the stated assumptions (Saunders and Maidment, 1996).

Land cover is a primary driver for N, P, and TSS concentrations and loadings. Available data for West Virginia support using urban, open/brush, agriculture, woodland, barren, and wetland cover classes. Each of these classes has unique loading coefficients based on event mean concentrations for N, P, and TSS. This type of modeling is equivalent to the generalized watershed loading function (Haith and Shoemaker, 1988). Using the GIS, the appropriate values for each class when converted to a grid are used as the weight grid in the modeling process. Multiplying this land cover grid by the runoff grid creates a cell based loading grid. The cell based loading grid is used as the weight grid in the flow accumulation function. The resulting stream grid values provide estimates of in-stream concentrations for all cell locations. When converted back to vector format, the stream colors indicate concentrations. This technique allows the streams to show the combination of pollutants as concentrations and loadings to stream water quality from the expected mean concentrations of the loading coefficients. The GIS provides a relatively easy method of combining a variety of spatially diverse data sources for analysis.

Watershed Ranking

While the techniques described help identify problem areas, the extent of the pollution, and the locations to optimally sample or monitor, a management problem of concern deals with how to prioritize or rank areas to receive reclamation or remediation activities. This problem is essentially a spatial allocation problem with multiple, goals, objectives, and evaluation criteria.

WCMS includes a methodology for systematically assembling GIS data that can be used to choose among or rank alternative projects or decisions. Combining a multiple criteria decision making (MCDM) framework with the data collection and analysis capabilities of a GIS produces a powerful decision support system (Strager and Fletcher, 1999). Within the GIS all data are collected to meet evaluation criteria and a user interface can be created to query the decision makers preferences toward specified criteria. This allows the user to test the spatial sensitivity of criteria preferences that could represent different policy alternatives and visually present the output to the decision maker. Much of the following discussion is from Strager et al. (1995) and Strager et al. (in review).

The most common environmental problem associated with coal mining in West Virginia is acid mine drainage (AMD). AMD is defined as mine-water runoff with high concentrations of acidity, iron, manganese, aluminum, and suspended solids toxic to aquatic life (Squillace and Dotter, 1990). Early on, *The West Virginia Water Quality Status Assessment* (WVDNR-OWR, 1989a, 1989b) found AMD to be the number one water quality problem in the state polluting up to 477 streams totaling 2,427 miles.

WVDEP often approaches the AMD problem at the watershed level where physical interactions between pollution sources, the water chemistry, and land characteristics can be modeled to develop an appropriate treatment plan. This watershed level approach creates the need for a workable methodology for selecting watersheds for treatment given limited AMD abatement funds. A ranking model to prioritize AMD-affected watersheds for treatment can help support allocation decisions.

An obvious way of prioritizing is in order of net benefits generated per dollar of expenditure. There are at least two problems with this approach. First, many of the benefits from watershed restoration such as improved fishing or appearance are nonmarket in nature and difficult to quantify without expensive studies. The sheer number of environmentally damaged watersheds in West Virginia, coupled with very limited funds, precludes conducting benefit studies for all competing watersheds. Second, the WVDEP is a state agency and subject to political forces within government and from public interest groups representing difficult factors, if not impossible, to measure in dollars.

A multiple-criterion decision-making framework was adopted to address these problems. The multiple-criterion framework combines criteria measured in dollars with physical or other

factors important to the decision without first converting all goods to dollar terms. Moreover, because it is necessary to specify weights for each of the criteria in the objective function, this method allows exploration of perspective and preferences on watershed selection. Interest groups within the state assign varying levels of importance to different watershed evaluation criteria. By eliciting relative preference weights for each criterion from the different groups, it is possible to examine the sensitivity of watershed ranking to political perspective.

Multiple Criteria Decision Making (MCDM)

MCDM helps decision makers choose among alternatives by showing the tradeoffs among the criteria and helping decision makers voice their preferences while making choices in a rational, consistent manner that can be readily documented (Duckstein et al., 1989). MCDM was developed to fill weaknesses in conventional mathematical programming applications to decision-making problems. Romero and Rehman (1989) argued that decision makers are usually not interested in ordering the feasible set according to a single criterion but strive to find an optimal compromise among several objectives. In a multiple criterion problem human value judgments, tradeoff evaluations, and assessments of the importance of criteria are an integral part of the problem. This is certainly relevant to the AMD problem in West Virginia.

Compromise Programming. One technique for solving multiple criteria problems is compromise programming. The concept of non-dominance is used in compromise programming to select the best compromise solution or choice of alternative. A solution is non-dominated (similar to pareto optimal) if there is no other feasible solution that will cause an improvement in a value of the objective function without making a value of any other objective function worse. For a detailed description of the MCDM approach used in WCMS, see Strager (1995) and Strager and Fletcher (2001).

Prioritizing Mine Affected Watersheds for Reclamation in West Virginia

The MCDM approach can be described through a specific application – prioritizing watersheds affected by AMD from abandoned mine lands (AML) in WV to received limited reclamation or restoration funds.

Defining the Evaluation Criteria. Any prioritization model or decision support system requires a statement of the factors that drive the analysis and ultimate decisions. We assume that

an optimal watershed abatement schedule should be based on directing efforts to watersheds which (1) are most severely impacted by AMD, (2) have the greatest benefits possible after treatment, and (3) have the lower costs of AMD treatment. For each of these three broad-based criteria, specific criteria characterized by available data were selected.

Severity of Impact. Water quality in the receiving stream was used to determine the severity of the AMD problem in a watershed. Criteria characterizing the water quality included net acid loading in pounds per day, iron loading in pounds per day, percentage of samples violating the statewide standard for pH (6.0 to 9.0 standard units), percentage of samples violating the standard for aluminum (748 ug/l), and the percentage of samples violating the standard for manganese (1.0 mg/l). Additional criteria used to identify the most severely impacted watersheds were the percentage of watershed stream miles affected by AMD, and the percentage of watershed area that is unreclaimed mine land.

Water Use Benefits. Two criteria were used to identify the benefits from treating the watersheds-- impacted stream use and water uses impacted downstream of the watershed.

Costs of Treatment. To identify watersheds which have lower costs of AMD treatment, an estimated AMD abatement cost for the watershed was calculated (Phipps et al., 1994, 1995; Fletcher et al., 1991).

Documenting the Preferences of Different Interest Groups. After defining the evaluation criteria, the preferences of different interest groups toward the criteria provide the necessary information to assign weights in the analysis. In an initial study, Strager (1995) solicited information on preferences from the WVDEP/DMR, the WV Division of Natural Resources Office of Wildlife and Fisheries (WVDNR/OWF), the Sierra Club Monongahela Group, Trout Unlimited Pendleton Kennedy Chapter, and a rafting organization, Appalachian Wildwater. These organizations represent two state agencies, an environmentalist group, and river and stream users. Each organization was contacted to explain the nature of the research and how their responses would be used in the study. They were asked to rank each criterion based on its importance toward selecting AMD affected watersheds for treatment. After obtaining responses from each organization, a follow up phone call was made to confirm the responses. Using Saaty's (1977) pairwise comparison technique, weights for each criteria were assigned from the responses.

Practical Applications

Strager's (1995) initial study provides a formal, workable approach to selecting AMD-affected watersheds to receive limited program funds. The results from his study indicated that, due to the multitude of criteria to consider in prioritizing watersheds and the lack of detailed data in terms of benefits available, the MCDM approach represents a viable option to approach the problem. A complete ranking of watersheds is possible given the limited data available. An MCDM analysis points out areas of agreement and difference among groups and allows discussion to focus on differences crucial to the analysis. Strager's study found that even though the watershed rankings varied among groups, the most and least preferred watersheds were relatively consistent.

CHIA Related Enhancements to WCMS

As noted previously, WVDEP/DMR support for additional development of WCMS capabilities to support the cumulative hydrologic impact assessment (CHIA) process included six separate tasks:

1. Migration from the ArcView environment to the ArcGIS environment,
2. Completion of the high resolutions (1:24,000) National Hydrography Dataset (NHD) data for West Virginia,
3. Development of a significantly enhanced hydrology component with links to the Hydrological Simulation Program—Fortran (HSPF) model,
4. Development of a new mine drainage water quality modeling component for the ACIDPH routine in HSPF,
5. Links to the Environmental Quality Information System (EQuIS) database under development at WVDEP, and
6. Training and support for WVDEP staff on the software and modeling capabilities.

The migration to ArcGIS is complete and the high resolution NHD for WV is now available on the USGS website (http://nhd.usgs.gov). The need for better hydrologic modeling capabilities to determine stream flows for water quality modeling was apparent. This work has been largely completed (Eli et al., 2004). Training and support are ongoing activities. As WCMS has evolved, training for WVDEP staff has accompanied major releases of the application. Most WVDEP permit writers use some version of the WCMS application.

A VBA macro has been developed that can be used to convert spatial data in the form of DEM's, Land Cover, Flow Accumulation Grids, NHD (or other) streams, and sub-watershed boundaries (all of which are provided for West Virginia with WCMS) into a series of input files for HSPF. The input files are a preliminary step in the processing of input to the HSPF model. We will incorporate the macro into WCMS and work is ongoing to develop the ability to bypass the preliminary inputs and instead create the full UCI file required to run HSPF. This will be another good example of how WCMS can transform a potentially difficult and complicated modeling technique into a one or two-step process with meaningful results.

Current efforts focus on the water quality modeling component (Fletcher et al., 2001). A significant amount of research on AMD has been conducted at WVU. Specific support for this model is based on the work by Sun (date?). The ACIDPH routine in HSPF has been modified to reflect the latest AMD research. The EQuIS water quality data base has been delayed due to development problems and the additional time required to enter data. An updated version of the EQuIS software is being installed in early December 2004 which should support the inclusion of the trend stations water quality data collected by WVDEP to be integrated into the Oracle environment. It will then be possible to calibrate and test the model using the latest data from the coal mining areas of West Virginia. When complete, this database will support simulation of the water quality impacts of common AMD parameters (acidity, alkalinity, pH, iron, manganese, aluminum, and sulfate) for the trend stations in the coal mining areas of WV.

WCMS Use by WVDEP

Division of Mining and Reclamation (DMR)

The Division of Mining and Reclamation is using the WCMS toolbar and its associated databases everyday and in many ways. The primary use of the WCMS toolbar is in the CHIA process. The WCMS toolbars and databases are used in almost every CHIA report written by DMR staff. The toolbar is used delineate Cumulative Impact Assessment watersheds. It is also used to show and analyze the cumulative mining within the CIA area. It can also be used to determine rough flow values and assist in mass balance calculations. In the future, the new HSPF and AMD chemistry modeling features will allow much more accurate quantity and quality modeling to be used in the CHIA decision-making process.

The WCMS toolbar is also being used in the development of every new DMR NPDES permit being written. In particular, it is used to help calculate the new Anti-Degradation limits required for all new NPDES permits. The toolbar and database are used to develop segment level watersheds for all NPDES outfalls and 7Q10 flow figures for each point of interest. This information supports the development of defendable, calculated NPDES limits.

The databases created by NRAC are being used by DMR staff every day for a variety of tasks. The permit, valley fill, and water course files created for the WCMS toolbar have been used in dozens of statewide technical investigations. These uses include flood studies, valley fill studies and the monumental federal Mountaintop Removal EIS. These databases are on our website and are often downloaded by the public (http://gis.wvdep.org/). The permit and deep mine outlines polygons are used in almost every geologic investigation conducted by the state. By importing these NRAC polygons into ArcPAD PDA systems this data can be taken into the field and checked against real world activities.

Summary and Conclusions

The information provided in this paper will provide insight into many of the raster based hydrological functions and capabilities in the ARC/INFO GRID module and the ArcView Spatial Analyst extension within WCMS. The major components described: an overland flow model that provides insight into optimum water quality sampling locations, a flow estimation technique for all streams, an instream water quality and loading model for pollutant levels, and a watershed ranking model to prioritize where to focus remediation programs.

The hydrologic modeling tools available in ARC/INFO Grid and ArcView with the Spatial Analyst extension provide the ability to extract the topographic structure from the digital elevation data for characterizing the pollution sources. Using a hydrologically corrected DEM developed through preprocessing analysis improves the accuracy of runoff directions, watershed delineations, and the transport of pollutants within the streams.

This paper includes a discussion of the use of geographic data within a multiple-criteria decision-making framework. The methodology can be incorporated across projects that require the identification or prioritization of alternatives among conflicting goals and objectives. Conflicts can be examined by changing relative criteria weights or excluding specified criterion from the analysis to account for different individual or organizational preferences. In addition,

the sensitivity of results to different criteria and preferences can be displayed graphically and/or text results printed for the decision maker.

One of the primary, but unintended, outcomes of the use of this approach has been the support for additional data development received by state environmental agencies when the usefulness, and necessity, of additional data becomes apparent to watershed groups, other agencies, and policymakers through a pragmatic approach to developing solutions to problems.

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