WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Prediction of Ground Water Vulnerability to Animal Waste/Fertilizers in Karst Topography Using Fuzzy Logic.

Focus Categories: MOD, NC, GW, AG

Descriptors: Ground Water Modeling

Duration: March 1, 2000 – February 28, 2001

Federal Funds:

Direct	$24,690
Indirect	$---0---
Total	$24,390

Non-Federal funds:

Direct	$11,727
Indirect	$38,655
Total	$50,382

Principal Investigator(s) and Universit(ies):

H.D. Scott[1], B. Dixon[1], A. Mauromoustakos[1], J.C. Dixon[2], and J. V. Brahana. [1]

[1] Dept. of Crop, Soil, and Environmental Science, 115 Plant Sciences, Fayetteville, AR 72701

[2] Dept. of Geosciences, 113 Ozark Hall. University of Arkansas, Fayetteville 72701

Congressional District of the University Where the Research is to be Conducted: Third

Statement of Critical State/Regional Water Problem:

Contamination of surface and subsurface waters by agricultural and municipal wastes has been a major concern in recent years of many agencies involved with water management, water quality, water quantity and human health. A study conducted by Petersen et al., (1998) reported that water from parts of the Springfield Plateau aquifer, which lies beneath the proposed study area, had higher nitrate concentrations than the national

median. The dominant landuses of this area are agriculture (primarily pasture/cattle) and a growing urbanization. The major sources of nitrogen in the study area are poultry/cattle wastes and fertilizers (Petersen et. al., 1998). Many of the soils in the Ozark Region are highly permeable and well drained and the geology is karst. Delineation of vulnerable areas and selective applications of fertilizer/animal/ municipal wastes in those areas can minimize contamination of ground water. Assessment of ground water vulnerability to agricultural inputs and understanding the spatial and temporal variabilities of the most important parameters is imperative before undertaking monitoring, rehabilitation or regulatory efforts at the watershed or regional scales. However, assessment of ground water vulnerability or delineation of the monitoring zones is not easy since contamination depends upon numerous and complex interacting parameters. Uncertainty is inherent in all methods of assessing ground water vulnerability, and will arise from errors in obtaining data, the natural spatial and temporal variability of the hydrogeologic parameters in the field, and in the numerical approximation and computerization (National Research Council, 1993).

We propose to develop a relatively simple (user friendly), useful, flexible and affordable model that has inherent capabilities to deal with uncertainty and which, integrates geophysical attributes, climatic attributes (storm events), animal waste/fertilizer applications, landuse and human interactions in a GIS using fuzzy logic and relational data structures. This model will be developed on a representative watershed, the Savoy Experimental Watershed (SEW) and its surroundings in the Ozarks, which is threatened by agricultural waste applications and encroaching urbanization. Assessing risk with our new approach will be more realistic as our proposed method will innovatively extend the capability of overlay and index (O/I) methods of modeling ground water vulnerability to NO_3-N by incorporating fuzzy logic and relational data structures in a GIS platform. This approach will have built in capability to deal with uncertainties, tolerate imprecision, minimize propagation of errors and information losses that are common with boolean logic analyses. Our approach will also have the capability to incorporate scientific expert’s opinion directly into the model. Evans (1990) stated that the probability of pollution occurring at a given location is a function not only of its hydrogeologic setting but also of anthropogenic pollution in the area. Our models not only consider hydrologic parameters, but also incorporate landuse and applications of animal wastes/fertilizers with respect to storm events. Moreover, our models assume that parameters affecting the vulnerability of ground water vary spatially and temporally in the watershed. The results of this research will be shared through dedicated Internet access available to interested individuals, communities and policy makers and collaboration with local, state and federal agencies. Interested individuals and communities can gain access to vulnerability maps of NW Arkansas through the Internet (dedicated web site) to determine whether they live/work in an area of high risk. Cooperative Extension Service (CES) personnel and other state and local level environmental/natural resource groups can use the Internet site to enhance the community’s understanding of vulnerability to ground water contamination, disseminate knowledge gained in this research to the community and encourage people to protect vulnerable areas. It will also have link to other web sites and water information systems.

Statement of Results or Benefits:

Results: Our fuzzy logic models will generate maps that show regions of ground water in the SEW having more or less potential vulnerability to NO_3-N than others. Coincidence reports will be generated indicating interactions among major parameters. Methodologies employed in this project will be applicable and readily transferable to other watersheds in the Ozark Highlands for improving our understanding of processes that impact the fate of contaminants in watersheds having permeable soils and karst topography. The results will be made available to interested individuals, communities and policy makers through the Internet and partnerships with local, state and federal agencies.

Short-term Benefits: The results obtained by this project will contribute to the development of strategies for protection of ground water quality in areas having the combination of animal wastes/fertilizers and karst topography. The methods used in this project will be applicable and readily transferable to watersheds in other areas with either no or few modifications. This project can also serve as a model for watershed level environmental assessments of ground water vulnerability to various contaminants, not only animal wastes/fertilizers but also for pesticides.

Long-term Benefits: The data bases and models developed for this project will provide the basis for a new project in the future involving neural networks and real-time modeling capability via the Internet that will be accessible to any interested individuals, community, watershed managers, CES agents and policy makers. Information gained in this study will provide the basis for a future study which includes other important components of SEW and its surroundings such as the risk of ground water contamination due to urban encroachment.

Nature, Scope, and Objectives of the Research:

The overall purpose of this research is two fold: (1) to innovatively extend the capability of overlay and index methods of modeling ground water vulnerability to agricultural chemicals at the regional scale by using fuzzy logic in a GIS platform, and (2) to develop a web site to disseminate results of this research to watershed managers/planning groups, interested individuals and communities via the Internet.

Despite being commonly used at the regional scale, overlay and index methods do not have built in mechanisms to deal with uncertainties, nor do these models consider spatial and temporal variability of parameters affecting ground water vulnerability. Most models based on overlay and index methods use physiographic parameters and do not consider physical and chemical properties of the contaminant and their interactions with the solid matrix or with landuse. This project offers great promise in expanding modeling capability by addressing meaningful and relevant interactions of hydrogeologic settings, soil properties, potential for preferential flow, landuse, storm events and animal wastes/fertilizers on ground water quality of watersheds in karst topography. Reliable and cheap prediction of the locations of vulnerable ground water areas is imperative before undertaking preventive/rehabilitation efforts at the watershed level or regional scale.

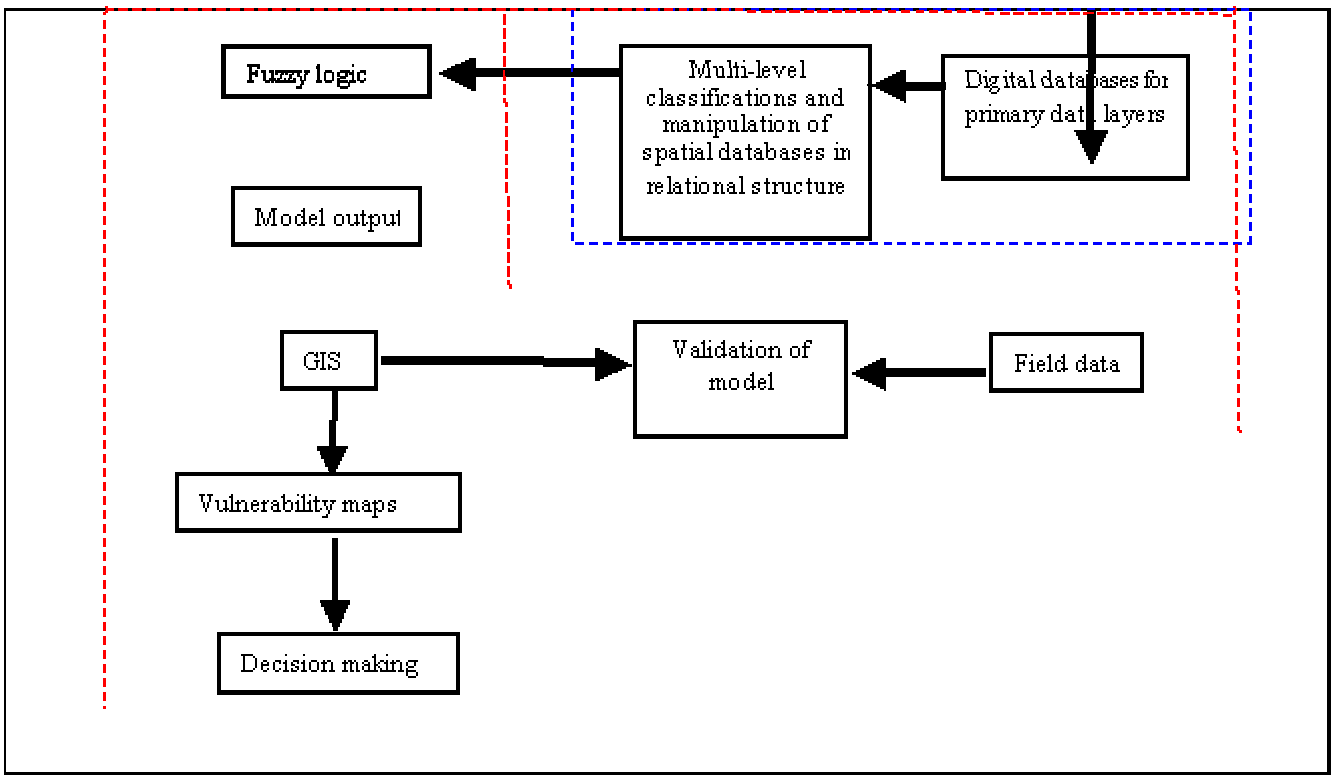
The specific objectives of this research project are to:

1. Develop models using fuzzy logic to predict ground water vulnerability in a large watershed and to integrate the spatial databases and fuzzy logic model in a GIS platform, and

2. Develop a multi-level classification scheme and relational data structure for digital data layers to be used in the development of the fuzzy logic-based model.

Methods, Procedures, and Facilities:

Our proposed fuzzy logic model has the inherent capability to deal with uncertainties of the data, tolerate imprecision, and minimize propagation of errors and information loss common with Boolean logic. One of the many strengths of this new approach is that it incorporates spatial and temporal relationships among the parameters that affect ground water contamination such as geology, soils, potential for preferential flow (fractures/joints), landuse/landcover (LULC), time and amount of animal wastes/fertilizers applied, time and intensity of storm event and discharge. Expert knowledge, which is a valuable source of information on the physical, chemical and biological parameters that are hard to measure, as well as experimental information will be used in this research project. This project will maintain a web site with an on-line relational data base and published results, i.e. vulnerability maps. Moreover, this research will incorporate information available from other water information systems. A flow chart of approaches used in this study is presented in Figure 1. The components of each objective are surrounded by a colored dash line. Figure 2 shows our proposed Internet-based site and information transfer approach.


Fuzzy logic
Multi-level classifications and manipulation of spatial databases in relational structure
Digital databases for primary data layers
Model output
GIS
Validation of model
Field data
Vulnerability maps
Decision making

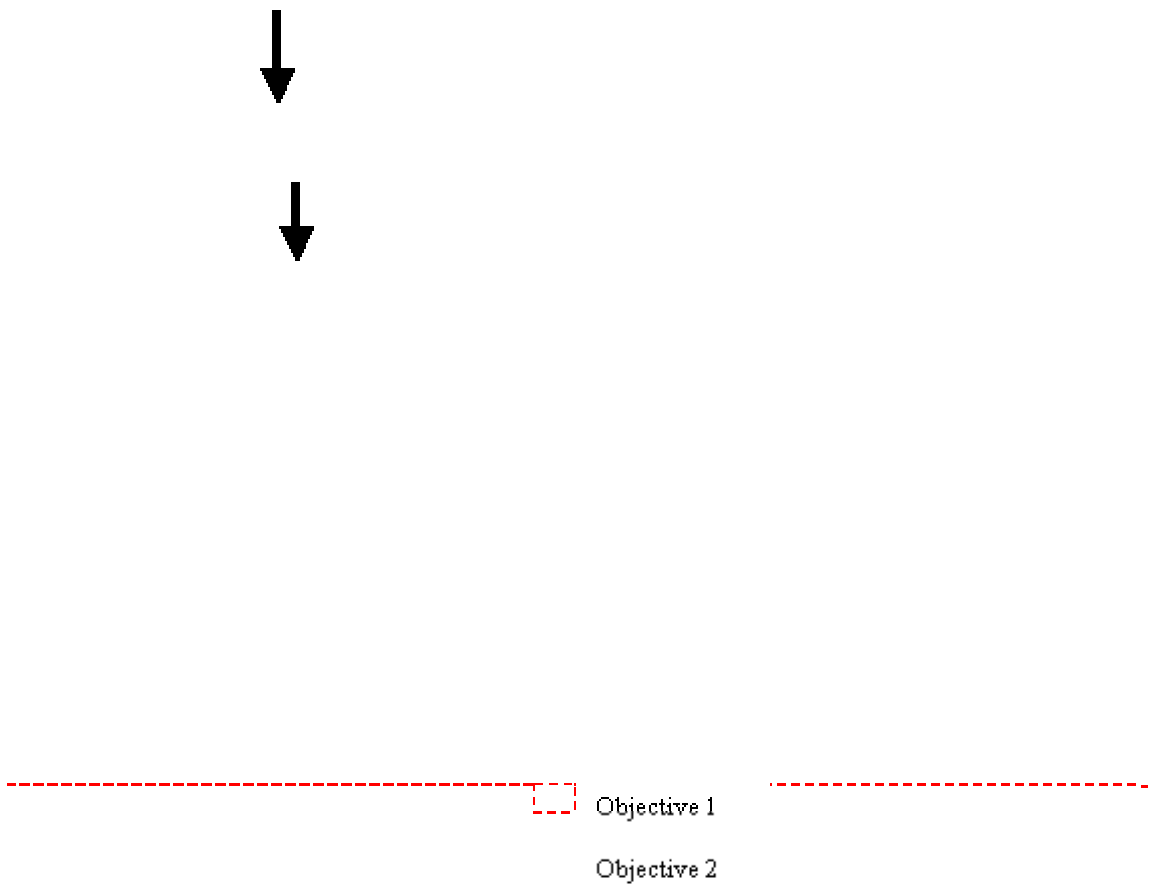


Figure 1. Diagram showing our proposed approach for modeling ground water vulnerability in the watershed.

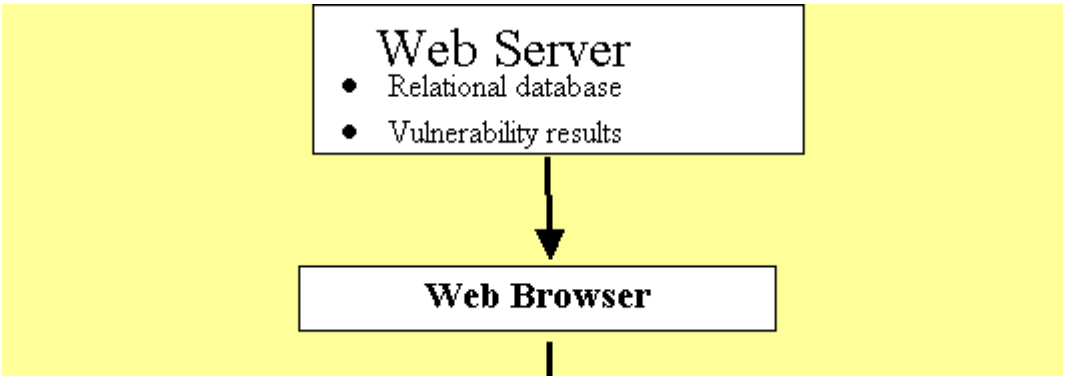


Figure 1. Diagram showing our proposed approach for modeling ground water vulnerability in the watershed.

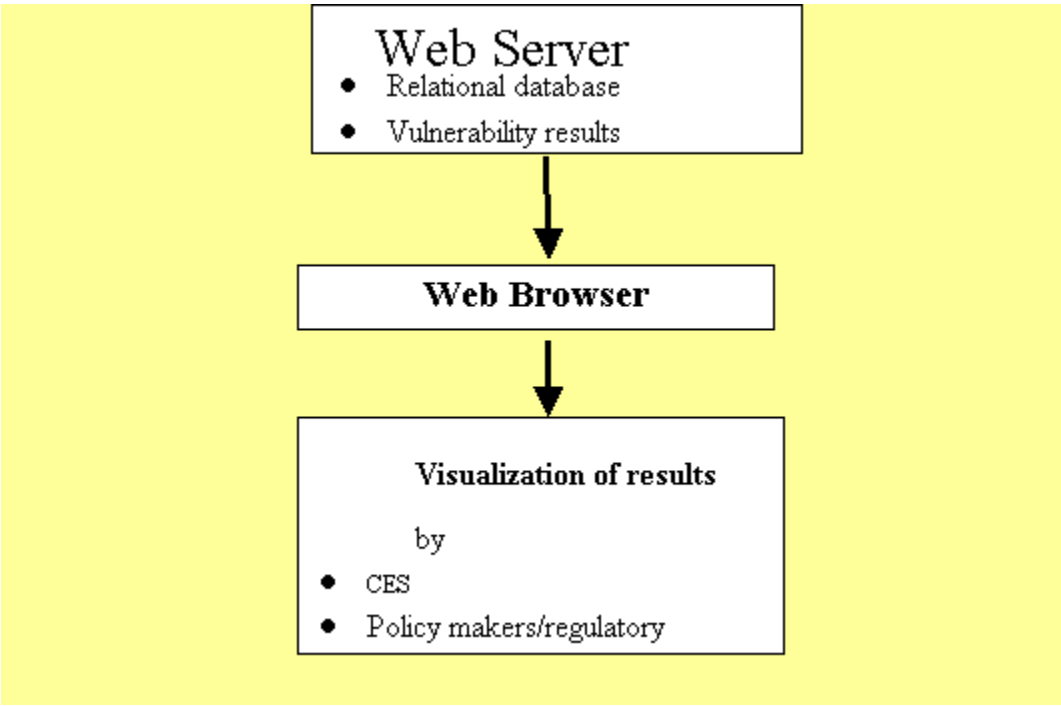


Figure 2. Schematics showing the proposed approach Internet-based on-line result display.

Methodologies

The fuzzy logic- and neural networks models will be developed based on the characteristics of the Savoy Experimental Watershed (SEW) and its surroundings. This is an intensely monitored watershed in northwest Arkansas. SEW is a University of Arkansas (U of A) property of approximately 1250 hectares located in the Illinois River watershed 24 km west of the U of A campus in Fayetteville, and about 26.4 km east of the Arkansas-Oklahoma border (Figure 3). This watershed has diverse soils, landuse and karst topography and is affected by urban encroachment.

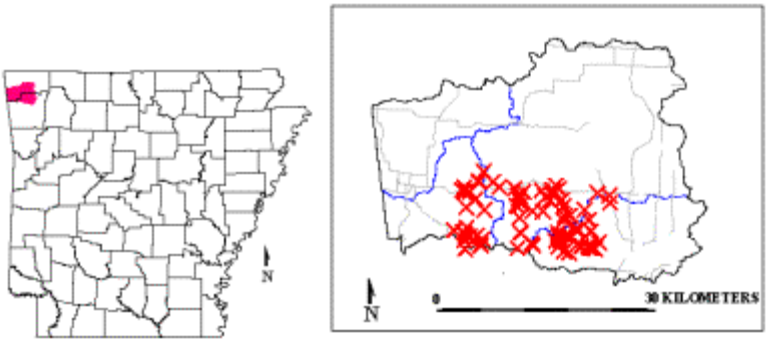


Figure 3. Location of the study area and existing water quality sampling sites (x).

Objective 1: Development of Fuzzy Logic Model and Integration of Databases with the Models in a GIS Platform.

Fuzzy logic model: A fuzzy logic-based approach will be used to model potential groundwater vulnerability by incorporating hydrogeologic parameters, soils, potential for preferential flow and chemical application with respect to storm events. The fuzzy logic software developed by Numata (1991) will be used. Five input fuzzy sets, (i) soils (ii) fractures/joints (preferential flow), (iii) geology, (iv) animal wastes/fertilizers, and (v) LULC, and one output fuzzy set for ground water vulnerability will be used. Level III data will be used for all the fuzzy sets except geology (Level II). Details of this multi-level classification scheme are presented under Objective 2. Unique numbering systems will be assigned for all the members of each parameter. Fuzzy sets for each parameter will have fuzzy subsets that will map the relative influence of each parameter (e.g. low, moderate and high subsets for fuzzy set soil permeability). Fuzzy rulebases composed of fuzzy rules, fuzzy sets and fuzzy subsets provide flexibility for customizing individual situations. Examples of fuzzy rules to be used are:

If SPH and HPFC and AsHP and N1 and RDH, then HC.

If SPL and LPFC and AsLP and N2 and RDL, then LC

The first rulebase indicates that if the soil profile is thin, structure is favorable, permeability is high (SPH) and density of fractures/cracks are high (HPFC) and rock porosity is high (AsHP) and a contaminant was applied in large quantities immediately before a storm event (N1) and the root system is deep (RDH), then the potential for contamination of the ground water is high (HC). The second rulebase indicates that if the soil profile is thick, structure is not favorable, permeability is low (SPL) and density of fractures/cracks are low (LPFC) and rock porosity is high (AsLP) and a contaminant was applied in large quantities long before a storm event (N2) and the root system is shallow (RDL), then the potential for contamination of the ground water is low (LC).

Validation of the model.

Comparison of Predictions from Fuzzy Logic with Field Data: Comparison of predictions between fuzzy logic-based model with field water quality data will be performed. Predictions will be compared with field data to assess their accuracy. Correlation analyses will be performed between fuzzy logic model predictions and field data using the statistical software Jmp v. 3.2. The geostatistical software GS^+ v. 3.1 will be used to generate (kriging) surface map from water quality site data. Coincidence reports will be generated using GRASS v. 4.2 between fuzzy logic output and water quality site data as well as fuzzy logic model output and kriged data for water quality.

Objective 2: Development of Classification Scheme and Databases.

This study will use several geo-referenced (spatial) primary and secondary digital databases to predict vulnerability of the ground water, and climatic data (no manipulation required). The primary digital databases will be obtained from various sources and in various formats (Table 1). Numeric and alpha-numeric codes will be used in the relational database. Watershed boundaries will be used to delineate the general study area, however, they will not be used as model inputs. The ground water basins and water quality data have been and are being collected by studies funded by several federal and state agencies. Details of the classification schemes are described below. Location of the study area and sampling sites for water quality are presented in Figure 3. Examples of spatial datasets and spring data collected in the SEW are presented in Figures 4 and 5, respectively.

Table 1. Description of the primary data layers.

Primary Data layers	Source	Scale/resolution	Comments
Watershed boundaries	USGS	1:24,000	Digital
Climatic data	Recorded at SEW	N .A .	Agricultural Research Services (ARS), U of A
Ground Water basin boundaries	Field determined	1:24,000	Paper format or thesis
Location of Springs/wells	Field determined	N. A.	Savoy Web site and USGS- GWSI database
Water Quality data	Collected at SEW and surroundings	N. A.	Savoy Web site and USGS-ADAPS database
Geology	Arkansas Geological Commission	1:24,000	Digital
Lineaments (fractures and joints)	USGS, Masters Thesis (U of A)	1:24,000	Aerial photograph, RADAR
Soil Mapping Units	Natural Resources Conservation Services (NRCS) and ARS	1:24,000	Mylar for primary and Tabular for secondary attributes
LULC	Center for advanced spatial technique (CAST)	30 m, 2 ha	Landsat TM 92
Animal wastes/fertilizer used	Individual survey/ NRCS (CES)	N.A.	Survey Research Center (U of A)

Primary Data (Spatial):

The primary data layers used in the fuzzy logic model are (i) boundaries of the ground water basins, (ii) location of springs/wells, (iii) surficial geology, (iv) lineaments for preferential flow (fractures and joints), (v) soil mapping units, (vi) LULC and (vii) animal wastes/fertilizers use. Location and contamination data for wells will be used for validation of the fuzzy logic model, not as an input.

Reclassification of Data into Secondary Databases (Spatial):

With the exception of watershed boundaries, all of the primary spatial data layers will be reclassified into three progressively more detailed levels (I, II and III) except the data layers for soils and fractures/joints needed to characterize potential of preferential flow

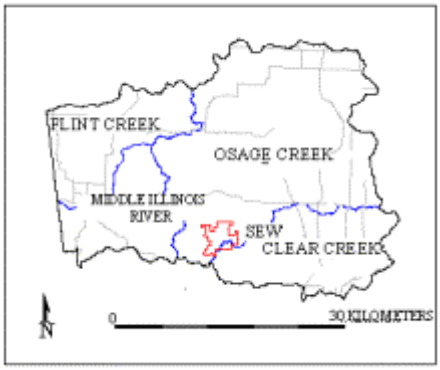
(levels I through IV). This reclassification is essential for creating input fuzzy sets, developing fuzzy rulebases and for integrating the databases with the model in a GIS domain as this classification maps complex spatial and temporal relationships between parameters.

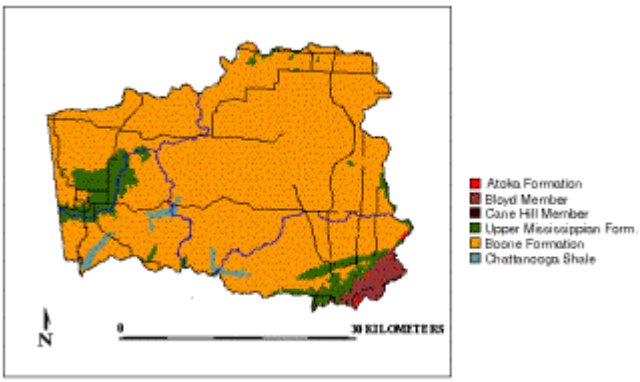
1. Ground Water Basins

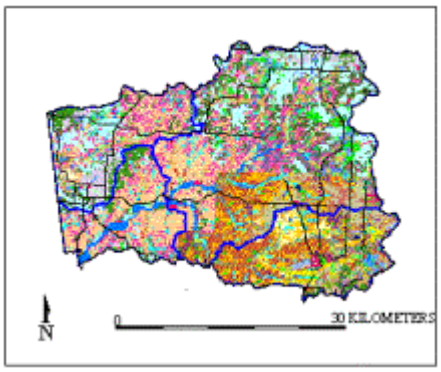
Ground water basins will be classified by major sub basins in Level I. Ground water basin boundaries will be delineated using the following methodologies:

> (i) in-depth, site-specific study area reconnaissance, involving karst inventory, spring inventory, surface water seepage, investigations, and hydrologic boundary delineation (Quinlan, 1989);
>
> (ii) application of standard ground-water fluorescent dye-tracing techniques applicable to karst terrane (Aley, 1997; Quinlan, 1989; Davis et al., 1998);
>
> (iii) determination of overall size of the basin contributing recharge will be approximated using normalized base flow techniques in which low flow of springs is proportional to basin size, given specific hydrogeologic and climatic variables (Quinlan and Ray, 1995; Brahana, 1997; Brahana and Davis, 1998);
>
> (iv) Compilation of well driller's logs; geophysical wireline logs; geologic maps; topographic maps; relevant published reports; and low level aerial photography (Brahana, 1997).

For level I classification, the sub-basins will be given unique names such as 01 and 02. For level II classification, number of springs for the sub-basins will be assigned. For level II classification, the designation 0103 means sub-basin number 01 has three springs. Level III classification will add a name for each spring in the sub-basin. This is imperative for digital characterization of the ground water basins using relational data structure.


FLINT CREEK
OSAGE CREEK
MIDDLE ILLINOIS RIVER
SEW
CLEAR CREEK
N
0
30 KILOMETERS


Atoka Formation
Bloyd Member
Cane Hill Member
Upper Mississippian Form.
Boone Formation
Chattanooga Shale
N
0
30 KILOMETERS


N
0
30 KILOMETERS

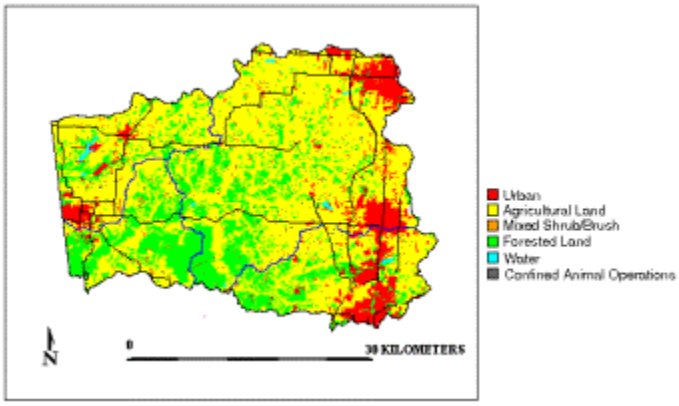

Urban
Agricultural Land
Mixed Shrub/Brush
Forested Land
Water
Confined Animal Operations
N
0
30 KILOMETERS

Figure 4. Sample of primary data sets required by proposed models. Upper: (L) Watersheds and (R) Geology. Lower: (L) Soil Mapping Units and (R) Landuse/landcover.

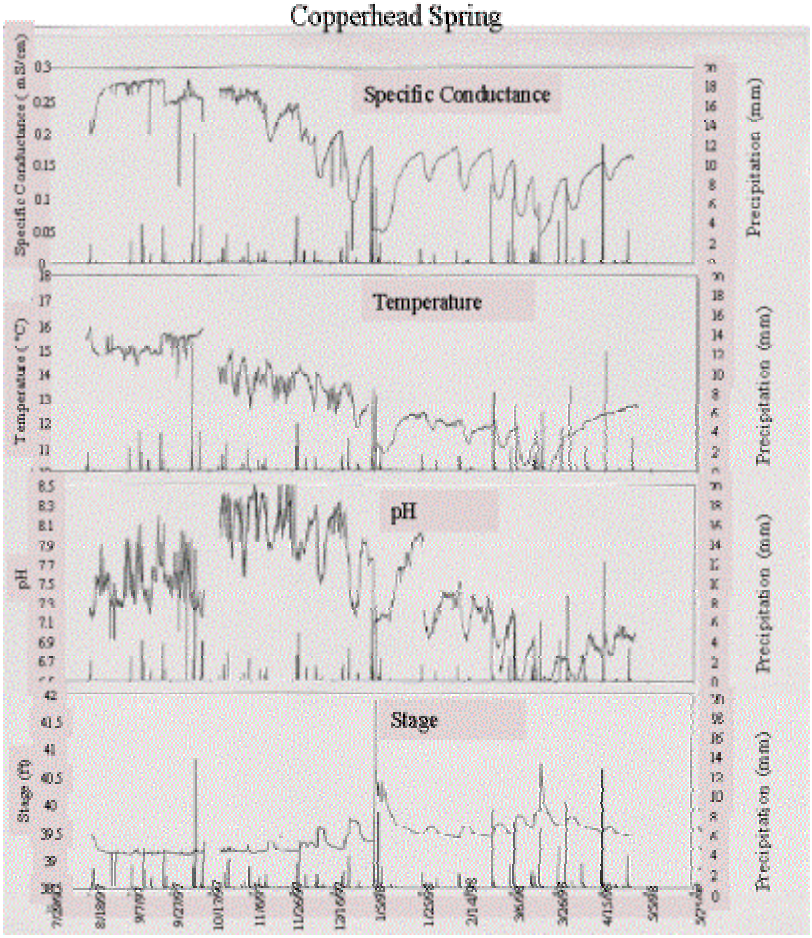


Figure 5. Example of continuous data collected for response of flow and selected water-quality attributes in response to storm events at Copperhead Spring.

The level III classification describes the relationship between storm events, discharge records, and contamination levels (NO_3-N in particular) for each spring. Information on discharge after storm events is critical for identifying preferential flow in fractures and joints.

3. Geology

Level I classification entails the identification of major rock units and geological structure for each sub-basin. In level II classification each rock type will be classified according to its inherent porosity. Level III classification involves relating level II classification of geology to level III classification for spring discharge and contamination. Simple coincidence analysis in GIS will be performed to establish the link between geology and spring data.

4. Soils

Level I classification involves identifying soil map units for each sub-basin. The Order II soil survey data developed by NRCS and digitized at the U of A Soil Physics Laboratory will be used for level II classification of depth (thickness) of the soil mapping units. Level III classification uses information on soil structure particularly shape of the peds. It will be assumed that platy structure will transmit less water vertically than blocky structure, and that prismatic structure will transfer more water than blocky structure, but less than granular structure. Level IV classification involves relating thickness of soil horizons and shape of peds (soil structure) information to the hydraulic properties of soil mapping units. It will be assumed that if soil horizons are thin and structure is favorable (granular) and permeability is high, chances of contamination of the ground water will be higher than if thickness is high, structure is unfavorable (platy) and permeability is low.

5. Fractures and Joints (Preferential Flow Paths)

Potential for preferential flow will be identified from density of fractures/joints. Preliminary maps of fractures/joints exist for SEW and its surroundings (MacDonald et al., 1977). Karst inventory data set available for SEW and its surroundings will be used to refine and update this data layer. Density of fractures/joints will be obtained from total length of fractures/joints in a given area (spring basin). The location and length of the identified fractures/joints will be saved as a level I classification. Level II classification will involve classification of the density of the fractures/joints by using the ratio: S L/A, where, SL = total length of fractures/joints and A = area, i.e. area of ground water sub-basins. We will assume that potential for preferential flow increases as density of fractures/joints increases.

For level III, a relational join will be established between level IV soils classification and density of fractures/joints to identify potential for preferential flow. It is assumed that if the soil layer is thick with unfavorable soil structure (platy) and low permeability above and around fractures/joints, contamination will be less than fractures/joints with thin soil layer, favorable soil structure (granular) and high permeability above and around. The level IV classification involves relating potential for preferential flow characteristic data with spring discharge and contamination.

6. Landuse and Landcover (LULC)

Predominant LULC types classified for the Arkansas GAP project will be used for the level I classification scheme. Level II reclassification will involve identification of different types of pastures (eg. bermuda and tall fescue). Low altitudinal aerial photographs and extensive ground truthing will be used for pasture classification. Level III reclassification will involve relating root depth information to level II pasture categories. Root depth is an important factor in the transport of contaminants at a faster rate to a greater depth. It is assumed that the deeper the root systems the greater the chances of contamination.

7. Animal Wastes/Fertilizers Used

Data regarding use of animal wastes/fertilizers, particularly amount, and time of application are most critical. These data will be obtained either by individual surveys of farmers in the watershed or from County Extension Offices. Level I classification involves types of animal waste/fertilizer. Level II classification involves time and amount of application. Level III classification is aimed at establishing relations between level II classification with respect to storm events.

Justification*: Why reclassify spatial data into multi-level relational structure?*

Reclassification of spatial data will help redefine the complex relations between model parameters. It will reduce the number of input sets required by the model without losing the information. For example, instead of using multiple fuzzy sets for soils data, we will use one fuzzy set for soil as input. An example is shown in Figure 6.

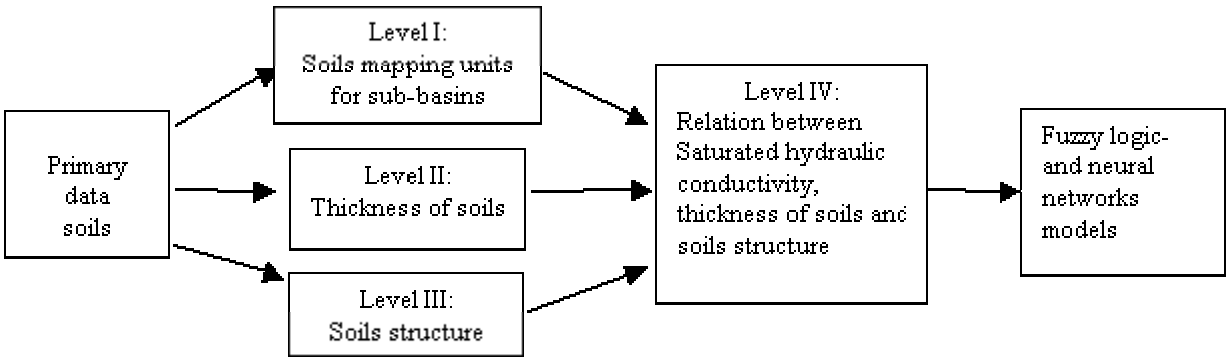


Figure 6. Example of basic classification tree for soil.

Facilities

Existing Infrastructure: An integrated research effort between the U of A, the U.S. Geological Survey (USGS), Arkansas Department of Environmental Quality (ADEQ), Agricultural Research Service (USDA-ARS), and the Natural Resources and Conservation Service (USDA-NRCS), has been established for SEW. The current data-collection infrastructure of SEW includes: 1) two continuous spring sampling stations with 20 minute monitoring for stage, water temperature, specific conductivity, NO_3-N and pH (Campbell Scientific data logger with CSIM11, 247-L, 247W-L, specific ion probes, and Keller Series 169/173 pressure transducer); 2) one surface runoff sampling station in a (normally) dry drainage basin; 3) USGS stream gauging station on the Illinois River at the southwest corner of SEW on Highway 16; 4) 32 augered boreholes, with observation-well completion within regolith at or above the epikarst; 5) well inventory of SEW and contiguous areas to a distance of 5 kilometers, including compilation of geologic logs from existing wells, existing records of water quality, and geophysical logging of six rotary-drilled wells, and two additional wells contiguous to the SEW property; 6) complete weather station, including continuous precipitation record (tipping-bucket rain gages); 7) determination of infiltration using double-ring infiltrometers on

selected soil mapping units and geomorphic settings within SEW; and 8) background determination of selected water-quality parameters sampled from 38 different surface and subsurface locations.

In our laboratories we have the computer facilities needed to develop the spatial databases and GIS, fuzzy logic and neural networks software for modeling. These include six SUN SPARC Stations, five PCs, six printers, digitizer, two scanners, GPS, etc.

Quality Assurance Narrative: Assuring quality of laboratory and field measurements is critical. It is through appropriate QA practices that confidence in the validity of data and reliability of model is achieved. Since various sources/types of data will be used in this study we will discuss all necessary aspects of QA/QC for each data set.

Location information were obtained with two GPS units (PLGR Trimble ProExcell) as well as with standard surveying techniques with levels and total stations. Known benchmark locations were used for accuracy and precision of GPS data. GPS data were differentially corrected with reference to the CAST base station for accuracy.

Ground water basins, spring sub-basins and recharge zones were delineated by multiple dye tracer. Normalized base flow calculations (Brahana 1997) were used to approximate basin size. Dye injection points were used to refine ground water basin boundaries. Dye tracing protocols and procedures followed the methods of Aley (1997) and Quinlan (1989).

Discharge from selected springs in the SEW and its surroundings was measured using continuous V-notch weirs, calibrated with standard USGS stream-gaging techniques. At least 20 sections (5% of flow) for high-flow conditions were used. For low flow conditions, volume/time bucket and a stop watch technique was used. Stage-discharge relations at the Illinois River gage were used for computation of surface water inflow to the study area. Whenever an anomaly was observed, calibration of the equipment and resampling was done. Discharge measurement of ungaged springs were done using standard USGS flow measurement techniques. Discharge was measured from average velocity using pigmy meters and average area of the spring.

Details of the instrumentation are presented in page 12 under the existing infrastructure. Continuous water-quality (W-Q) data were verified by known concentration every two – four weeks, periodic field measurements, and laboratory analyses. Field samples collected for analysis in the laboratory were clearly identified with a label on the sample container and a chain of custody log were maintained from collection through the final disposal of the sample. Samples were analyzed by USDA-ARS, USGS, and AWRC Water Quality Laboratory (U of A) according to their internal standards. QA/QC was conducted on duplicates and blanks. Analytical precision were monitored by duplicate samples that represents at least 10% of the total number of samples collected. QA data are (will be) kept in a notebook, along with the test results. In this fashion, data are readily associated with its sample batch. Information in the notebooks are recorded in ink and archived in Dr. Brahana’s Office. These data along with other spatial data used in

this study will be converted into a readily accessible online data base. Climatic data collected at the SEW was compared to data collected by the Horticulture deptarment periodically.

Some of the landuse data were obtained from CAST, which developed these data as a part of AR-GAP project (CAST 1999) and meets their internal standard. Detailed classification of pasture will be done following procedures by Jensen (1996).

Geology and soils data were obtained from Arkansas Geological Commission and Natural Resources Conservation services (NRCS), respectively, and consequently these data comply with their internal standards. Digital conversion of data for geology and soils were done according to USGS standards where acceptable Root Mean Square (RMS) was less than two for 8 known locations.

Elements of comparability will be ensured by consistent reporting units, using appropriate significant digits and standardization of data format. Ms. Dixon will keep metadata for reclassified digital spatial data (DSD).

Related Research

Justification: W*hy Fuzzy Logic Models?*

Modeling vulnerability of ground water to contamination from non-point sources is not simple. Most, if not all, soil-geo hydrological systems are extremely complex or ill-defined. This causes problems related to parameter estimation and parameter uncertainty that hinder precise mathematical analysis (Fang 1997). Vulnerability is not an absolute property, but a relative indication of where contamination is likely to occur. Uncertainty is inherent in all methods of assessing ground water vulnerability. Assessment only distinguishes some areas in the region as being more or less vulnerable than others (NRC, 1993). Uncertainties arise from errors in methods of obtaining data, the natural spatial and temporal variability of the parameters in the field, and in the numerical approximation and computerization (NRC, 1993).

Methods of assessing ground water vulnerability has been classified as overlay and index, process based, and statistically based. Each method has strengths and weaknesses that affect its suitability for particular applications. Overlay and index methods are commonly used for vulnerability assessment at the regional scale because of availability of data required by these models (NRC, 1993) and the advent of Geographical Information Systems (GIS). However, most GIS applications use Boolean methods. The use of Boolean methods leads to information loss and inaccuracy in analysis; whereas fuzzy logic methods help to cope with problems of uncertainty (Wang et al., 1990). Use of fuzzy logic with DRASTIC parameters has been shown to predict the locations of pesticides contaminated wells better than traditional approaches (Dixon and Scott, 1998; Dixon et al., 1999).

Fuzzy logic models are useful when handling fuzzy inputs because they tolerate imprecision and uncertainty and show marked reduction in information loss (Burrough et al., 1992; Mitra et al., 1998). According to Dou et al. (1997a) the expense of characterizing aquifer spatial variability often results in a lack of available or realistically obtainable direct measurement data. The imprecise model parameters may come from indirect measurements, expert judgment and subjective interpretation of available information. According to Fang (1997) fuzzy logic models help in quantifying conceptual and qualitative models because they emulate the flexibility of human reasoning in drawing conclusions from imprecise and incomplete information.

Several studies have shown that the geologic environments of ground water resources are highly variable, and in general, our quantitative knowledge remains limited (Freeze et al., 1990; Reichard and Evans, 1989). Dou, et al. (1997b) mentioned that incorporation of fuzzy logic techniques in transport modeling of a nonreactive solute material in ground water flow holds the potential to be useful since model parameters or solute concentration calculations are rarely perfectly known (imprecise) and vary with space and time.

Zhu et al. (1997) used fuzzy logic to estimate ground water quality and concluded that multiple mathematical models can be applied to simulate the zonation of contamination, the spatial distribution of contaminants, and the prediction of contaminant concentrations. Moreover, this modeling approach takes advantage of the defensive nature of fuzzy logic, which never excludes areas with slightest potential as ‘not vulnerable area’. Therefore, none of the areas with the slightest vulnerability will be left out. (Mitra et al. 1998; Dixon and Scott, 1998).

Justification: ***Selection of Parameters for Ground Water Vulnerability.***

Oostindie and Bronswijk (1995) proposed a method using climatic, soil physical and hydrological data to assess contamination risk of shallow aquifers by preferential flow of contaminants through fractures. Preferential flow, bypassing flow or macropore flow has been suggested as the cause of higher than normally expected concentrations of nitrate and many pesticides found in ground water (Cohen et al., 1986). According to Kanwar (1991), the appearance of contaminants in large concentrations in water in tiles immediately following rainfall suggests the preferential movement of contaminants to ground water. Steenhuis et al. (1994) suggested that when water and solute loss occurs by preferential flow to deeper soil horizons or ground water, little modification takes place. In Ohio, Edwards et al. (1993) showed that Atrazine transport was affected by factors influencing the amount of preferential flow and by storms relative to the herbicide application. Leidy (1989) found that in karst terrain of northwest Arkansas, contamination is accelerated through fractures particularly when a storm event occurs immediately after fertilizer application. Gaines (1978) compared the contamination of wells between on-lineament wells and off-lineament wells and found that higher concentrations of contaminants were found in the on-lineaments wells. Quisenberry et al., (1993) pointed out that while the importance of soil structure in water and solute transport has been recognized, the quantification of soil structure in a manner that would be useful for modeling transport is lacking. Impacts of the shape of peds on soils

hydraulic properties are mainly related to the continuity/connectivity and amount of interpedal pores (Lin, 1995).

References

Aley, T. 1997. Ground water tracing in the epikarst. In (Beck, B. F. and B. F. Stephenson, eds.), The engineering geology and hydrogeology of karst terranes. A.A. Balkema, Rotterdam, 207-211.

Brahana, J.V., 1997. Rationale and methodology for approximating spring-basin boundaries in the mantled karst terrane of the Springfield Plateau, northwestern Arkansas. In (Beck, B. F. and B. F. Stephenson, eds.), The engineering geology and hydrogeology of karst terranes A.A. Balkema, Rotterdam, 77 - 82.

Brahana, J.V. and R.K. Davis. 1998, Methodology for delineating ground-water recharge areas of springs in the carbonate-rock terrane of northwest Arkansas, and application to five separate spring basins within the region. In (Davis, R.K, J.V. Brahana and J.S.Johnston, eds.), Ground water in northwest Arkansas:minimizing nutrient contamination from non-point sources in karst terrane. Final report for tasks 94-300 and 95-300 to Arkansas Soil and Water Conservation Commission for USEPA, Project # C9996103-02 and C9996102-03, 56.

Burrough, P.A., R. A. MacMillan, and W. Deursen. 1992. Fuzzy classification methods for determining land suitability from soil profile observations. J. Soil Sci. 43:193-210.

CAST (1999). http://www.cast.uark.edu/gap

Cohen, S. Z., C. Eiden, and M. N. Lorber. 1986. Monitoring ground water for pesticides in the USA. In: Evaluation of pesticides in ground water. AGS Symposium series, #. 315, Am. Chem. Soc., 170-196. Washington D.C.

Davis, R.K., J.V. Brahana, and J.S. Johnston. 1998, Ground water in northwest Arkansas: Minimizing nutrient contamination from non-point sources in karst terrane: Final Report for Tasks 94-300 and 95-300 to Arkansas Soil and Water Conservation Commission for U.S. Environmental Protection Agency Projects numbers C9996103-02 and C9996102-03. p. 56.

Dixon, B. and H. D. Scott. 1998. Use of fuzzy logic with modified DRASTIC parameters to predict ground water contamination. In (H. D. Scott, ed.)Vulnerability and use of ground and surface waters in the

southern Mississippi Valley region. AWRC, Pub # 269, pp. 16 - 51. Fayetteville, AR.

Dixon B., H. D. Scott, H. Lin, K. Steele, and J. C. Dixon. 1999. Comparison of modified DRASTIC and fuzzy-logic predictive models in ground water contamination by pesticides. (Submitted to J. Environ. Quality).

Dou, C., W. Woldt, M. Dahab and I. Bogardi. 1997a. Transient ground-water flow simulation using a fuzzy set approach. Ground Water. 35 (2): 205-215.

Dou, C., W. Woldt, I. Bogardi and M. Dahab. 1997 b. Numerical solute transport simulation using fuzzy sets approach. J. Contaminant Hydrology. 27:107-126.

Edwards, W. M., Shipitalo, M. J., Owens, L.B. and Dock, W. A. 1993. Factors affecting preferential flow of water and Atrazine through earthworm burrows under continuous no-till corn. J. of Enviorn. quality. 22: 453-457.

Evans, B. M. 1990. A GIS-based approach to evaluating regional ground water pollution potential with DRASTIC. J. Soil and Water Conservation. 45(2): 242-245.

Fang, J. H. 1997. Fuzzy logic and geology. Geotimes. 10: 23-26.

Freeze, R.A., J. Massmann, L. Smith, T. Sperling, and B. James. 1990. Hydrological decision analysis:1. A framework. Ground water. 28(5):738-766.

Gaines, E. 1978. LANDSAT linear trend analysis: a tool for ground water exploration in northwest Arkansas. 44 - 77 . Masters Thesis. University of Arkansas, Fayetteville.

Jensen, J. R. 1996. Introduction to digital image processing. Printice Hall, NewJersy. p. 318.

Kanwar, R. S. 1991. Preferential movement of nitrate and herbicides to shallow ground water as affected by tillage and crop rotation. In (T. J. Gish and A. Shirmohammadi, eds.). Preferential flow, Proceedings of the National Symposium. American Society of Agricultural Engineers. Michigan. pp.328-337.

Leidy, V. A. 1989. Determination of ground water quality and pollution potential for karst terrain in northwest Boone County, Arkansas. p.154. Masters Thesis. Dept. of Geology. University of Arkansas, Fayetteville.

Lin, H.S. 1995. Hydraulic properties and macropore flow of water in relation to soil morphology. Ph.D dissertation, Texas A&M University, College Station, TX. p. 229

MacDonald, H.C., F.K.Steele and E.Gaines. 1977. Landsat linear trend analysis: A tool for ground water exploration in the northern Arkansas. Arkansas water resources Research center. Pub. #46B. University of Arkansas, Fayetteville. p. 121.

Mitra, B., H. D. Scott, J.C. Dixon and J.M. McKimmey. 1998. Application of fuzzy logic to the prediction of soils erosion in a large watershed. Geoderma. 86:183 - 209.

National Research Council. (NRC). 1993. Ground water vulnerability assessment: contamination potential under conditions of uncertainty. Committee on Techniques for Assessing Ground Water Vulnerability, Water Science and technology Board, Commission on Geosciences, Environment, and Resources. National Academy Press, Washington D.C. p.179.

Numata, K. 1991. General purpose fuzzy reasoning library, v3.0. Tokyo University, Japan.

Oostindie, K. and J. J. B. Bronswijk. 1995. Consequences of preferential flow in cracking clay soils for contamination-risk of shallow aquifers. J. of Environmental Management. 43:359-373.

Petersen, J.C., Adamski, J.C., Bell, Davis, J.V., Femmer, S.R., Freiwald, D.A., and Joseph, R.L., 1998, U.S. Geological Survey Circular 1158, on line at <URL: http://water.usgs.gov/pubs/circ1158>

Quinlan, J.F. 1989. Ground-water monitoring in karst terranes: Recommended protocol and implicit assumptions: U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada, EPA/600/X-89/050. p.88.

Quinlan, J.F., and J. A. Ray. 1995. Normalized base-flow discharge of ground water basins: A useful parameter for estimating recharge area of springs and for recognizing drainage anomalies in karst terranes: In (Beck, B. F. and B. F. Stephenson, eds.), The engineering geology and hydrogeology of karst terranes A.A. Balkema, Rotterdam, pp. 149-164.

Quisenberry, V. L., B. R. Smith, R. E. Phillips, H.D. Scott and S. Nortcliff. 1993. A soils classification system for describing water and chemical transport. Soil Science. 156: 306-315.

Reichard, E. G. and J. S. Evans. 1989. Assessing the value of hydrogeologic information for risk-based remedial action decisions. Water Resource Research. 25(7):1451-1460.

Steenhuis, T.S., J. Ball, G. Shalit, J. S. Selker and I. A. Merwin. 1994. A simple equation for predicting preferential flow solute concentrations. J. of Envion. Quality. 23:1058-1064.

Wang, F., G. Hall and Subaryono. 1990. Fuzzy information representation and processing in conventional GIS software: database design and application. Int. J. GIS. 4:261-283.

Zhu X-Y, Xu S-Hi, Zhu, J-J, Zhou, N-Q, and Wu, C-Y. 1997. Study on the contamination of fracture –karst water in Boshan District, China. Ground Water. 35:538-545.