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Annual Conference:

Environmental Hydrology

Held April 4 and 5, 2000

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AWRC

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PREFACE

The papers and abstracts in these proceedings are the result of a joint conference of the Arkansas Water Resources Center (AWRC) with the South-Central Section of the Geological Society of America. The joint conference was a success with about 250 participants. AWRC sponsored two sessions on Environmental Hydrology and a short course titled "Hydrogeology and Geochemistry of Salt Water Contamination." The Environmental Hydrology presentations covered wide-ranging topics that reflect the diversity of the environmental settings across Arkansas. Topics ranged from salt water and critical ground water issues in the Delta to endangered species and interbasin ground-water recharge in the Ozark Mountains. Other topics covered aspects of source water assessment of public drinking water supplies, water sampling strategies, and constructed wetlands. These topics are excellent examples of the work that state and federal agency water scientists and AWRC affiliated researchers are conducting to provide information that will allow for better management and protection of our water resources. We are very fortunate to have these dedicated scientists working in Arkansas.

All of the papers underwent peer review. We are grateful to Donald Whittemore and Marty Matlock for taking time to help improve our proceedings. Other reviewers have requested to remain anonymous.

Some of the abstracts have previously been published in the Geological Society of America, 34th Annual Meeting South-Central Section, 2000 Abstracts with Programs, Vol.32, No. 3, March 2000 and are reprinted here with permission.

Kenneth F. Steele, Director
Arkansas Water Resources Center

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SOURCES OF SALTWATER INTRUSION IN THE ALLUVIAL AQUIFER IN PARTS OF CHICOT COUNTY, ARKANSAS

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INTRODUCTION

A zone of alluvial ground water containing elevated concentrations of chloride greater than 200 mg/L exists in Chicot County, Arkansas, in a north-south trending band approximately 25 miles in length and 5-6 miles in width. This zone of elevated chloride concentrations (saltwater zone) extends approximately 3-4 miles north of Hwy 144 and south to Hwy 52, near the Arkansas-Louisiana border, and is bounded approximately by Big Bayou to the west and Hwy 65 to the east (Figure 1). The largest chloride concentration in any one well sampled to date is 1,460 mg/L. High levels of chlorides have forced many farmers to abandon row-crop agriculture in favor of fish-farming.

The occurrence of saltwater in the alluvial aquifer in Chicot County was documented as early as 1955 (Onellion and Criner, 1955), and subsequent investigations have sought to delineate the extent and magnitude of the contamination as well as potential sources (Fitzpatrick, 1985; Huff and Bonck, 1993). Potential sources are theorized, as there is a lack of deeper wells in the area by which to document the presence and chemical character of saltwater in lower Tertiary and deeper formations. A present investigation by the authors will contribute to the understanding of sources and transport mechanisms through the drilling of 5-7 wells into the Cockfield and Sparta formations for stratigraphic and chemical analysis. Also, chemical data will be obtained from two deep, thermal wells (Wilcox Formation?) used for fish farming and from brine samples extracted from the Smackover Formation.

GEOHYDROLOGY

Chicot County lies within a region of the state known as the Mississippi Embayment. The deposits underlying this region consist of clay, silt, sand and gravel. Chicot County is underlain entirely by Quaternary-aged alluvial sediments, which were the product of large-scale deposition during the Pleistocene and Recent Epochs. The Quaternary alluvium is characterized by change from fine-grained material at top to a coarse sand or gravel at its base.

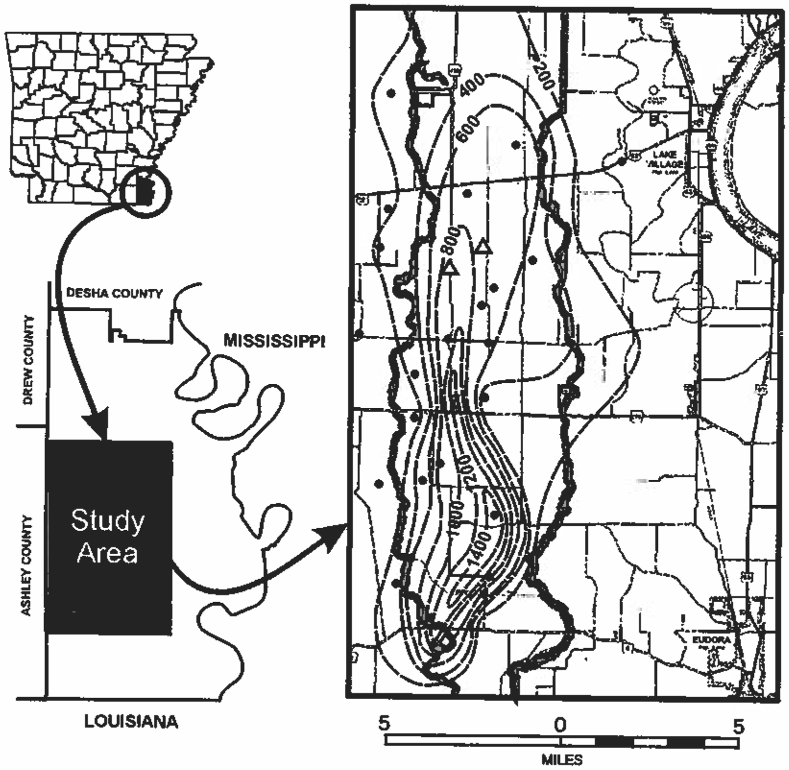

Figure 1. Chloride isoconcentration map of zone of elevated chlorides in Chicot Country Arkansas, Arkansas. Circles represent alluvial wells; triangles represent Cockfield Wells.

The water-saturated portion of the Quaternary deposits is referred to as the alluvial aquifer, and provides water for much of the eastern half of the state. During 1995, 5062 mgd of water was withdrawn from the alluvial aquifer, as compared to approximately 400 mgd for all other aquifers of the state, making the alluvial aquifer the highest-use aquifer in the state (Holland, 1999). Most of the water withdrawn from the alluvial aquifer is used for irrigation purposes. Elevated chloride concentrations can damage crops. Frits et al. (1990) cite chloride concentrations of 100 mg/L and 350 mg/L as threshold and limiting concentrations, respectively, for all crops. Chapman (2000) cites chloride concentrations of 70 mg/L as the upper limit for use on rice crops. As such, much of the ground water within the saltwater zone in Chicot County is supplemented with re-lift water from stream channels for row-crop production, and many farmers have switched to fish-farming because of the poor yields and the toxic effect of chloride to various crops.

GEOCHEMISTRY OF ALLUVIAL AQUIFER

Ground water in the alluvial aquifer varies widely in chemical composition, with total dissolved solids ranging from less than 100 mg/L to greater than 700 mg/L outside of the saltwater zone in Chicot County. The water type in nearly all cases is a calcium-bicarbonate chemistry. Calcium constitutes up to 75% of the total cations and averages approximately 60% of the total. Bicarbonate can constitute up to 98% of the total anions and averages 80% of the total. Chloride is generally low outside of the saltwater zone and averages approximately 30 mg/L. Typically, sodium/chloride molar ratios are greater than one, whereas calcium/bicarbonate ratios are less than one, indicating exchange processes that have enriched sodium in the aquifer at the expense of calcium.

This chemical fingerprint for the alluvial aquifer changes drastically upon entering the saltwater zone in Chicot County, and the chemical gradients are steep. Traveling east from Portland, Arkansas, along Hwy 160, one can move from an area with approximately 100 mg/L chloride to an area with greater than 1000 mg/L in less than two miles. This relationship is shown in Figure 1 in an area of constriction in the middle of the saltwater zone. Within this constriction, the distance from the 400 mg/L contour on the western extent to the 400 mg/L contour line at the eastern extent is less than three miles. At the eastern extent there is a "smearing" of the 200 mg/L and 400 mg/L contours; possibly a reflection of regional ground-water flow direction.

Table 1 provides selected statistics from 24 samples taken in the saltwater zone from the alluvial wells depicted in Figure 1. Although three samples had chloride concentrations less than 100 mg/L, the remaining 21 samples had chloride concentrations greater than 200 mg/L. The minimum chloride concentrations reflect alluvial aquifer chemistry common across most of the Mississippi Embayment area, where calcium concentrations are normally 2-3 times that of sodium, and bicarbonate concentrations are 7-10 times that of chloride. Within the saltwater zone, chloride is the dominant anion at chloride concentrations greater than 200 mg/L in comparison with the calcium-bicarbonate type water outside the zone. The maximum values in Table 1 depict sodium and chloride concentrations 2-3 times that of calcium and bicarbonate, respectively. Factorial increases from the minimum to maximum concentrations demonstrate significant increases in sodium, chloride, sulfate and bromide ions over those of calcium, magnesium, potassium and bicarbonate, and indicate mixing with a source water rich in the former ions. In all samples with chloride concentrations greater than 200 mg/L, the sodium/chloride molar ratio is less than one, indicating a reversal of the exchange process described previously. In addition, although bromide concentrations increase with increasing chloride concentrations, the chloride increase is much greater than the bromide increase so that there is a decrease in bromide/chloride weight ratios. This relationship indicates a source water with bromide/chloride weight ratios less than 2.0×10^{-3}.

Table 1. Selected statistics for analyese from Chicot Monitoring Area Wells.

Parameter	Range	Max/Min	Mean
Calcium (mg/L)	84 – 320	4	195
Sodium (mg/L)	29 – 621	21	232
Magnesium (mg/L)	19 – 148	8	60
Potassium (mg/L)	2.3 – 8.6	4	4.6
Bicarbonate (mg/L)	325 – 569	2	449
Chloride (mg/L)	48 – 1460	30	527
Sulfate (mg/L)	12 – 455	38	139
Bromide (mg/L)	0.2 – 6.8	34	1.9
Br/Cl x 1000 (weight ratio)	6.0 – 2.2	0.4	3.8
Na/Cl (molar ratio)	1.9 – 0.5	0.3	0.8

POTENTIAL SOURCES OF SALTWATER

Causes for the elevated chlorides in Chicot County may be reduced to three potential sources (Fitzpatrick, 1985): 1) upward leakage of saline water from underlying Tertiary formations, 2) encroachment of brine water through abandoned oil-field wells, and 3) movement of brine water along faults extending into deep, brine-producing formations, including the Smackover Formation.

Because of the lack of wells below the alluvial deposits, the presence of saline water in the lower Tertiary units dominantly has been hypothesized from a review of electrical logs from oil and gas exploration wells. Fitzpatrick (1985) suggests that most of the water in the Cockfield and Sparta has become mineralized as a result of increased residence time along its flowpath, and leakage might occur through thinning intervals of the confining Jackson Formation. In comparison, samples collected for this study from two Cockfield wells (represented by triangles in Figure 1) reveal chloride concentrations (380 and 385 mg/L) which are approximately half of that in nearby alluvial wells (750 - 850 mg/L). In addition, two wells in the Cockfield for municipal use in Eudora (Figure 1) have chloride concentrations less than 100 mg/L. In regard to thinning of the Jackson Formation, a review of available well logs and geophysical logs of wells completed for this study in Chicot County does not reveal any thinning of this unit in the area of study.

A review of abandoned oil-field wells in Chicot County revealed that most of these wells were drilled between 1960-1980. One well drilled in 1944 is located near the southern edge of the saltwater zone, and alluvial wells in the vicinity of this well are considerably below the maximum chloride concentrations listed to date. In addition to this fact, many elderly homeowners, who have lived in the area all of their lives, describe the presence of salty water in early, shallow domestic wells. This anecdotal evidence strongly suggests that abandoned oil-field wells are not the primary source for elevated chlorides in Chicot County.

Huff and Bonck (1993) discuss faulting within the Smackover Formation as mapped by Zimmerman (1992). Zimmerman cited the intersection of two wrench faults in the vicinity of the saltwater zone in Chicot County. He states that these faults have been active as recently as the Pleistocene or Holocene Epochs. Zones of increased permeability along these faults could provide flow pathways necessary for movement of brine from deeply buried formations under elevated head pressure into the upper Tertiary and alluvial deposits.

Different scenarios have been proposed to explain the elongated shape and north-south orientation of the saltwater zone. Fitzpatrick (1985) stated that the shape represents a line source rather than a point source, possibly reflecting a fault, although he cited no evidence for faulting. Huff and Bonck (1993), while finding evidence of faulting, provide a map of the elevation of the top of the Cockfield Formation, which depicts a series of stream channels incised into the Cockfield. One main channel extends from Chicot County into northeastern Louisiana. They use the channel theory and density-controlled flow to explain the elongated shape and the fact that migration is restricted in the east-west directions, and suggest that saltwater in the alluvial aquifer is diverted along the channel into northeastern Louisiana. However, Huff and Bonck do not address the presence of the Jackson confining unit, which appears to have a consistent thickness (100' - 150' thick) throughout Chicot County. Another controlling mechanism may be Big Bayou and Boeuf River to the west and east, respectively, as shown in Figure 1. These streams have acted as receiving streams in the past, and, if presently behaving as losing or gaining streams, could provide hydraulic control of the shape of the saltwater zone.

PROPOSED ACTIVITIES FOR CURRENT INVESTIGATION

The present workplan for the ongoing investigation by the Arkansas Department of Environmental Quality and the U. S. Geological Survey proposes the drilling of 5-7 wells in the saltwater zone. Locations and permission by the land owners have been secured for the five sites chosen for the study. Three of the sites are located along an east-west trending line in the vicinity of the constriction noted in Figure 1. Two of these three sites are located near Big Bayou and Boeuf River, and the third near the center of the saltwater zone. Chemical analyses should reveal if there is a similar relationship to the shape of the saltwater zone in the alluvial deposits.

Two wells have been completed at the present date to the south of the area of constriction. One of these wells was drilled to 740' in the vicinity of the well within the 1400 mg/L contour on Figure 1, and is screened at the top of the Sparta Formation. A second well will be advanced into the Cockfield Formation at this same site. The second completed well is located to the east of this site and is one mile east of Boeuf River. This well is screened in the Cockfield Formation at two ten-foot intervals: between 300' and 310' and between 370' and 380'. Sampling from each screened interval will provide information on vertical stratification of the saltwater within the Cockfield formation.

In addition to the advancement and sampling of the 5-7 wells for the project, sampling and analyses also is proposed for 25-30 alluvial wells, 5-10 older wells completed in the Cockfield Formation, two deep wells believed to be completed in the Wilcox Formation (1,500' and 1,800'), and 4-5 wells completed in the Smackover Formation in the El Dorado area and used for extraction of bromide-rich brine water. Analyses from all of these formations will include major and minor ions, trace metals, and isotopic analyses. This information will provide chemical signatures for correlation purposes to aid in the identification of the source water for the elevated chlorides. Valuable stratigraphic information also will be obtained from the drilling of the 5-7 wells and the review of various oil-field electrical logs. Completion of the project including chemical analyses and report preparation is projected for January, 2001.

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SUMMARY CHARACTERIZATION AND SPATIAL DISTRIBUTION OF IRRIGATION WATER QUALITY PARAMETERS IN DESHA COUNTY, ARKANSAS

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INTRODUCTION

Water is one of the most valuable natural resources of the world. For many regions of the world, use of water for irrigation is vital to profitability of production agriculture. Arkansas is one of those regions where dependence upon irrigation is such that those without access to irrigation struggle to sustain profitability, in spite of receiving in excess of 120 cm yr^{-1} precipitation.

Development of saline soils across the world has been predominantly associated with arid or semi-arid climates (U.S. Salinity Lab Staff, 1954). Because all irrigation waters contain some soluble salts, addition of salts to soils via irrigation water exceeding the rate of removal by leaching and surface runoff can result in accumulation of salts in the profile. Many of the soils in Arkansas have low permeability and may have horizons that restrict water and salt movement (Scott et al., 1998a). Because of these properties, salt accumulation occurs in some regions of Arkansas (Slaton et al., 1996).

Arguably one of the more important problems associated with crop irrigation using poor-quality water is the development of alkaline soils. In Arkansas, these soils develop from the use of irrigation water extracted from the alluvial aquifer that is supersaturated with carbonate minerals. The carbonate minerals precipitate in the field in response to changes in CO_2 solubility after the water enters the field (Gilmour et al., 1978). Based on University of Arkansas Soil Test Summaries, as much as 20% of the soils in the Mississippi Delta region of Arkansas may be influenced by $CaCO_3$ precipitation (DeLong et al., 1998). Because most of the alkaline soils in Arkansas result from $CaCO_3$ precipitation, the soil pH in the surface horizon tends to range from 7.0 to 8.3 (Gilmour et al., 1978).

Researchers in the past have characterized the irrigation water quality of Southeast Arkansas, however, few have included geo-reference points for each well nor been all-inclusive of a given region (Baker et al., 1996; Fitzpatrick, 1985). One of the areas identified for possible salinity problems is Desha County in Southeast Arkansas. Significant spatial variability in water quality has been demonstrated within this region and may be significant within a few hundred meters (Moore et al., 1993, Fitzpatrick, 1985).

The overall goal of this project was to characterize the quality of irrigation water sources of Desha County, AR and develop a database that can be utilized to forecast regions of the county where sustainability of the soils are threatened due to salinity and/or alkalinity. The specific objectives were 1.) to analyze irrigation water from each well and relift in Desha County for quality parameters such as electrical conductivity, pH, HCO_3^- concentration, and Cl^- concentration, and 2.) to present and summarize the spatial distribution of the water quality parameters for Desha county in a digital format.

METHODOLOGY

Water Analyses

Approximately 1 L of water was collected from 1,469 wells located in Desha County, AR after pumping for at least 30 minutes. Electrical conductivity (EC) was measured with a Orion© portable conductivity bridge. Bicarbonate (HCO_3^-) concentration was determined by titration with H_2SO_4 and bromocresol green-methyl red indicator solution. Chloride (Cl^-) concentration was measured by titration with $AgNO_3$. The titrations were performed with a portable burette (Hach, Inc.) and calibrated to established laboratory procedures for Cl^- (Cotlove et al., 1958) and HCO_3^- (Kopp and McKee, 1983).

Table 1. Frequency distribution of electrical conductivity (EC) levels in water from irrigation wells and relifts in Desha County, AR

EC	Wells		Relifts		Combined	
	Number	Frequency	Number	Frequency	Number	Frequency
dS m^{-1}		%		%		%
0-0.6	406	33.0	44	31.7	450	32.9
0.6-1.2	712	57.9	74	53.2	786	57.5
1.2-1.5	70	5.7	9	6.4	79	5.7
1.5-2.0	34	2.8	8	5.8	42	3.1
>2.0	7	0.6	4	2.9	11	0.8
Total	1,229	100.0	139	100.0	1,368	100.0

Each well was geo-referenced with a Trimble™ hand-held global positioning system (GPS) receiver and post-corrected with data from the U.S. Coast Guard. Arcview©, a vector geographical information system (GIS), was used to manipulate and develop maps depicting the spatial distributions of the data.

RESULTS AND DISCUSSION

Electrical Conductivity

The salinity of over 90% of the irrigation water sampled in Desha County, AR is below the established threshold of 1.2 dS m^{-1} (Table 1). However, there are regions in the county where potential problems may develop. These include portions in the southeastern part of the county, and portions in the north-central region of the county. The overall impact of EC, without consideration of other factors, is minimal. Only about 10% of the wells have salinity levels that exceed that which is considered to be potentially hazardous to the overall sustainability of the soils (Table 1). In contrast, water from more than 14% of the relifts contained EC levels that exceeded safe thresholds. With an average of approximately 40 ha irrigated per well, more than 5200 ha could potentially develop salinity problems with long-term use of the water.

Chloride Concentration

Chloride (Cl^-) deposition onto soils due to irrigation is an important consideration because of the potential toxic effects of Cl^- to soybean. The distribution of Cl^- concentration in irrigation water in Desha County is varied in its quality. There are several wells in the north-central region and the extreme southern region of the county where Cl^- concentrations are above the critical threshold of 30 mg L^{-1}. Of the 1229 wells tested, 50.7% have Cl^- levels that exceed the threshold for potential accumulation and an additional 34.4% with high enough concentrations for possible accumulation (Table 2). Only 15% of the wells have Cl^- levels considered safe for long-term use. Similarly, 61.9% of the surface water sources contain excessively high Cl^- with an additional 25.9% containing marginal quantities of Cl^-. This indicates that many of these areas have potential for injury to soybean with long-term, continuous use of the water and Cl^- tolerance should be a factor in soybean variety selection.

Bicarbonate Concentration

The distribution of irrigation wells that contain HCO_3^- in excess of the critical threshold of 300 mg L^{-1} suggests that this problem is widespread (Figure 1). According to the data from the water sources sampled, in excess of 45% of the irrigation wells contain levels of HCO_3^- that exceed the threshold of 300 mg L^{-1} (Table 3). An additional 51.5 % contain levels that are just below the threshold in the range of 100 to 300 mg L^{-1}. Due to the potential for development of alkaline soils, this is probably the most serious problem associated with irrigation water in this region, particularly with respect to rice production. Although salinity can be detrimental, the development of calcareous soils is more permanent than salinity in the humid climates of Arkansas, due to greater mobility of the soluble salts.

While the data suggest that many of the wells are not suited to long-term use for irrigation, soil information has not yet been incorporated into this characterization study. Many of the soils of Desha County have a high buffering capacity and may tolerate higher levels of HCO_3^- and Cl^- than suggested by these thresholds. Continued work is needed to evaluate the combined effects of water quality and soil chemical and physical properties. It is believed that current crop management practices are not sustainable and alternatives should be explored.

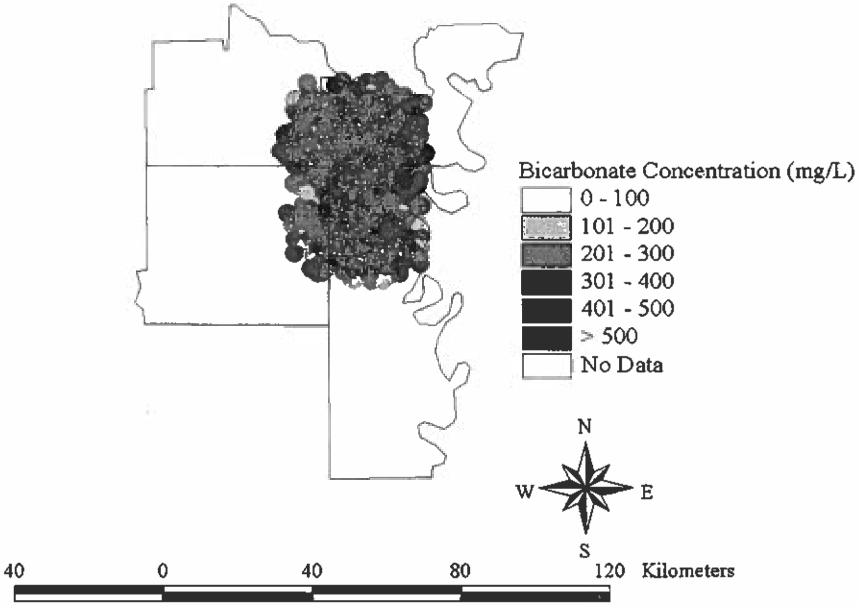

Figure 1. Spatial distribution of HCO_3^- concentration in wells and relifts in Desha County, AR.

Table 2. Frequency distribution of bicarbonate concentrations (HCO_3) in water from irrigation wells and relifts in Desha County, AR.

Cl^-	Wells		Relifts		Combined	
	Number	Frequency	Number	Frequency	Number	Frequency
mg kg^{-1}		%		%		%
0-30	182	14.8	17	12.2	199	14.5
31-70	423	34.4	36	25.9	459	33.6
71-100	214	17.4	14	10.1	228	16.7
101-300	363	29.5	58	41.7	421	30.8
>300	47	3.8	14	10.1	61	4.4
Total	1,229	100.0	139	100.0	1,368	100.0

Table 3. Frequency distribution of bicarbonate concentrations (HCO_3) in water from irrigation wells and relifts in Desha County, AR.

HCO_3^-	Wells		Relifts		Combined	
	Number	Frequency	Number	Frequency	Number	Frequency
mg kg^{-1}		%		%		%
0-50	13	1.1	4	2.9	17	1.2
51-100	20	1.6	4	2.9	24	1.8
101-300	627	51.0	70	50.4	697	51.0
301-500	545	44.4	59	42.4	604	44.2
>500	23	1.9	2	1.4	25	1.8
Total	1,228	100.0	139	100.0	1,367	100.0

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HYDROGEOLOGIC INVESTIGATIONS REVEAL INTERBASIN RECHARGE CONTRIBUTES SIGNIFICANTLY TO DETRIMENTAL NUTRIENT LOADS AT BUFFALO NATIONAL RIVER, ARKANSAS.

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INTRODUCTION

Buffalo National River is located in the Ozark Plateaus of northern Arkansas, one of the nation's largest karst regions. Approximately two-thirds of the Buffalo River's 857,607 acre watershed has soluble limestone and dolomite exposed at the surface (Scott and Hofer, 1995). The study area (Figure 1) covers approximately 57,000 acres and contains numerous springs and caves including a commercially operated tour cave (Mystic Caverns) and the longest mapped cave in Arkansas (Fitton Cave). The study area is characteristic of the National River's broader karst environment and an understanding of ground water processes here can be applied to other karst basins which contribute flow to the Buffalo River.

Water quality monitoring determined that Mill Creek contributes as much as 96 percent of the nitrate load in the Buffalo River below their confluence (Maner and Mott, 1991). Subsequent investigations showed that elevated nutrient (nitrate and phosphate) concentrations impact aquatic communities in both Mill Creek and the Buffalo River (Mathis, 1991; Bryant, 1997). A synoptic study over the length of Mill Creek showed that these nutrients originate from two springs (Upper and Lower Dogpatch) near the head of this tributary (Maner and Mott, 1991).

DISCUSSION

Field observations suggested that the Dogpatch Springs discharged a relativel high volume of water considering their position near the head of the Mill Cree topographic basin. Average yearly base-flow for Mill Creek (23.6 cubic feet pe

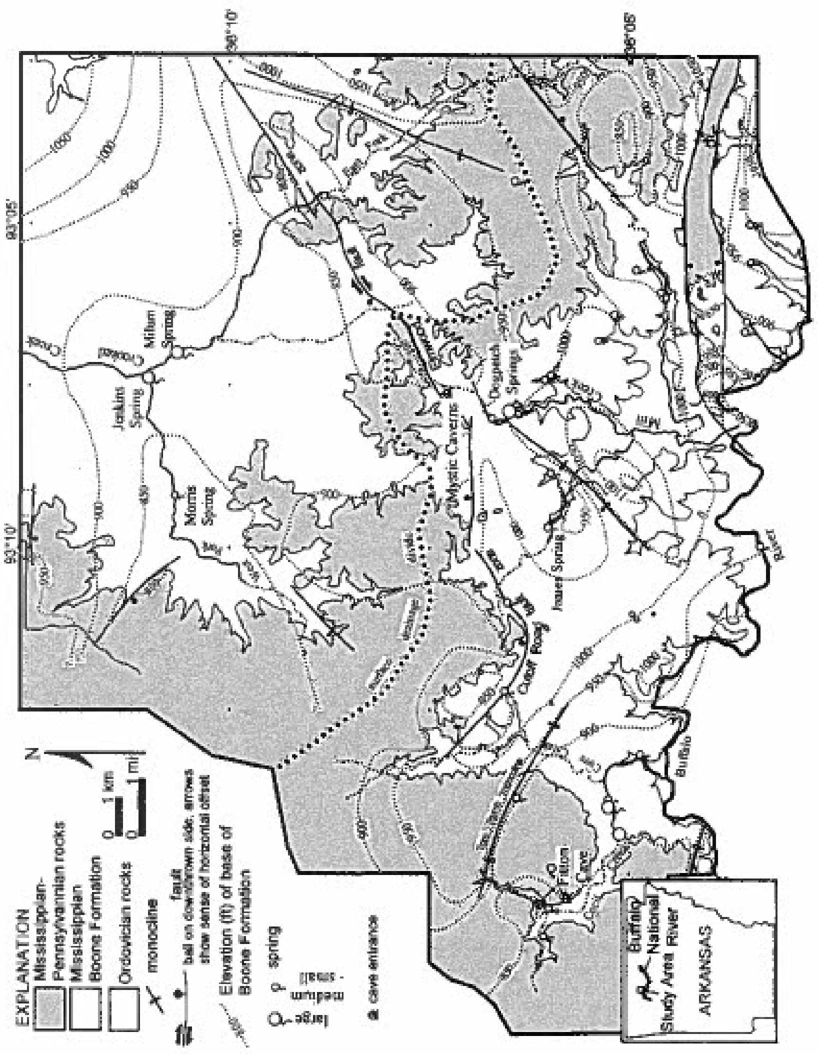

Figure 1. The study area and relevant aspects of its hydrology and geology.

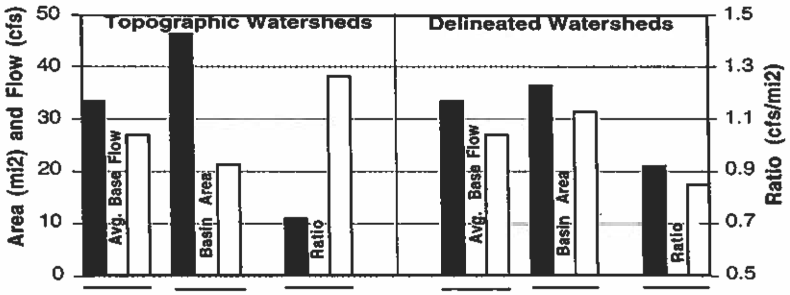

Figure 2. Average base flow, basin size, and discharge/drainage-area ratios for topographic and delineated basins.

second) was divided by its topographic watershed area (21.3 square miles; Sullivan, 1974) to yield a discharge/area ratio of 1.1 cfs/mi^2 (Figure 2). Similar measurements for the adjoining Crooked Creek basin yielded a discharge/area ratio of 0.65 cfs/mi^2. The discrepancy between these ratios provided the first quantitative evidence that flow in Mill Creek is augmented by ground water transferred from the Crooked Creek basin via a subsurface drainage network.

Geologic controls on ground water movement are three dimensional. The distribution of springs is strongly influenced by the stratigraphy of the study area (Figure 3). Fifty-three percent of the thirty inventoried springs of the study area discharge within 40 feet of the unconformable contact between the Mississippian Boone Formation and the underlying Ordovician Everton Formation. The high frequency of springs near this contact is attributed to the less permeable nature of Everton Formation sandstones and dolomites, which variably underlie the 400-ft-thick limestone of the Boone Formation that is more permeable due to secondary porosity. Thirty-six percent of the remaining springs lie near faults

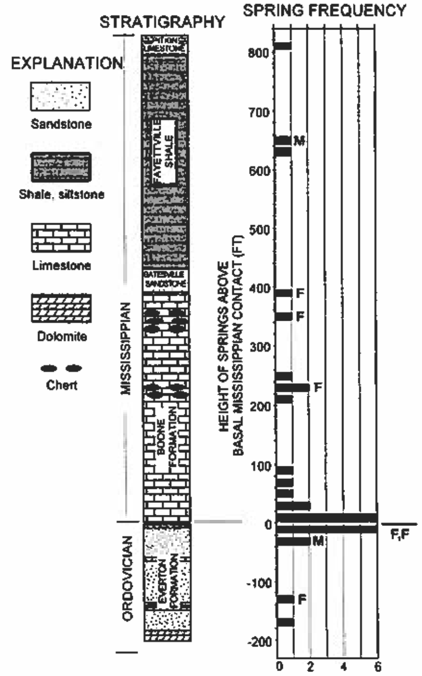

Figure 3. Relation of spring frequency to stratigraphy (F = fault M = monocline).

and monoclines (Hudson, 1998). Three springs issuing from the middle of the Boone Formation are associated with a major chert horizon that is most prominent in the Crooked Creek portion of the study area.

Structure contours show the elevation of the base of the Boone Formation in map view (Figure 1). Large springs within the Buffalo River basin in the southern part of the study area are spatially associated with structural lows, suggesting that these lows may develop extensive karst networks and preferentially gather ground water from surrounding regions. In the southwest part of the study area for example, large springs along Cecil Creek, as well as Fitton Cave, all lie within a broad structural trough bounded on the north by the Tom Thumb monocline. Another example is the location of Upper and Lower Dogpatch springs which emit near the base of the Boone Formation just south of a large low caused by downdrop of the area north of the intersecting Elmwood and Cutoff Road fault zones. Given the present topography, the Dogpatch springs occupy the lowest point where ground water flowing through the Boone Formation can exit adjacent to the corner of this downdropped structural block, thus providing an element of structural control over the location of these large springs.

The northeast-striking Elmwood fault zone trends toward the Dogpatch springs and contains an array of en echelon faults and associated fractures. This zone is the only major structure that traverses both the Crooked Creek and Mill Creek basins. A concentration of karst features (caves, enlarged fractures, sinkholes and losing streams), including Mystic Caverns, that coincides with the fault zone suggests that fractures associated with the zone have enhanced solutional processes. Based on these observations, this zone of solutionally enlarged fractures may preferentially drain ground water within the Crooked Creek watershed and allow it to flow southwest across the watershed boundary to discharge at the Dogpatch springs.

A total of 12 dye traces were conducted to delineate ground water recharge areas and test the interbasin flow hypothesis that was developed from the preliminary karst hydrologic inventories and geologic mapping. Paths of the various dye traces (Figure 4) along with intervening surface topography were used to delineate that 10.2 mi^2 of the Crooked Creek topographic basin supplies ground water to the Dogpatch Springs. The total area of the Dogpatch Springs' ground water basin is thus 13.8 mi^2, or almost four times larger than their topographic watershed (3.6 mi^2). Adding this additional area (10.2 mi^2) to the Mill Creek topographic basin, and subtracting this same area from the Crooked Creek topographic basin, resulted in discharge/area ratios for the delineated basins of 0.75 and 0.82 cfs/mi^2, respectively (Figure 2). These numbers are similar within accepted measurement errors, substantiating the accuracy of the karst aquifer delineations.

The shape of the topographic and delineated basins relative to the Elmwood

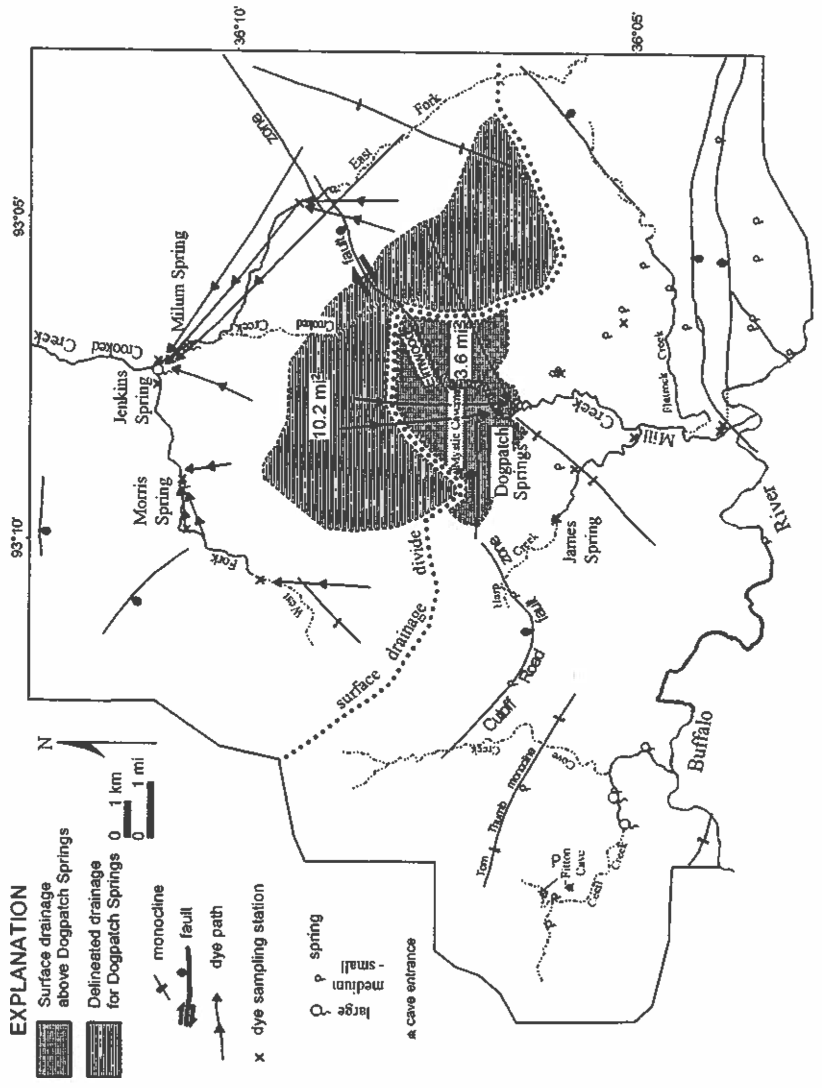

Figure 4. Dye trace paths and topographic and delineated watersheds.

fault zone provides an indication of its influence on surface runoff and ground water recharge. This fault zone appears to influence the shape of the surface basin probably as a result of decreased erosional resistance within this fractured lineament (Figure 4). However, the shape of the ground water basin appears to be independent of this structure as indicated by several dye introductions into this zone along its northeastward trend. The location and elevation of the delineated recharge divide, intermittent and perennial streams, and springs within the study area were used to simulate ground water gradients within the Boone Formation. The southward gradient toward the Dogpatch springs (0.008) is about twice as steep as the northward gradient (0.004) toward Jenkins Spring, and is consistent with the regional potentiometric surface (Pugh, 1998). These results suggest interbasin transfer is mostly independent of interbasin structures, and is principally a function of hydraulic gradient. The location of springs and the size of their recharge areas, however, appear to be controlled by combined elements of ground water gradient, stratigraphy, and structure.

Land use in the Crooked Creek basin is dominated by agriculture, whereas the Mill Creek basin is dominantly forested. Agricultural land uses within the Crooked Creek basin include confined poultry operations, dairies, hay production, and beef cattle operations. Other ground water concerns arise from subdivisions served by on-site septic systems, service stations, illegal dumping in sinkholes and losing streams, and highways upon which hazardous materials are transported. The above concerns are heightened by the fact that karst ground water transport is rapid and provides little chance for attenuation of contaminants. As an example, dye introduced into a sinkhole filled with cattle carcasses moved over two miles from the Crooked Creek basin to the Dogpatch Springs at the head of Mill Creek in less than five days.

Four base-flow water samples were collected and analyzed for a suite of water quality parameters during 1998 and 1999 at major springs within the Crooked Creek and Mill Creek basins, and at a reference spring (Luallen Spring) within a nearby forested basin (Figure 5). In comparing spring water quality it was noted that James Spring was not a recovery point for any of the dye traces from the Crooked Creek topographic basin, Upper Dogpatch Spring received dye from one trace, and Lower Dogpatch Spring received dye from two traces. The highest nutrient concentrations were recorded at springs within the Crooked Creek topographic basin, as would be expected given the more intensive agricultural land use there. Nutrient concentrations within the Crooked Creek springs, however, were closely mirrored by those Mill Creek springs that received dye from the Crooked Creek topographic basin (Upper and Lower Dogpatch). James Spring was significantly lower in nitrate than either the Crooked Creek or the Crooked Creek-influenced springs, and the reference spring was significantly lower than all sites for both nitrate and phosphate. Average fecal coliform bacteria concentrations showed similar relationships.

During summer, high water clarity, low discharge (and therefore low dilution), slow velocities, and warm temperatures make the Buffalo River susceptible to enhanced algal and cyanobacterial production caused by elevated nutrient levels. For perspective, the average nitrate-N concentration in the Buffalo River is 0.06 mg/L, whereas the average nitrate-N concentration at Lower Dogpatch Spring is 1.52 mg/L, twenty five times greater (Mott, 1997). Dissolved reactive phosphorus averages were five times greater for this spring than for the river.

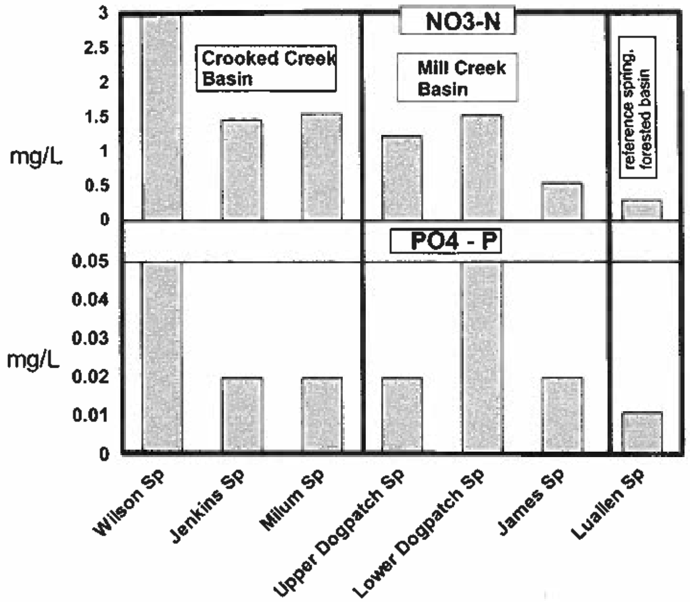

Figure 5. Average nitrate and soluble reactive phosphate values at major springs in the study area and at a reference spring.

Because nitrogen and phosphorus are limiting nutrients, raising their concentrations increases primary productivity. Increased aquatic plant production alters stream communities at various trophic levels, skewing them toward pollution-tolerant species or toward benefiting functional groups (filter feeders, scrapers or grazers, and herbivorous fish) (Mathis, 1992; Bryant, 1997; Petersen, 1998). To park visitors, increased productivity means green water (phytoplankton), green slime (*Spyrogyra* and other filamentous green algae), and a general reduction in aesthetic appeal.

CONCLUSIONS

This study yielded the following conclusions: 1.) base flow discharge/area ratios can be used to screen areas for interbasin transfer; 2.) detailed geologic mapping and karst inventories, combined with dye tracing, can elucidate physical properties of aquifers which influence interbasin transfer and are therefore critical scientific, managerial, and interpretive tools in karst settings; 3.) areas of interbasin transfer can be significant both in their size and in their influence on water quality and aquatic communities, and must be accurately delineated for effective water resource management; and 4.) hazardous materials derived from spills, dumps, or leaks can be rapidly transported long distances via karst ground water systems.

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OPTIMUM SAMPLING INTERVALS FOR CALCULATING POLLUTANT LOADS IN STREAMS

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INTRODUCTION

Accurate measurements of pollution loads in streams are critical for determining the impacts of non-point source (NPS) pollution and for developing total maximum daily loads (TMDLs). A common sampling method for determining pollution loads is to continuously monitor flow and intermittently collect water samples. Loads are then calculated by multiplying the measured concentration by the discharge between sampling times or between the mid-point of sampling intervals. This method, in effect, assumes that the sample concentration represents the concentration in the stream between samples. This approach can lead to errors when the concentrations are not steady. Much or most of the load in a stream is transported during storms, and often the majority of the storm load is transported during the "first flush" or the rising limb of the hydrograph. This load may be missed unless storms are intensively sampled.

Storm loads can be estimated from limited data using a load calculation model that incorporates the correlation between concentration and flow (Haines, 1997). Usually the sampling data does not contain enough high flow concentration data to confidently make those correlations (Green, 1998), the correlations are not very strong, and the resulting load calculations can be inaccurate and imprecise. Intensive storm sampling using frequent discrete samples or flow-weighted composites can be used to more accurately measure storm loads.

The purpose of this study was to determine the optimum number and timing of storm and baseflow water quality sampling to determine pollutant loads in streams with high precision and accuracy. The objectives of this study were to:

1.) Accurately determine pollutant loads at two sites by sampling storm runoff events at thirty-minute intervals.
2.) Develop sub-sampling and other data analysis techniques to determine the effect of sample interval on load calculation accuracy.
3.) Find the minimum sample interval required to determine storm loads at a required accuracy.

This study used two sites in the Illinois River basin in Arkansas. Nutrient loads in the Illinois River are of great interest to the states of Arkansas and Oklahoma. The two states have agreed to a 40% reduction in total phosphorus load entering Lake Tenkiller in Oklahoma. The baseline is the 1980-1993 monitoring data and a five-year moving average is used for assessment. By 1997, sampling data indicated a total phosphorus reduction of 22.9% in the main stem of the Illinois River (Maner, 1998). These data sets have resulted from bimonthly grab sampling. The Illinois River basin includes point and non-point pollution sources. Point sources, namely wastewater discharges, have been improved in the past couple of decades and the current focus is on non-point sources. Northwest Arkansas is home to many confined animal operations and a number of best management practices (BMPs) for agricultural non-point pollution control have been researched, demonstrated, and implemented in the region.

METHODOLOGY

The two sampling locations used were:

1.) Moores Creek, a small 1st order stream with a drainage area of about 1000 hectares in the headwaters of the Illinois River. Moores Creek is impacted primarily by non-point source pollution from agriculture, forest, and low-density housing.

2.) Illinois River near Siloam Springs Arkansas, a larger 3rd to 5th order stream with a drainage area of about 150,000 hectares. The Illinois River is impacted by urban point source and rural non-point source pollution.

Gauges at the sites continuously measured and recorded stage and calculated discharge. Automatic samplers installed at the sites were triggered by the stage gauges to take storm samples at 30-minute intervals during the rising limb (the first 24 samples) and 60-minute intervals during the falling limb (the second 24 samples) of the storm hydrographs. All samples were collected from the sites

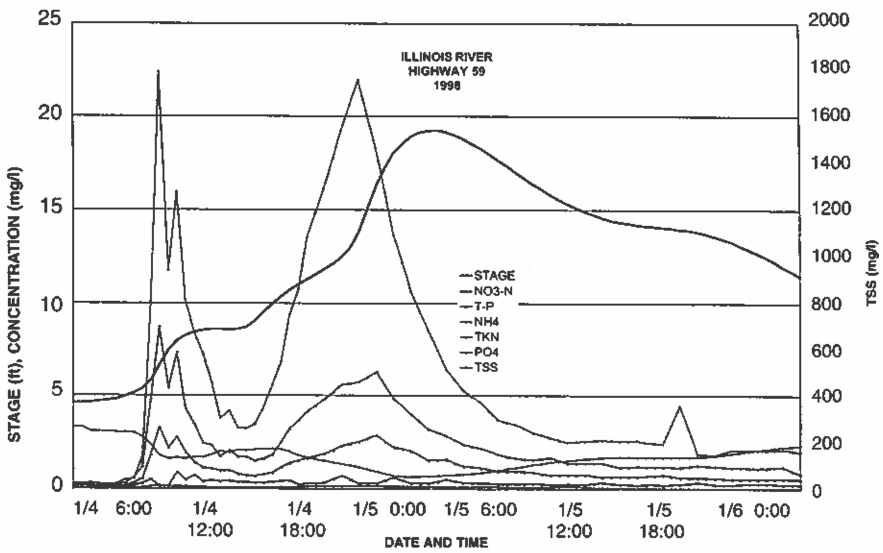

Figure 1. 1/4/98 Storm discharge and concentrations - Illinois River at Hwy 59.

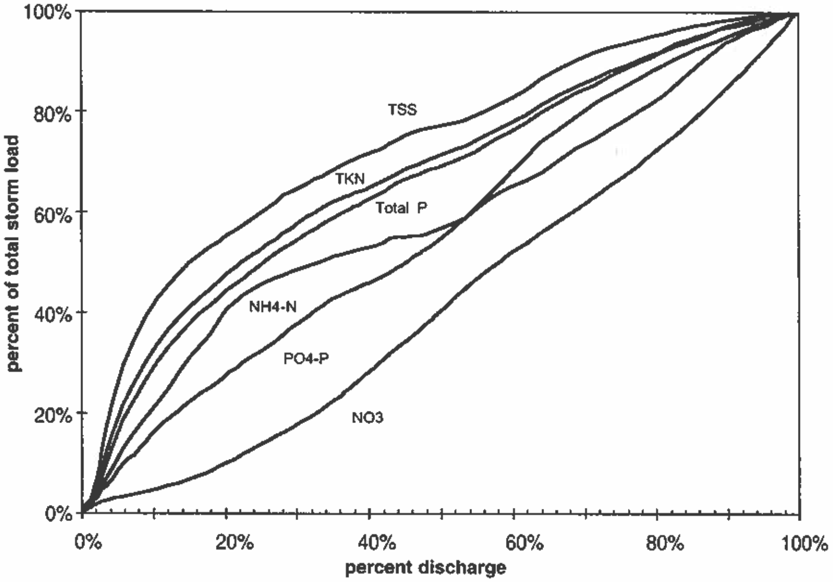

Figure 2. Percent load versus percent volume.

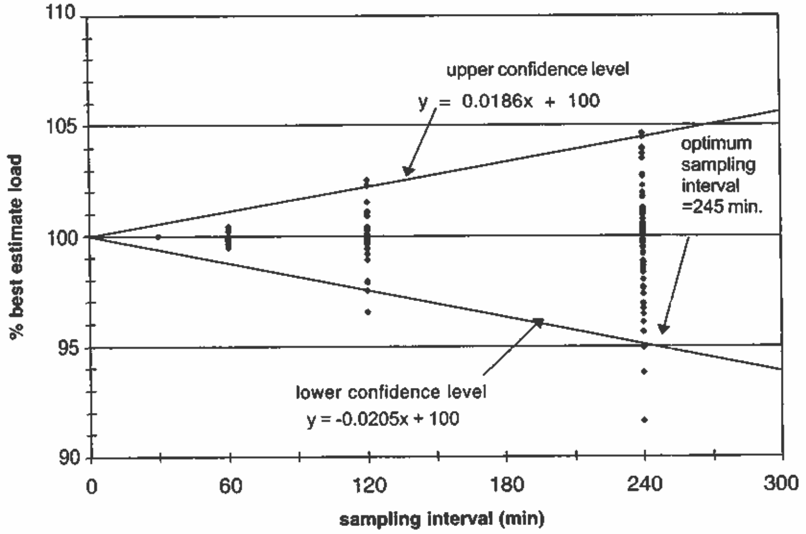

Figure 3. TKN Loads as percent of best estimate load - Illinois River at Hwy 59.

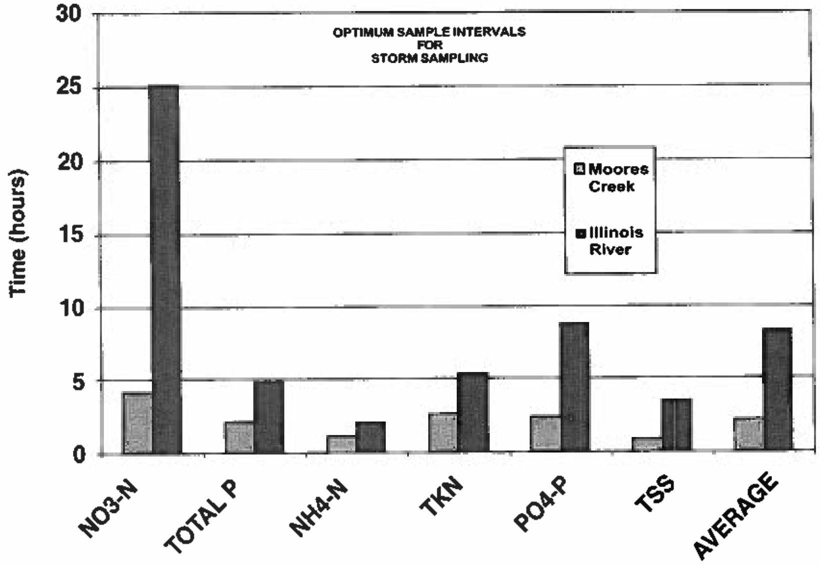

Figure 4. Optimum sampling intervals.

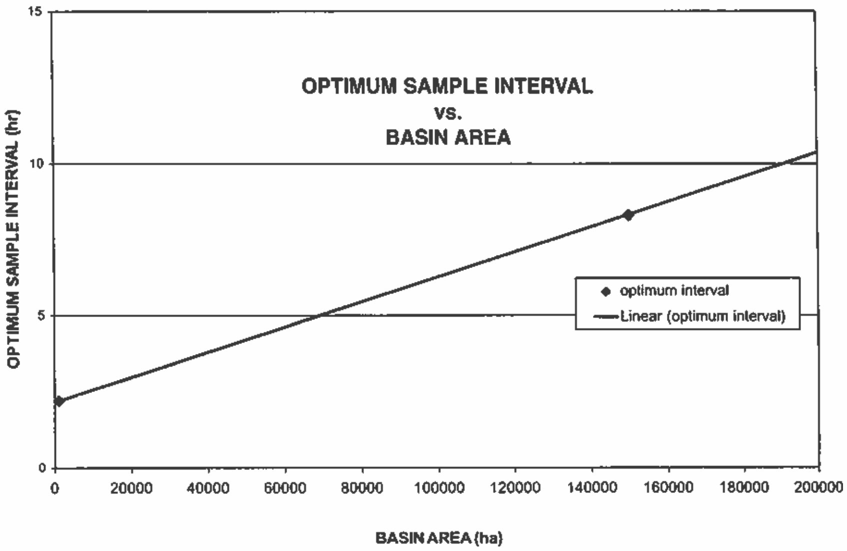

Figure 5. Possible relationship of optimum sampling interval to basin size.

within 24 hours and analyzed at the Arkansas Water Resources Center Water Quality Lab using EPA approved analysis and quality assurance / quality control (QA/QC) procedures. The samples were analyzed for nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_4-N), total Kjeldahl-nitrogen (TKN), ortho-phosphate (PO4-P), total-phosphorus (T-P), and total suspended solids (TSS).

In the time period from September 1997 to June 1999 a total of 750 samples were taken at the main stem of the Illinois River site and 450 samples were taken at the Moores Creek site. These samples covered 14 storm events on the Illinois River and eight storm events on Moores Creek. Storm loads were calculated by multiplying discharged volume by concentration for each sampling interval and summing these increments over the storm. Concentrations for the "missing" data points between each of the 60-minute samples on the falling hydrograph were filled in by interpolation. Thus, each storm event had 30-minute concentration data for the first 36 hours of the storm. The loads calculated using the 30-minute interval data were termed the "best estimate" loads. Loads were also calculated for 60, 120, and 240-minute sampling intervals using subsets of the data. The load estimates for the longer sampling intervals were expressed as a percentage of the best estimate load.

Optimum sampling intervals were calculated as the sampling interval that gives an estimate within five percent of the best estimate load with ninety-five percent confidence. An approximate 95% confidence interval for the mean load estimate error for each sampling interval was calculated as the mean plus or minus 1.96 multiplied by the standard deviation. A regression line was then fit to the upper and lower confidence levels versus sampling interval (forced to 100% at t=0). The optimum sampling interval is the lesser of the intervals where the upper or lower line crosses five-percent error.

RESULTS

A plot of the discharge and the relative TSS concentrations at the Illinois River Hwy 59 site during a storm starting January 4, 1998 is shown in Figure 1. A "slug" or spike of solids came through during the first flush of the storm. A second, larger increase in rainfall and discharge produced another slug of solids. Note that the second peak of nearly ten times greater discharge produced a concentration spike similar to the first spike. Also note that after the spike on the rising limb of the hydrograph, the discharge remained high but the TSS concentration had decreased. TKN and T-P concentrations followed the pattern of the TSS concentrations. Nitrate-N decreased with higher flows, showing a dilution effect. Ortho-phosphate and ammonia-N acted in an intermediate fashion.

A plot of percent of storm load versus percent of volume for the January 4, 1998 storm at the Illinois River Hwy 59 site is shown in Figure 2. More than 50% of the TSS load is transported during the first 20% of the discharge volume. Because of the high concentrations during the rising limb of the hydrograph, all of the parameters except nitrate-N have most of their load transported during the first portion of the storm.

The calculated TKN loads for nine of the fourteen storms at the Illinois River Hwy 59 site as a percent of the best estimate load is plotted versus sampling interval in Figure 3. As sampling interval increased, the error of the load estimate increased. The optimum sampling interval calculation is demonstrated on Figure 3. If the calculated load is to be within 5% of the best estimate load with a 95% confidence level, Figure 3 shows that samples should be collected at least every 4 hours during a storm. Using these criteria, the optimum sampling interval for TKN at the Illinois River Hwy 59 site is 4 hours.

This optimum sampling interval varies with the parameter measured and with the stream order or basin size. The optimum sample interval for the six measured parameters for both sites and an average value for all six is shown in Figure 4. We see that the pollutants that show the most peaking effect during a storm require the smallest sampling interval. Also, Moores Creek, which is flashier than the main branch of the Illinois River, requires a shorter sampling interval for accurate storm load calculations.

DISCUSSION

The optimum sampling interval appears to be a function of the parameter measured and of the drainage basin size or stream order. It is much more sensitive to the parameter measured than drainage basin size. It is desirable to quantify the effect of these variables on the optimum sampling interval. A possible relationship between sample interval and basin size using the average value for the six parameters measured is shown in Figure 5.

CONCLUSIONS

The following conclusions can be made from this study:

1.) The sample interval affects load calculation precision and accuracy.
2.) An optimum sample interval can be calculated using sub-sampling techniques.
3.) The optimum sample interval varies by parameter measured and by drainage basin size but is most sensitive to the parameter measured.

ACKNOWLEDGEMENTS

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DESIGNATION OF CRITICAL GROUND-WATER AREAS IN ARKANSAS, UTILIZING HYDROGEOLOGIC AND GEOGRAPHIC INFORMATION SYSTEM TECHNIQUES

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ABSTRACT

The Arkansas Soil and Water Conservation Commission (Commission), pursuant to the Arkansas Ground Water Protection and Management Act of 1991, has designated two critical ground water areas. The first critical ground water area was declared for the Sparta Sand in five counties of southern Arkansas in 1996. The second critical ground water area was designated in July 1998, and included both the alluvial and the Sparta aquifers in a six county area of east-central Arkansas. Designation of a critical ground-water area is in response to hydrogeologic data presented to the Commission annually. Criteria defined in the Commission's Rules For The Protection and Management Of Ground Water include: water-levels declining at an average annual rate of one foot per year or more, a saturated thickness of fifty percent or less of the formation (water level below the top of the formation for a confined aquifer), water quality degradation, trends indicating water-level declines and/or water-quality degradation, and safe yield. The data are analyzed using hydrogeologic and geographic information system techniques. A trend of water-level declines, which exceed critical area criteria, is observed in both the alluvial and Sparta aquifers, as indicated by cones-of-depression in the potentiometric surface, hydrographs, water-level change maps, and ground-water flow model projections. Once a critical ground water area is established, State and Federal agencies focus resources on the enhancement of conservation and education programs. The Arkansas General Assembly also targets legislation toward these areas.

THE SOURCE WATER ASSESSMENT PROGRAM IN ARKANSAS

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ABSTRACT

The main purpose in establishing the Arkansas Source Water Assessment Program (SWAP) is to provide another means to enhance the Arkansas Department of Health's (AHD's) continuing efforts to protect public drinking water supply sources. Providing public water systems and their customers with information concerning their drinking water supply enables them to implement protection activities. Such activities can help to assure a continued safe drinking water supply and, in some cases, limit capital expenditures for treatment.

The second purpose of the work is to develop base data that can be used by ADH. Because of the large number of drinking water sources and potential sources of contamination (PSOCs), it would be enormously expensive to field map all this data, however some Global Positioning System (GPS) work will be done. Using Geographic Information Systems (GIS) technologies and existing and edited data, the goal of this effort is to develop a data set that can serve as a useful basis for assessing the vulnerability of the public drinking water sources. With cooperative partners, database and GIS development is being performed. This includes the creation of seamless statewide coverages of all drinking water sources, PSOCs, and numerous GIS data layers. Several GIS macros will be developed in order to process the GIS data analysis of each source into a useful form and for map creation.

The Arkansas SWAP establishes a methodology to perform vulnerability assessments in an effort to provide information / data to water systems and their customers. This information / data will be pertinent to promoting drinking water source protection programs.

ARKANSAS' SOURCE WATER ASSESSMENT PROGRAM DELINEATIONS FOR GROUNDWATER AND IMPLICATIONS IN MANTLED KARST AQUIFERS

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ABSTRACT

The Arkansas Source Water Assessment Program (SWAP) has been approved by the EPA and is currently being implemented. Due to the karst hydrogeology in northern Arkansas special delineations are made for springs and wells that are influenced by surface water.

In Arkansas, a 1/4 mile radius drawn around the wellhead delineates wells that are not under the influence of surface water. Springs and wells in which groundwater is under the direct influence of surface water (GWUDI) are delineated by a 1/2 mile radius drawn around the spring or wellhead. As final criteria, if a stream crosses the 1/2 mile radius around a spring or GWUDI well, then a three-mile radius becomes the delineated area.

While in some areas delineations made in accordance with the SWAP are sufficient, in many areas they are not. Delineations made by dye tracing, pump tests, computer modeling, and other field studies show the inadequacies of the SWAP delineations of 1/4, 1/2, or 3-mile radii. Beyond inadequacies, the delineations may also include areas that are not in the recharge and contributing areas for the springs or GWUDI wells. This becomes important if Source Water Protection Plans are developed for the delineated area. Correct delineations are imperative to adequately define potential sources of contamination for the public water supply and to avoid unneeded planning and management from non-contributing areas. This is especially critical in Northwest Arkansas due to the karst hydrogeologic environment.

SURFACE WATER SOURCE METHODOLOGY FOR ARKANSAS' SOURCE WATER ASSESSMENT PROGRAM

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ABSTRACT

A Source Water Assessment Plan (SWAP) is being developed as a management tool for public-water systems to enhance the protection of their water source as required by the Safe Drinking Water Act Amendments of 1996. This plan is to delineate source-water assessment areas and identify potential contaminant sources within these areas, and perform a susceptibility assessment to provide public-water systems and their customers with information regarding their drinking water supply. These three elements, source-water assessment area delineation, potential contaminant source inventory, and susceptibility assessment, make up a source-water vulnerability assessment.

The State of Arkansas has approximately 1,519 individual public drinking-water sources from both ground and surface-water sources. Included in this total are 101 surface-water sources of which 69 are reservoirs, lakes, or ponds and 32 are rivers or streams. A vulnerability assessment will be conducted for each of the 101 surface-water sources.

A methodology has been devised to perform vulnerability assessments to provide information that will enhance the implementation of drinking-water source protection programs. Within an assessment area, each potential source of contamination will be identified, categorized according to its relative public health significance and proximity to the drinking-water source intake, and mapped. Each water system will receive a report compiling all of the vulnerability information related to their drinking-water source. The culmination of the vulnerability assessment will result in a designation of low, medium, or high source susceptibility for each public drinking-water supply.

TRAJECTORIES OF WATER QUALITY PARAMETERS AND ENDANGERED BIOTA IN CAVE SPRINGS CAVE, ARKANSAS

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ABSTRACT

The Ozark Plateaus are a karst physiographic region with many caves that harbor troglobites (obligate cave fauna), some of which are rare and endangered. Cave Springs Cave, in Benton County, Arkansas, contains several of these animals including Ozark Cavefish (Amblyopsis rosae), a cave amphipod (Stygobromus ozarkensis), and gray bats (Myotis grisescens). Monitoring of these species during the past two decades has revealed an increase in cavefish, possible extirpation of the amphipod, and a decrease in numbers of gray bats during this time. Concurrently, the water quality has declined. Statistically significant trends of increase in conductivity, nitrate, zinc, and lead occurred. Several metals are present in toxic concentrations in the water, sediments, and tissues of troglophilic (facultative cave fauna) crayfish (Orconectes punctimanus). The phthalates DEP and DEHP, which are thought to be carcinogens and hormone disruptors, are present in the water and crayfish tissue. No pesticides have been detected in the cave water, crayfish tissue, or bat guano. Fecal coliform densities regularly exceed Arkansas'water quality standards in samples collected upstream of the area where bats roost. Furthermore, concentrations of nutrients, metals, and total coliform bacteria were highest during storm flows. This indicates that pollution of the ground water may originate from land application of confined animal wastes (primarily poultry lifter) or from septic system leachate in the recharge area of this cave spring. Reduction or cessation of the land application of municipal sewage sludge and confined animal waste in cave recharge zones is recommended.

USING CONSTRUCTED WETLANDS FOR REMEDIATION OF WASTEWATER ORIGINATING ON SWINE FARMS

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ABSTRACT

Nutrient management on modern swine rearing facilities is an environmental concern as a large number of animals may be confined to a limited land base. Constructed wetlands used for nutrient reduction are a potential solution to this problem. This study was designed to assess surface and ground water in constructed wetlands associated with swine farms, demonstrate the efficiency of two different wetland designs for nutrient removal from water originating in swine rearing facilities, and demonstrate that constructed wetlands are a best management practice that farmers can utilize at a relatively low cost. Constructed wetlands at three swine farms located in Arkansas were monitored for nutrient concentrations and mass loads in inflow and outflow surface waters. Total P concentration reductions averaged 82%, while P mass load reductions averaged 48%. Total nitrogen (N) concentration and mass load reductions averaged 91% and 60%, respectively. The constructed wetlands in this study were efficient in nutrient concentration and mass load reductions. However, more research is needed to determine how long it will take for the constructed wetland soil to become saturated with P, rendering them less efficient in P removal. Construction of the wetlands proved costly, and seasonal fluctuations in water posed additional problems.