EXTENDED ABSTRACTS FROM

FIFTH TENNESSEE WATER RESOURCES SYMPOSIUM

Nashville, Tennessee
October 19-21, 1992

Sponsored by

U.S. Geological Survey, Water Resources Division • Tennessee Valley Authority
Oak Ridge National Laboratory • Environmental Consulting Engineers, Inc.
American Institute of Hydrology • Tennessee Technological University
Tennessee Department of Environment and Conservation • Memphis State University
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In cooperation with

Tennessee Section of the American Water Resources Association

Cover Photo: Ranger Falls in the Savage Gulf State Natural Area, Grundy County, Tennessee. This picturesque natural karst area along the edge of the Cumberland Plateau is famous for its numerous springs, waterfalls, and disappearing streams. Water in Ranger Creek flows from the Cumberland Plateau, drops over the 25 foot high Ranger Falls, forms a pool, disappears into a cave at the base of the cliff, and eventually reappears as springs feeding Big Creek.

Photo by G.E. Hileman, U.S. Geological Survey

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Maxwell House Hotel
Nashville, Tennessee
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Edited by

Ferdinand Quinones
and
Katrina L. Hoadley

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GLOSSARY OF ACRONYMS:

USGS - U.S. Geological Survey
TVA - Tennessee Valley Authority
ORNL - Oak Ridge National Laboratory
ECE - Environmental Consulting Engineers, Inc.
AIH - American Institute of Hydrology
TTU - Tennessee Technological University
TDEC - Tennessee Department of Environment and Conservation
MSU - Memphis State University
USACOE - U.S. Army Corps of Engineers

PREFACE

Late in 1987, the idea of organizing a forum for researchers studying the water resources of Tennessee germinated during a meeting I held with Mike Yurewicz (USGS) and Dr. Dale Huff (ORNL). Mike also was engaged in organizing the Tennessee Section of the American Water Resources Association, while Dale was actively launching the Tennessee Chapter of the American Institute of Hydrology. I was equally busy adapting to my new position as Director of the USGS in Tennessee. Our enthusiasm prevailed, and after recruiting Larry Richardson (TVA), Dr. Bill Miller (Saturn), and representatives from the U.S. Army Corps of Engineers, Tennessee Technological University, and several State agencies, the First Tennessee Hydrology Symposium was successfully organized and held in Nashville in 1988, with 24 papers presented and about 125 attendees. From the beginning, we knew that naming an activity the "First" implied a series of future similar meetings. Annual symposia were held each year from 1989 to 1991, but the symposium name was changed in 1991 to the "Water Resources Symposium" replacing the more limiting "Hydrology Symposium" title. The 1991 Symposium, chaired by Dr. Mike Sale (ORNL) and held in Knoxville, was the most successful of the series, with 39 papers, 14 posters, and with an attendance of about 250 people.

The Fifth Tennessee Water Resources Symposium promises to follow the successes of the previous meetings. The theme of the Symposium is "interorganizational cooperation" through exchanges of data and sharing of resources. The papers to be presented during the meeting and summarized in these proceedings testify to the spirit of this theme. The keynote speaker, Dr. Neil M. Woomer, TVA, will address the important issue of the "invasion" of zebra mussels into the streams and lakes in the Tennessee Valley, and their potential impact. Researchers from the USGS, TVA, TTU, TDEC, UT, ORNL, MSU, and private consultants will present 32 papers in two concurrent sessions that are divided in four general themes: Ground Water and Karst Hydrology, Surface Water Hydrology, Water Quality, and General Hydrology. A panel representing the three Institutes involved in water-resources research at TTU, UT, and MSU will present a summary of their activities and goals. Two evening poster sessions including 10 formal and several informal presentations will supplement the oral presentations. The scope of the oral papers and posters address the most important water-resources issues in Tennessee, and the results of the investigations provide an insight into specific water research in the State.

In spite of the breadth of the abstracts presented at the Symposium, many water-resources related issues in Tennessee are not addressed. Although Tennessee is blessed with abundant water resources, many actual and potential problems threaten this important resource. The goals of the sponsoring organizations of the Fifth Tennessee Water Resources Symposium are to continue these forums, which in many ways will help to optimize the use and conservation of the water resources in Tennessee.

Ferdinand Quinones, Editor

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Board Members of the
Tennessee Section of the American Water Resources Association
and
Organizing Committee of the Fifth Tennessee Water Resources Symposium

ZEBRA MUSSELS - THE SPREADING INVASION

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The zebra mussel (Dreissena polymorpha) was accidentally introduced into the Great Lakes from Europe about 1986. It is an extremely prolific animal forming a strong byssal attachment to virtually any firm submerged surface. Its subsequent rapid spread throughout the Great Lakes Basin has resulted in extensive economic and ecological impacts, including clogging and fouling of power plant and water supply intakes; damage to boats, motors and navigation facilities; and destruction of native mussel communities. It has now spread to other river systems in the U.S., including the Hudson, Susquehanna, Ohio, Mississippi, Cumberland and Tennessee. It was first discovered in the Tennessee River in September 1991 and has now reached Nickajack Dam at river mile 425. Predictions are that it will rapidly become established in all suitable habitats form the extreme southern U.S. to central Canada. TVA has established a monitoring program at all of its fossil, hydro and nuclear power facilities in an effort to enable control efforts service water systems. The U.S. Army Corps of Engineers has a Congressional mandate to develop "environmentally sound" control strategies for zebra mussels at public facilities, which include locks, dams, reservoirs, hydroelectric power stations and stream gauging stations, among other things. Coordinated efforts are also under way to determine the life cycle characteristics of the zebra mussel in southern waters, evaluate its ecological impacts and plan for possible mitigative measures, especially regarding its effects on the extensive native mussel fauna of the Tennessee Valley.

INJECTION TESTS VERSUS SLUG TESTS FOR WELLS IN FRACTURED ROCKS[1]

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About 750 slug tests but only 10 pumping tests have been completed on the Oak Ridge Reservation (ORR) of the U.S. Department of Energy. There are several reasons for this difference. First, slug tests can be run without producing wastes in areas where groundwater might be contaminated. Second, pumping tests may require a considerable use of people, time, and funds, and there is not general agreement on a best method for analysis of drawdown and recovery data in fractured rocks. Finally, pumping rates may need frequent adjustment in wells of low yield, and drawdown data may include anomalies that are difficult to analyze. There are, however, a number of problems with the accuracy of slug tests, and only the aquifer characteristics close to the well are measured. A solution to these problems may be the use of injection tests and the analysis of water level data in the injection well by the Theis recovery method (Theis 1935, p. 522). Injection tests are relatively simple, and two tests per day have been completed compared with four tests per day for slug tests.

The injection tests were run by pumping water from a plastic tank into a well with a peristaltic pump or a small submersible pump. The injection rate was adjusted with a speed controller on the pump and was measured at the end of the injection period with a stopwatch and a container. The injection rates for 39 tests had a range of 0.018-1.8 gal/min. Water levels were monitored with pressure transducers. The objective during the injection period was to maximize the aquifer volume that was tested. Thus, water was injected at nearly the maximum rate for each well. The injection rate was adjusted as needed during the first 15 min of the test but was not changed during the last 30 min. Injection was continued until there was <0.1 ft of water level change in 5 min; the typical injection period was 1 h. After injection was stopped, water level recovery was monitored for a period of 4-24 h.

Analysis of the recovery data for an injection test began with a graph of water level versus log time for detection of any anomalies in the data. A graph of log water level versus log time was also made for a few tests (Fig. 1, for example); a straight-line trend shows that the earliest data are affected by borehole water storage (Novakowski 1990, p. 100). The Theis recovery method produced the best results for analysis of the data from most injection wells (Fig. 2). Driscoll (1986, pp. 252-60) describes interpretations of Theis recovery graphs but omits the effects of borehole water storage. A long delay (>10 min) in the beginning of a straight-line trend on the Theis recovery graph causes oversteepening of the line. Transmissivity is calculated from the slope of the Theis recovery graph or a water level recovery graph.

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[1]Research supported by Nuclear and Chemical Waste Programs of the Office of Energy Research, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.
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Storativity cannot be calculated from the injection test data, but from Darcy's law and the cubic law for groundwater flow in a fracture (Domenico and Schwartz 1990, p. 87),

$$Q = KIA = (gb^2/12v)I(bW), \qquad (1)$$

where Q is flow rate, K is hydraulic conductivity, I is hydraulic gradient, A is cross-sectional area, g is acceleration of gravity, v is kinematic viscosity of water, b is aperture, and W is width of the fracture orthogonal to groundwater flow in the length direction. At 58°F, $v = 0.100$ m^2/d and $g = 7.32\times10^{10}$ m/d^2. For T in m^2/d and b in m,

$$g/12v = 6.07\times10^{10},$$

$$Q = 6.07\times10^{10}(b^2)I(bW), \qquad (2)$$

$$T = Kb = 6.07\times10^{10}b^3, \qquad (3)$$

$$b = (1.65\times10^{-11}T)^{1/3}. \qquad (4)$$

Equation (4) can be used to calculate fracture aperture from the transmissivity value measured with an injection test. If fracture spacing is known or can be estimated, a one-dimensional measure of fracture porosity (Snow 1968, p. 80) is

$$q = b/D, \qquad (5)$$

where q is fracture porosity and D is fracture spacing.

The results of the injection tests show that transmissivity values from slug tests are too large because the effect of borehole water storage on early water level data is ignored (Fig. 3). For example, the geometric mean of transmissivity from a group of slug tests on piezometer wells in Melton Valley on the ORR is 0.36 m^2/d, whereas the geometric mean value from more accurate injection tests on the same wells is 0.13 m^2/d. The similar slopes of the two probability plots show, however, that the standard deviations of the data sets are the same.

About 85% of the injection tests in Melton Valley showed recharge boundaries (Fig. 2) that are interpreted to represent the water contributions of pervious, intersecting fractures. If this interpretation is correct, the geometric mean of transmissivity calculated from late data should represent a larger volume of rock than that of the early data. Cumulative probability graphs of early and late transmissivity data are somewhat irregular because of the small number of tests (Fig. 4). Nevertheless, straight lines through the plotted points are parallel, thereby indicating the same standard deviation for both data sets. The geometric mean of transmissivity for late data is 0.65 m^2/d and is 5 times larger than the geometric mean for early data (0.13 m^2/d). For comparison, Moore (1992, p. 394) used hydrograph analysis to calculate an average transmissivity of 0.75 m^2/d for the headwaters area of Melton Branch. These results are nearly the same, and it thus should be possible to measure the transmissivity of the continuum in an area of fractured rocks by any of several methods: analysis of observation well and streamflow hydrographs, analysis of water level drawdown and recovery data in observation wells during pumping tests, or analysis of late water level data from pumping wells or injection wells.

Borehole flowmeter surveys on the ORR have shown that median fracture spacing is about 0.35 m (Moore and Young 1992, p. 14), and the injection tests have shown that the geometric mean of fracture aperture is 0.12 mm. The average of effective fracture porosity is thus about 3.4×10^{-4}. For comparison, 26 storativity values, calculated from observation-well data during aquifer tests, have a geometric mean of 7.6×10^{-4}. This result is larger but not greatly larger than that of average effective porosity. Also, hydrograph analysis indicates an average specific yield of 2.3×10^{-3} for the permeable zone at the water table in the headwaters area of Melton Branch (Moore 1992, p. 394). This result is larger than average storativity and average effective porosity, but drainage from the regolith, including delayed drainage, may increase the specific yield near the water table. Storativity is apparently about the same as fracture porosity and specific yield in this area.

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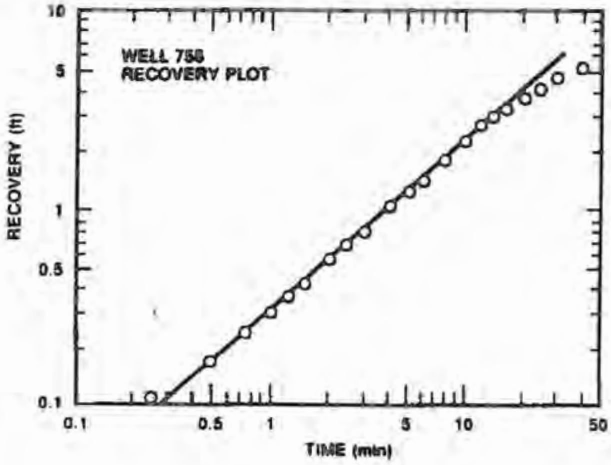

Figure 1: Graph showing effects of borehole water storage on the recovery of water levels.

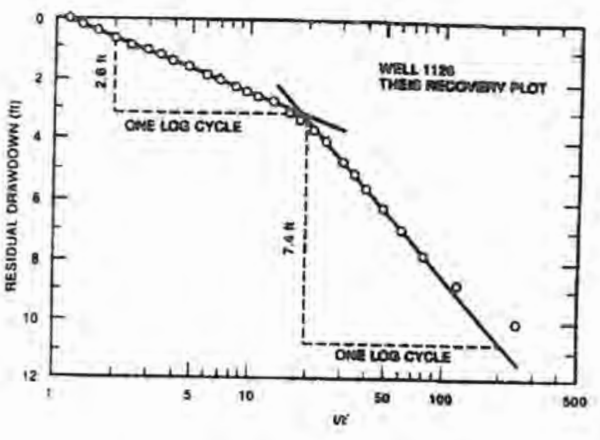

Figure 2: Theis recovery graph of water levels after injection was stopped.

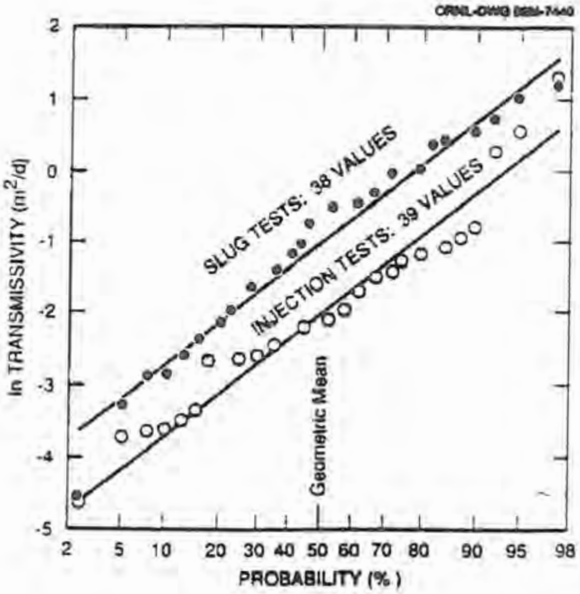

Figure 3: Comparison of probability graphs for slug tests and injection tests.

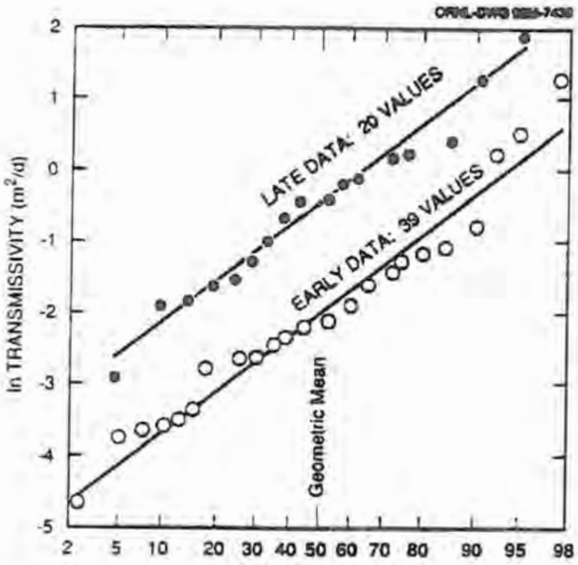

Figure 4: Comparison of probability graphs for early and late water level data.

EVALUATION OF COMBINED METHODS OF SUBSURFACE EXPLORATION, SAMPLING, AND WATER-QUALITY ANALYSIS FOR DETECTING CREOSOTE CONTAMINATION IN GROUND WATER

By William S. Parks[1], John K. Carmichael[2], and June E. Mirecki[1]

Combined methods of subsurface exploration, ground-water sampling, and water-quality analysis were used to confirm the presence of a creosote plume in ground water at the American Creosote Works, Inc., Superfund site at Jackson, Tennessee. These methods were evaluated to determine their suitability for use in an investigation of ground-water contamination in nearby offsite areas.

A subsurface exploratory procedure, known as Direct Push Technology[3] (DPT) of In-Situ Technology, Inc., was used to obtain lithologic information and water samples for analysis at two onsite stations where information about aquifer lithology and contaminant concentration had been collected previously. In anticipation of dense sediments beneath the site, a U.S. Geological Survey (USGS) auger rig was available to extend the DPT depth of exploration. The depth of refusal for the DPT equipment was about 35 feet below land surface. Attempts to extend the depth of exploration by pushing the DPT tools out the bottom of hollow-stem augers was only partly successful. After work with the DPT equipment was completed, additional holes were augered at the stations using the USGS auger rig and water samples were collected through a perforated auger modified to contain a small-diameter well screen.

Four analytical methods were used to collect data confirming the presence and partly identify the vertical extent of the plume: (1) gas chromatography, using photo-ionization detection (GC/PID); (2) high-performance liquid chromatography (HPLC); (3) total phenol colorimetric analysis; and (4) a toxicity bioassay.

The DPT methods demonstrated were very useful for providing detailed lithologic information and for collecting water samples above a depth of refusal of about 35 feet below land surface. The auger method of collecting water samples left doubt as to the source and integrity of the samples. The GC/PID and HPLC methods of analysis were the most effective for contaminant-plume identification.

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[3]Use of trade or firm names in this paper is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

STRATEGY FOR DEFINITION AND PROTECTION OF EAST TENNESSEE KARST GROUNDWATER BASINS

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Introduction

The bedrock geology of eastern Tennessee is typical of the southern Appalachian Valley and Ridge province. Carbonate beds (limestones and dolomites) of the Knox and Chickamauga Groups are bounded by non-carbonate beds, most of which strike northeast and dip steeply (10°-45°) to the southeast. The carbonate aquifers are maturely karstified and are extremely vulnerable to contaminant infiltration, thus necessitating appropriate land use planning focused on their environmental sensitivity. Urban expansion is resulting in greater land development in karst regions. Planned and existing activities produce wastes that may potentially leach into underlying karst systems. This waste may flow rapidly and untreated for many miles along strike. The potential degradation of aquifers and receiving streams due to the cumulative waste loading of numerous small enterprises may be more environmentally destructive than a few hazardous waste sites. Costs to remediate contaminated water supplies and streams can be in the millions of dollars versus the substantially lower costs of prudent land use planning.

Limestone and dolomite have approximately equal solubility in groundwater, with dolomite being volumetrically more soluble than calcite below 23°C (Palmer and Palmer, 1991). Although the ridge-forming Knox Group dolomites have a greater topographic relief than Chickamauga limestones owing to their greater resistance to weathering, exposure to millions of years of erosion has resulted in both operating as one carbonate hydrologic unit. This fact is amply demonstrated by the abundance of sinking streams, sinkholes, caves, springs, and wells encountering "cavities" in all carbonate units. Most cavities encountered during drilling probably represent dissolution along fractures, bedding planes, and conduits that integrate into connected solution conduit systems (or caves), because the removal of bedrock requires a conduit flow path with one or more spring discharge points.

East Tennessee Karst Aquifers

A strategy to protect karst groundwater basins begins with a conceptual model of the karst systems. Figure 1 is a cross section of a typical east Tennessee karst aquifer. The karst system as a whole is a mixed-flow system, containing slow-flow and quick-flow components (Davies, 1992). Infiltration may occur quickly in some portions of the epikarst (e.g., sinkholes, losing streams, and grike infiltration) and slowly in others. Karst aquifers are comprised of a continuum of increasingly more efficient flow paths, from slow-flow in poorly interconnected fractures and phreatic conduits to storm-induced quick-flow in dissolutionally enlarged fractures, bedding planes, and conduits. Most well-developed cave systems comprise vadose components that develop downward and downdip (e.g., northwestern portion of open cavity infeeder extending from conduit well in Fig. 1) until converging into phreatic segments that enlarge along strike, often well below the water table. Groundwater flow, and possibly contaminant transport, can occur along these coalescing flow paths. As aquifer discharge points, springs represent the mixed-flow of various portions of a karst system.

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*Managed by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy.

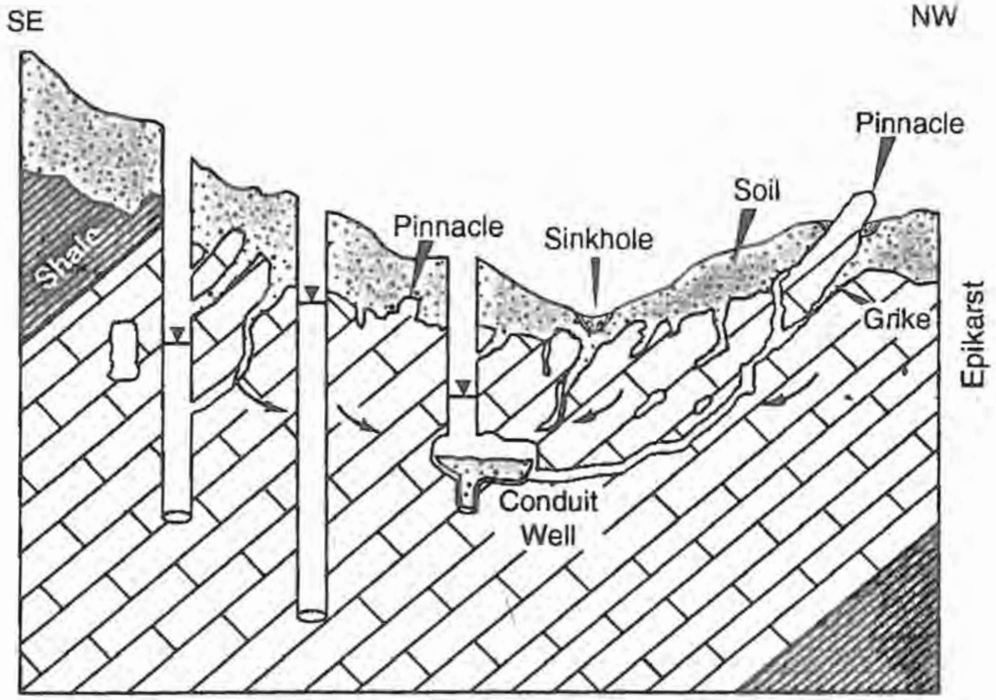

Fig. 1. Schematic showing a typical east Tennessee karst aquifer. The conduit contains mixed-flow integrated from slow-flow components (e.g., poorly interconnected fracture porosity and slow soil water percolation) and quick-flow components (e.g., sinkhole and losing stream recharge, grike infiltration). The flux in the karst system at any given time reflects a continuum of different water velocities. Whereas the discharge in the phreatic conduit normally reflects slow-flow, it may transmit quick-flow during storm events.

Water quality, hydraulic head, and hydraulic conductivity present in individual wells may not permit a true representation of karst aquifer conditions. The reason is that many fractures encountered in boreholes are poorly interconnected within the aquifer. They may comprise the slow-flow zone and may be poorly integrated with other slow-flow or quick-flow portions of the karst network. Figure 1 illustrates how marked water level differences can occur in a physical setting with wells placed only tens of meters apart, where one of the wells intersects a solution conduit. Wells within a few meters of a major flow path may provide no evidence of the existence of a solution conduit; other wells may intersect dissolutionally enlarged fractures. Differences in water levels can occur owing to the substantially different hydraulic conductivity and storativity between fractured bedrock and integrated dissolutionally enlarged fractures, bedding planes, and conduits. These differences in groundwater levels are important to consider when constructing groundwater contour maps.

Groundwater flow in mature karst settings converges toward large phreatic passages where zones of low head attract vadose and phreatic water from surrounding openings (Palmer, 1991). Short flow routes may also occur in the vadose zone, forming canyon-shaped passages in a downdip direction. Cave systems in the Valley and Ridge province can develop spatially, one above another. Often, a continuum of cave evolution may be seen in an area: from relict caves, to shallow caves draining to nearby stream baselevels, to deep master cave systems that may resurge many miles from their recharge areas.

Land Use Planning Above Karst Aquifers

Land use planning and watershed protection in karst groundwater basins must be within the natural constraints of a basin's geology and hydrology (Rubin, 1992). It is critical that the special concerns of karst watersheds be addressed by local planning boards, environmental conservation departments, and other state agencies. For example, towns continue to receive applications for single residences and planned developments atop maturely karstified limestone aquifers. The sale of property downgradient of hazardous waste sources fails to receive sufficient attention. An appropriate land use plan should evaluate the entire karst system, throughout the groundwater basin, before permitting additional development in any isolated segment of the aquifer. This evaluation should include characterizing items such as, the extent of the aquifers' watersheds, geology, flow paths, baselevel, and discharge area. Defining topographic and lithologic basins aids in defining the boundaries of groundwater basins; however, topographic divides rarely coincide with subsurface divides in karst terranes (Quinlan, 1989). Only after such characterization is complete, can the net effects of multiple contaminant inputs on the assimilative capacity of an aquifer be judiciously evaluated. Studies of this nature must not only define the dynamics of the karst system, but land use planners must then use the knowledge gained to protect subsurface and surface water resources.

A full inventory and characterization of karst features is needed to assess the karst system's recharge, discharge, water quality, and environmental sensitivity. Some of the important features and items that should be included in a karst inventory are the locations of 1) sinkholes; 2) caves; 3) springs; 4) sinking streams; 5) seasonally active overflow springs; 6) limited-to-nonexistent surface drainage; and 7) conduit wells. As karst features are added to the inventory, comprehensive evaluation of the importance of each and how they combine to define the hydrology of an area is necessary. Such an inventory is important in focusing future development proposals, in land use planning, and in aquifer characterization.

Because conduits represent significant drainage pathways for karst groundwater basins, determining either the location of solution conduits downgradient of waste sources or at least the springs where conduits discharge is necessary to adequately monitor and characterize carbonate groundwater flow systems. Unlike groundwater flow in porous or uniformly fractured media, preferential flow paths in carbonates cannot be predicted without detailed knowledge of solution conduit pathways (Palmer, 1992). In eastern Tennessee, information on geology (e.g., stratigraphic and structural controls), karst features, and baselevel make it possible to predict general areas of likely aquifer discharge. Spring discharge points for deep flow paths are likely to occur along carbonate strike-bands near a regional baselevel, such as the Clinch River (Rubin and Lemiszki, Fig. 1, this volume) or sometimes at more distant lower baselevels. Occluded conduits and/or shallower conduit flow paths, however, may resurge as springs and underflow in and along smaller surface streams. Conduit pathways may be identified through cave mapping, geophysical surveys, borings, and tracer tests. Tracer tests are particularly important for delineating aquifer flow routes to spring and underflow discharge points. Once discharge points are known, select water quality indicators, as well as suspected and known contaminants, should be monitored during periods of low flow and, most importantly, during short-term flood events. Without this knowledge, a defensible pathways' analysis for risk assessments is impossible.

Base maps should be maintained for plotting karst features. Placing known or suspected contaminant sources (e.g., sinkhole dumps, landfills, waste sites, junk yards) on this base map is also important. Continuous sources of contamination (e.g., feed lots, effluents from large and small industry, garage and dry cleaner effluents) must be placed on this map as well, for in combination, their waste streams may comprise much of an aquifer's contaminant assimilative capacity during periods of base flow. Assessing whether leakage from individual waste masses is likely to have transported contaminants away long ago, or whether waste continually leaches into the flow system, is also valuable. An aquifer's assimilative capacity and vulnerability to contamination requires information on recharge, subsurface flow paths, water quality, storage, and base flow.

An example of the steps involved in proper land use planning is presented using as a model the DOE Oak Ridge Reservation, where groundwater flow in steeply dipping carbonate beds is constrained by non-carbonate lithologic barriers.

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THE USE OF MICROGRAVIMETRY IN KARST STUDIES ON THE OAK RIDGE RESERVATION

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Microgravimetry is a reliable tool for delineating karst features in the subsurface. Surface microgravimetry was successfully used in two karst investigations on the Oak Ridge Reservation, Oak Ridge, Tennessee. The microgravity method measures the earth's gravitational field which is used deduce subsurface density structure. Geological structure is then inferred from the density to structure. The first geophysical study focused on the feasibility of microgravity and electrical methods to detect known karst features and if feasible to delineate their subsurface extent. This karst investigation was part of the hydrogeological characterization at a potential landfill site. The second geophysical investigation focused on locating potential subsurface contaminant migration pathways and detecting cavities down hydrologic gradient from a waste burial site where contaminant movement is suspected.

Microgravity data were collected and reduced to Bouguer residuals at each site. Two-dimensional forward modeling was utilized to analyze Bouguer residuals. Site information derived from monitoring well installations and soil borings were used to constrain the gravity models.

The first microgravity survey was able to locate and delineate the probable extent of a known subsurface cavity. This survey also located several other probable cavities. Microgravity surveying proved more useful than electrical methods. The second microgravity survey located a relatively narrow and continuous bedrock trough, trending down hydrologic gradient from the burial area. This bedrock trough is believed to be a major controlling factor in the movement of contaminants at the site. A probable cavity was also detected with the microgravity survey. Both karst investigations have shown that microgravity is a valid method for detecting and delineating karst features on the Oak Ridge Reservation.

THE HYDROLOGY OF THE OAK RIDGE RESERVATION - A CONCEPTUAL MODEL

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W. M. McMaster, and D. D. Huff[1]

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Oak Ridge, Tennessee

This first status report on the Hydrologic Studies Task of the Oak Ridge Reservation Hydrology and Geology Study (ORRHAGS) revises earlier concepts of subsurface hydrology and hydrogeochemistry of the ORR. A new classification of hydrogeologic units is given, as well as new interpretations of the hydrologic properties and processes that influence contaminant migration. The conceptual hydrologic framework introduced in this report is based primarily on reinterpretations of data acquired during earlier hydrologic investigations of waste areas at and near the three U.S. Department of Energy Oak Ridge (DOE-OR) plant facilities. In addition to describing and interpreting the properties and processes of the groundwater systems as they are presently understood, this report describes surface water-subsurface water relations, influences on contaminant migration, and implications to environmental restoration, environmental monitoring, and waste management.

Some Implications to Environmental Restoration, Environmental Monitoring, and Waste Management

The understanding of hydrogeologic properties and processes, as briefly summarized later, is important because of implications to environmental management on the ORR. Some practical conclusions are evident: With few exceptions, groundwater discharges within the ORR presently meet drinking water standards.

The restoration of contaminated groundwater of the ORR to pristine quality is not a technologically realistic goal. One major reason for this is that transport processes in the subsurface - diffusion from fracture to the rock matrix, sorption, and exchange - have resulted in an accumulation of contaminants downgradient of the sources. The flushing of these contaminants and eventual return of water to the original quality could require time periods on the order of centuries; the time frame and end result will not be much different whether by natural processes or if remedial technology is applied.

The use of wells for the monitoring of contaminant migration from waste areas on the ORR is unreliable and may produce misleading results, although such monitoring has limited value for assessing general water quality at specific locations. Most groundwater travels to nearby streams through the uppermost part of the groundwater zone. Contaminants in the subsurface at waste areas are discharged to local surface streams; it is more valid to monitor surface-water quality and contaminant load than to monitor wells in order to characterize contaminant mass flow.

Effective surface-water-contaminant monitoring systems must be established. One basis for system design would be the identification of the discrete points at which contaminants are discharged to surface drainageways.

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Waste area groupings on the ORR occupy relatively large areas, but contaminant discharge to streams occurs only at a few distinct and identifiable points, such as seeps. The characteristics of flow paths must be understood well enough to enable tracking along pathways from known points of surface discharge to locations of discrete contaminant sources in waste burial areas. This information would then be used in designing remedial measures for hydrologic isolation of the source. In the case of buried wastes, a relatively small number of concentrated sources are very likely the origin of most contaminant flux. Thus, remedial actions in waste burial areas should focus on the area containing the concentrated source rather than on waste-area-wide remedial actions.

Transport processes effectively buffer migration of contaminants in the subsurface. An instantaneous release of contaminants from a primary source, such as from the failure of a container, does not result in an immediate loading to streams. Transport processes must be quantified to allow prediction of lag time between peak contaminant release at the source to peak contaminant release to the stream. This also is essential for accurate estimation of time required before effects of corrective actions will be observed. Sorption and exchange are weak processes in the case of some contaminants, but matrix diffusion significantly alters the rate of flux of all contaminants.

Although transport processes have significantly attenuated and buffered past contaminant releases from waste areas, they have resulted in secondary contaminant sources along flow pathways. These secondary sources could, in the case of older waste areas, contain more contaminants (at lower concentrations) than the original site currently contains. Contaminants are transported off the ORR by surface water rather than by groundwater. Significant contaminant movement and discharge take place during periods of high runoff.

Deep flow of groundwater off the ORR, such as under the Clinch River, if it occurs, does not endanger groundwater supplies outside the ORR because of long paths, slow travel times, and relative isolation from contaminant sources.

Given that (1) virtually all contaminated groundwater from waste areas underlain by aquitards (see below) is discharged to local surface streams within the ORR and (2) groundwater restoration is not a practical alternative, engineering feasibility studies should be undertaken for treatment of surface water at points where contaminant-bearing streams leave the ORR. On the other hand, some flow paths from waste areas underlain by the Knox aquifer, as described below, may discharge to the surface at points beyond the ORR boundary.

Basic Conceptual Framework

Geologic units of the ORR are assigned to two broad hydrologic groups: (1) the Knox aquifer -- formed by the Knox Group and the Maynardville Limestone-- in which flow is dominated by solution conduits and which stores and transmits relatively large volumes of water and (2) the ORR aquitards --made up of all other geologic units of the ORR-- in which flow is controlled by fractures, and fairly large volumes of water may be stored, but only limited amounts of water is transmitted.

In the vertical, both the Knox aquifer and the ORR aquitards are divided into the following:

* The stormflow zone, a thin region at the surface in which transient, precipitation-generated flow accounts for an estimated 90% or more of the water moving through the subsurface. This zone is a major pathway for transporting contaminants from the subsurface to the surface.

* The vadose zone is a mostly unsaturated zone above the water table.

* The groundwater zone, which is continuously saturated, is the region in which most of the remaining 10% of subsurface flow occurs.

* The aquiclude is a zone in which water movement, if it occurs, probably is on a geologic time scale.

Flow in the aquitards is shallow; ~98% is to depths of <30m. Water in the aquitards travels along flow paths having lengths of tens to a few hundred meters before being discharged to local surface drainageways. Water in the aquitards is at best a marginal resource. A typical well yields <0.02L/s (0.25 gal/min); in many places, wells are incapable of producing domestic quantities of water. Groundwater flow volume decreases and solute residence times increase sharply with depth. Mean solute transport rate in the stormflow zone is on the order of meters per hour, but in the intermediate and deep intervals of the groundwater zone, representative transport rates are as low as a few centimeters per year. In the vertical, most groundwater flow in the aquitards occurs through a few widely spaced (7-50 m) permeable regions.

The Knox aquifer is the only true aquifer of the ORR and is the primary source of sustained natural flow in perennial streams such as upper Whiteoak Creek, Walker Branch, Scarboro Creek, East Fork Poplar Creek, and Bear Creek. In some places the Knox aquifer can supply large quantities of water to wells. Flow volumes are significantly larger than in the aquitards, and flow paths are deeper. The potential groundwater flow path length in the Knox aquifer is substantially greater that in the aquitards --on the order of kilometers rather than tens of meters or a few hundred meters. The one strongly suspected instance of groundwater flow across the ORR boundary occurs along Chestnut Ridge, where water from the Knox aquifer travels >2.5km and discharges to Scarboro Creek.

There is no evidence of contaminant migration along deep, long subsurface flow paths. Virtually all mobile water in the aquitards is discharged to local streams within the ORR. However, it is likely that some flowpaths in the Knox aquifer lead to discharge points outside the ORR boundary.

Residence times of solutes near the water table in the aquitards range from a few days to a few years. In the intermediate and deep intervals, estimates of residence times derived from 14C measurements and modeling are hundreds to tens of thousands of years.

Geochemical processes (adsorption and ion exchange) and the matrix diffusion process significantly alter chemical concentrations of solutes in the ORR groundwater. One result is retardation and storage of any contaminant in the rock matrix.

The conceptual framework is believed to be fundamentally complete and correct. The basic premises are unlikely to change with further findings. Some details remain uncertain, and additional data are necessary to prove and refine some parts of the framework.

DEVELOPMENT AND USE OF A GROUND-WATER FLOW MODEL AT ARNOLD AIR FORCE BASE, TULLAHOMA, TENNESSEE

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U.S. Geological Survey

The U.S. Geological Survey (USGS), in cooperation with the Arnold Engineering Development Center (AEDC), conducted a base- wide hydrogeologic investigation at Arnold Air Force Base. The base is located in Coffee and Franklin Counties near Tullahoma in south-central Tennessee. The base encompasses about 39,000 acres (61 square miles) of which approximately 3,000 acres are devoted to testing and support facilities known as AEDC. The mission of AEDC is to support the development of aerospace systems. AEDC conducts a wide range of tests and simulations in aerodynamics, propulsion, and aerospace systems.

Local ground-water contamination resulting from base operations and past disposal practices has been identified. Numerous contractors have been conducting Remedial Investigation/Feasibility Studies at individual sites of potential ground-water contamination on the base. However, until recently, no work had been done to integrate the data and interpretations from the site-specific studies into a base-wide assessment of the ground-water flow system and the potential directions of contaminant migration.

The USGS developed a three-dimensional ground-water flow model for the base and adjacent areas that can be used to quantify the natural system, to test concepts within the system, and to investigate possible flow paths of contaminant migration. The steady-state model includes a variably spaced grid of 106 rows by 95 columns that represents an area of approximately 167 square miles.

The model simulates ground-water flow in three aquifer layers: the shallow, the Manchester, and the Fort Payne aquifers. The Chattanooga Shale forms the lower boundary of the ground- water system in the model. The model was calibrated using data from approximately 160 wells and the sensitivity of model results to variations in model input parameters was analyzed. A particle-tracking post-processor program was used on a limited basis to determine potential flow paths and time-of-travel of potential contaminants. Results from the model calibration indicate that the model adequately simulates the natural ground- water flow system and provides a powerful tool for determining the direction of ground-water flow, defining flow paths of contaminant migration, estimating relative time-of-travel of contaminant migration, and delineating recharge areas to wells.

METHODS FOR PREDICTING THE DIRECTIONS OF CONTAMINANT TRANSPORT IN FLAT-LYING AND FOLDED CARBONATE ROCKS

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Introduction

To better understand ground water movement in the carbonate rocks of Tennessee, orientation measurements were made of joints, straight cave passage segments, sinkholes, and photo-lineaments. This information is particularly useful in predicting the pathways of contaminants from hazardous waste facilities, landfills, and leaky underground storage tanks. To date, the author and his students have made orientation measurements of 2,514 joints, 2,795 straight cave segments, 3,337 sinkholes, and 1,549 photolineaments.

Methods

Straight cave segments of 50 feet length were delineated from cave maps provided by the Tennessee Cave Survey. Sinkholes were randomly chosen from 1:24,000, U.S.G.S. topographic maps within the two study areas to delineate the orientations of their long and short axes. Joint orientation measurements were made using a Brunton compass. Photo-lineaments were delineated from 1:20,000, black and white, stereo aerial photographs. The orientations of the straight cave segments, sinkhole axes, joints, and photo-lineaments were then placed in 10 degree classes and plotted as rosette diagrams.

Results

Figures 1 through 4 present the orientation measurements for the Cookeville area. Straight cave segments (Figure 1) show a broad range of orientations, but passages in a north/northeast direction are predominant. Joint orientations (Figure 2) are predominantly between N 30 - 70 E and N 20 - 60 W. Rosettes were made for straight cave segments in nine counties of east Tennessee, and a strong predominance of orientations in a northeast direction can be seen (Figure 5). The northeastern trend closely follows the strike of the rock and the Appalachians in the different counties. Although some similar trends are seen for the joints measured in east Tennessee (Figure 6), a strong correlation does not exist. There is a significant difference in the spread of the data compared to the flat-lying rocks of the Eastern Highland Rim around Cookeville. Where the rocks are flat-lying, there is greater likelihood of cave development occurring along all dominant joint directions. In the steeply dipping rocks of east Tennessee, ground water moves rapidly down dip until reaching the water table, and then moves along strike within lithologically favorable beds. As a result, the cave patterns in east Tennessee show a strong linear angulate pattern whereas in central Tennessee cave patterns are sinuous or maze-like.

Figure 3 shows the orientations of photo-lineaments in the Cookeville area. A moderate comparison can be seen with the cave segment data suggesting that fractures, as interpreted from photographs, may be more important for controlling ground water flow direction and contaminant transport than joint orientations. Figure 7 shows that the orientations of the photo-lineaments in east Tennessee are more tightly grouped in the northeast and northwest quadrants than around Cookeville. Many of the linear features depicted from photographs in the folded rocks were moisture patterns occurring along strike-oriented bedding planes, and lineations of sinkholes developed along strike. As a result, a close comparison of the northeastern measurements is seen. The rosette for the long and short sinkhole axes around Cookeville (Figure 4) shows no particular trends, whereas in east Tennessee two strong trends usually occur (Figure 8). The explanation for this is similar to that provided for the cave passage trends. In addition, many of the sinkholes are actually developed on top of collapsed or open cave passage, thus helping to explain some of the similar trends.

Conclusions

In general, cave passages and sinkholes from along a wide-range of orientations in the flat-lying rocks of the Eastern Highland Rim corresponding to joint and photo-lineament trends. In the folded rocks of east Tennessee, most caves and sinkholes are strongly aligned along stratigraphic strike within bedding planes of the more soluble lithologies. These results can be readily applied to contaminant transport. A contaminant plume in east Tennessee will likely be narrow and developed along strike, whereas, a broad plume can be expected to develop in the flat-lying rocks of central Tennessee assuming the pollutant does not reach a cave. Cave passage trends represent actual or paleo avenues of ground water movement and should be analyzed at the beginning of any remedial action in karst. This information, in addition to mapping photo-lineaments, will greatly aid in the placement of monitoring wells and searching for springs that should be included in the monitoring program.

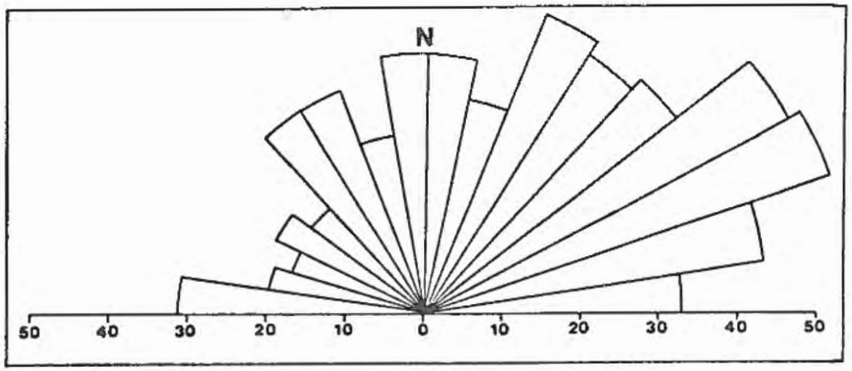


Figure 1. Straight 50 ft length cave segment orientations, Cookeville, Tennessee area.

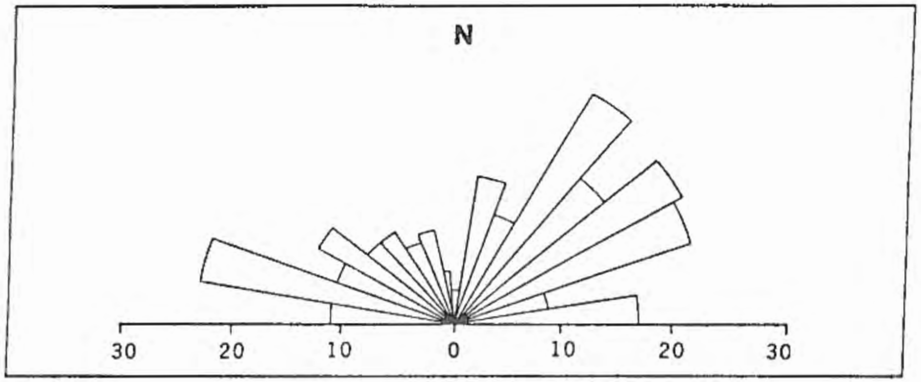


Figure 3. Orientations of photo-lineaments in the Cookeville, Tennessee area.

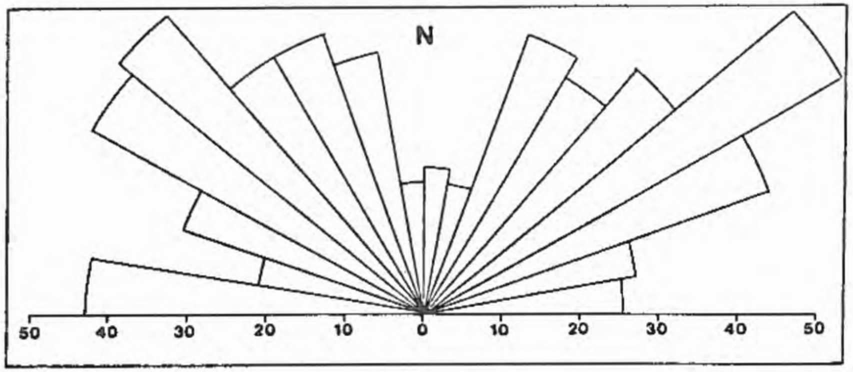


Figure 2. Joint orientations, Mississippian carbonates, Cookeville, Tennessee area.

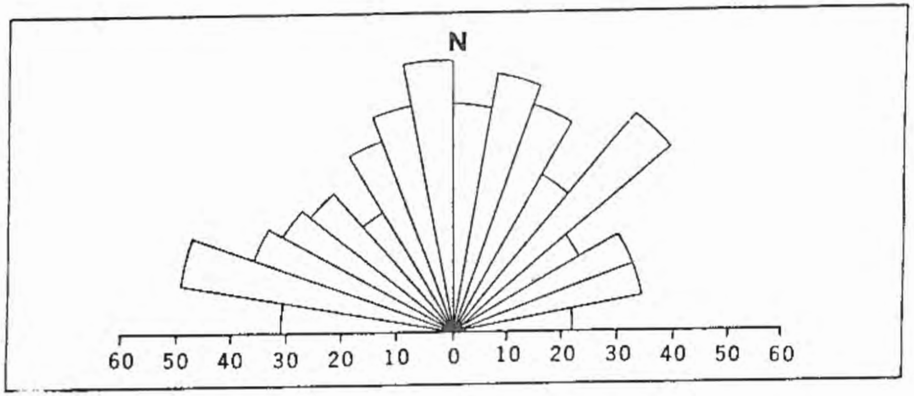
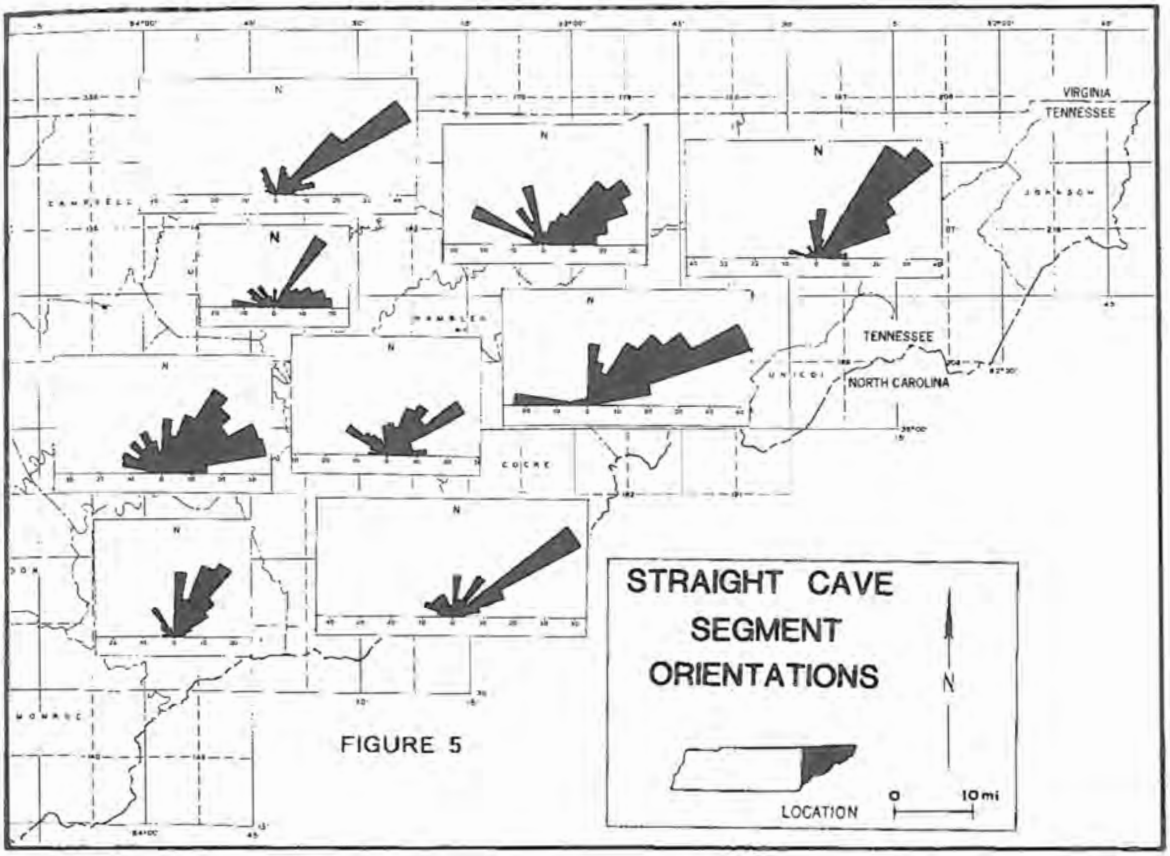
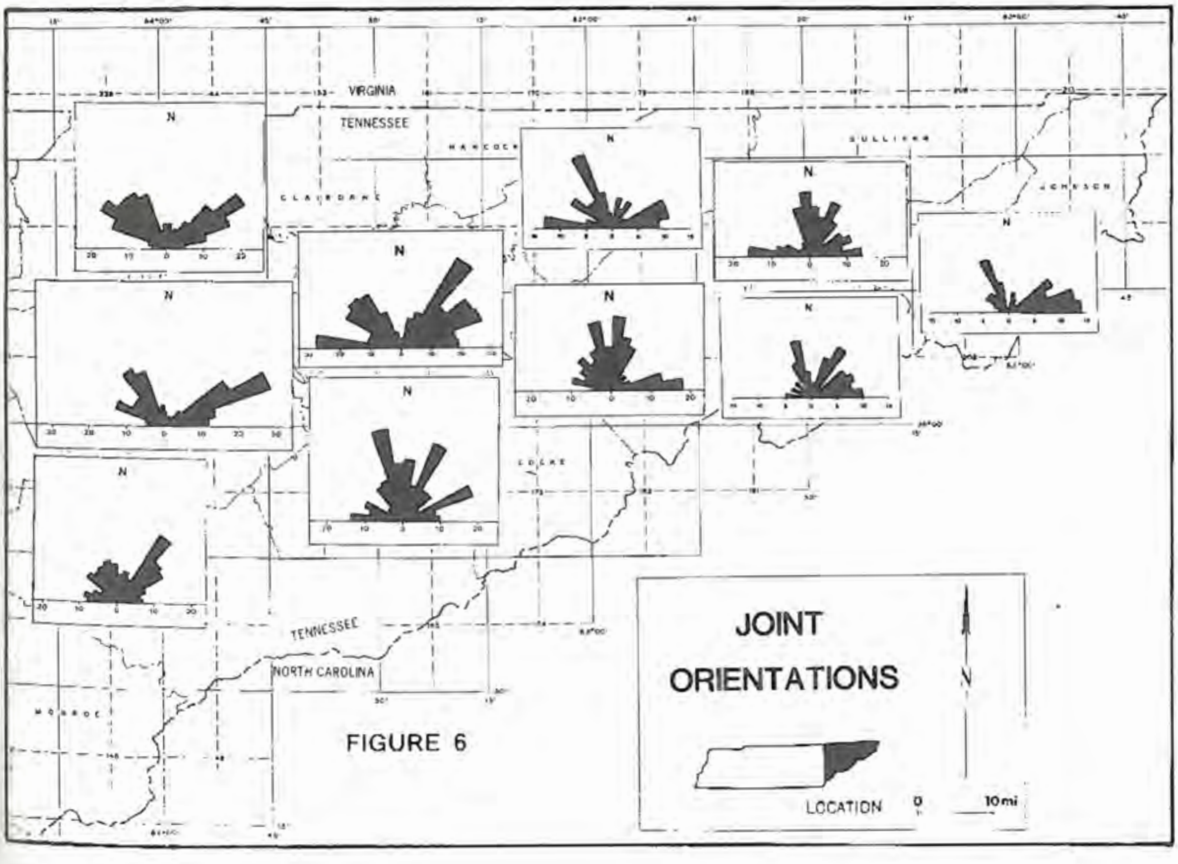


Figure 4. Orientations of long and short sinkhole axes in the Cookeville, Tennessee area.


VIRGINIA
TENNESSEE
TENNESSEE
NORTH CAROLINA
STRAIGHT CAVE SEGMENT ORIENTATIONS
LOCATION
0 10 mi
FIGURE 5


VIRGINIA
TENNESSEE
TENNESSEE
NORTH CAROLINA
JOINT ORIENTATIONS
LOCATION
0 10mi
FIGURE 6

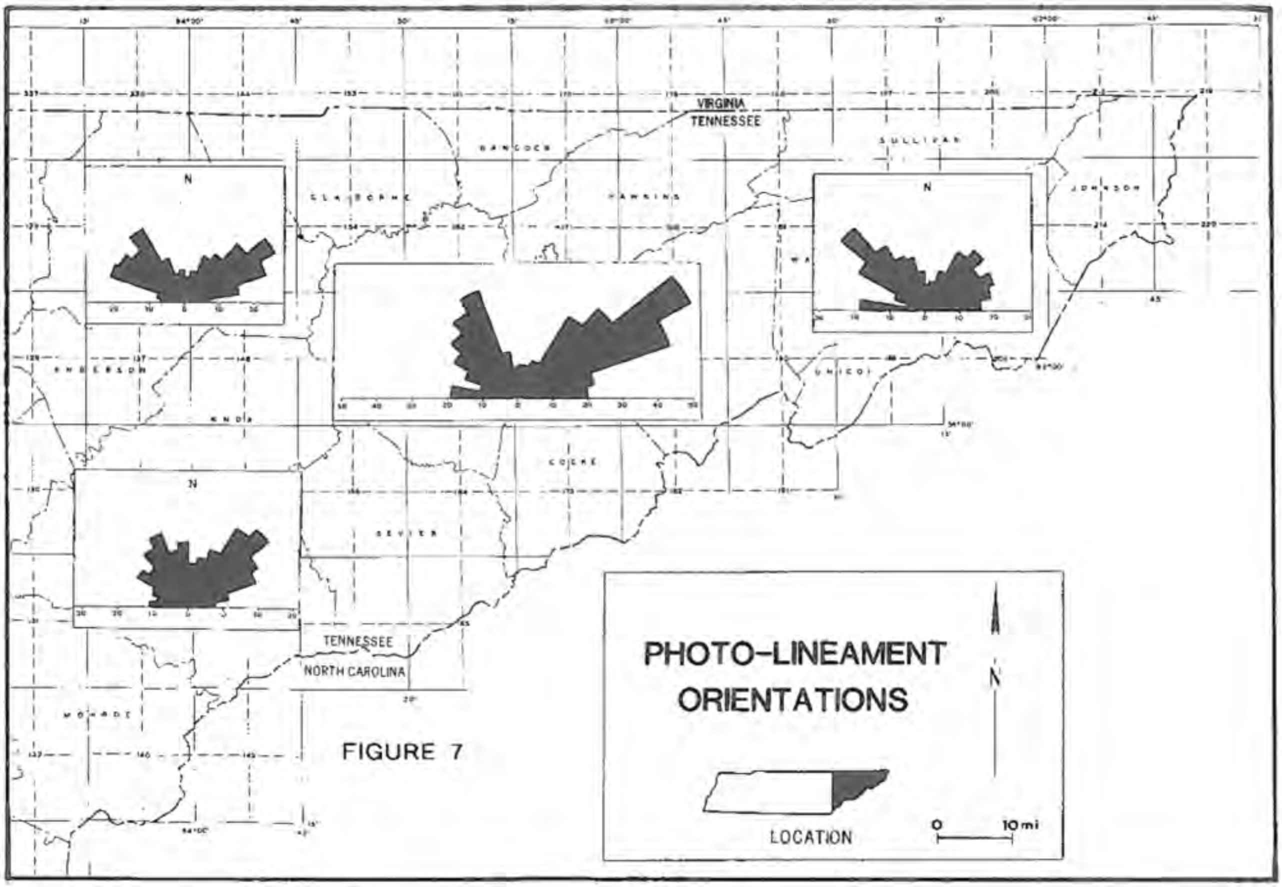


FIGURE 7

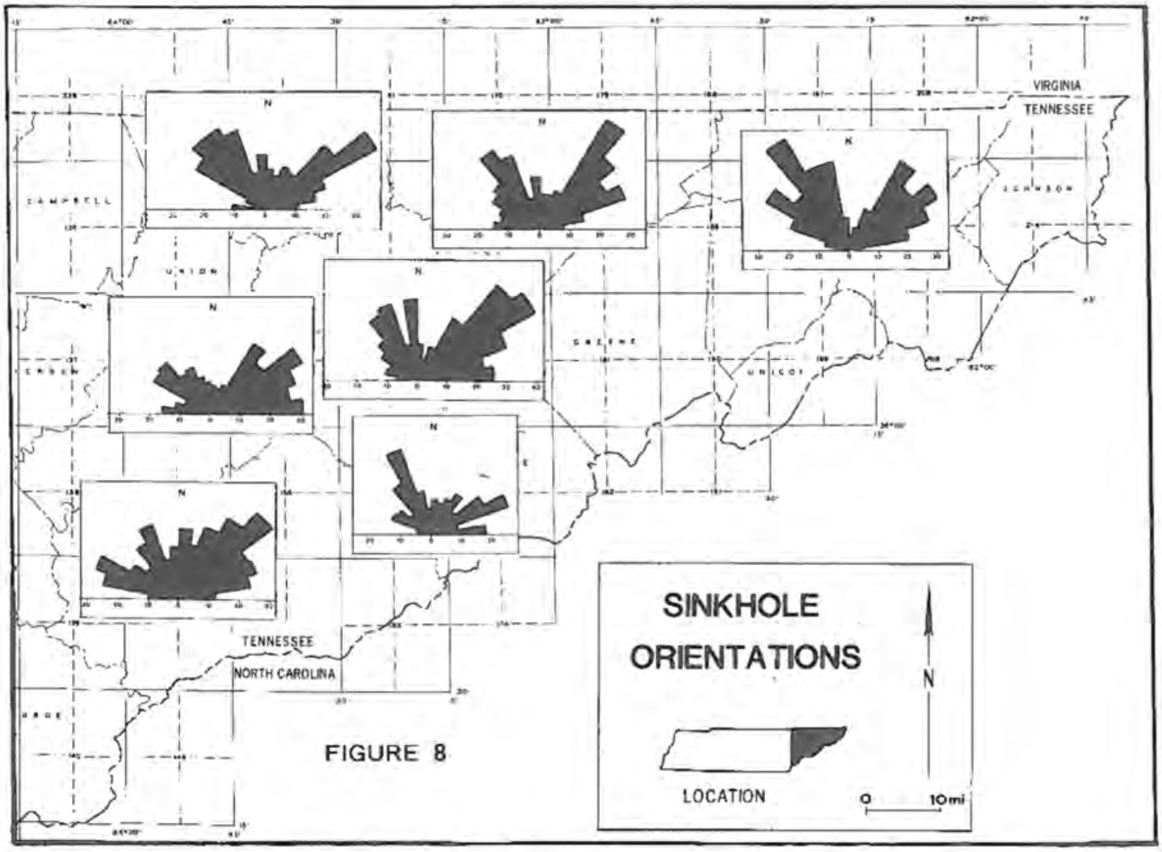


FIGURE 8

ANALYSIS OF SORPTION/ELUTION DYNAMICS AND ITS IMPLICATION ON TRACER TESTS IN KARST TERRAINS

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The task of tracing groundwater flow with dyes in karst terrain can be difficult due to the uncertainty of fracture continuity, dilution and direction of flow. The analyst must have a practical method of detecting dye at the selected discharge points. Considerations of accuracy and economics demand that dye detection techniques be compared. Must the dye be detected visually be field personnel or can a dye trap (i.e. a charcoal "bug") be used to collect dye from the water for later extraction and analysis? This paper compares results of activated charcoal "bugs" versus visual observations to detect the presence of dye in water under laboratory conditions. Also considered are the factors of dye concentration and contact time on the effectiveness of the selected dye trap. Two commonly used dyes, fluorescein and Rhodamine-WT, were tested. The results indicate that the charcoal "bug" is more effective than visual monitoring of the dye's presence.

FIELD-SCALE EXPERIMENTS ON 3-DIMENSIONAL MULTI-REGION TRANSPORT OF TRACERS AT MELTON BRANCH

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At the Oak Ridge National Laboratory (ORNL), waste sites have supplied mixed contaminants to the unsaturated soil adjacent to burial trenches thereby inundating pores within the soil matrix. The hydrogeologic conditions at ORNL are such that streamflow is generated predominantly by subsurface flow through the upper soil layers during storm events (Moore, 1988, 1989; Solomon et al., 1989; Wilson et al., 1991a,b, 1992) designated the stormflow zone. These upper soil layers (i.e., stormflow zone) are maintained under wet but unsaturated conditions between storm events. Their propensity is to quickly develop perched water tables during events that are capable of rapid transport of contaminants. Storm events have been estimated to result in 65% of the annual transport of tritium to surface waters through the stormflow zone (Solomon et al., 1989). Waste storage problems at ORNL are typical of much of the humid regions of the eastern United States in which shallow soils overlying highly fractured material are prevalent. Investigations at ORNL have demonstrated significant continuous movement of reactive and nonreactive tracers through small soil pores with transport through large pores occurring as discrete pulses during storm events (Jardine et al., 1990). The need exists to quantify the matrix flow-preferential flow processes at the field-scale and to couple these processes into an integrated transport model. Field-scale experimental data for conditions where shallow lateral stormflow predominates are lacking, and no field-scale transport study to date has directly measured the subsurface transport flux. The objectives of this project were to develop a comprehensive data base for validation of a three dimensional multi-region flow and transport model (Gwo et al., 1992a, b) for the stormflow zone of a highly heterogeneous field soil.

Materials and Methods

A subsurface transport facility has been constructed on a 0.67 ha subcatchment of a proposed solid waste storage area on the Oak Ridge Reservation. The subcatchment has developed within the Conasauga geologic formation which is the most common geologic formation used for waste disposal operations at ORNL. The strata of the Conasauga group weather to a shallow (< 1 m) soil overlying saprolite that retains the bedding and structure of the original limey shale rock. The saprolite is such that there are large fractures between the rock-like features, as well as, extensive microfractures with μm-size apertures within the rock-like features. These secondary fractures are coated with Fe- and Mn-oxides, and contain translocated clay that has plated-out, indicating that they serve as preferred flow paths for oxygenated water.

These facilities are unique in that subsurface drainage can be collected and monitored from a 2 m deep by 16 m long trench that has been excavated across the outflow region of the subwatershed. Six stainless steel pans (Fig. 1) pressed into the face of the trench intercept the subsurface outflows. The top three pans have their bottom edges at the interface of the B and C soil horizons, and therefore collect flow from the A&B horizons (0 to 0.6 m). The bottom three pans are designed to collect flow from the C horizon (0.6 to 1.8 m). Pans 1 and 4 (8.2 m long) were designed to collect flow from the eastern hillslope, pans 2 and 5 (4.2 and 3.0 m, respectively) from the central region, and pans 3 and 6 (4.0 and 4.7 m, respectively) from the western slope. The flows from the six pans, a surface collector, and water from below the pans (1.8 to 2.0 m depth) along the trench floor are continuously monitored. A buried line source has been installed at the top of the eastern hillslope for tracer releases. A grid of hydrologic instruments have been installed below the line source totaling 75 tensiometers, 45 solution samplers and 15 wells. Fifteen additional wells 1.5 m deep equipped with sensitive pressure transducers were positioned in two transects on the subwatershed for monitoring the perched water table.

The buried line source (6 m long, 5 cm O.D. slotted pipe) was located at the 0.5 m depth positioned on a 0.2 m thick bed of crushed marble. Two tracer releases were made during the winter storm period of 1991 with only the second release presented here. The second release was made on 18 February at 0950, of 3200 L of 8000 mg/L Br- ($MgBr_2$) over a 16.5 h period. During storm events, subsurface flow samples were manually collected from individual pans, and from a natural pipe that fed the trench floor below the center pan (pan 5). Tracer concentrations and fluxes through the hillslope were assessed for ten storm events during a seven month period. During the first week of August when subsurface flow was negligible, soil samples were taken at 14 locations on the eastern hillslope at 0.3 m increments in the upper 1.5 m and 0.5 m increments to a depth of 5 m or auger refusal.

Spatial and Temporal Variability in Tracer Export:

The upper 1.5 m of the soil profile on the subcatchment was unsaturated prior to each storm event and perched water tables were observed to rapidly develop within these layers during events. The draw region of the subcatchment corresponds to the bottom area where stormflow from the adjacent slopes converge. It was expected that the majority of stormflow transport would be observed in the center pans (2 and 5) that receive flow from the draw region. Limited transport was expected through pan 1 that receives flow from the upper layers of the eastern slope. Flow was rarely observed in pan 1, occurring only during intense flow periods, such as the 17-23 Feb. event. However, pan 1 flow was minimal even during this event when compared to flow through the other pans, thus, even though Br- concentrations were high (8.5 mg/L) the mass transported through pan 1 was negligible (Fig. 2). Despite pan 4 having the highest Cl concentration during the first tracer release, Br- export through pan 4, that received flow from the C horizon of the eastern slope, was negligible (Fig. 3). It was hypothesized that essentially no export of tracer would occur from the western slope (pans 3 and 6). Despite a piezometer 11 m from the trench face on the western slope that never exhibited a perched water table, flow was consistently observed from this hillslope through pan 6. As anticipated, Br- was hardly detectable in flow through pan 3 since it received flow from the A&B horizons of the western slope (Fig. 2). However, Br- concentrations were high (7 mg/L) in flow through pan 6. Variations in flow through pan 6 generally corresponded very closely with flow through pan 5 in timing and intensity. Therefore, we believe that the majority of flow that was collected by pans 1 and 6 was flow through the draw region.

The most significant observation of this tracer study was the potential of the stormflow zone to transport solutes. Bromide was first observed in pan 6 approximately 65 m from the line source at just 3.2 hours after tracer release. This was followed by breakthrough in the next sampling of the natural pipe and pans 1, 2, 3, and 5 at 5.2 hours after release (Figs. 2 and 3). The concentration in the natural pipe initially peaked at 12.1 mg/L at relative time (rt) 27.7 h, dropped to 7.4 mg/L at rt=29.7 h, then reached a second peak of 10 mg/L at rt=53.7 h. In contrast, the peak concentrations were 9.5 and 7.3 mg/L for pans 5 and 6, respectively, at rt=39.7 h.

An amalgamated sample of pans 4, 5, and 6 (designated C horizon) was collected. The amalgamated sample for the C horizon and samples from the natural pipe from the April storm event presented in Fig. 4 represent the dynamics observed for the February, March, May, and June events. The C horizon sample showed a dilution effect of pan 4 flow on the Br- export through pans 5 and 6. Bromide concentrations were consistently higher in the flow through the natural pipe than in the C horizon. The contrast in Br- concentrations was more than merely the dilution from pan 4 since grab samples from pan 5 and 6 were consistently lower in Br- than in the natural pipe flow. Geochemical analysis indicated that flow through the natural pipe had a different source from flow through the C horizon. The inorganic carbon signature indicated that water from the natural pipe was supersaturated with respect to CaCO3 and was distinctly different from water flowing through the C horizon. The natural pipe appears to receive water that is exposed to limestone, whereas the source for C horizon flow is water perched above the Cr horizon. One would expect that higher concentrations would be observed in the C horizon flows since this is the zone of tracer release. The fact that the natural pipe had higher Br- concentrations indicates that a significant portion of the tracer followed a path deeper than 1.8 m. This does not necessitate that there is interaction between the shallow storm flow zone and the groundwater system since soil sampling revealed limestone at 2.5 to 3.0 m on the eastern slope where the groundwater table is approximately 16 m.

Sharp decreases in Br- concentrations in the natural pipe and C horizon flows corresponded to sudden increases in flow rate (Fig. 4). Wilson et al. (1991a) concluded from si,ilar studies on Walker Branch watershed on the Oak Ridge Reservation that as flow continues it acquires the chemical composition of old water stored in the soil. As the subsurface flow continued in our study, the Br- concentration increased to a level higher than before the hydrograph, followed by a concentration decrease back to the original level (Fig. 4). This was also observed for all other storm events not presented here. We believe this delayed increase in solute concentration was due to flushing of solutes from the micropores into macropores via convective flow through mesopores. Hydrographs were separated into old water/new water contributions based upon chemical concentrations in soil solutions prior to, and subsurface flows during each event. This analysis suggested that the April 14 -16 hydrograph was initially 37% old water and decreased to 30% during the sharp rise in flow. As flow decreased, the old-water contribution increased to 70 %. The dynamics were more dramatic for the March 22 -25 event in that the sharp increase in flow rate consisted of only 30% old-water and the recession limb of the hydrograph consisted of 100% old-water. Thus it was clearly seen that upon the onset of a storm event, the initial stages of subsurface flow are dominated by new water that by-passes soil matrix pores. However, after rainfall ceases and subsurface flow begins to decrease the contribution of old water increases and eventually dominates the flow. The displacement of old-water during the recession limb of subsurface flow events would result in the flushing of contaminants from the soil matrix pores.

Tracer Immobilization

Soil samples were obtained at 14 locations on the eastern hillslope in an attempt to identify the Br- plume and quantify the magnitude of Br- immobilized in the soil matrix (micropores). Limestone was encountered at 2.5 m depths at three sites preventing deeper sampling. The soil Br- data at the 14 locations were supplemented with 15 locations and three depths of solution sampler Br- concentrations from the 26 June 1991. Geostatistics was used to krige the Br- plume by depth from the surface to 5 m. The soil Br- concentration was kriged on a 20 x 20 grid with 4 m by 3 m intervals in the North and East directions, respectively. This analysis gave a clear indication of the Br- path during the February through August storm events that resulted in a plume of Br- immobilized within soil micropores (Fig. 5). The plume moved southwest, becoming deeper with greaterdistance from the line source and was driven by the fracture system and the surface topography. It was evident that Br- was partially refracted in the southern direction following the saprolite dip near the line source. At greater distances from the source, Br- mobility appeared to be dominated more by surface topography. Samples analyzed from the wells utilized to monitor the perched water table dynamics along the draw region during the 17-23 February event, suggested that Br- entered the draw region between 36 and 46 m south of the trench. The interpolations of the kriged Br- plume (Fig. 5) corroborate this observation.

Mass Balance Computations

The flux was computed as the product of the Br- concentration at each sample time and the volume of subsurface flow between sample times. The total mass of Br- exported from the subcatchment through the stormflow zone was calculated by summing the Br- fluxes during and between each storm event from the time of tracer release through August 1991. Despite the tracer release occurring under optimum conditions for transport, only about 20% (5150g Br-) of the nonreactive tracer was exported from the subcatchment through the stormflow zone during the six month study period. Geostatistical analysis of the soil Br- plume resulted in an estimated 47% (12000 g) of the applied Br- remaining in the soil matrix pores on August 1991. Of the 12000 g of Br- estimated to be stored within micropores, 8, 24, 33, 22, 6 and 6% was within the 0 to 60, 60 to 120, 120 to 200, 200 to 300, 300 to 400, and 400 to 500 cm depth increments, respectively. Soil sampling suggested that vertical transport below the stormflow zone and into the groundwater system was limited in that Br- was rarely detectable below 3 m. However, only about 70% of the applied tracer could be accounted for by both rapid transport through the stormflow zone and immobilization within soil micropores. The remaining portion of Br- was either transported vertically towards the groundwater system, or transported laterally through the stormflow zone deeper than the 2 m depth of the trench (export under trench). We believe the latter hypothesis was the predominant mechanism given the significance of the natural pipe at the bottom of the trench, but no evaluation of the likelihood of this hypothesis is possible.

Conclusions

Transport through macropores was extremely rapid with Br- breakthrough at the trench approximately 65 m from the line source occurring just 3 h after the release. The shallow perched water table present during the Br- release resulted in a tracer plume that was refracted in the direction of the fracture dip. During subsequent events, micropores served as a source in that Br- was flushed from soil matrix pores into macropores and exported from the subcatchment. The initial subsurface flow response to storms was a dilution of Br- due to an increase in the contribution of new water, followed by a flushing of micropores that resulted in significant concentration increases. Interaction between the shallow (< 2 m) stormflow zone and the groundwater system during storm events was indicated by soil sampling to not be significant. However, since only 70% of the tracer was observable and since transport was predominantly through the lower part of the trench, stormflow below 2 m was concluded to be significant.

Acknowledgement

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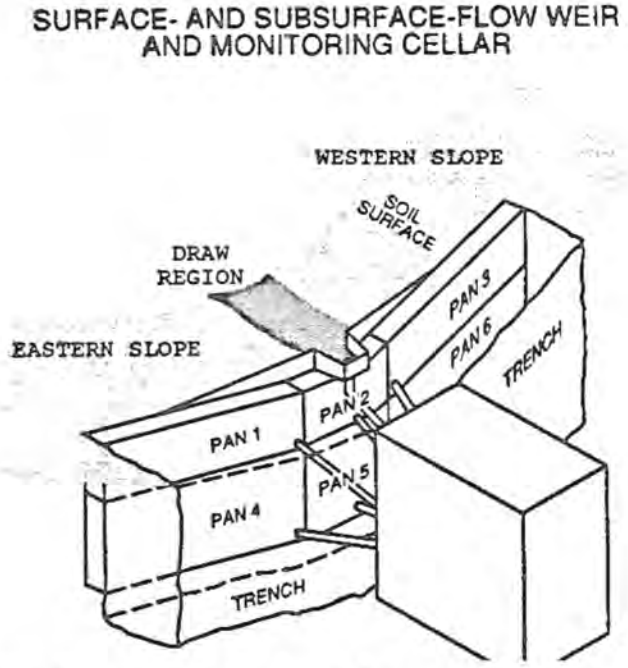

Fig. 1. Schematic of stainless-steel pans placed against trench face for collecting subsurface flows from the subcatchment.

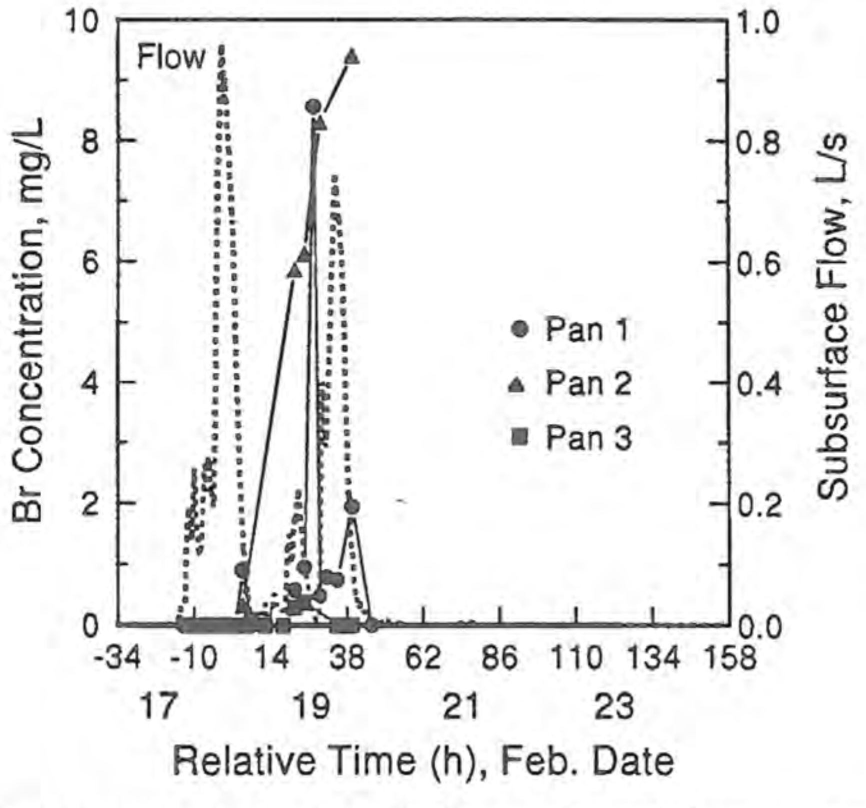

Fig. 2. Subsurface flow hydrograph (dashed line) for the upper flume and Br^- concentrations of pans 1, 2, and 3, (solid lines) during the February storm event.

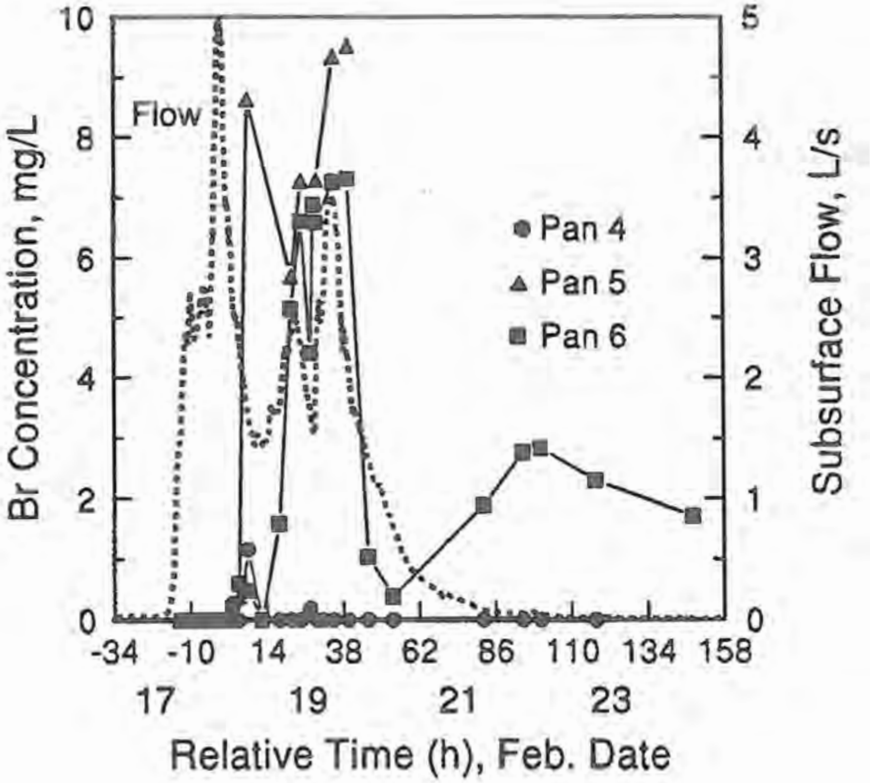

Fig. 3. Subsurface flow hydrograph (dashed line) for the lower flume and Br⁻ concentrations of pans 4, 5, and 6, (solid lines) during the February storm event.

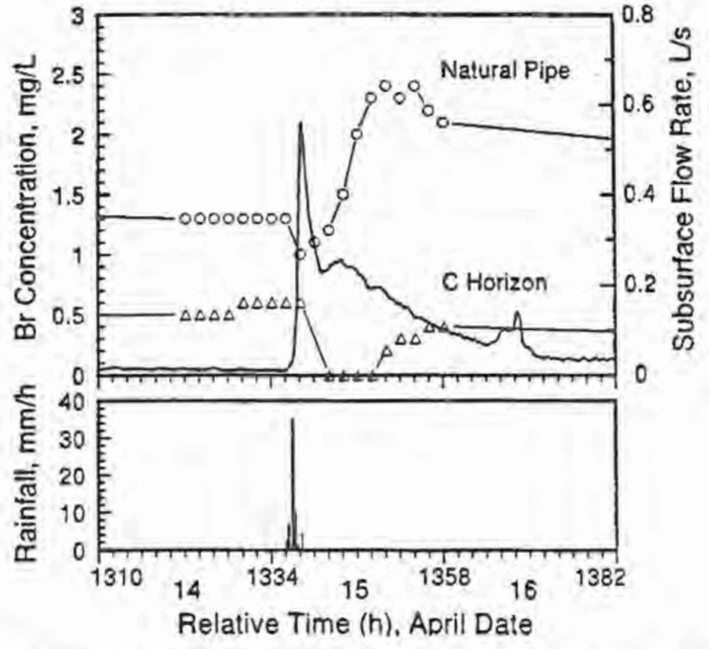

Fig. 4. Subsurface flow hydrograph (solid line) for the lower flume, the Br⁻ concentrations of the amalgamated samples of the C horizon, and the natural pipe, and the associated rainfall pattern for the April storm event.

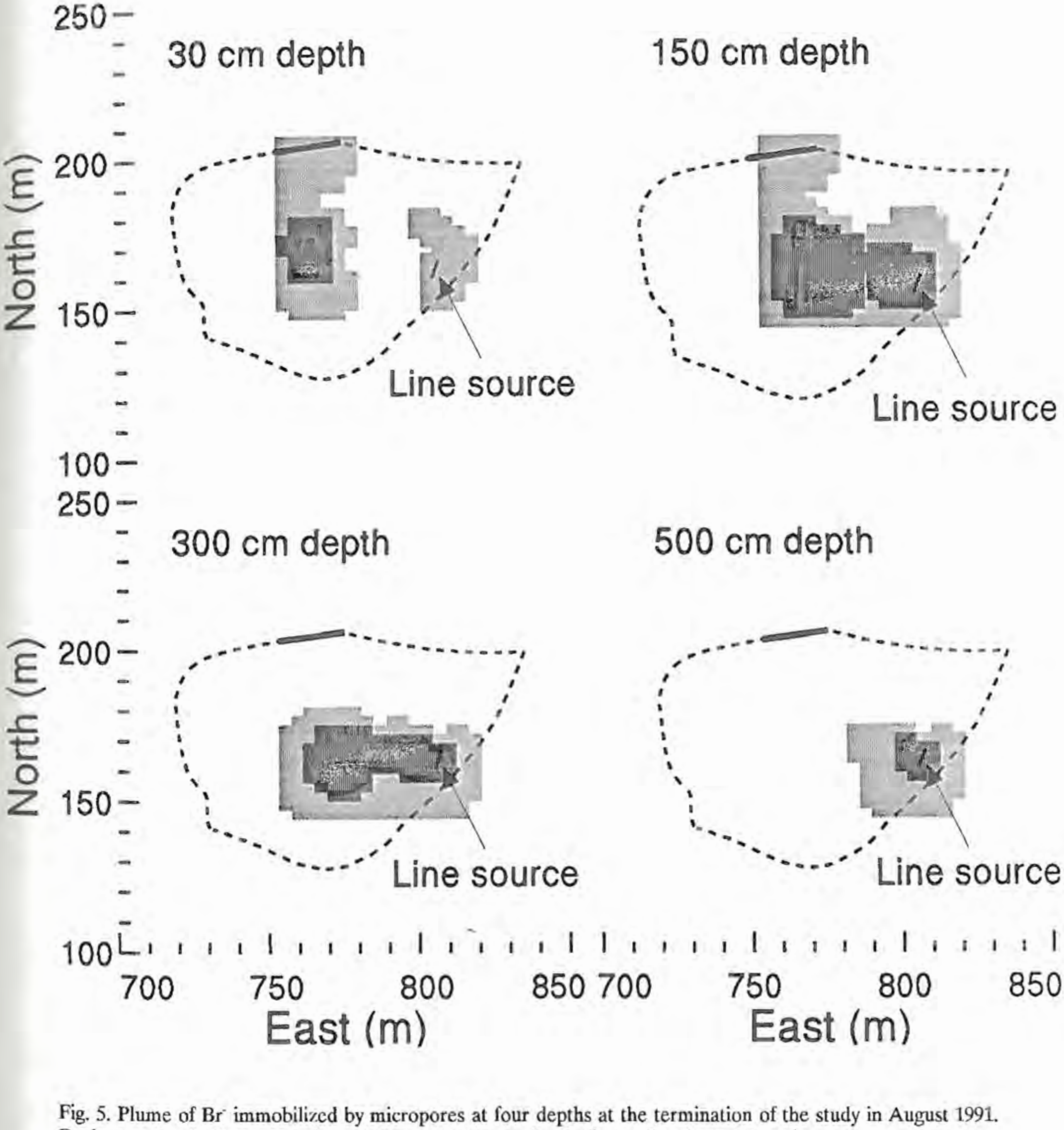

Fig. 5. Plume of Br^- immobilized by micropores at four depths at the termination of the study in August 1991. Darkest region indicates Br^- above 1.0 $\mu g/g$, lighter region indicates Br^- above 0.1 $\mu g/g$.

GROUND-WATER RESOURCES OF MILL HOLE SPRING AND THE ADJACENT CARBONATE AQUIFER IN THE VALLEY AND RIDGE PROVINCE, EAST TENNESSEE

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The U.S. Geological Survey, in cooperation with the Alpha-Talbott Utility District, is conducting a study of the ground-water resources of Mill Hole Spring and the adjacent carbonate aquifer. Mill Hole Spring is located near the upper end of a broad karst valley that has no perennial surface drainage. The spring seems to be part of a shallow, ground-water conduit system that mimics a "storm sewer" and responds quickly to rainfall events. During low-flow conditions water from the spring is fairly clear. Following precipitation events, both discharge and turbidity increase rapidly, indicating direct surface connection. The lowest measured discharge of Mill Hole Spring was 630 gallons per minute (gpm).

Ground-water flow in the carbonate aquifer is primarily through fractures and solution openings. Yields of wells completed in this aquifer depend on the number and size of solution openings penetrated below the water table. Fourteen wells were drilled and tested as part of this study; 4 are located up valley near Mill Hole Spring and 10 are located several miles down valley. Yields of wells, measured during drilling, ranged from less than 1 to 220 gpm. Six of the 10 down valley wells intersected openings yielding 15 gpm or more at depths from 120 to 180 feet below land surface. All 14 wells penetrated dry or mud-filled openings within 40 feet of land surface. During an aquifer test conducted at the most productive well, the well was pumped at 300 gpm for more than 24 hours. This pumping resulted in a maximum drawdown of 6 feet in the pumped well and a cone of depression in the aquifer that was elongated parallel to the strike of the formation. Test results indicated that deep conduits are capable of transmitting large quantities of water to wells.

STATUS AND PERFORMANCE OF AERATING WEIRS FOR TVA'S LAKE IMPROVEMENT PLAN

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Background

TVA is constructing aerating weirs below certain of its hydropower dams to 1) improve minimum flows between generating periods and 2) increase tailwater dissolved oxygen (DO) content during generation. Aerating weirs represent one of many alternatives that are being considered at each site as part of TVA's Lake Improvement Plan, which will be implementing minimum flow and DO improvements in the releases of 16 dams over the next five years.

TVA has recently completed a labyrinth aerating weir on the South Fork Holston River below South Holston Dam, and is currently constructing an infuser aerating weir on the Hiwassee River below Chatuge Dam. Developmental aspects of the South Holston labyrinth weir were presented at last year's symposium during its construction (Hauser, 1991). The weir has now been completed so this year's status report includes early performance results. The infuser weir below Chatuge Dam is a new type of aerating weir not yet completed, so this year's status report will discuss the developmental aspects of this weir.

Both of these weirs are designed to sustain a target minimum flow by slow drainage of the weir pool through low-level pipes and valves that maintain a constant flow when the upstream turbine is not operating. Aeration occurs as the weirs are overtopped during turbine generation. The weirs were designed to maximize the value of the tailwater while minimizing the hydropower impact, unsafe hydraulic conditions, and environmental disturbance.

Labyrinth Weir - South Holston Dam Tailwater

TVA completed construction of the labyrinth aerating weir downstream from South Holston Dam on December 31, 1991 and the weir is now in operation.

For flow control, the weir was designed with a pipe and valve arrangement to maintain a target 90 cfs minimum flow as the pool drains. The weir pool volume was calculated to be sufficient to maintain this flow for about 20 hours. To avoid confusion and help river users become accustomed to the routine of refilling the weir pool, the pool is refilled with short pulses from South Holston Dam twice a day at regular times (6a and 6p) rather than once every 20 hours.

Initial performance tests on the minimum flow conducted during January 1992 indicated that the weir was maintaining flow between 88 and 96 cfs for 20 hours after shutoff. Trash racks installed later in the spring appear to have reduced the minimum flow by about 3%. Such a small apparent reduction requires more confirmation. If adjustments are deemed necessary to reset the weir to its target 90 cfs, there is considerable flexibility to do so by opening capped pipes in the weir or adjusting valve arms.

For aeration, the labyrinth weir has an extended crest length (2100 ft) that reduces the unit discharge along its overflow sections. Reduced unit discharge minimizes the intensity of the downstream roller to safe levels and reduces the overflow nappe to a thickness that will aerate effectively. Aeration is achieved primarily by entrainment of air bubbles impinged by the nappe as it enters the downstream plunge pool. During generation, the water drops 4.5 ft from headwater to tailwater and is designed to aerate turbine flow (2500 cfs) to 6 mg/L minimum during the critical fall low DO period. Aeration measurements have been limited because of the well aerated winter and spring from South Holston Dam. However, available measurements during turbine discharge (Table 1) indicate the weir is recovering about 60% of the oxygen deficit. Based on temperature correction relationships, this value should increase to about 63% in the warmer fall period when South Holston release DO is at its seasonal low (2-3 mg/L). This suggests that the weir will increase DO from about 3 mg/L to over 7 mg/L in the critical fall period when saturation is about 10 mg/L.

Table 1.

Aeration Measurements at South Holston Labyrinth Weir

Date	Time	Weir flow (cfs)	HW-TW drop (ft)	Location	u.s. Temp (C)	u.s. DO (mg/L)	d.s. DO (mg/L)	DOsat (mg/L)	r	e
12/31/91	0750	500	6	lc (avg)	8.5	9.4	10.5	11.1	2.8	65%
12/31/91	1145	2400	4.5	lc (avg)	9.0	7.3	9.45	10.95	2.4	59%
12/31/91	1310	2400	4.5	rc (avg)	9.2	7.4	9.50	10.90	2.5	60%
1/17/92	1338	2400	4.5	lc (avg)	7.6	9.4	10.5	11.34	2.3	57%
1/17/92	0930	2400	4.5	rc (avg)	7.7	9.7	10.70	11.31	2.6	62%
5/04/92	1338	2400	4.5	lc (avg)	7.5	9.75	10.9	11.37	3.4	71%
estimate of aeration during fall low DO period										
fall 93 (est)		2400	4.5	lc+rc	13	3.0	7.4	9.95	2.7	63%

lc = left channel weir rc = right channel weir
r = deficit ratio (u.s. to d.s.) e = %deficit removed (1-1/r)
turbine flow = 2400 cfs

Observations of hydraulic conditions in the plunge pool indicate that a small recirculation zone exists at the base of the weir, in agreement with earlier flume tests with a segment of the weir (Hauser, 1990). Preliminary safety tests using a tethered floating object indicate that this recirculation is not a "keeper", due largely to the low intensity of the roller and the significant longitudinal flow component that develops along the labyrinth legs. No life-threatening hydraulic conditions have been observed during operation of the weir.

Infuser Weir - Chatuge Dam Tailwater

TVA is currently constructing a second aerating weir below Chatuge Dam, scheduled for completion around the end of 1992. This weir is designed to maintain a target minimum flow of 60 cfs using a similar pipe and valve arrangement as the South Holston weir. The aeration component of this weir, which has been dubbed the "infuser", incorporates a completely different design from that of the labyrinth at South Holston.

The infuser weir for Chatuge consists of a lined timber crib weir and a downstream horizontal infuser deck that is essentially a broadcrest weir with rectangular openings oriented transverse to flow. The openings create a succession of waterfalls normal to the river flow that impinge on the plunge pool beneath the deck, entraining bubbles and creating turbulence that provide the aeration mechanism. Relative to the labyrinth, the infuser thus creates an equivalent length of waterfall in a much more compact area of the river. The openings increase in size from upstream to downstream as the head over each opening decreases, providing a more or less uniform flow through each opening. The infuser deck is overlain with a foot grating for safety reasons and to break up the otherwise laminar nappes or water "curtains" that are formed as water flows through the openings. Chimneys oriented longitudinal to flow are provided in the infuser deck to ensure sufficient air flow from the atmosphere to the area beneath the deck where aeration is occurring.

The deck is designed to pass most of the flow through the openings, with a small fraction of the flow remaining to overflow the downstream end of the infuser deck. This overflow will occur for all flows greater than the minimum turbine discharge as a means to prevent accumulation of debris and trash on the infuser deck.

For equivalent drop height and flow conditions, the infuser achieves nearly the same aeration efficiency as the labyrinth (55% to 60% deficit recovery), based on full-scale flume tests (Rizk and Hauser, 1992). Estimated cost to construct a prototype infuser weir at Chatuge were about half that of a prototype labyrinth for Chatuge.

Discussion and Conclusions

These results indicate that the South Holston labyrinth weir is achieving a high level of performance in maintaining minimum flows at target levels and aeration efficiencies slightly exceeding expectations. The DO improvements measured with the labyrinth weir are about 20%-30% greater than those predicted with the conventional weir aeration equations of Nakasone (1987). This result combined with other observations suggest that in addition to the aeration that occurs during the nappe impingement on the plunge pool, further aeration is occurring along the length of the labyrinth legs as the bubbles are repeatedly reentrained along the length of the labyrinth legs.

Based on laboratory test results with the infuser, it should aerate about the same as the labyrinth weir for about half the construction cost. Its main disadvantage relative to the labyrinth is that it requires more head to pass the same flow, causing more backwater on the upstream turbine or forcing a more downstream location to avoid the backwater, and creating more inundation during flood conditions. A second disadvantage which may develop is that it may require more maintenance to remove trash and debris on the infuser deck.

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SOURCES OF OXYGEN DEMANDING MATERIALS TO TVA RESERVOIRS FROM DIFFUSE NON-POINT SOURCES

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Introduction

Diffuse sources of oxygen demanding materials such as particulates and dissolved organic carbon and organic and ammonia nitrogen are transported into reservoirs by hydrologic processes of precipitation, infiltration, surface runoff and streamflow. While some organic material enters with subsurface recharge (i.e. septage), most enters via surface runoff and streamflow. Oxygen demanding materials are seldom introduced by direct precipitation. Thus, the diffuse sources of oxygen demanding materials are primarily linked to the basin hydrology.

Loadings of oxygen demanding materials are functions of rainfall, runoff and the resulting streamflow hydrographs. Because, of this link to watershed hydrology, the loadings will have certain random characteristics. However, if the links between rainfall, runoff, and oxygen demanding loadings can be adequately described and related to land use within the basin, then predictions of the effects of non-point materials on the oxygen dynamics of the reservoir are possible.

This project involves sampling 13 different streams which flow into eight tributary projects within the Tennessee Valley. The eight reservoirs being studied include Douglas, Cherokee, Norris, South Holston, Watauga, Chatuge, Nottely and Blue Ridge. The study is investigating oxygen demanding materials within inflow streams which may be related to possible non-point source pollution. Six drainage basins are expected to contain higher loadings of nutrients and materials which would exert a higher oxygen demand, thus lowering the oxygen level within the hypolimnion of the reservoir. Watauga and Blue Ridge reservoirs are being studied as the control reservoirs. These two reservoirs should have minimal oxygen demanding problems.

The project requires sampling the inflow streams over three years from 1992 through 1994 during mid-February to the end of August. The reservoirs have been divided into three focal groups, which will be sampled for baseline data during two years and runoff events during the third year. Norris, Douglas and Cherokee are being studied as focal reservoirs during 1992. Blue Ridge, Nottely and Chatuge will be focal reservoirs during 1993 and South Holston and Watauga will be focal in 1994.

Method

This project will utilize grab and composite samples taken from the 13 inflow streams. All sampling stations have been located near U.S.G.S. streamflow gages or TVA gages or dams. The flow data will be used to determine nutrient and organic mass loadings entering each reservoir. Sampling visits for the focal reservoirs will be such that approximately equal numbers of site visits will be made on the rising and falling limbs of the hydrograph. Emphasis has been placed on sampling free-flowing stretches of the inflow streams before the streams are inundated by the impoundment. The flow data will also allow the determination of when the sample was taken with respect to the rising limb, falling limb or baseflow portion of the hydrograph.

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This sampling strategy is based on a review of Reckhow and Stow (1990) who concluded that monthly monitoring for nutrients seems a reasonable choice for trend detection. More frequent sampling has been reported to lose efficiency due to autocorrelation. Smith and McBride (1990) reported on a network for water quality monitoring. They commented that: (1) the minimum effective sampling interval for non-runoff flows is of the order of two weeks due to autocorrelation and (2) the number of samples needed for a reasonable standard deviation is 50 to 100. Thus for sampling biweekly, the system must cover three to four years.

From this, it is apparent that samples should follow the rising limb, falling limb, and baseflow hydrology. Approximately 12 to 15 samples should be taken per stream during the February to August period. Time frequency of sampling is not important as long as hydrologic events are changing. Sampling will occur at a minimum of two weeks apart unless rainfall/runoff events have taken place and warrant more frequent sampling.

After sampling, testing in the laboratory will begin. Biological oxygen demand (BOD), the complete nitrogen series, suspended solids, total and dissolved organic carbon and total and orthophosphates will be performed by EPA approved laboratory procedures. The samples are being tested for both five and 50 BODs. This data will give insight to the oxygen demand that the reservoir is experiencing during the impoundment period from March to September based on the loadings that are observed during the sampling season. Temperature, dissolved oxygen, pH, oxidation-reduction potential (ORP), and conductivity are being taken in the field as the sites are sampled.

Results

Sampling began in late March of this year. We are anticipating having between 12 and 14 samples for each site for the 1992 sampling season. Figures 1 and 2 are plots of the data collected at the French Broad and Clinch Rivers, respectively. Mass loading calculations and further analysis will begin after the final sampling date on August 30th. The initial analyses will begin with the classification of samples to the rising limb, falling limb, or baseflow portions of the hydrograph. Then, effects of mass loadings on the reservoirs will be investigated.

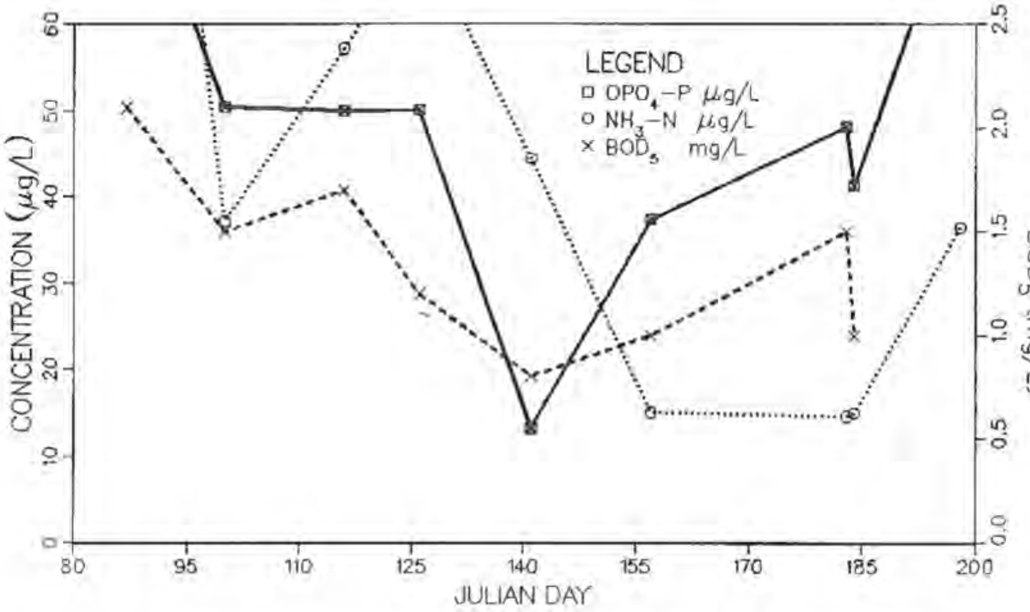

Figure 1 Concentrations for French Broad River 1992

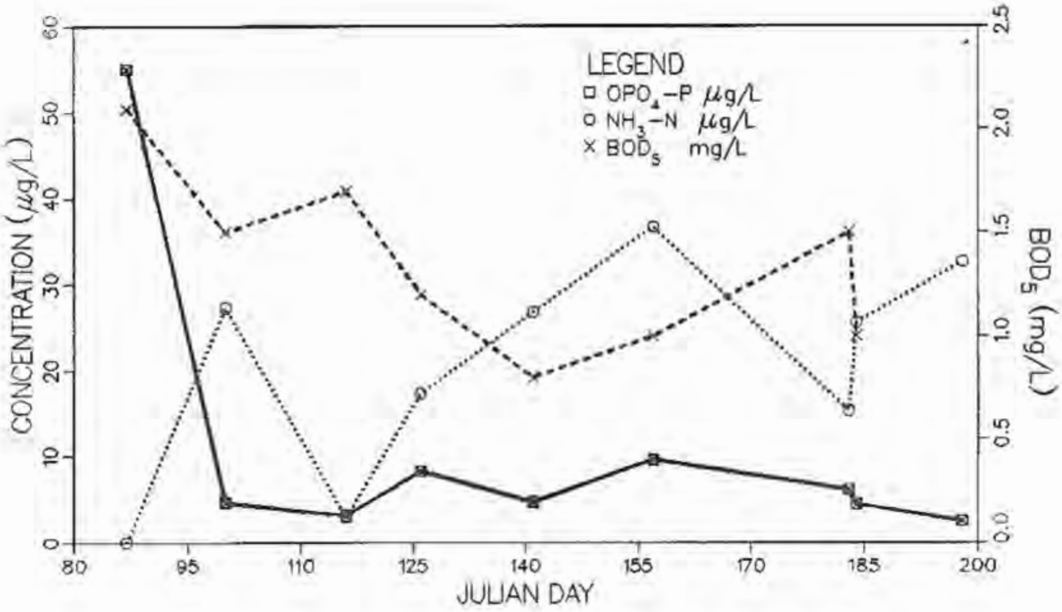

Figure 2 Concentrations for Clinch River 1992

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CHANNEL EVOLUTION ALONG A REACH OF THE NORTH FORK FORKED DEER RIVER, NEAR DYERSBURG, TENNESSEE

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In the summer of 1991, a study of past and present characteristics of flow paths was conducted along a 7.5-mile reach of the North Fork Forked Deer River near Dyersburg, Tennessee. The study was conducted in cooperation with the Tennessee Wildlife Resources Agency.

Characteristics of the natural channel before settlement are unknown, but the presence of ponded areas on a map made in 1819 suggests that not all the flood plain was well drained at that time. At some time after 1819, a 3-mile reach of the natural channel along the north side of the valley was abandoned, probably as a result of sedimentation at the mouth of RoEllen Creek, and a new channel location along the south side of the valley was occupied. Prior to construction of a drainage ditch intended to replace the natural channel, bankfull capacity of the channel was about equal to present summer base flow. Since this ditch was completed in 1921, sedimentation has divided the natural channel into several sloughs.

The ditch has been subject to aggradation and debris accumulation since construction, and has been kept open by repeated excavation and clearing. Remnants of several large debris jams remain in the ditch, and the potential for debris jams remains high.

The natural channels of tributaries entering the study reach also have undergone aggradation and occlusion, and the locations of their channels have changed. These changes are the result of sedimentation, debris jams, and beaver dams, and commonly occur at the flood-plain margin. Ditches dug to restore flow through the areas of occlusion have undergone the same changes.

CHRONOLOGY AND SPATIAL PATTERNS OF ACCELERATED SEDIMENTATION IN A FORESTED RIVERINE WETLAND NEAR DYERSBURG, TENNESSEE

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Flood-plain stratigraphy and historical sedimentation rates were investigated along a 7.5-mile reach of the North Fork Forked Deer River near Dyersburg, Tennessee. Radiocarbon dating and tree-ring analysis indicate three distinct modes of wetland sedimentation: (1) vertical accretion of seasonally ponded flood plain, (2) filling of permanently ponded sloughs, and (3) deposition associated with distributary flow of tributaries near the flood-plain margin.

Vertical accretion of seasonally ponded flood plain was the dominant mode of sedimentation for about a century after settlement in the early 1800's. It resulted in 5 to 12 feet of sediment deposition, particularly in areas near the natural river channel. After excavation of a drainage ditch in about 1920, vertical accretion was abruptly reduced in many areas, probably because of increased sediment transport in the new ditch or reduced flooding of these areas. Concurrently, sedimentation in the natural river channel increased, eventually dividing it into a series of sloughs.

By the 1960's, the highest sedimentation rates, which in some areas exceeded 0.2 foot per year, were in areas near tributary streams along the flood-plain margins of the North Fork Forked Deer River. High sedimentation rates in these areas were the result of high erosion rates in the tributary basins and ponding caused largely by the re-introduction of beaver. High erosion rates in the tributary basins were due, in part, to the removal of hedges and fence rows following widespread consolidation of land holdings.

GIS/HSPF Modeling of West Sandy Watershed

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Introduction

West Sandy Watershed is a 150 square mile area that drains into a dewatering area adjacent to Kentucky Lake. The watershed is managed by TVA to provide multiple benefits: protection of waterfowl, fisheries and bottomland timber as well as vector control. The management program is controlled by manipulation of the pump station and sluice gates located at the West Sandy Dewatering Area Dike. Water quality problems in the watershed include nutrients, organics, and low dissolved oxygen levels.

A Geographic Information System (ARC/INFO) was used in conjunction with a nonpoint water quality model (HSPF) to model the hydrologic, hydraulic, and water quality processes in the watershed. Land use data, soils information, topography, and other data were digitized into a GIS database. These data were then used in land segmentation and parameter development to facilitate HSPF modeling. The primary goal was to demonstrate the utility of GIS/HSPF modeling in watershed management and planning in Tennessee.

Modeling Approach

The initial phase of the West Sandy effort involved the digitization of land use, general soils groupings, and topography into a GIS database. Land use maps prepared by TVA via interpretation of low-altitude color infrared photography obtained in October, 1989, were used to develop the GIS land use database. A general soils map from the Soil Conservation Service was used to prepare the GIS soils database. Topography adjacent to the major streams was digitized from USGS quadrangle maps.

Based on meteorological, soils, and topographic data, the authors treated the entire watershed as a single segment group. Although three or more weather stations would have been desirable, only the Paris Landing weather station provided meteorological data. Because of fairly uniform soils and topography and because of one set of meteorological data, there was no justification for more than one segment group.

Modeling of hydraulic routing and instream processes requires proper segmentation and characterization of the major streams. The stream bed profiles for Clifty Creek, West Sandy Creek, Bailey Fork Creek, Holly Fork Creek, and the Dewatering Area were created in the ARC-INFO Triangular Irregular Network analysis. In view of channel hydrogeometry and confluence points of the streams, the watershed was divided into nine subwatersheds (Figure 1). Reach 1 (Dewatering Area) was treated as a completely mixed reservoir, while Reaches 2 through 9 were typical channels.

Using the GIS land use database, the watershed was divided into six land uses (land segments)--- cropland, hay cropland, pasture, forest, animal waste, and other. Wetlands outside the Dewatering Area were included in the Forest land segment. "Other" consisted of urban, gullies, quarries, and miscellaneous land uses. All land segments except animal waste sites were treated as pervious land segments; animal waste areas were treated as impervious land segments.

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Water quality parameters simulated in the watershed model included suspended sediment, dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), and orthophosphorus (PO_4-P). Nutrient loadings from cropland and hay cropland were simulated by detailed modeling of land surface and soil processes. Nutrient loadings from pasture, forest, and other were simulated using potency factors and subsurface concentrations. Organic loadings from each pervious land segment were calculated with potency factors and subsurface concentrations. The potency factor approach is used exclusively for surface loadings, while the subsurface concentrations are user-specified. The detailed modeling approach uses soil chemical and biochemical processes that, in conjunction with hydrologic and erosion modeling, calculate both the surface and subsurface nonpoint loadings. For modeling nonpoint nutrient loadings from pervious land segments (PLS), this usually involves the calculation of mineralization, nitrification/denitrification, immobilization, sorption/desorption, plant uptake, and other soil nutrient processes as impacted by fertilizer applications, agronomic practices, hydrologic conditions, and soil moisture and temperature.

Hydrology, sediment, and DO simulations are based on the same procedures, using the same HSPF modules for all pervious land segments. Hydrology for impervious land segments (ILS) uses a different module. Sediment from a PLS considers detachment of sediment particles by raindrop impact, attachment of fine sediment particles, washoff of detached sediment, and soil scour by overland flow. DO concentration of overland flow, which is assumed to be saturated, is calculated from surface soil temperature and surface runoff temperature. DO concentrations in interflow and active groundwater flow are specified by the user.

To represent animal waste contributions, the authors designated them as impervious land segments (ILS). This was done to conceptually model a rain-driven source of pollutants with constant concentrations. Although several of the approximately 15 animal waste sites have 2-cell anaerobic lagoons, these operations probably discharge during storm events. The concentrations used for the animal waste runoff are listed below:

Parameter	Concentration (mg/l)
BOD	200
Nitrate - N	10
Ammonia - N	20
Ortho - P	10
TSS	500

Each animal waste site was assumed to be 2 acres in size.

Based on information provided by the University of Tennessee Extension Office in Henry County, approximately 85% of the farmers in the watershed use conservation tillage and a 2-year crop rotation of:

Spring	-	No-till corn in bean stubble
Fall	-	Disk or chisel and plant wheat
Spring	-	No-till beans in wheat stubble
Fall	-	Harvest beans; leave stubble for no-till corn next spring

To simplify the modeling effort, a composite crop was used assuming that half of the cropland was in the first year and half was in the second year of the rotation. The effects of frozen ground, thawed ground, tillage during wheat planting, and fertilizer application were included in the modeling process by using the Special Actions Block of HSPF. As stated previously, hay cropland was designated as a separate land category, and it was impacted by frozen and thawed conditions as well as by fertilizer application. Fertilizer application rates were obtained from the local UT Extension Office.

Two point source discharges, the Paris Wastewater Treatment Plant (WWTP) and an industrial waste discharge, were included in the modeling process. The Paris WWTP discharges into Bailey Fork Creek, and the industrial discharge is into Clifty Creek. The flows and waste loadings from these sources were input to the model as external time series. Actual operating data were used for the WWTP, while the industrial loadings were estimated because of limited data.

The discharge from the watershed is controlled by the pump station and sluice gates at the West Sandy Dewatering Area Dike. The last full year of daily TVA records of pumping times, sluice gate settings, Dewatering Area elevations, and Kentucky Lake elevations was 1987. Even though little water quality data for 1987 were available, the GIS/HSPF model was calibrated for meteorological and hydraulic conditions of 1987. All pumps were assumed to be operating at 80% efficiency, and flow through the four 8 foot by 8 foot sluice gates was calculated as a function of upstream and downstream depths, gate opening, and gate geometry. Elevations in the Dewatering Area are typically controlled by the pumps during April - October and by the sluice gates during November - March. Furthermore, leakage through the dike was considered because it has been observed by TVA personnel.

To calibrate the model, water quality data obtained by TVA in 1990-91 were used. In addition, the authors and TVA cooperated on a weekly monitoring program during May - August, 1991, at five locations (Figure 1). All available water quality data were averaged to obtain typical constituent concentrations for all months except January and October, when data were unavailable. Consequently, only an approximate calibration was achieved.

Results

Hydrologic/Hydraulic Calibration   Because flows from the watershed are controlled and because no discharge data are available for the tributaries, hydrologic/hydraulic calibration was obtained by adjusting model parameters so that simulated elevations in the Dewatering Area matched actual elevations reasonably well.

Sediment Calibration   Sediment calibration was achieved by attempting to match simulated and actual sediment concentrations in the tributaries and Dewatering Area. In addition, sediment washoff rates were examined for the pervious land segments to make sure they were reasonable for the given soils, topography, land use, management practices, and meteorological conditions. Annual sediment washoff rates were 0.91 tons/acre and 0.25 tons/acre for cropland and hay cropland, respectively, while the annual rates for pasture, forest, and other were 0.17, 0.13, and 0.13 tons/acre, respectively. Simulated 1987 sediment loads and annual loads estimated by TVA for the tributaries are shown in Table 1.

Water Quality Calibration   Water quality calibration was also attained by matching simulated and actual constituent concentrations in the watershed streams. Dissolved oxygen is a critical parameter because violations of the 5 mg/l water quality standard frequently occur during the summer. This is especially true in Clifty Creek and the Dewatering Area. Simulated and actual average monthly concentrations of DO, BOD, NO_3-N, NH_3-N, and PO_4-P for Clifty Creek are shown in Table 2. In most cases, the simulated water quality data agree reasonably well with the actual data. The high BOD's are apparently caused by the industrial discharge and accumulation of organic debris caused by beaver dams.

Annual constituent loads for the tributaries are given in Table 1. The simulated annual loads are typically less than the loads estimated by TVA because 1987 was a dry year. Furthermore, the calibration was not based on the TVA mass estimates.

Complete calibration results and the impacts of various BMP's on water quality in the West Sandy Watershed will be presented at the symposium.

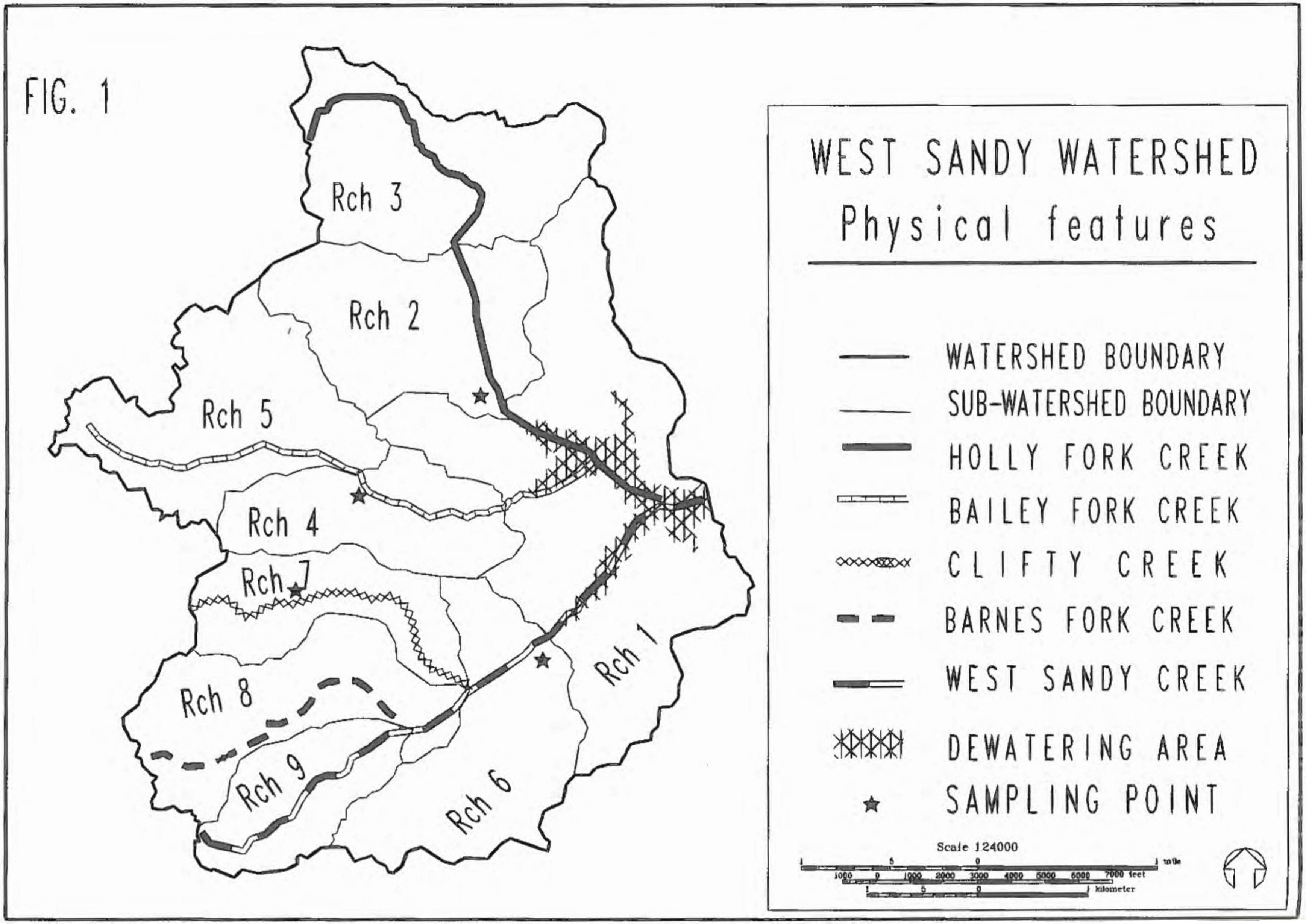
WEST SANDY WATERSHED
Physical features
WATERSHED BOUNDARY
SUB-WATERSHED BOUNDARY
HOLLY FORK CREEK
BAILEY FORK CREEK
CLIFTY CREEK
BARNES FORK CREEK
WEST SANDY CREEK
DEWATERING AREA
SAMPLING POINT
Scale 1:24000
Rch 1
Rch 2
Rch 3
Rch 4
Rch 5
Rch 6
Rch 7
Rch 8
Rch 9
FIG. 1

Table 1
Annual Constituent Loadings for the Subwatersheds
(Average Annual TVA Estimates Versus 1987 Model Simulation)

	Clifty Creek		W. Sandy Creek		Holly Fork Creek	
	TVA Estimate	Model Simulation	TVA Estimate	Model Simulation	TVA Estimate	Model Simulation
BOD,lb/yr	125,347	60,927	784,793	207,196	446,119	203,043
NO3-N,lb/yr	9,443*	2,976	129,595*	15,603	57,896*	9,819
NH3-N,lb/yr	5,746	1,608	34,340	9,325	15,869	5,733
PO4-P,lb/yr	896	959	6,749	6,096	3,399	3,753
TSS,tons/yr	504	2,580	5,632	5,592	5,736	4,457

* includes nitrite - N

Table 2
Average Monthly Constituent Concentrations for Clifty Creek

	Dissolved O2		BOD		NO3-N		NH3-N		PO4-P	
	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated
Feb	12.7	10.1	1.6	1.8	0.15	0.25	0.06	0.08	0.01	0.02
Mar	9.4	9.4	1.3	1.6	0.12	0.23	0.14	0.08	0.02	0.01
Apr	7.2	9.0	2.9	1.5	0.13	0.22	0.13	0.10	0.03	0.02
May	5.5	7.5	1.5	0.6	0.23	0.28	0.14	0.07	0.06	0.05
Jun	6.9	6.6	2.4	2.6	0.23	0.59	0.15	0.10	0.12	0.07
Jul	5.8	5.9	5.7	5.0	0.09	0.12	0.06	0.14	0.06	0.05
Aug	4.7	4.7	16.0	9.9	0.09	0.06	0.14	0.26	0.07	0.09
Sep	-	7.0	3.4	0.1	0.01	0.04	0.01	0.01	0.02	0.01
Nov	6.3	8.0	3.8	0.7	0.14	0.09	0.04	0.12	0.04	0.06
Dec	10.5	9.8	1.5	2.3	0.17	0.18	0.13	0.11	0.02	0.08

* All values are mg/l

Development of a Data Input Program for HSPF

by

James L. Smoot[1]
and
C. Gregory Phillips[2]

Abstract

Data input to the comprehensive water quality model, HSPF, has been simplified through use of a personal computer based data input program. This program was developed using data from Long Creek and Big Limestone Creek watersheds, both of which are located in the Nolichucky River Basin, in Northeast Tennessee. Consequently, HSPF input file sets generated with this data input program will reflect a bias to this general physiographic region or similar region. This includes the topography, rainfall patterns and intensities, temperatures, evaporation and transpiration potentials, agricultural crops and practices, and soil characteristics.

The data input program is designed to: 1) relatively quickly, generate input data sets for HSPF that can be used in model simulations to produce estimates of runoff volumes and sediment yield for a watershed, and 2) generate input data sets that can be used to compare the relative effects on potential sediment yield of one or more selected BMPs in a single watershed. The program is not designed nor intended to generate input data to replace a calibrated HSPF input data set. However, it may be used to construct base data sets that can be user calibrated for a specific watershed in a different physiographic region, with different landuses, crops, BMPs, and other properties.

In addition to its primary use, the program simplifies and reduces the number of parameters a user must provide values for in order to utilize the simulation capabilities of HSPF. This is accomplished through extensive use of data files which have been compiled for various landuses, agricultural practices, soils, and weather information representative of the Northeast Tennessee area. Primary information supplied by the user is reduced to: 1) defining the stream network; 2) indicating the applicable landuses, hydrologic soil groups, slope of the land surface, agricultural BMPs, and their associated areas; 3) length of the model simulation; and 4) desired model output. The data input program writes the HSPF user control input (UCI) file set based on these 4 primary user responses. Thus, the data input program is designed to reduce the complexity of user input, the time required to assemble a UCI file set, and allow easy simulation of selected BMPs. Figure 1 outlines this process. Table I shows both the user's input to the data input program and the data input program's input to the HSPF UCI file set based on user responses and existing data files. Complexity of user input is reduced from the parameters listed by *2 in Table I, to detailed user selection and input of the: landuse, Hydrologic Soil Group (HSG), erodibility factor (K), BMP(s), and land slope. These five factors are used to adjust information called from the existing data files to write the HSPF UCI file set.

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Table I. User input to Data Input Program, and input to HSPF from Data Input Program.

User Input Options to Program	Data Input Program, input to HSPF
Input file name Length of simulation Number of reaches Reach length Reach elevation drop Reach order Drainage area to reach Landuses in reach Area of each landuse HSG of each landuse K factor for each landuse Slope in each landuse Best Management Practices	Weather information Header information Operational sequencing information Special actions*1 Sets active sections Parameter input for each landuse*2 Monthly landuse parameter adjustments Reach length, elevation drop Reach, stage-volume-discharge relation Reach network information *1 Relating to agricultural practices and landuse *2 Parameters are called from data file and are: soil moisture storage, infiltration information, slope length, baseflow recession information, ET information, interception storage information, Manning's number for overland flow, management practice factors, soil detachment and attachment information, soil washoff and scour information, and relative soil composition information.

The data files consist of information required by HSPF that can be directly linked with the landuse/landcover or agricultural practices. This information was compiled from the sources listed in 'References'. Values appearing in the data files follow the recommendations set forth in these materials. Many of the values have been further refined (calibrated) to more closely approximate actual conditions found in the Northeast Tennessee area. However, values reflecting the effects of certain specific BMPs have not been modified from the literature, because no data specific to the Northeast Tennessee area were available.

Landuse information has been compiled for 18 specific landuses, including 11 agricultural landuses. These 18 landuses represent either a significant percentage of the total land area, or a potential significant contribution to nonpoint source pollution from sediment. Agricultural landuses reflect various cropping practices and crop uses. Each practice has been closely coordinated with weather events. Various BMPs are available as modifiers for all of the cropping practices.

Table II. Landuses.

Landuse Category
1. Residential
2. Commercial/ Industrial
3. Shrub/Brush
4. Forest
5. Disturbed areas
6. Cropland
7. Pasture land
8. Feedlot areas
9. Transportation

Landuse categories are menu selected from the list shown in Table II. Cropland landuse categories are menu selected from the list shown in Table III. Most of the landuses can be linked with BMPs. A single BMP may be associated with some or all of the applicable landuses. These BMPs are shown in Table IV, linked with their applicable landuses. All BMPs can be specified to apply, only to a percentage of the landuse area, or to all of the landuse area. A single BMP may be linked to more than one specific landuse category for a model simulation.

Table III. Cropping Practices.

Single Crops

1. Corn for silage
2. Corn for grain
3. Beans for hay or silage
4. Beans for grain
5. Wheat for grain
6. Wheat for hay or silage

Double Crops

7. Corn (grain or silage) & Wheat (hay or silage)
8. Beans (hay or silage) & Wheat (silage or grain)
9. Corn, Wheat, Beans (all for grain, hay or silage) (in rotation)

Table IV. BMP Practices and Landuses.

BMP	Applicable Landuse
Contour Cropping	Cropland
Strip Cropping	Cropland
No till	Cropland
Winter cover crop	Cropland
Terraces	Cropland, Pasture land
Grassed waterways	Cropland
Erosion control measures	Cropland, Pasture land, Disturbed areas

Cropland landuse has 9 different cropping practices available for user selection. These are shown in Table III. The cropping practices include 'single crops' and 'double crops'. A double cropping practice is where two crops are grown on the same plot of ground in a single year. Also the crop useis specified because of it's importance relative to the amount of residue left on the soil after harvest, and the correlated erosion potential. The final cropping practice is a rotational crop, which grows 3 crops every 2 years. No further allowance is made for crop rotations.

The data input program is not designed to replace a calibrated and verified HSPF data input file set. The data input program will, relatively quickly, produce HSPF input data sets that can be used to simulate runoff and sediment yield to be used in comparing the relative effects of selected BMPs in a single watershed, or used to construct base data sets that may be user calibrated for a specific watershed.

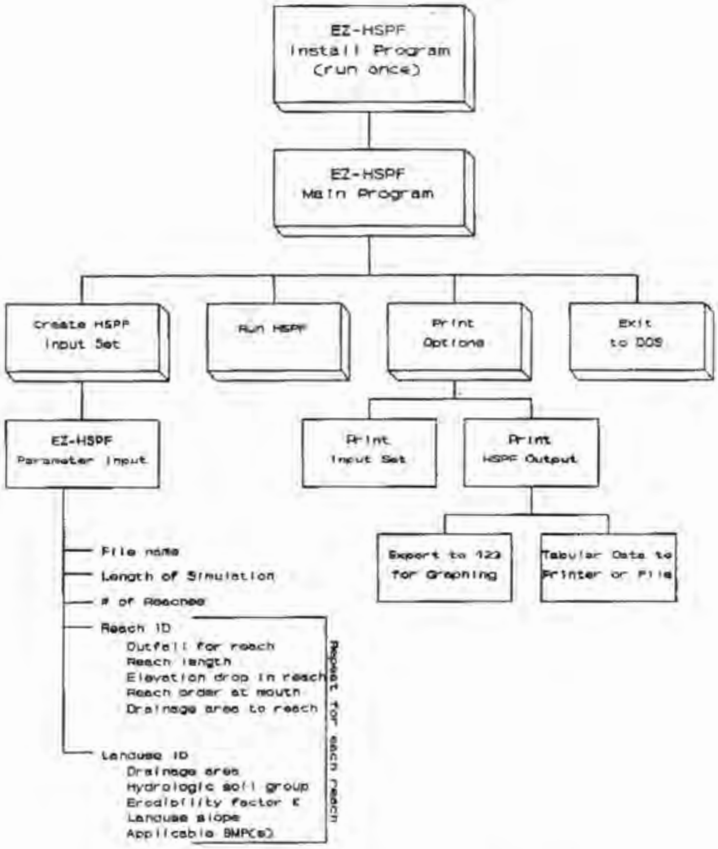

Figure 3. Operational Flowchart

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FLOOD FREQUENCY OF NATURAL STREAMS IN RURAL BASINS IN TENNESSEE

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ABSTRACT

A procedure for estimating the magnitude and frequency of floods on natural streams in Tennessee has been developed from an analysis of peak-flow data at 223 rural gaging stations where 10 or more years of discharge record are available. As part of this analysis, regression equations were computed from data for these 223 gaging stations using the generalized least-squares procedure. The regression equations and station flood-frequency curve data were used to calculate weighted average discharges at these sites. The regression equations can be applied to ungaged sites to estimate the magnitude of floods having a recurrence interval of as much as 500 years. Estimates of the magnitudes of floods at an ungaged site, which has a drainage area within 50 percent of that at a gaged site on the same stream, can be made using a combination of the regression equation approach and the flood-frequency characteristics at the gaged site.

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A STRATEGY FOR DESIGN OF IMPROVEMENTS TO NASHVILLE'S COMBINED SEWER SYSTEM USING SYNTHETIC RAINFALL

By

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The Department of Water and Sewerage Services for the Metropolitan Government of Nashville and Davidson County is required to eliminate all unpermitted overflows from its combined sewer system by 1 July 2001. This action is required as one of the provisions of a State Commissioner's Order issued in March 1990. To establish a practical basis of design, the State accepted the proposal that eight overflows would be allowed annually from those sites that discharge to the Cumberland River. From previous studies, this level of control had been determined as adequate for protecting water quality in the River.

The firm of Consoer, Townsend & Associates, as the Manager of the Nashville Overflow Abatement Program (OAP), was assigned the task of developing the design criteria to meet this goal. Since the peak pumping/treatment rate from the combined sewer system will be limited to 160 mgd, rainfall intensity and duration will be the remaining, significant factors affecting the design. Accordingly, it was decided to create and test a synthetic storm that would define the outer "envelope" of flows and the storage required to contain runoff from storms that would cause more than eight overflows per year. Intensity-duration tables were not available for this return frequency. Therefore, hourly records for 43½ years of rainfall (collected at the Nashville Airport) were searched and ordered using a computer program to evaluate various durations.

The analysis of the rainfall records produced 3184 unique storms ranging in duration from 1 hour to 95 hours. These storms were each analyzed to evaluate rainfall intensity for durations ranging from 1 to 72 hours, starting with any hour in each of the 3184 storms. The second series of storms was then examined to obtain a maximum depth for selected durations starting in each rain. The resulting storms of each duration were then numbered in descending order from largest to smallest.

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***Gresham, Smith & Partners

The total precipitation for the 349th value was selected on the basis that, on the average, 8 storms per year would produce allowed overflows (43.5 years x 8 per year = 348). There are usually several storms with the same average intensity clustered about the 349th value. It is essential that the events analyzed in this way be independent of each other. (For example: the dissipated effects of a major tropical storm in the Gulf resulting in 24 hours of very heavy rain in Middle Tennessee only constitutes one event, even if more than one peak value for a given duration occurs in that 24-hour period.) The results of this analysis are shown in Table 1.

TABLE 1
Rainfall Quantity for Various Durations and
8 Per Year Frequency with 10 Hour Inter-Event Period

Duration (Hours)	Rainfall Amount* - Inches
1	0.51
2	0.70
3	0.82
6	1.00
12	1.20
18	1.32
24	1.36
30	1.41
36	1.45
42	1.47
48	1.51
54	1.56
60	1.59
66	1.64
72	1.67

*349th value in ranked table.

A synthetic hyetograph was constructed containing the peak rainfall for each duration period (one hour would have a peak of 0.51", a 2-hour period would have a total of 0.70", etc.). The simplest arrangement was to center the durations around the peak 1-hour rainfall. For the purpose of comparison with a two successive rainfall events example, the centroid also was skewed to occur late in the 24-hour period. The two event example was tested to determine the impact of completely saturated soil on storage volumes.

This synthetic hyetograph is intended to represent the worst case convergence of each of the durations and rainfall depths that should not be exceeded, on average, more than 8 times per year. In reality, events that exceed the design frequency rainfall for a given duration, e.g. 12 hours, may contain a shorter duration period that also exceeds the depth criteria for that shorter duration. The reverse is also true. The 48th ranked 1-hour duration rainfall (1.05") was contained in an event that totaled 1.08" for 3 hours. While that amount exceeded both the 1-hour and the 3-hour criteria, when considered as a 12-hour event, it was ranked below number 420.

By implication, the design criteria of "8 overflows per year" (accepted by the State of Tennessee for this portion of the Nashville CSO system) will also be used by the State in developing the compliance criteria for NPDES permits for these discharge points. This simple criteria was a conclusion based on a study of the probabilities of occurrence of rainfall intensity and duration with an average frequency of return. This requirement has evolved into a detailed and complex set of specific criteria for a model storm to assure that sufficient storage, transport, and pumping capacity will be provided. To fairly express the expectation of compliance with permit conditions for a facility constructed with this specific basis of design, the NPDES permit language should contain a similar level of detail and reliance on the <u>same parameters of probability</u> as those used in the development of that design.

Accordingly, it is recommended that the portion of the NPDES permit which describes the allowable number of CSO's for <u>each discharge point</u> be dependent on rainfall measurement as criteria to determine compliance in the following manner:

1. The rainfall record for each discharge point shall be based on measurements collected from the closest appropriate Metro rain gauge or group of gauges (for each combined sewer sub-basin). While the NWS rain gauge was used for the study as providing the best continuous record, that gauge may not reflect representative rainfall for a given sub-basin.

2. It is assumed that there will be no significant change in climate over the next 43.5 years compared to the past 43.5 years of the rainfall study. Accordingly, the discrete rainfall depths for each of the various duration intervals identified in the past should not be exceeded more than 348 times in the next 43.5 years (or an <u>average</u> of 8 times per year) for each overflow point.

3. The rainfall criteria threshold levels measured at an appropriate rain gauge for an average frequency not to be exceeded 8 times per year are shown in Table 1.

4. A rainfall event shall be defined as a period of rainfall preceded and followed by a period of time without rain greater than or equal to ten hours (the rainless, interevent period).

The significance of this recommendation is that it recognizes the significant negative impact on the combined sewer system of a short duration, high intensity period of rainfall. For example, a gauge may only have recorded 1.2" of rainfall in 24 hours, a depth-duration combination which does not exceed the design criteria, at the time of an overflow. However, if that gauge also showed that 1.0" fell during 3 hours of that same storm, then that measurement (which exceeds the threshold criteria) would indicate that the associated CSO was not a permit violation because it resulted from an event that exceeded the overall design criteria for the system.

NPDES compliance is documented on monthly DMRs (Discharge Monitoring Reports) submitted to the State. Using the above procedure, it would be possible to identify, each month, those CSOs that resulted from rainfall that exceeded the design criteria. By definition then, these discharge events would be counted as part of the "8 overflows per year" on the average and not be considered as violations of the permit conditions.

Estimated Use of Water in Tennessee in 1990

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The need for detailed water-use information for Tennessee has become increasingly important. Competing demands for local sources of surface and ground water continue to increase. Detailed accounting of the rate at which water resources are being utilized and the locations where the demands are greatest is needed in order to develop management strategies necessary to ensure both sufficient water supply and adequate water quality. The U.S. Geological Survey (USGS), in cooperation with the Tennessee Department of Environment and Conservation, Division of Water Supply conducted an inventory of water use in Tennessee for 1990. The water-use data and the data from other inventories conducted by the USGS since 1950 document the increasing trend in total water withdrawals statewide.

- Water withdrawals during 1990 were estimated to average 9,189 million gallons per day (Mgal/d) for offstream uses-- an 8.7 percent increase from the 1985 estimate. Average per capita water use for all offstream uses was 1,884 gallons per day.

- Public-supply withdrawals during 1990 (695 Mgal/d) represented an 11 percent increase from 1985 withdrawals.

- Self-supplied withdrawals during 1990 and the percentage change since 1985 were as follows: domestic, (59 Mgal/d) 14.8-percent decrease; industrial, (988 Mgal/d) 45-percent decrease; irrigation, (38.3 Mgal/d) 326-percent increase; agricultural, (49.4 Mgal/d) 24-percent decrease; and, thermoelectric, (7,320 Mgal/d) 21-percent increase.

- Water use for hydroelectric power, the only instream use compiled, was estimated as 159,743 Mgal/d during 1990, which represents a 35-percent increase since 1985.

- Total surface-water withdrawals during 1990 averaged 8,686 Mgal/d, which represents an 8-percent increase since 1985.

- Total ground-water withdrawals during 1990 averaged 496 Mgal/d, which represents a 12-percent increase since 1985.

WATERSHED RECOVERY FROM DROUGHT

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Introduction

The period from 1985 to 1988 had an unusual persistence of low rainfall. At Newport in East Tennessee the cumulative rainfall deficit for this period reached about 1000 mm, an amount close to the station's annual average rainfall of 1135 mm, Fig. 1. The question arises: how much surplus rainfall will it take for watersheds exposed to such rainfall deficits to recover to a normal flow regime? An important factor in this recovery is the capability of a watershed to store part of the rainfall for gradual release later on. This distributive capability of a watershed can be significant or nonexistent. It is significant in watersheds with large underground or surface storage, for example, watersheds with springs and lakes. It is nonexistent in a watersheds that respond solely to rainfall regardless of the length and cumulated deficit, such as parking lots or house roofs. Between these extremes lies usual watershed behavior. Its response to rainfall deficits will be discussed.

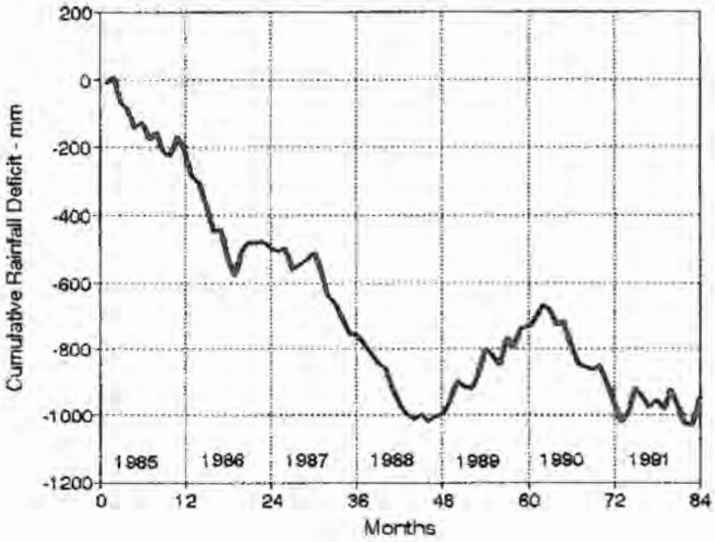

Figure 1 - Cumulative Monthly Rainfall Deficit for Newport, Tennessee, 1985-1991.

Drought Characteristics

A drought is a persistent precipitation deficit that reduces runoff, streamflow, soil moisture, and groundwater levels significantly below expected levels. Usually higher than normal temperatures are associated with droughts during the warm season which tend to increase evapotranspiration leading to accelerated depletion of soil moisture and near-surface groundwater. Increased pumping for agricultural and municipal water demands also accelerates the exhaustion of watershed storage.

A common drought signal is the absence of precipitation during periods when high rainfalls are normally expected. In the Southeast the lack of winter and spring rains is such an indicator. While the number of rain days may not be substantially different from normal weather, there may be a lack of moderate to heavy rains that replenish soil moisture and groundwater (Changnon, 1980).

The rainfall record for Newport, Tennessee (1927 to 1991) shows multi-year below-average rainfall periods at about 10-year intervals (according to TVA records). The 1985/88 (calendar year) period was the second occurrence in 65 years of a 4-year below-average rainfall period. Its cumulative deficit reached 1036 mm. The first four-year period, 1978/81, accumulated only a 274 mm deficit. The four-year average rainfall for 1985/88 was still about 77% (876 mm) of the 1927/91 average (1135 mm). The drought it caused was judged moderate in East Tennessee.

Water Storage and Water Holding Capacity

A watershed can hold water in three major storage compartments: surface, soil and underground. A water balance for each compartment keeps track of water storage at the end of each time step:

$$
\begin{aligned}
DSs &= P - Rs - ETs - I \\
DSm &= I - ETm - Rc \qquad (1) \\
DSg &= Rc - Rg - ETg
\end{aligned}
$$

DSs, DSm and DSg are the rates of storage changes for the time step for the surface, soil moisture and groundwater compartments, respectively; P is precipitation; Rs is surface runoff; ETs, ETm and ETg are evapotranspiration abstractions from the three compartments; I is surface infiltration; Rc is groundwater recharge, and Rg is the baseflow released from the groundwater compartment, all are average flow rates for the time step. Other terms can be introduced, such as pumping for various purposes, stream bed infiltration, pond evaporation, etc., as required to fit a particular case. Here, streamflow consists of surface runoff and baseflow, SF = Rs + Rg. For any time step it can be represented by

$$SF = P - (DSs + DSm + DSg) - (ETs + ETm + ETg) \qquad (2)$$

Eq. 2 presents streamflow as a function of precipitation, storage changes and evapotranspiration fluxes. The total ET and SF must come from storage whenever P = 0. Storage release can be spontaneous, such as soil moisture seepage and groundwater releases (springs) into streambeds, or forced, such as ET withdrawal from soil moisture and groundwater by plants, or pumping from surface or groundwater storage.

According to Eq. 2, next to direct rainfall and ET, the rates of storage change are important for streamflow recovery. They depend on the water transfer rates among storage compartments, as shown by the right hand sides of Eq. 1. With DS = DSs + DSm + DSg = (S-So)/dt, the water storage at the end of time step dt is

$$S = So + DS\ dt \qquad (3)$$

So is the starting storage. If DS = 0, all rainfall is going into SF and ET, and storage remains unchanged. For a house roof or parking lot, DS as well as So are zero. If DS > 0, storage is increased thereby decreasing streamflow. If DS < 0, water is released from storage to supply streamflow and ET. Increases and reductions of S can only happen within the storage limits, $0 \le S \le SX$. The available free space is the water holding capacity, W:

$$W = SX - S \qquad (4)$$

The time derivative of Eq. 4 shows that DW = - DS. When the watershed storage is full, S = SX, W = 0. When the storage is empty, S = 0 and W = SX.

None of the above defined quantities is precisely known. Also the interrelationships among the variables, such as the effect of W or S on I, ET, and Rc, are not known. Attempts have been made to relate antecedent baseflow to soil moisture storage or to total waterholding capacity. The Emory and Doe River basins in East Tennessee (1979 km^2 and 355 km^2, respectively) were estimated to have a maximum waterholding capacity of about 125 mm each (Shiao and Wunderlich, 1982). Lynch and Corbett (1983) estimated the soil moisture storage of a 0.079 km^2 (7.9 ha) test watershed to be about 320 mm. In all but the smallest watersheds, the various storage components vary with man-made or natural surface storage, soil thickness and types, underlying geologic features, etc. Smith et al. (1983) used Q90/QA as a quantitative indicator for flow sustaining characteristics (Q90 is flow available 90 percent of time, and QA is average flow). For watersheds underlain by folded carbonate rocks and metasedimentary and igneous rocks, they reported Q90/QA = 0.2 to 0.4. For watersheds underlain by flat-lying and folded shales and sandstones they reported 0.03 to 0.09. The first category included the South Fork Holston River (0.23), the Nolichucky River (0.3), and the French Broad River (0.38). The second category included the South Fork Kentucky River (0.03) and the Cumberland River (0.07). For two small East Tennessee watersheds these ratios are: Sinking Creek at Afton (1977-1991, 35.4 km^2), Q90/QA = 0.33; and Big Creek near Rogersville (1941-1991, 122.5 km^2), Q90/QA = 0.22.

Indicators of Recovery

Some available data will be used as indicators to demonstrate the recovery of the Big Creek watershed. A watershed analysis based on the water balances outlined above was beyond the scope of this investigation. Rainfall in calendar year 1989 at Newport was 1392 mm, 257 mm above the long term average (1135 mm). Figure 1 shows the cumulative deficit of the 1985/88 period reduced from about 1000 mm in late 1988 to about 700 mm in early 1990. The impact on streamflow is shown in Table 1. While from April 1988 to March 1989 the lowest low flows in forty years occurred in almost all consecutive-day categories, the highest low flows of the forty-year record occurred in all consecutive-day categories from April 1989 to March 1990. This indicates that complete recovery of the watershed had occurred within this period, regardless of the remaining 700 mm rainfall deficit.

Table 1 - Ranking of Lowest Flows for Consecutive Days for Big Creek near Rogersville, Tennessee (1942-1991)*
Drainage 122.5 km^2 (data from U.S. Geol. Survey, Knoxville)

	Number of Consecutive Days								
	1	3	7	14	30	60	90	120	183
4/1988-3/1989	1	1	1	1	1	1	2	1	4
liter/(s km^2)	0.32	0.35	0.41	0.50	0.53	0.75	0.97	0.98	1.70
4/1989-3/1990	40	40	40	40	40	40	40	40	40
liter/(s km^2)	3.93	4.00	4.62	4.83	6.86	9.64	12.23	12.02	13.82

*nine-year gap from 1949-1958; 1 and 40 are lowest and highest ranks of low flow of record, respectively.

Conclusion

The question discussed here is: Will the effects of drought on streamflow linger until the entire rainfall deficit has been reduced by rainfall surplus? The answer is: No! The lingering effect of a drought depends on how much water the watershed can store and how fast this storage is filled. The watershed can 'remember' rainfall deficits only to the point of storage depletion, when the maximum water holding capacity is reached. A watershed cannot run more than dry, but also cannot fill more than full. The maximum waterholding capacity is difficult to determine, but averaged over a watershed it may be on the order of 100 mm to 400 mm. This quantity is considerably less than the rainfall deficit of a major drought. Therefore, memory may be short and recovery may be quick. U.S. Geological Survey data analysis shown in Table 1 indicates that the examined watershed (Big Creek, 122.5 km^2) recovered from the 1985/88 drought within one year, after only a partial (30%) rainfall deficit reduction.

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SUMMARY OF FISH TISSUE DIOXIN LEVELS IN TENNESSEE

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Introduction

Dioxin is a generic term commonly used for 75 related compounds in the dibenzo-p-dioxin group and 125 compounds in the dibenzofuran group. It is a relatively simple pair of benzene molecules, connected by either two oxygen atoms (dioxin) or one oxygen atom (furan), with attached chlorine atoms in various positions. The positioning of these chlorine atoms gives each of the dioxin compounds its chemical characteristics.

The most potent of these dioxin forms, 2,3,7,8 tetrachlorodibenzo-p-dioxin or 2,3,7,8 TCDD, has been researched the most thoroughly and inspires the most fear. EPA has called it the most carcinogenic substance ever tested. First noted as a byproduct of herbicide production, EPA testing on laboratory animals indicated that dioxin caused a wide variety of toxic effects and led to the ban of a specific category of herbicides, 2,4,5-T.

In the mid-1980's, EPA began the National Dioxin Survey. During this project, fish tissue samples were collected at selected sites, paticularily below pulp and paper mills. Initial EPA sampling in Tennessee concentrated in the Pigeon River below Champion Paper in Canton, North Carolina, but later branched out to include the South Fork of the Holston River, the Hiwassee River, the Tennessee River, and other sites.

The State of Tennessee's initial dioxin sampling occurred in 1988 on Douglas Reservoir and the Pigeon River as follow-up to the EPA Pigeon River survey. In 1990, fish were collected in the Memphis area in response to EPA's documentation of dioxin in McKellar Lake fish and in the sludge produced by the Memphis sewage treatment plant.

In 1991, an EPA Statewide Lakes Assessment Grant made possible an expansion of dioxin monitoring. Goals for this monitoring were to determine dioxin levels in lakes not assessed in EPA's survey and to attempt to identify true background dioxin levels in high-quality lakes removed from non-atmospheric sources.

Lakes sampled in the first year of the project included Boone, Fort Loudoun, Chickamauga, Cheatham, and Cherokee reservoirs, plus McKellar Lake near Memphis. Sites to be collected in 1992 will include Watts Bar Reservoir, Kentucky Reservoir, Pickwick Reservoir, Fort Patrick Henry Reservoir, Chickamauga Reservoir, Center Hill Reservoir, Parksville Reservoir, Reelfoot Lake, and Dale Hollow Reservoir. Figure 1 identifies sites at which fish tissue dioxin monitoring has occurred.

WEST TENNESSEE MONITORING SITES

1. Memphis Area Sites
   - Mississippi River above Memphis
   - Mississippi River at I-40 Bridge
   - Mississippi River below Memphis
   - McKellar Lake
   - Wolf River
   - Loosahatchie River
2. Mississippi River at Tiptonville
3. Kentucky Reservoir at Hardin

MIDDLE TENNESSEE MONITORING SITES

4. Cheatham Reservoir at Nashville
5. Buffalo River

EAST TENNESSEE MONITORING SITES

6. Nickajack Reservoir
7. Chattanooga Creek
8. Hiwassee River
9. Little Tennessee River
10. Fort Loudoun Reservoir
11. Douglas Reservoir
12. Pigeon River (multiple sites)
13. Cherokee Reservoir
14. Boone Reservoir
15. South Fork Holston River

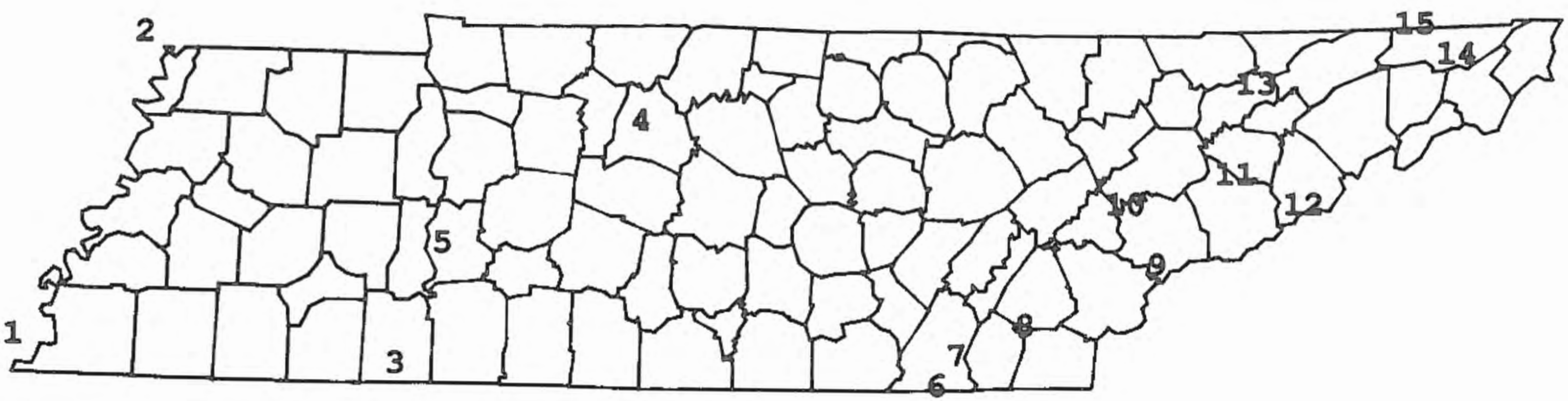

FIGURE 1. Location of Historical Dioxin Monitoring Sites in Tennessee.

Results

Dioxin monitoring has occurred in rivers downstream of sites historically considered to be prime candidates for elevated dioxin levels: pulp and paper mills, certain types of refineries, and large cities. Dioxin has generally been found at these sites in varying amounts. The only sites at which dioxin has not been detected are those relatively remote sites where only one sample has been collected: Cherokee Reservoir, the Little Tennessee River, and the Buffalo River.

A comparison of the percent of data collected during this period that exceeded 5 and 10 parts per trillion TEQ appears in Table 1. (A TEQ is calculated by summing the relative toxicities of the various dioxin and furan isomers.) The South Fork Holston and the Pigeon River are the only two streams in Tennessee where levels over 20 ppt have been documented. The percentage of total samples that exceed 10 parts per trillion are similar in the Pigeon and South Fork Holston (20 and 18 percent, respectively). All the samples with dioxin concentrations over 20 ppt were carp.

Dioxin has been detected in every sample collected in the Mississippi River and McKellar Lake with the exception of a largemouth bass composite sample from McKellar Lake. Of the sixteen dioxin samples collected in the Mississippi River and McKellar Lake, five samples exceeded five parts per trillion and two samples of these exceeded ten parts per trillion. A list of sites where samples have exceeded 5, 10, and 20 ppt appears as Table 2.

TABLE 1

PERCENTAGE OF INDIVIDUAL SAMPLES EXCEEDING 5 AND 10 PPT TEQ

SITE*	NUMBER OF SAMPLES	NUMBER OF SAMPLES OVER 5 PPT	PERCENT OVER 5 PPT	NUMBER OF SAMPLES OVER 10 PPT	PERCENT OVER 10 PPT
Pigeon River	30	14	47	6	20
South Fork Holston**	61	17	28	11	18
Mississippi River (incl. McKellar Lake)	16	5	31	2	13
Hiwassee River**	34	3	9	0	0
Douglas Reservoir	20	0	0	0	0
All Other Sites	26	3	12	0	0

* Sites with over ten individual samples listed separately.
** Extrapolated data used at these site.

TABLE 2

INDIVIDUAL SAMPLES THAT EXCEEDED 5, 10, AND 20 PPT TEQ

DIOXIN LEVEL	NUMBER OF SAMPLES EXCEEDING	SAMPLE LEVEL	TYPE FISH SAMPLE*	SITE
OVER 20 TEQ	7	39.31	Carp ind. F	South Fork Holston River at Mead.
		28.74	Carp comp. F	Pigeon River at Denton.
		25.10	Carp ind. WB	Pigeon River above Newport.
		23.00	Carp ind.WB	South Fork Holston River at Mead.
		22.65	Carp comp. F	Pigeon River above Newport.
		20.82	Carp ind. WB	South Fork Holston River at Mead.
		20.48	Carp comp. F	Pigeon River at Denton.
10 -20 TEQ	12	17.53	BlCat ind F	Mississippi River below Memphis.
		17.49	Carp ind. F	South Fork Holston River at Mead.
		17.08	Carp ind. WB	McKellar L. @ mouth of Nonconnah Cr.
		15.81	Carp comp WB	Pigeon River mile 0.2.
		15.09	Carpsucker WB	South Fork Holston River at Mead.
		14.55	Carp comp F	Pigeon River near Denton.
		14.30	Carp ind. F	South Fork Holston River at Mead.
		13.88	Carp ind. F	South Fork Holston River at Mead.
		13.41	Carp ind. F	South Fork Holston River at Mead.
		12.51	ChCat comp F	South Fork Holston River at Mead.
		11.89	Carp comp WB	South Fork Holston River at Mead.
		10.51	ChCat ind. F	South Fork Holston River at Mead.
5 - 10 TEQ	21	9.86	SmBuff ind WB	South Fork Holston River at Mead.
		9.43	Carp WB	Hiwassee River at Bowater.
		8.15	SmBuff ind. F	South Fork Holston River at Mead.
		7.70	SMBuff comp F	Pigeon River mile 24.5.
		7.57	Carp ind. WB	South Fork Holston River at Mead.
		7.12	RBSun comp F	Pigeon River at Denton.
		6.82	RHSuc comp WB	South Fork Holston River at Mead.
		6.76	Carp ind. F	South Fork Holston River at Mead.
		6.60	Carp comp F	Pigeon River mile 12.8.
		6.53	Sucker WB	Hiwassee River at Bowater.
		6.51	Bass comp F	Pigeon River at Denton.
		6.22	ChCat ind F	Mississippi River above Memphis.
		6.20	SMBass comp F	Pigeon River at mile 24.5.
		6.10	ChCat comp F	Pigeon River mile 16.5.
		6.02	SMBuff comp F	Pigeon River mile 8.5.
		5.94	Carp comp F	South Fork Holston River at Mead.
		5.72	RBSun comp F	Pigeon River at Denton.
		5.55	Carp comp WB	Kentucky Reservoir at Hardin.
		5.55	Carp comp WB	Nickajack Reservoir below Chattanooga.
		5.42	LMBass comp F	Fort Loudoun Reservoir below Knoxville.
		5.24	BlCat ind F	Mississippi River above Memphis

*Abbreviations: RBass=Rock Bass. RBSun=Redbreast Sunfish. LMBass=Largemouth bass. BlBuff=Black buffalo. SMBuff=Smallmouth buffalo. ChCat=Channel catfish. RHSuc=Redhorse sucker. BlCat=Blue catfish.

Acknowledgements

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EFFECTS OF STORM SAMPLING STRATEGIES ON LOAD CALCULATIONS FOR AGRICULTURAL NONPOINT-SOURCE SEDIMENT AND NUTRIENTS

Angel Roman-Mas[1], Timothy H. Diehl[1], and Stephen Klaine[2]

The low sampling intensity and the absence of continuous discharge records of most monitoring programs in the past, have precluded the evaluation of sampling requirements to obtain accurate storm loadings. As a result, the development of specific guidelines for sampling storms and the assessment of agricultural nonpoint-source pollution and best management practices have been limited.

Runoff discharge and water-quality data were collected for 55 storms in four small agricultural basins in the Beaver Creek watershed, West Tennessee. Samples of storm runoff were collected and analyzed for concentrations of total and dissolved nitrogen and phosphorous species and for concentrations of suspended sediments. Sampling intervals ranged from 5 to 15 minutes. Continuous discharge records were developed from stage-discharge relations and stage measurements made at intervals of 0.5 to 5 minutes. The discharge and water-quality data were used to determine the sensitivity of storm-load calculations to sampling intensity and accuracy of discharge records. Storm loads were calculated using the entire data set and partial data sets created by random deletion of a number of data points. The differences between the loads calculated using the entire data set and those calculated using the partial or reduced data set were computed as percent error. The data also were analyzed using regression techniques to evaluate the potential for using regression models to predict concentrations of these constituents from discharge.

Sensitivity analyses indicated that errors in load calculations ranged from 25 to 125 percent as the sampling interval increased from 5 to 60 minutes and from 100 to 200 percent as the time interval between stage measurements increased from 0.5 to 10 minutes. Regression models proved to be unreliable in predicting concentrations of these constituents; regression coefficients were less than 0.25 when the entire data set was used. When the water-quality data were subdivided on the basis of their position in the runoff hydrograph (rising limb, falling limb, and recession flow), a more reliable regression model was obtained for recession flow, but regression coefficients for rising and falling limbs remained low.

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DESIGN CONSIDERATIONS FOR SEDIMENT BASINS USED IN CONTROLLING SEDIMENT-RELATED NONPOINT-SOURCE POLLUTION FROM DISTURBED LANDS

Telena D. Moore[1], James L. Smoot[2], and Bruce A. Tschantz[3]

Control of sediment-laden runoff from disturbed lands often involves the use of sediment basins. These basins allow for the separation of suspended sediments and other associated pollutants from runoff waters by gravity settling. When properly designed, constructed, and maintained these basins can effectively mitigate sediment related nonpoint-source pollution. However, improper design, construction, and maintenance can drastically reduce a basin's pollutant removal efficiencies. Sediment basins can be used for sediment control during construction activities and then converted to stormwater management ponds after construction to help control the quantity and quality of stormwater runoff.

Generally, the greater the velocity of the water, the greater the particles in suspension. As velocities decrease, the suspended sediment will begin to settle with the larger and denser particles preceding the smaller and less dense particles. Because sediment basins are designed to provide for gravity settlement of suspended sediment, the design of sediment basins will vary according to the characteristics of the suspended sediment. For example, if sand is the primary sediment particle size in suspension then a smaller basin volume is needed than for the trapping of smaller particles, such as those of clay and silt sizes. In situations where large amounts of clay and fine silt are expected, chemical flocculation may be employed to enhance particle settlement and then a smaller, more practical detention volume may be adequate (Moore, 1992).

Three basic approaches are commonly used as a basis for the sizing and design of sediment basins. The simplest approach is to use "rule-of-thumb" sizing based on knowledge of the contributing drainage area and by assuming the site and runoff conditions to be typical. An improvement to this method is to use design charts and nomographs which are applicable to a variety of site and runoff conditions. The third approach is to consider temporally and spatially varying site and runoff conditions and other factors. This most sophisticated approach usually involves computer modeling.

Common rule-of-thumb sizing for the volume of sediment basins is approximately 1,800 cubic feet per acre of drainage area. This size is based on "typical" conditions and is representative of a "low-maintenance" basin but actual sediment removal efficiencies can vary tremendously depending on the characteristics of the contributing watershed and the sediment basin design. Dominant watershed characteristics include soil types, topography, and land cover. Sediment basin design considerations include basin shape, surface area to flow ratio, size and density distribution of suspended sediment, inlet and outlet structure size and configuration, design runoff event, and maintenance (Smoot and others, 1992; and Moore, 1992).

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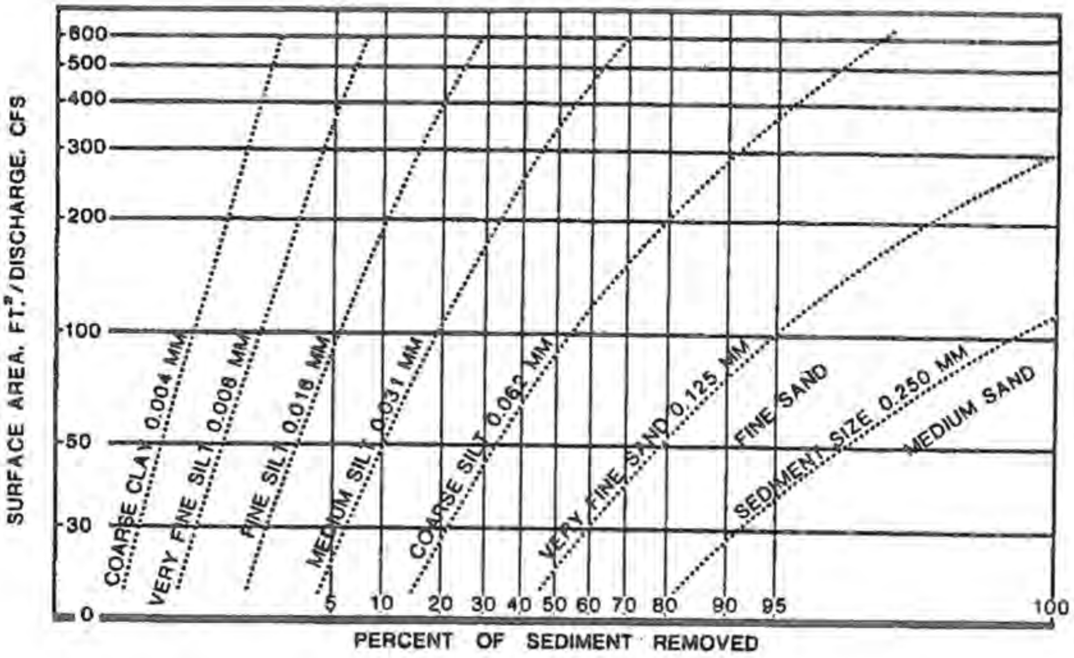
One design chart that is commonly used in design of sediment basins was prepared by the Colorado Department of Highways (1978) and is reproduced below. As shown, by varying the sediment basin surface area to discharge ratio for a given sediment size the removal efficiency can be varied. Therefore, if one can estimate the incoming sediment size distribution and the runoff discharge from the watershed, basin dimensions can be selected to achieve a desired removal efficiency.



Percent of sediment removed for different discharges and basin and sediment sizes

(Colorado Department of Highways, 1978).

To optimize the design of a sediment basin, several factors must be considered. Therefore, rule-of-thumb sizing information only provides the designer a starting place for the design and it must be modified to account for the above considerations along with site conditions and other constraints. Several computerized design programs such as SEDCAD+ can be used to optimize a sediment basin design (Warner and Schwab, 1992).

The pond geometry is an important design consideration for detention facilities. Even if adequate volume is provided to allow for gravitational settling, poor basin geometry can produce "short-circuiting" and result in ineffective sedimentation control. Wedge-shaped basins with the narrow end at the inlet usually function efficiently. However, when other shapes are unavoidable, baffles can be added to create an effective length of flow and minimize dead storage. (Barfield and others, 1981). Several example designs will be presented for comparing different methods.

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NITRATE AND SULFATE EXPORT FROM A GREAT SMOKY MOUNTAIN SPRUCE-FIR WATERSHED

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The high elevation spruce-fir forests of the Great Smoky Mountains National Park (GRSM) receive some of the highest rates of nitrogen (N) and sulfur (S) deposition in North America. This deposition occurs in an ecosystem naturally acidic and currently experiencing catastrophic change as a result of insect-caused mortality in Fraser fir. Nitrate (NO3) and sulfate (SO4) are found to leach below the rooting zone in the soil (Lindberg and Johnson et al., 1988) where they mobilize hydrogen ions and cationic plant nutrients. Consequently, with NO3 and SO4 the dominant stream anions, episodic acidification of poorly buffered, high elevation streams is likely to occur. We monitored precipitation, soil solutions and stream chemistry in Noland Divide watershed in order to evaluate the effects of atmospheric deposition on forested ecosystems and the likely occurrence of episodic stream acidification.

Site Description

The Noland Divide site is one of the highest gauged watersheds in the eastern United States . It encompasses 17 ha (40 acres) of spruce-fir forest at 1695 m (5560 ft) elevation in GRSM. Geologically, the site is underlain by the Thunderhead Sandstone (Upper Proterozoic) of the Great Smoky Group, composed principally of quartz and potassic feldspar (King et al., 1968).

The overstory vegetation is primarily old-growth red spruce (Picea rubens) with some mature yellow birch (Betula alleghaneinsis). A dense understory is composed of Fraser fir (Abies Fraseri), red spruce, blackberry (Rubus canadensis), witch hobble (Viburnum alnifolium), blueberry (Vaccinium erythrocarpum), sorbus (Sorbus americana), and rhododendron (Rhododendron maxima) (Johnson et al., 1989).

Previous Research

Noland Divide was one of 17 sites in North America and Norway monitored from 1986-89 for atmospheric inputs as part of the Integrated Forest Study. Of those, Noland Divide received the highest N and had high S deposition.

Soils are acidic with pH ranging from 3.8 (A horizon) to 4.7 (B horizon) and are N saturated. In addition, N and S leach below the rooting zone (Johnson et al., 1989). These results indicate a considerable source of acidification for the streams.

Previous research on streams in the GRSM indicate stream chemistry is related to soil chemistry and that NO3 can strongly contribute to decreases in stream pH (Silsbee and Larson, 1981). In addition, GRSM streams were found to experience storm-related episodic acidification (Olem, 1986; Cook et al., 1990)

Methods

We monitored nutrient fluxes in Noland Divide by sampling precipitation, soil solutions and streams. We monitored atmospheric deposition on 2 sites: an open site, with no canopy, and a throughfall site, under the canopy. Data on rainfall and precipitation samples were collected twice weekly. We also monitored nutrient cycling in the soils through 12 tension lysimeters at 3 depths: below the forest floor, in the A horizon and in the B horizon. Soil solutions were collected monthly and soil temperatures were measured for the same 3 depths. Two streams, designated southwest and northeast Noland creeks, were gauged through 3 foot H-flumes; stream height and flow were recorded every 15 minutes. Stream chemistry was monitored with a Hydrolab water quality monitor and pH, conductance, and temperature were recorded every 15 minutes. Stream water samples were collected weekly. We analyzed all samples for pH, conductance, major cations and anions.

Results

Precipitation

High levels of N and S entered the site as throughfall deposition; SO4 was dominant. SO4 concentrations ranged from 6 to 140 μeq/L (open site) and 30 to 600 μeq/L (throughfall site). N chiefly deposited as NO3 but also as ammonium(NH4). NO3 concentrations ranged from 2 to 162 μeq/L (open site) and from 3 to 390 μeq/L (throughfall site). NH4 concentrations ranged from 3 to 47 μeq/L (open site) and 3 to 82 μeq/L (throughfall site). Precipitation samples were strongly acidic with pH ranging from 4.0 to 5.0 (open site) and from 3.5 to 4.6 (throughfall site).

Soils

Soil solutions were acidic with pH ranging from 3.5 to 3.8 (forest floor), 4.2 to 4.6 (A Horizon), and 4.5 to 5.0 (B Horizon) (Johnson and Lindberg, 1992). Samples are currently being analyzed for cations and anions.

Streams

NO3 and SO4 were dominant anions in stream water samples. SO4 concentrations ranged from 21 to 65 μeq/L and NO3 concentrations ranged from 36 to 63 μeq/L. Stream pH of weekly samples ranged from 5.4 to 6.1 whereas during storm events stream pH was observed to drop almost 1 unit. Although both streams showed low alkalinity and conductance, the southwest stream was consistently slightly higher than the northeast stream in both analyses.

In two successive storm events, the stream exhibited distinctly different chemistries. In the first event, which followed a 7 week drought, pH decreased slightly, alkalinity increased and all stream anions and cations increased. However, during the second event which occurred one week later, stream alkalinity dropped dramatically (-10) and SO4 concentrations peaked at 65 μeq/L whereas other ions exhibited small increases or decreased in concentration (Figures 1 and 2).

Watershed Anion Budgets

Budgets for S by the Integrated Forest Study indicated an annual deposition of 2465 Eq/ ha/ yr and an annual loss of 2052 Eq/ ha/ yr (Johnson and Lindberg, 1992). Totals from the first 20 weeks of monitoring at Noland Divide recorded an influx in throughfall of 1043 Eq/ ha and export through the streams of 435 Eq/ ha resulting in a net retention of S in the watershed (Figure 3).

Budgets for N indicated an annual deposition of 1086 Eq/ ha/ yr and an annual loss of 1485 Eq/ ha/ yr (Johnson and Lindberg, 1992). Totals from the first 20 weeks of monitoring at Noland Divide recorded an influx in throughfall of 370 Eq/ ha and export through the streams of 512 Eq/ ha resulting in net loss of N in the watershed (Figure 4).

Conclusions

Results from this study indicate that in the high elevation watershed at Noland Divide, high levels of N and S are deposited, leached below the rooting zone, and exported from the watershed via the stream.

The high concentrations of acidic anions in the poorly buffered streams result in episodic acidification of the stream environment. In the first event, stream alkalinity increased due to the release of cations accumulated in the soil during the drought. Once the buffering cations were exhausted from the soil, subsequent increases SO4 resulted in decreased alklinity.

A comparison of annual N and S budgets from the Integrated Forest Study to monthly N and S budgets from the Noland Divide study indicate a net loss of N and S from below the rooting zone, yet on a watershed basis S is retained while N is lost.

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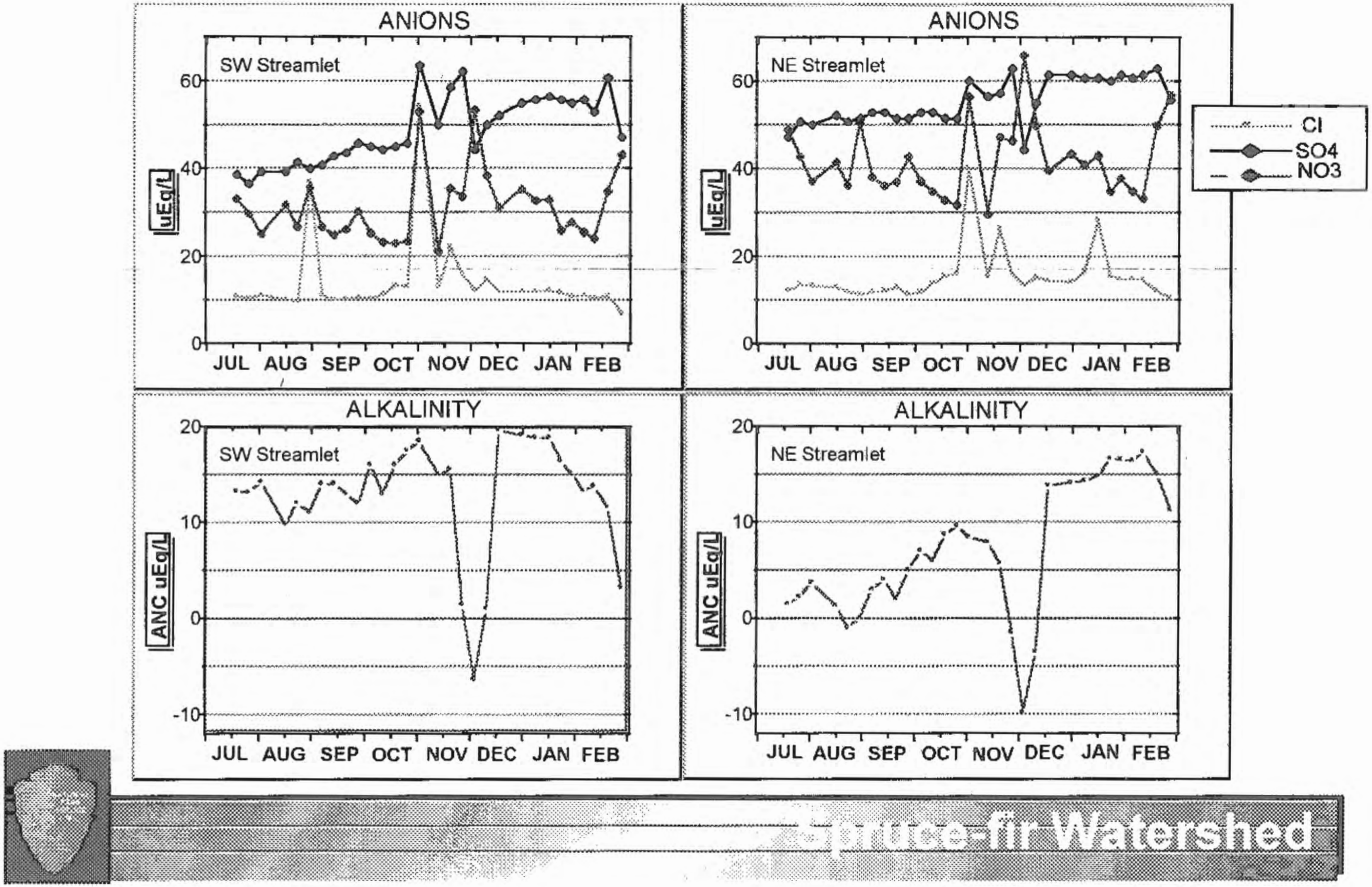
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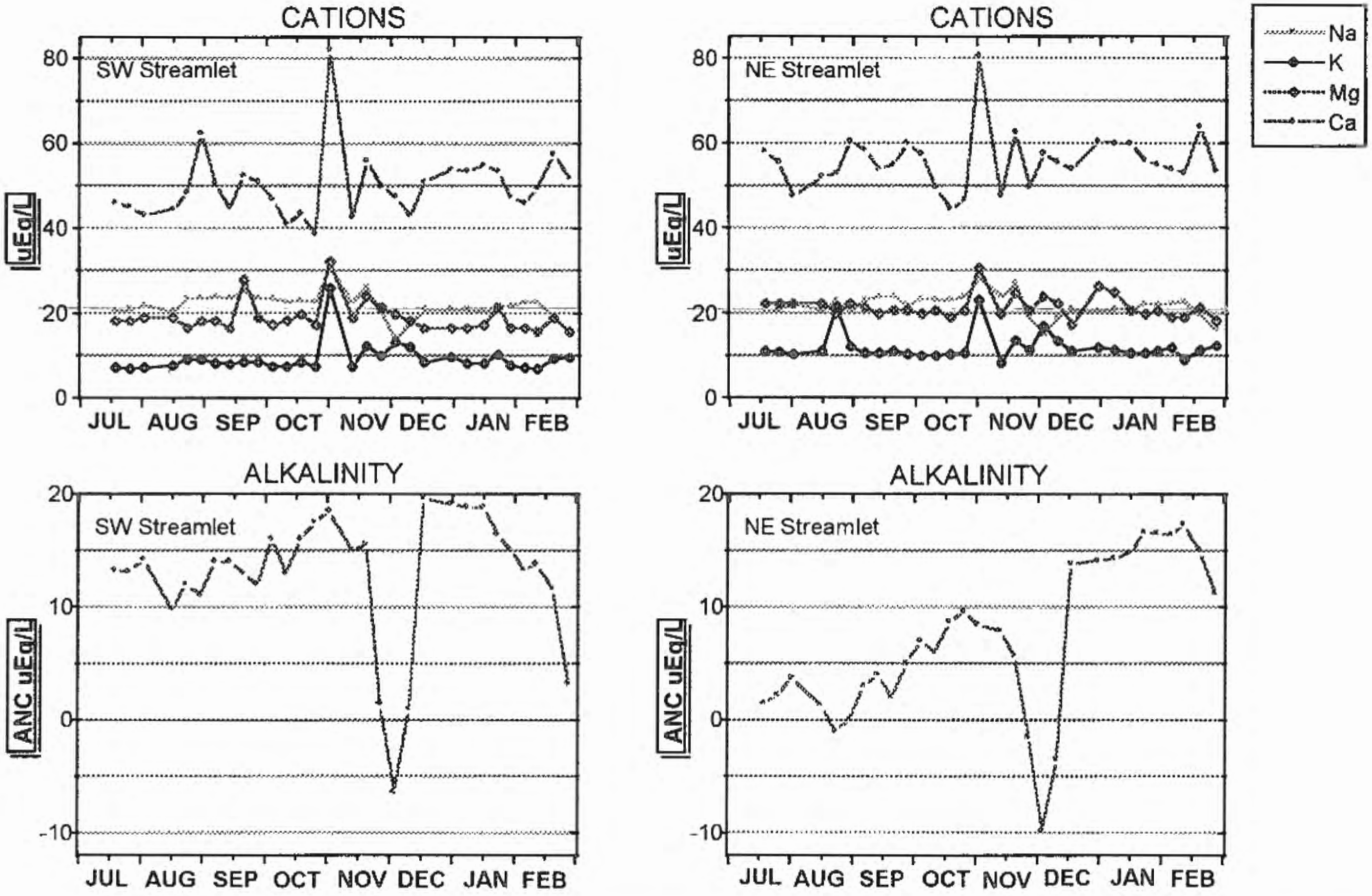
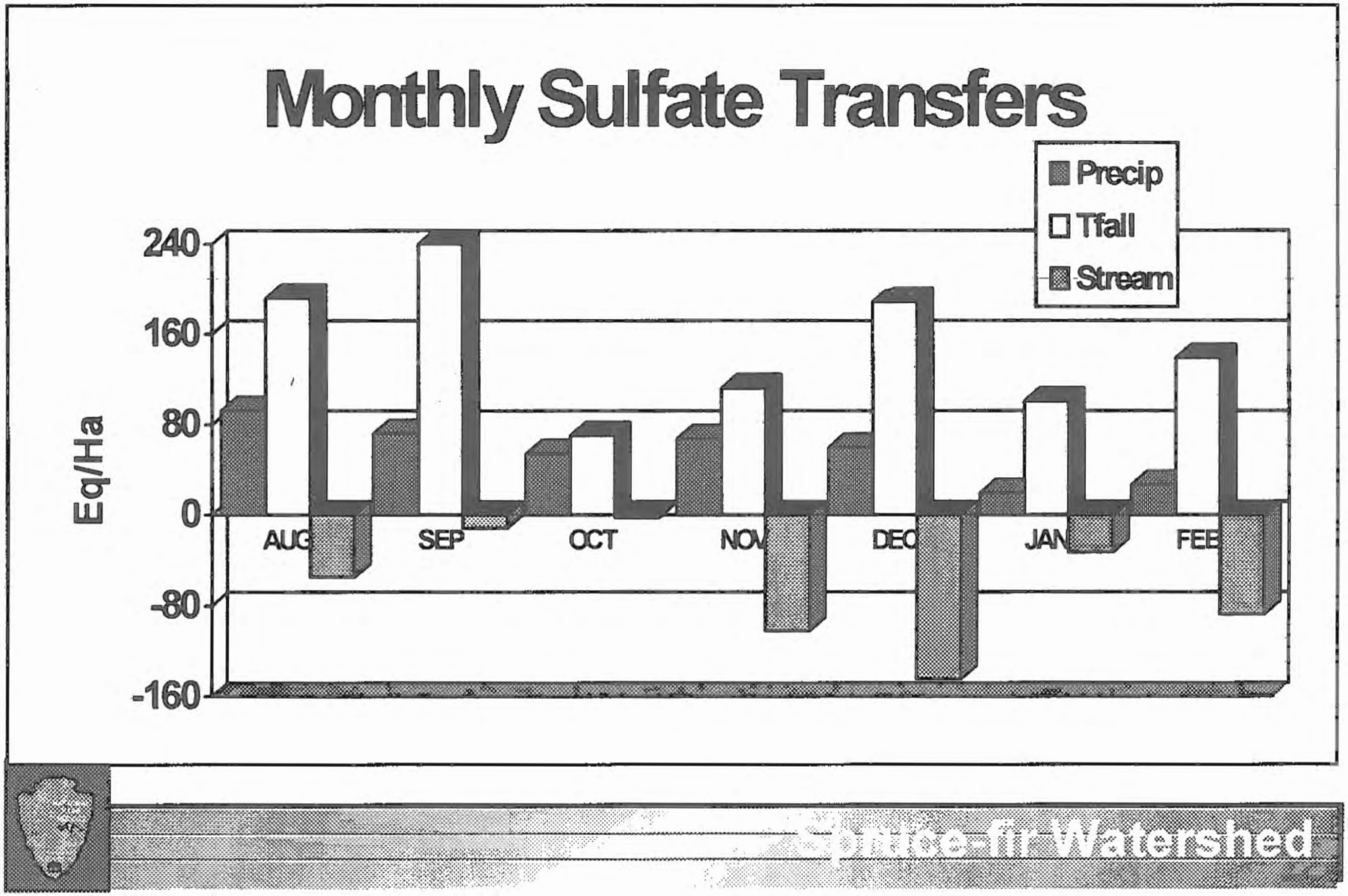
Spruce-fir Watershed

Fig. 1



Spruce-fir Watershed

Fig. 2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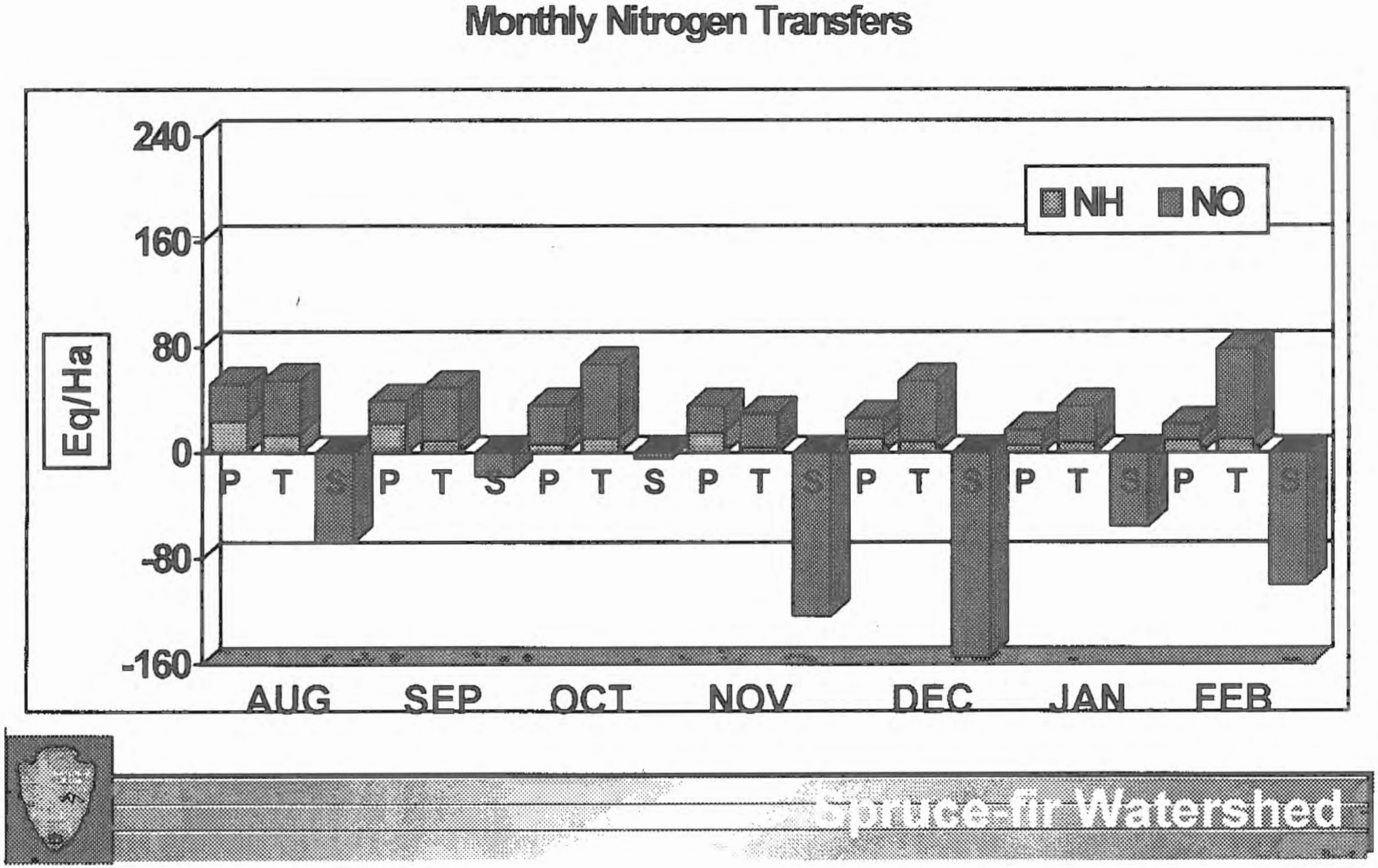
Spruce-fir Watershed

Fig. 3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Spruce-fir Watershed

Fig. 4

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This paper describes the integrated management approach currently in progress to address the problem of pollution in the Cumberland River. This collective effort includes Metro's Department of Water Services, Tennessee's Department of Environment and Conservation, the U.S. Army Corps of Engineers and the U.S. Geological Survey. Consoer, Townsend & Associates and Vanderbilt University provide project management and technical services. The objectives are to share resources and information, and to jointly develop and implement strategies to improve the water quality of the Cumberland River.

The need for integrated water resources management first became obvious during the course of two separate water quality sampling and modeling efforts completed in 1988 and 1989. The mathematical models showed that the Old Hickory Dam discharge flow rate and water quality control the dissolved oxygen levels in the river, and that under average conditions the degree of treatment at Nashville's wastewater treatment plants has little effect on the water quality downstream. Sampling and modeling also indicated that, at low river flows, stormwater runoff was as detrimental to the river's water quality as combined sewer overflows, and that dissolved oxygen stratification was taking place during the summer months. These and subsequent investigations resulted in an exchange of information and resources which greatly increased our understanding of the river's dynamics. Since the Cumberland River is a regulated stream with complex flow and water quality transport processes, it became clear that the answer to the problem of low dissolved oxygen levels would have to incorporate non-structural solutions and more effective management strategies by the local, state and federal agencies concerned with the river's environmental condition.

The solutions presently under consideration include aeration of the dam tailwaters, release of a minimum flow during the summer months, and improvements on the collection and treatment systems. The integrated approach to water quality management has already resulted in significant capital expenditure savings and considerable improvement of the river's water quality.

WHERE HAVE ALL THE BUGS GONE?
A SUMMARY OF STREAM SURVEYS IN MIDDLE TN

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Over the past two and a half years, the author, working as a biologist in the Nashville field office, Division of Water Pollution Control, conducted twenty stream surveys in middle Tennessee. A summary of the overall findings from these surveys was compiled for this paper. The result of the compilation indicates that a number of the State's receiving streams are experiencing water quality degradation from both point and non-point source influences.

Stream surveys were conducted in the receiving waters of both municipal and industrial dischargers. Each survey included, in varying degrees, biological and chemical sampling. The majority of the surveys were targeted at "problem" National Pollution Discharge Elimination System (NPDES) permitted facilities which included thirteen (13) STP's, four (4) industries and three (3) non-point source situations.

The results from these surveys generally found that the chemical samples (or permit monitoring requirements) did not indicate problems (or show permit violations) in the receiving waters. On the other hand, in all but two surveys, the biological data showed subtle to gross impact on the resident aquatic biota of the streams.

Approximately half of the surveyed streams were found to be heavily impacted below the studied discharge location. Proportionally, STP's and industrial dischargers were equally represented in this category. Table I lists the studied receiving streams, the type of discharge flowing to the stream and the relative degree of impact to aquatic macroinvertebrate communities that was observed.

It is commonly recognized, by professionals in water quality related fields, that aquatic organisms are better indicators of water quality than are discrete chemical samples which monitor one point in time rather than a long term exposure. Macroinvertebrates can indicate conditions that effect their ability to live and reproduce simply through presence or absence from an area. Obviously, there are natural environmental conditions which can have the same effect on organisms, but if a study is designed properly, these kinds of variations can be eliminated among the study sites.

TABLE I
STREAMS INCLUDED IN SURVEY
BIOLOGICAL ASSESSMENT STUDIES

	STREAM SURVEYED	TYPE OF DISCHARGE	YEAR	EXTENT OF IMPACT
1.	Carr Creek	STP	1989	Hvy./Ext.
2.	Rockcastle Creek	STP/IND	1989	Mod.
3.	Cheatham Branch	NPS	1989	Low
4.	Crowson Creek	IND	1989	Low
5.	Gilliam Branch	STP	1989	Hvy./Ext.
6.	Sims Branch	IND	1989	Hvy./Ext.
7.	Browns Creek	IND	1989	Hvy./Ext.
8.	E. Fork Globe Creek	ALT	1990	Hvy.
9.	Pigeon Roost Creek	STP	1990	Hvy./Ext.
10.	Big Bigby Creek	IND	1990	Hvy./Ext.
11.	Carr Creek	STP	1990	Hvy./Ext.
12.	Town Creek (Overton)	STP	1990	Mod.
13.	Harpeth River	STP	1990	Mod.
14.	Cumberland River	STP	1991	Mod.
15.	Rock Creek	STP	1991	Mod./Hvy.
16.	Henson Creek	CON	1991	Mod.
17.	Jones Creek	STP	1991	Mod.
18.	Mine Lick Creek	STP	1991	Hvy./Ext.
19.	Town Creek (Marshall)	STP	1992	Mod.
20.	Little Trammel Creek	STP	1992	Mod./Hvy.

Notes and Definitions:

Impacts to Aquatic Benthic Macroinvertebrates

Hvy/Ext = Heavy to Extensive Impact - > 60% of upstream (u/s) aquatic taxa absent at the downstream (d/s) site.
Hvy. = Heavy Impact - > 45% of u/s taxa absent d/s
Mod. = Moderate Impact - > 35% of u/s taxa absent d/s
Low = Low Impact - < 25% of u/s taxa absent d/s

Type of Discharges

STP = Sewage Treatment Plant
IND = Industry
ALT = Stream Alteration
CON = Road Construction

There are approximately 450 NPDES permits issued to industries and municipalities within the forty county region included in the study. Each one of these facilities has routine sampling requirements in place. The mechanism of the requirement is to continually focus on the quality of the effluent and/or level of treatment being met. Without the limits and other regulatory components of the permit, many more receiving waters probably would be in poor health. Historical biological data, collected since the early 1950's, has shown that the enactment of the Water Quality Control Act (WCA) in 1971, along with a continually upgraded NPDES program, has created an observable improvement in water quality through out the state.

There are inherent weaknesses in the NPDES program however, which do lead to water quality problems below permitted facilities. The streams surveyed for the twenty studies were specifically targeted to assess water quality below problem facilities. Part of the problem stems from the self monitoring program coupled with the inability of regulatory agents to watch every discharger, all of the time. Annual inspections are performed at all major facilities to determine compliance with their NPDES permit, but this covers only one or two days of discharge per year.

In a hypothetical situation, it would be easy, for instance, for a STP to measure total residual chlorine (TRC) once per day at 0700 and meet their chlorine limit. Then at, 0800, plant personnel increase the chlorine dosage to help lower the fecal coliform concentrations so that they can meet that limit; and so on. In the meantime, they are probably then violating their chlorine limit. The monthly operating reports (MOR) will show compliance at the time of sampling yet the aquatic organisms in the receiving stream will be screaming that violations have occurred.

Another problem, that can be difficult to assess, is whether or not the permit has established limits to cover all constituents of concern. The data compiled for the purpose of this paper suggests that the limits established in the permit (1) may not be stringent enough, (2) may not be inclusive and/or (3) are not being diligently met by the discharger.

There is one obvious question which comes to mind upon compiling these results,are the issued NPDES permits protecting waters of the State? This discussion is not intended to undermine the NPDES program and as a partial answer to the question above, the NPDES program has helped to improve water quality in many receiving streams as well as increased plant operators' awareness of the importance of putting out a quality effluent to maintain clean waters. However, the studies reviewed in this paper indicate that the NPDES program, as it exists today, may not be protecting water quality at a level necessary to meet Tennessee's fish and aquatic life usage criteria. This is especially true in small or low flow stream systems where the chronic impacts of long term discharges, at or below concentration based discharge limits, appear to be the greatest.

As mentioned earlier, instream bioassessments often provide a better indication of water quality conditions than do chemical samples. This leads to a second question, why not make instream biomonitoring a standard permit requirement? This concept has been discussed within the Division of Water Pollution Control over the past few years. Most regulators agreed that bioasssesments are valuable tools for determining impacts from permitted discharges, but many did not think that instream bioassessments could be effectively used as a permit condition. It was decided that the responsibility of determining instream biological impact should remain with the Division biologists.

A third question which should be addressed is, what steps has the Division of Water Pollution Control taken to correct the problem NPDES facilities? The Division has initiated several enforcement cases based primarily on biological assessments such as those discussed in this paper. Although most enforcement actions include civil penalties, the biggest thrust of a commissioners order is geared towards achieving compliance with the Water Quality Control Act and the NPDES permit. Plant upgrades, new treatment processes, clean-up activities and improved, reliable self-monitoring data have resulted from enforcement activities. Many of these actions help improve an effluent to meet the NPDES limits and therefore water quality. But there are only a few cases where the effluent is evaluated, through biological testing, to determine what is causing the instream toxicity. Therefore, the proposed engineering change may not improve effluent quality enough to avoid continued stress on the instream aquatic organisms. The point here is that we must continue to integrate effluent evaluation and treatment technologies, both engineering and biological, to achieve the goal of protecting a natural resource.

In conclusion, it is obvious that conscientious efforts from the regulating and regulated communities must be extended to improve the quality of effluents being discharged to waters of the State. Additionally, an upgraded regulatory system, which is completely dedicated to implementation of a strong NPDES program, must be a continual goal of the State. Reviews of biological and chemical data from the passed two decades have already shown that progressive actions can result in improvements in water quality. Through the issuance of quality NPDES permits and by insuring compliance with those limits and the Water Quality Control Act, there is great potential for a continued trend towards clean waters flowing across the state.

A COMPARISON OF TWO METHODS FOR ESTIMATING SPATIAL PATTERNS OF SEDIMENT ACCUMULATION IN THE CLINCH RIVER-WATTS BAR RESERVOIR SYSTEM[1]

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The U.S. Department of Energy has recently undertaken an environmental restoration program designed to achieve remediation of hazardous materials released from the Oak Ridge Reservation (ORR) in eastern Tennessee. One component of this program is the Clinch River Environmental Restoration Program (CR-ERP), which focuses on portions of the Clinch River and Watts Bar Reservoir that may have been adversely affected by contaminants released from the ORR. Contaminants include radionuclides, metals, and organic compounds that were released during the past 50 years from various facilities located on the ORR. Because many of the contaminants are strongly adsorbed to sediments, identifying areas of sediment accumulation is important to understanding the nature and extent of contaminant accumulation. This paper describes and compares two methods of estimating sediment accumulation rates in Watts Bar Reservoir.

Methods

TVA Siltation Data

The Tennessee Valley Authority (TVA) conducts periodic cross-section depth surveys in the Clinch River-Watts Bar Reservoir system to estimate siltation of the reservoir. Following closure of the dam in 1942, the reservoir and major tributaries were divided into 41 segments by establishing cross-sections at right angles to the channel. Monuments were installed on the left and right banks to permit accurate location of the cross-sections. For each cross-section, water depth was measured along a line connecting the two monuments using a boat equipped with hydrographic survey equipment. The cross-sections were surveyed in 1946, 1951, 1956, 1961, and 1991. The change in water depth between surveys, adjusted for pool elevation, is an estimate of sediment accumulation at a cross-section. In this paper, we are only examining 12 reaches in lower Watts Bar Reservoir and the Clinch river arm of WBR (Figure 1).

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Total sediment accumulation in each segment is calculated by the constant factor method (McCain 1957). Each segment is divided into a series of vertical layers, typically 10 feet thick. The initial volume and end areas of each layer were calculated in 1946 from topographic maps. The constant factor for the jth layer in the ith segment is defined as:

$$F_{ij} = V_{ij} / A_{ij}$$

where V_{ij} is the layer volume (sediment and water) and A_{ij} is the combined area of the ends which bound V_{ij}. Once determined, the constant factor remains the same for all subsequent sediment calculations in the layer. Sediment volume (S_{ijk}) in a segment layer (ij) at time k is calculated by multiplying F_{ij} by the combined sediment area of the ends as determined from the kth hydrographic survey. Summing the sediment volumes for all layers in a segment gives the total sediment volume for the segment (S_{ik}) at time k.

CR-ERP Core Data

During 1986 and 1987, 58 sediment profiles were collected in Watts Bar Reservoir as part of a scoping study for the CR-ERP (Olsen et. al. 1992). After collection, each profile was carefully extruded from the coring device and sectioned into either 1-, 2-, or 4-cm increments. The sections were placed into plastic-lined aluminum cans, sealed, and returned to the laboratory where they were analyzed for 137Cs activity by gamma spectroscopy. Following laboratory analysis, the 137Cs activity concentrations of the segments were plotted versus depth within each core. The largest release of 137Cs from the ORR occurred in 1956. We calculated a sediment accumulation rate (cm/year) for each core by dividing the depth of the peak concentration within a core by the number of years between the core sampling date and 1956.

Olsen et. al. (1992) subdivided the reservoir surface area into polygons based on sedimentary characteristics determined from 187 sediment grab samples and bathymetry obtained from navigation charts. We calculated a polygon estimate of sediment accumulation by assigning cores to each polygon and averaging the core-based accumulation rates. We examined the cores collected in each polygon to determine whether or not there was agreement between the polygon sediment type and the core's sediment type. We also compared the sediment type of the polygon with that of any grab samples collected in the polygon. If there was a core (or cores) collected in the polygon and the sediment types agreed, we chose that core or cores to characterize the polygon. If there were no cores collected in the polygon, we examined sediment type and water depth of any grab samples collected in the polygon. We then chose nearby cores having sediment type, water depth, and location similar to grabs collected in that polygon. If there were no grab or core samples in the polygon, we chose nearby cores having similar sediment type as the polygon. Polygon sediment accumulation estimates were calculated by averaging the accumulation rates of the cores assigned to each polygon.

Comparison of Sediment Accumulation Estimates

We calculated a sediment accumulation estimate for each of the twelve TVA segments as follows. First we calculated the change in sediment volume (Sd) between 1956 and 1991 by subtracting the sediment volume estimates from the corresponding surveys. Next, Sd was divided by the bottom area of the segment to give the sediment thickness (cm). Finally, the sediment thickness was divided by 35 years (1956-1991) to give an annual segment accumulation rate (cm/year). The twelve segment rates were also averaged, weighted by segment area, to give an overall annual rate.

We used a Geographic Information System (GIS) to calculate a segment accumulation rate from the CR-ERP core data. The GIS was used to overlay the segment boundaries and the sediment polygon map to give the polygon composition of each segment. The polygon accumulation rates were then averaged, weighted by polygon area, to give a segment estimate.

Results and Discussion

Overall annual sediment deposition (cm/year) based on the TVA siltation data differs for the 1946-1951, 1951-1956, 1956-1961, and 1961-1991 time periods (Figure 2). The rate of 2.2 cm/year for the 1956-1961 is substantially higher than the rates for the other time periods. Averaging the 1956- 1961 and 1961-1991 TVA estimates gives an annual rate of 0.63 cm/year for the period 1956- 1991. The 137Cs-based rate estimate for approximately the same period (1956-1987) is 1.15 cm/year.

Sediment accumulation rates (cm/year) for the twelve reaches for the TVA and CR-ERP estimates are shown in Figure 3. Each point is labelled with its reach number. We fit a straight line to these data using ordinary least squares regression. This analysis showed a statistically significant fit with 63 percent of the variability in the CR-ERP estimates explained by the TVA estimates. The intercept of 0.8 cm/year is significantly different from zero ($p < 0.01$) whereas the slope is not significantly different from one ($p = 0.24$). These comparisons imply that the CR-ERP estimates are consistently larger than the TVA segments by approximately 0.8 cm/year. There also appears to be a spatial grouping of the data with the accumulation estimates increasing as one moves upstream from the dam. However, reaches 1, 2, 11, and 12 are exceptions to this trend. Proximity to the dam may increase the accumulation in reaches 1 and 2 as compared to reaches 3, 4, and 5. The lower values in reaches 11 and 12 may be related to the hydrologic effects of the confluence of the Clinch and Tennessee Rivers.

The larger CR-ERP estimates compared to the TVA estimates are probably due to preferential sampling of the CR-ERP cores. These cores were collected to identify possible areas of sediment accumulation in the reservoir. Therefore, the cores were taken in areas thought to be areas of high sediment deposition. In contrast, the TVA data includes areas of low sediment deposition as well as areas of high deposition.

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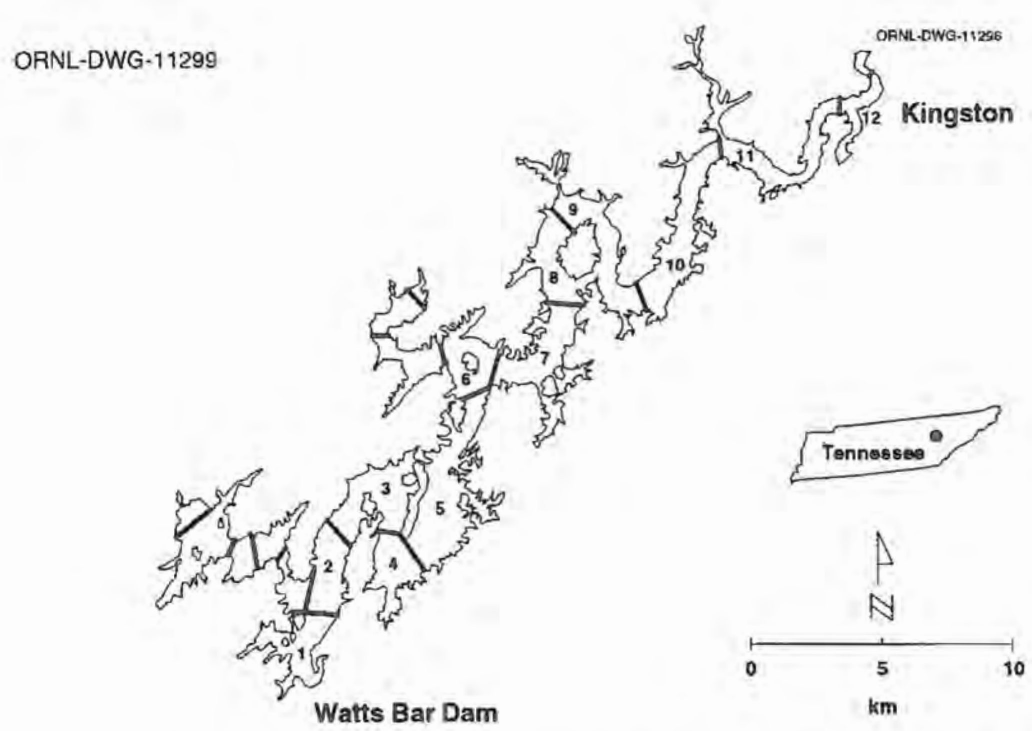

Figure 1. Map of Watts Bar Reservoir showing the location of the TVA siltation data cross-sections.

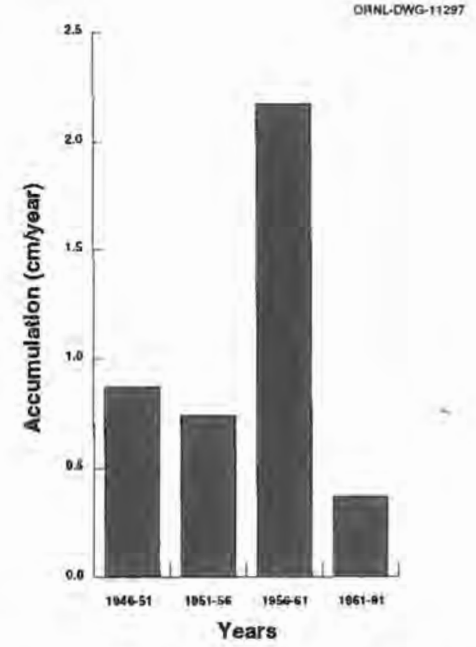

Figure 2. Histogram of average annual sediment accumulation rates based on TVA siltation data.

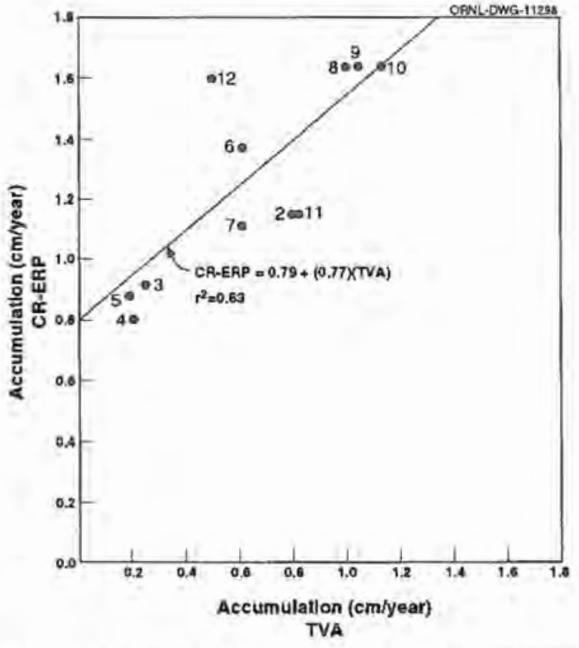

Figure 3. Plot of TVA and CR-ERP sediment accumulation rates for twelve segments in Watts Bar Reservoir.

TILLAGE AND COVER CROP EFFECTS ON NITRATE AND PESTICIDE LEACHING

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Introduction

In no other part of the United States is the erosion potential worse than in the western parts of Tennessee. It is an area of sloping loessial soils, with high rainfall intensities, and a high proportion of the area in row crops. No tillage (NT) has been adopted by many farmers in the area to control erosion. The no-tillage system has proven its effectiveness in reducing overland flow and sedimentation (Blevins, et al., 1989; Shelton, et al., 1983).

There is a tendency for macropores to form under NT. These macropores may be root channels, cracks between soil ped faces or earthworm burrows (Thomas et al., 1973; Thomas and Phillips, 1979; Edwards et al., 1988). Macropores potentially increase the amount of water entering the soil. This infiltration increase combined with lower evaporation from the soil surface under NT potentially leads to higher leaching. The effect of tillage on macropores and the flow of water and chemicals through macropores has been shown to be important (Thomas et al., 1973; Quisenberry and Phillips, 1976; Edwards, et al., 1988). In earlier lysimeter work at Lexington, Ky, Tyler and Thomas (1979) showed a tendency for more NO_3-N and Cl loss from no-tillage during the spring, but practically no difference during winter. However, Kanwar et al. (1985) concluded that increased macroporosity under NT results in decreased nitrogen leaching when the nitrogen source is within micropores. Under the latter scenario, new water entering the soil during storm events by-passes the solute-rich micropores via macropore flow.

No-tillage cropping is used with 48% of double-crop soybeans planted in Tennessee (Anon., 1988). The use of no-tillage cultural practices for cotton production is relatively new and little is known about how tillage systems influence nitrate movement in the soil and its potential to pollute the groundwater. The general objectives are to determine the effects of cropping systems and tillage practices on nitrate movement. We are comparing nitrate leaching under (i) NT and CT (conventional tillage) cotton with no-cover with 100 kg N ha^{-1} applied, (ii) NT and CT soybean-wheat-corn rotation, (iii) continuous NT corn planted in wheat, hairy vetch, and no cover with 112 kg N ha^{-1} applied. An additional objective is to evaluate the preferential flow under such systems by comparing leachate measurements from three size lysimeters and by comparing infiltration properties and dye staining patterns under saturated and unsaturated conditions. Selected pesticides such as fluometuron (Cotoran) are also being measured in leachate.

Procedures

Tension-free pan lysimeters were used to collect water draining from the soil profile. Three sizes of lysimeters (75 x 60 cm, 45 x 35 cm, and 30 x 13 cm) were used in the NT corn with hairy-vetch cover. The large pans were used in all other studies. Pans were installed under undisturbed soil at 90 cm depth by digging a trench into each plot and excavating laterally from the trench into the plot. A lysimeter was inserted into the excavated area with the outer edge at least 15 cm from the trench face into the plot. Each lysimeter was filled with sand and crushed marble to establish continuity with the soil profile. Tygon tubing was connected to the lysimeter to route water collected into a buried 60 L polypropylene carboy. Installation of all lysimeters was completed in May 1990 and leachate has been collected following storm events since that time. Nitrate concentrations and the quantity of subsurface flow has been recorded. Soil samples were collected at 15 cm intervals to a depth of 107 cm under each cropping system and resident nitrate and ammonium concentrations analyzed. Nitrate concentrations were determined by IC and ammonium by a colormetric method.

Fluometuron was extracted from depth-incremented soil samples by combining a 10-g soil sample with 20 mL methanol and shaking for 1 hour at ambient temperatures. Extractions were performed in triplicate. Fluometuron concentrations in the methanol extracts and the pan-lysimeter leachates were determined using the HPLC method of Mueller and Moorman (1991) and UV detection at 240 nm.

Results and Discussion

Preliminary findings reveal that 81% of all the leachate samples had NO_3-N concentrations below the 10 mg L^{-1} maximum contaminant level (MCL) (Table 1). Samples exceeding the MCL typically occurred during the growing season shortly after fertilization when flow out of the root zone was generally small (Fig.1). The general pattern observed was high preferential flow out of the root zone during winter and early spring periods when nitrate-N concentrations were low. Nitrate-N concentrations were generally high during periods following fertilization, however, preferential flow during these summer periods was low or non-existent. Nitrate-N concentrations were generally higher under hairy vetch than under wheat or no cover during the winter period.

No-tillage appeared to reduce nitrate leaching under cotton (Fig. 2) and under the soybean-wheat-corn rotation during the wheat-corn period (Fig. 3) as compared to chisel plowing. Between 1 October 1990 to 31 September 1991 there were 30 and 20 kg ha^{-1} of NO_3-N leached for conventional and no-tillage cotton, respectively, and 14 and 5 kg ha^{-1} leached for conventional and no-tillage wheat-corn system, respectively. For no-tillage corn (Fig. 4), average losses of nitrate-N were greatest under hairy vetch ($\approx$ 17 kg ha^{-1}), intermediate for winter wheat ($\approx$10 kg ha^{-1}), and lowest under no cover ($\approx$6 kg ha^{-1}). Nitrate-N losses ranged from 3 to 53 kg ha^{-1} with the 12 lysimeters under hairy-vetch cover. The small size lysimeter exhibited the greatest variability and greatest average loss ($\approx$20 kg ha^{-1}), and the medium size had the lowest average loss ($\approx$9 kg ha^{-1}).

Fluometuron (Cotoran) concentrations in depth-incremented soil samples taken from NT and CT cotton plots are shown in Table 2. Prior to application, fluometuron was detected at low concentrations in only the surface samples. After fluometuron application (May 24) and before the July 3 sampling, the plots received 3.8 cm of precipitation. This resulted in the redistribution of fluometuron throughout the 90-cm soil profile. Soil concentrations, however, do not adequately illustrate the extent of herbicide movement in the soil profile. Lysimeter leachate data (Table 3) show significant fluometuron movement below 90 cm. The rapid appearance of fluometuron at the 90-cm depth, coupled with the elevated concentrations, suggests the significance of macropore flow. Further, the lysimeter data illustrate the influence of tillage practice on herbicide migration through the soil profile. Fluometuron concentrations were greater in leachates below the NT plots than below the CT plots. Greater herbicide flux under NT management may be a result of greater macroporosity, or an enhanced availability of the compound at the soil surface (perhaps through an enhanced association with dissolved organic carbon) as compared to CT management.

Conclusions

To date 80% of leachate samples had NO3-N concentrations below the 10 mg L-1 MCL. Samples exceeding the MCL occurred during the growing season shortly after fertilization when flow out of the root zone was generally small. When large rainstorms occurred immediately following fertilization, as much as 30 kg ha^{-1} of NO3-N was leached. Flow was greatest during the winter and spring when concentrations were below the MCL. No-tillage appeared to reduce nitrate leaching under cotton and under corn systems. We observed that infiltration rates were relatively low with no significant differences between CT and NT. Thus, no-tillage not only improved surface water quality but did not increase the potential for leaching of nitrates toward groundwater due to greater infiltration. Preliminary data does suggest the potential for more leaching of herbicide such as fluometuron under NT compared to CT cotton.

Acknowledgements

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Table 1. Percentage of Tennessee samples with NO_3-N concentrations above 10, 5, and 1 mg L^{-1}.

Cropping System	10 mg L^{-1}	5 mg L^{-1}	1 mg L^{-1}
	----------- % ----------		
No-till Corn			
No-cover 41265			
Wheat142143			
Hairy vetch173370			
Cotton			
No-till 61769			
Chisel144272			

Table 2. Fluometuron concentrations averaged across plots in soil samples before and after application on 5-24-91.

Soil Depth cm	5-22-91 NT	5-22-91 CT	6-03-91 NT	6-03-91 CT
	ug kg-1		ug kg^{-1}	
0 - 8	53	19	496	441
8 - 15	57	21	86	126
15 - 30	<10	<10	69	129
30 - 60	<10	<10	34	130
60 - 90	<10	<10	12	91

Table 3. Fluometuron concentrations averaged across lysimeters in leachate samples before and after application.

Sampling Date	ug L^{-1}	
	NT	CT
5-15-91	5	11
5-21-91	3	6
application (5-24-91)		
5-28-91	1374	201
6-12-91	1684	186
6-26-91	187	100
7-26-91	no leachate	108

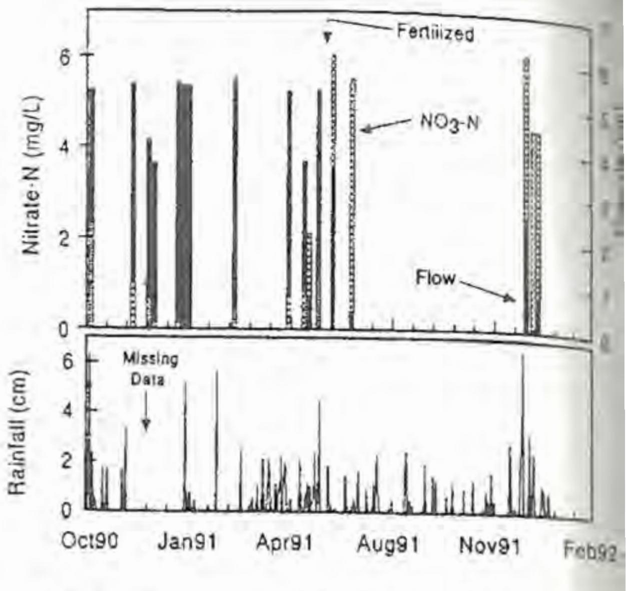

Fig. 1. Typical temporal variability of flow and nitrate-N concentration illustrated for NT corn with hairy vetch winter cover.

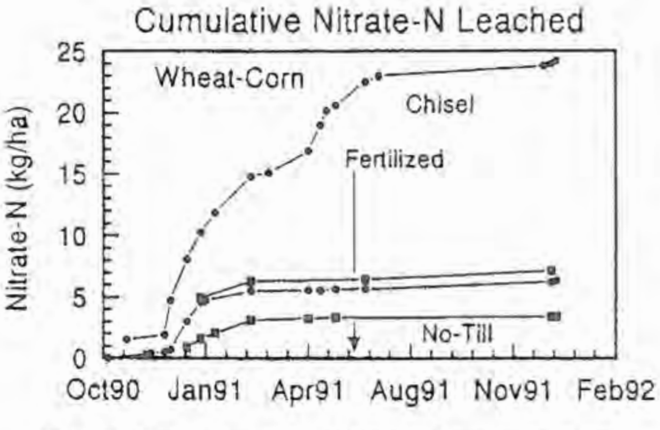

Fig. 3. Cumulative mass of nitrate-N transported out of the root zone per hectare under NT and CT soybean-wheat-corn rotation system in Tennessee.

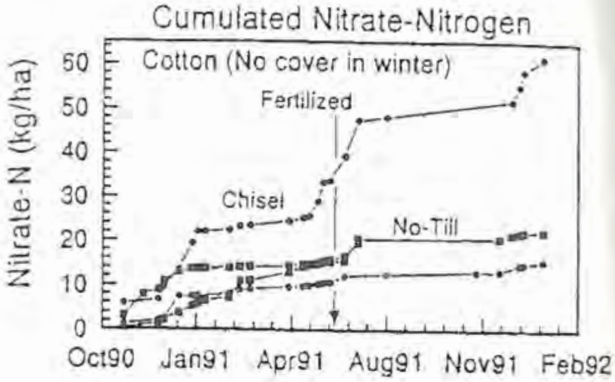

Fig. 2. Cumulative mass of nitrate-N transported out of the root zone per hectare under NT and CT cotton with no winter cover crop in Tennessee.

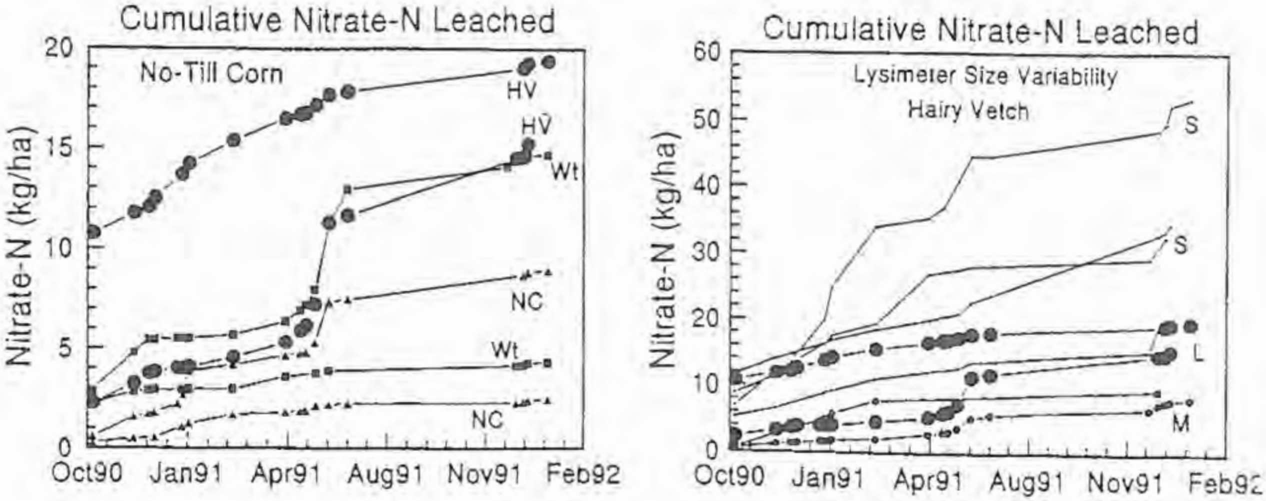

Fig. 4. Tennessee. Transport into a) large lysimeter pans under NT corn with hairy vetch (HV), winter wheat (Wt), and no cover (NC), and b) into large (L), medium (M) and small (S) pans under hairy vetch.

BROADENING FLOODPLAIN MANAGEMENT FOR NATURAL SYSTEMS PROTECTION

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Introduction

Some of Tennessee's most important assets are contained in its 20,000 miles of rivers and streams, and adjacent lands. These riverine corridors provide a variety of valuable resources and contain substantial capital investments in structures important to the people who live and work in the area and to transportation and commerce. They also contain a considerable portion of the State's most significant and diverse natural areas. These areas are sites with outstanding scenic or recreational importance or which are unique in natural or scientific value.

Management of the Tennessee's river and stream corridors involves a variety of disciplines, governments, programs, and activities and includes the private sector. The most resources probably are committed to the floodplain portion--the approximately six percent of the State's land area subject to the overflow of adjacent riverine watercourses. Within these floodplains, most management measures aim at reducing the economic losses resulting from flood events. Two major Congressional acts have had a significant impact on current floodplain management efforts--the National Flood Insurance Act of 1968 (P.L. 90-448) which focuses on flood loss reduction, and the National Environmental Policy Act of 1969 (P.L. 91-190) which provides for the consideration of environmental values.

Reducing Economic Losses

Under the National Flood Insurance Program (NFIP), relief from the impacts of flood damages became available to individuals in participating communities in the form of federally subsidized flood insurance, contingent on flood loss reduction measures embodied in local floodplain management regulations. Over 225 of Tennessee's 340 flood-prone localities currently participate in the program. Individuals in these localities may purchase flood insurance, intended as a substitute for post-flood disaster assistance and other forms of federal aid for flood recovery.

Where detailed flood hazard data are available, the NFIP criteria require adoption of local ordinances designating a floodway along the river or stream to allow for safe passage of floodwaters. Future development within the floodway is restricted to those uses which will not cause further obstructions to flood flows.

These floodways contain many natural resources and a sizeable portion of the State's riverine wetlands. By restricting development within the floodway, local measures provide a limited degree of resource protection. More importantly, however, they provide a framework for managing these and other areas for multiple objectives.

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The Framework for Managing Natural Systems

In enacting the National Environmental Policy Act (NEPA) of 1969, Congress formally recognized that environmental resources depend upon the functioning of complex natural systems. This act declared environmental quality to be a national goal and established a procedure for assessing the environmental impact of proposed federal projects and programs which could significantly affect the environment.

The goal of protecting and enhancing environmental quality is emphasized in other important legislation enacted over the past two decades, including the Wild and Scenic Rivers Act of 1968, the Endangered Species Act of 1973, the Clean Water Acts of 1972 and 1977, and the Water Quality Act of 1987.

Implementation of these and other legislation helped set the stage for the 1977 Executive Orders on Floodplain Management (11988) and Protection of Wetlands (11990). The Executive Order on Floodplain Management linked concerns for human safety, health, welfare, and property with concerns for restoring and preserving natural and beneficial floodplain resources. The Executive Order for Protection of Wetlands, issued at the same time, is closely related and similar in structure. Because most inland wetlands are located within riverine floodplains, the orders often cover the same areas.

A New Approach to Floodplain Management

With this management framework in place, and experience showing the drawbacks of working with limited objectives or floodplain areas, there is a growing interest in looking at the entire river corridor as a functioning system, even encompassing total watershed management. This interest, likely has several causes. Over the past few decades, better methodologies have been developed to identify and quantify the natural and beneficial resources and values found in river corridors. Impact analysis can not only determine the extent of benefits these resources provide, but also how they can be impacted, impaired, or even lost.

In addition, interdisciplinary and intergovernmental cooperation is increasing. Since most riverine wetlands are located within floodplains, wetland managers, floodplain managers, and other natural resources managers are discovering that their program goals overlap and they share many interests and needs.

Floodplain managers are discovering that single-objective management approaches do not work well. Most floodplain management objectives and practices use existing watershed and floodplain conditions to determine areas of involvement, focus on controlling future development rather than on existing problems, look at only a small portion of the floodplain and river corridor (the area that would be inundated by the one-percent annual chance flood), and have one purpose--flood loss reduction. To make matters worse, most existing programs deal with floodplain resource management decisions on a case-by-case basis.

As a result, communities and citizens have little interest in floodplain management for the sole purpose of flood loss reduction. Most programs exist because of NFIP requirements. What support exists is often tacit. Not only is the occurrence of the regulatory ("100-year") flood perceived as unlikely; many people believe the government will bail them out if a major flood occurs, restoring everything to preflood conditions or better.

Developing multipurpose management plans and programs to meet a number of community needs helps broaden the political and public support needed for success. This allows funding packages to be put together where resources and support often are not sufficient for single-objective approaches.

Finally, individual citizens and community groups are taking a greater interest in the welfare of river corridors. Whether government is ready or not, they are demanding an increased level of stewardship.

Natural and Cultural Resources of Floodplains

The National Environmental Policy Act and subsequent programs and policies have led to greater recognition of the multiple functions of floodplains and provided guidance for using these areas in a way that maintains or restores the natural and cultural resources they contain. Over the past few decades, better procedures have been developed to identify and document these resources, summarized in Figure 1.

Needs and Opportunities for Improving Resource Protection2

Significant advances have been made in our understanding of natural resource functions and the importance of maintaining the state's natural and cultural heritage. However, if we are to achieve our potential for resource conservation, water resources management professionals need to learn more about these functions and possible protection techniques. We also will need to better understand the benefits to be derived and more widely accept the need for our involvement. It is we professionals who develop programs and measures to implement policies and who can advocate for changes in present policies and programs to better promote resource conservation.

Various information and data sources have been developed which have already aided and can continue to aid this understanding. These include sources of data and information on natural and/or cultural resources, including resource quality and quantity; biodiversity; endangered and threatened species; unique resources; and environmental and cultural resource locations, sites, and networks.

Summary

Many of Tennessee's most biologically productive, environmentally sensitive, and culturally important areas are found in its floodplains. Most programs that serve to protect floodplain resources have not been developed specifically for floodplain application but apply to resources found outside the floodplain as well. A wide range of such programs, typically containing regulatory measures and requirements, have been enacted at all governmental levels.

Floodplain management can greatly benefit from a broadened mission. Integrating environmental protection measures with existing flood loss reduction strategies will increase interest and support for floodplain management at all levels and from nongovernmental sources.

Floodplain Natural and Cultural Resources

Water Resources

Natural Flood and Erosion Control

- Reduce flood velocities
- Reduce flood peaks
- Reduce wind and wave impacts
- Stabilize soils

Maintain Groundwater Supply and Balance

- Promote infiltration and aquifer recharge
- Reduce frequency and duration of low flows; i.e., increase/enhance base flow

Water Quality Maintenance

- Reduce sediment loads
- Filter nutrients and impurities
- Process organic and chemical wastes
- Moderate temperature of water
- Reduce sediment loads

Living Resources

Support Flora

- Maintain high biological productivity of floodplain and wetland vegetation
- Maintain productivity of natural forests
- Maintain natural crops

Provide Fish and Wildlife Habitat

- Maintain breeding and feeding grounds
- Create and enhance waterfowl habitat
- Protect habitat for rare and endangered species

Cultural Resources

Maintain Harvest of Natural Products Education Areas

- Create and enhance agricultural lands
- Provide areas for cultivation of fish and shellfish
- Protect silvaculture
- Provide harvest of fur resources

Provide Recreation Opportunities

- Provide areas for active and consumptive uses
- Provide areas for passive activities
- Provide open-space values
- Provide aesthetic values

Provide Scientific Study and Outdoor

- Provide opportunities for ecological studies
- Protect historical and archaeological sites

Source: Floodplain Management in the United States: An Assessment. Federal Interagency Floodplain Management Task Force, 1992

Figure 1. Summary of Floodplain Natural and Cultural Resources.

INTEGRATED REMOTE BIOSENSING FOR ENVIRONMENTAL MANAGEMENT IN REGIONAL MULTIUSE WATER RESOURCES

by

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More than two decades ago, Cairns (1967) and Cairns et al. (1970) first proposed a water-quality monitoring scheme that coupled multipurpose water-shed management objectives with an innovative stream survey approach which included automated biological monitoring devices. This combined monitoring system would have an advantage of providing an early warning to developing ecosystem stress in the ambient drainage, as well as specific toxic contributions from point sources. In meeting this goal, fish gill-ventilatory (breathing) events and swimming activities were automatically recorded at the same time selected physical/chemical values were being taken. Should potentially damaging conditions be detected, not only could corrective actions by taken but a site-specific stream survey (biological monitoring) would be carried out to access possible ecosystem stress or to provide quality assurance information. Through the coordination of a central resource management facility, this data would be addressed and appropriate measures taken to reduce or eliminate ecological risk. Several case studies have been reported that utilized this approach (Bonner and Morgan 1976; Cairns et al. 1980).

By 1977 and with the advantages of solid-state electronics, remote automated biomonitoring applications to a regional water-quality monitoring network were under development (Morgan et al. 1977, 1980). These studies resulted in portable, computer-automated biomonitoring devices that were data-linked to earth-satellite communications. Efforts in the following decade of the 1980's produced further support to the proposed regional watershed monitoring network by field testing portable biosensing devices in a small remote watershed in the southern Appalachians (Morgan et al. 1986), in mobile toxicity assessment laboratories (Morgan et al. 1988) and remote buoy applications (Morgan and Eagleson 1981) [Figure 1].

Over the past two decades, we have cooperated with various agencies in a series of ongoing laboratory and field tests to evaluate portable biosensing applications as components of a water quality monitoring network. The objective for the 1990's is to demonstrate this application in a multiobjective program utilizing remote sensing imagery and GIS support.

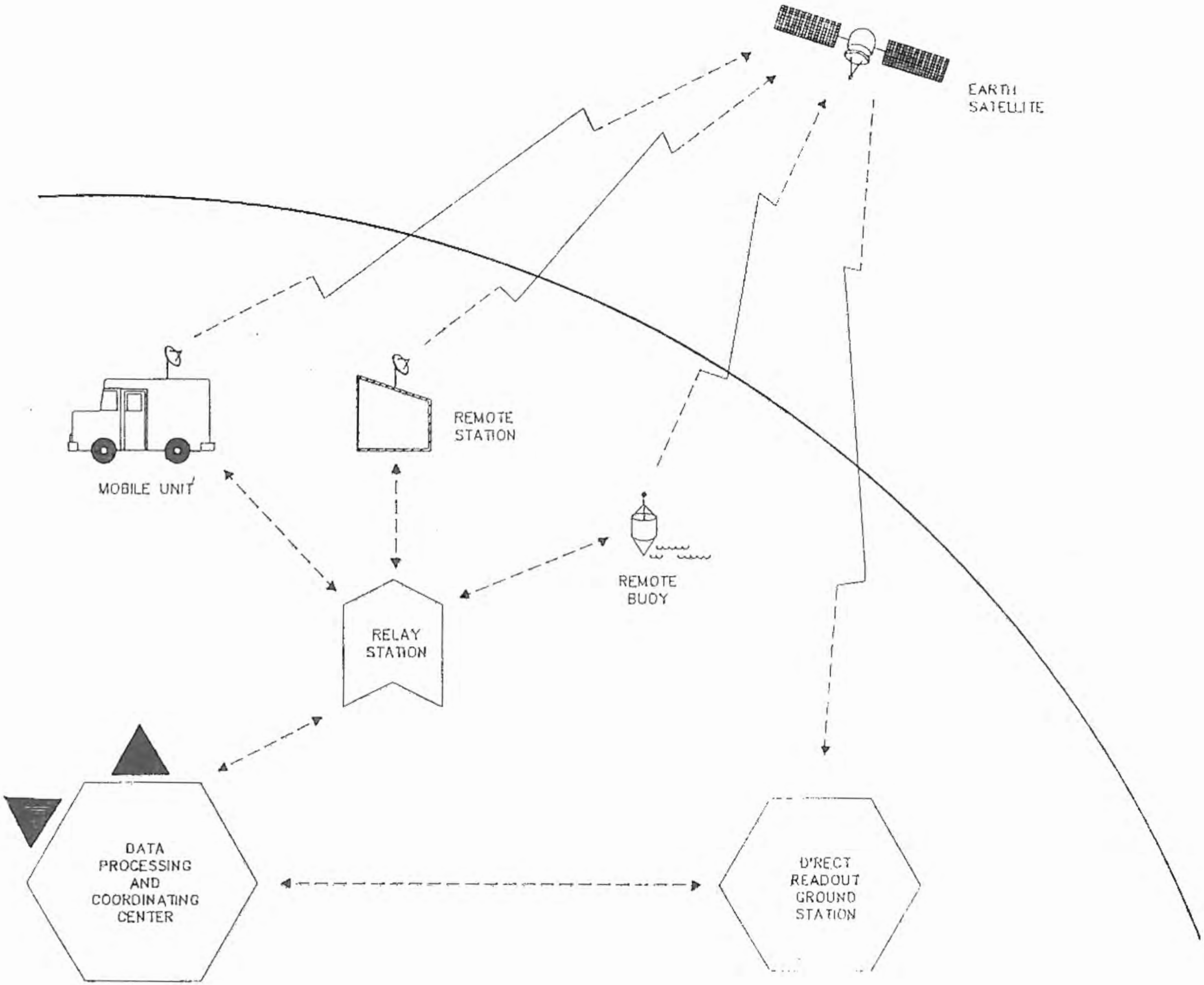

Figure 1. Proposed regional network using portable aquatic automated biomonitoring systems

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GROUND-WATER QUALITY OF THE UPPER KNOX AQUIFER, MIDDLE TENNESSEE

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The upper Knox aquifer in Middle Tennessee consists of a paleokarst system in the upper 200 to 300 feet of the Mascot Dolomite of the Knox Group. Water from the upper Knox aquifer in parts of Middle Tennessee is used for rural, domestic supply. An investigation was conducted by the U. S. Geological Survey to evaluate the water-quality of the upper Knox aquifer, using historical data and water samples collected form about 10 wells completed in this aquifer in Middle Tennessee. These samples were analyzed for major constituents and trace metals, and for carbon-14 and chlorine-36 to determine the apparent age of the ground water.

Most recharge to the upper Knox aquifer apparently occurs in the Central Basin. As the recharge water moves through the aquifer, it reacts with the aquifer matrix and becomes more mineralized. The direction of ground-water flow in the aquifer is primarily to the west.

In the recharge areas, ground water in the upper Knoz aquifer is primarily of the calcium-sulfate-bicarbonate type and typically has less than 1,000 milligrams per liter dissolved solids. The dissolved solids concentration increases and the water type changes toward the west.

In the southwestern part of the Highland Rim physiographic province in Middle Tennessee, the quality of water from the upper Knox aquifer is similar to that in the recharge area. This might indicate that, in this area, water flows more rapidly to discharge points near the Tennessee River and has less time to dissolve minerals from the aquifer matrix or that there is a closer recharge area.

TWO TENNESSEE RIVER MIXING STUDIES: KUWAHEE AND FOURTH CREEK WWTPS, KNOXVILLE UTILITIES BOARD

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Whole effluent toxicity limits, as well as chemical specific limits, are often required as part of a wastewater discharge permit. Tests for these parameters provide an indication of the potential impact the discharge may have on the receiving stream. Without information regarding the mixing characteristics of the effluent in the receiving stream, the regulatory agency may assign instream criteria as the end-of-the-pipe toxicity limitation. If the initial dilution of the effluent in the receiving stream is considered, less stringent toxicity limitations may be assigned.

Dye tracer studies can be used to observe mixing and dilution of an effluent in a receiving stream. These studies can measure the dilution available for different conditions of discharge flow and river velocity. Results from the dye studies can be used as input to a computer simulation model to predict dilution at critical low flow conditions. Dilution data from field studies and modeling studies combined with whole effluent toxicity data can be used to determine areas of acute and chronic instream toxicity.

Mixing characteristics of two WWTP discharges were evaluated to determine areas of potential instream toxicity. The Kuwahee and Fourth Creek WWTPs, located in Knoxville, Tennessee, discharge effluent to the Tennessee River. This paper presents results from two mixing studies conducted for the different outfall types utilized by the Kuwahee and Fourth Creek WWTPs.

Dye tracer studies were conducted under two different field conditions for the Kuwahee outfall, a submerged multiport diffuser. Two tracer studies were also conducted for the Fourth Creek outfall, a single port pipe outfall. The tracer studies were performed by dosing fluorescent dye in the WWTP effluent at a known concentration. Effluent dilution was determined in the river by measuring fluorescence (which is directly proportional to dye concentration) with a flow-through fluorometer. Additionally, whole effluent toxicity tests were conducted for each plant's effluent. Combined with model calibration and prediction, estimates of the areas of instream toxicity have been made. The mixing characteristics of the dischargers are discussed separately below.

Kuwahee WWTP

The river and effluent conditions for the two dye studies at the Kuwahee plant were:

Case	River		Effluent	
	Flow m3/s	Temperature (C)	Flow m3/s	Temperature (C)
High Flow	240	21	1.4	19.5
Medium Flow	131	20.8-19.4 (stratified)	1.0	19.8

Rapid initial dilution of the effluent was observed just downstream of the diffuser. Effluent dilution values observed ranged from 16, at 30 feet downstream from the diffuser, to infinite outside the plume. Effluent dilution and plume trajectory were affected by river and effluent temperature differences for the first 500 feet downstream. Beyond 1,000 feet downstream dilution increased to the maximum steady state dilution.

Fourth Creek WWTP

High and medium flow dye studies were conducted for the Fourth Creek plant. The river and effluent conditions were:

Case	River		Effluent	
	Flow m3/s	Temperature (C)	Flow m3/s	Temperature (C)
High Flow	286	20.1	0.27	19.5
Medium Flow	132	21-19.7 (stratified)	0.26	20.5

Dilution downstream of the outfall was impacted by interaction with currents from a nearby cove during both studies. High concentrations of dye were detected in the cove and along the near shore. Horizontal dispersion of the plume was limited during both studies. Dilution was approximately the same for both studies in the immediate vicinity of the outfall discharge (dilution factors less than ten).

Toxicity Studies

Two toxicity studies were conducted for each WWTP effluent. Chlorinated samples and samples collected prior to chlorination were tested for acute and chronic toxicity. Two test organisms, Ceriodaphnia dubia and fathead minnow, were observed for survival, reproduction and growth.

For both WWTPs, the chlorinated samples were more toxic and the Ceriodaphnia was the more sensitive species. Worst case results are summarized below.

WWTP	Acute LC50	Chronic NOEC	Dilutions Required to Meet Instream Acute Criteria
Kuwahee	26%	50%	12.7
Fourth Creek	17%	6.25%	19.7

Modeling Studies

Hydrodynamic mixing models developed by Cornell University (CORMIX1 and CORMIX2) were used in conjunction with the dye and toxicity studies to predict worst case dilution conditions. The models were calibrated to each dye study by adjusting Manning n roughness coefficients, river and discharge temperatures within the ranges of uncertainty. The models were then used to predict dilution at the critical low flow of the Tennessee River. Dilution information and the instream water quality criteria were used with the worst case toxicity test results to compute areas of instream toxicity. The following table details distances required to meet instream acute toxicity limits.

	Distance Downstream (ft)	
Case	Kuwahee	Fourth Creek
High Flow	7.5	150
Medium Flow	10	500
Low Flow	<10	1300

Summary

The potential zone of instream toxicity is insignificant for the Kuwahee WWTP for the worst case conditions of high toxicity, high WWTP flow, stratified temperatures, and low river flow. The potential zone of toxicity for Fourth Creek, however, could be as great as 1300 feet under similar worst case condition. The multiport diffuser at Kuwahee does an excellent job of dispersing the effluent over the width of the river. The pipe outfall at the Fourth Creek WWTP does not provide significant mixing.

WATER-QUALITY MONITORING ON A 2500 ACRE WEST TENNESSEE AGRICULTURAL WATERSHED

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Introduction

Water is a finite resource used by all mankind. As population increases, the competition for water and land increases along with the demand for high quality food and fiber. At the same time the impacts of agricultural production practices on water quality are coming under increased public scrutiny. Numerous reports have cited agricultural chemicals moving off target fields as the primary cause of local degradation of ground and surface water quality.

Further investigation in many of these cases has revealed two scenarios. In the first, contamination has occurred from a point source such as careless disposal of pesticide containers in sinkholes or near streams, disregard for standard safety practices such as backflow prevention devices or well head seals resulting in direct aquifer contamination via wells, or negligent spills or deliberate dumping of concentrated agricultural chemicals. In the second scenario, local conditions such as coarse textured soils, shallow ground water, steep field slopes, or erosive soils coupled with questionable management practices have degraded water quality. Because areas at risk are more easily identified and receive more publicity, the few comprehensive studies that have been conducted have focused on agricultural impacts in those areas. There is a dearth of research-based information relating local production practices to the off-site movement of agricultural chemicals in areas where soil type, topography, and aquifer depth are more appropriate for agricultural production.

Motivated by public concerns, regulatory and service agencies require or encourage "best management practices" to reduce environmental impacts from agricultural production. Because local information is often unavailable "best management practices" from other areas of the country with entirely different soils, crops, climates, and attitudes are sometimes recommended without validation. This raises serious questions about whether "best management practices" for one region are cost effective measures to protect water quality in another region.

There may be tradeoffs when choosing "best management practices". For example, conservation tillage practices have reduced soil erosion and associated sediment pollution of surface water in the state and region (Shelton and Bradley, 1987). Research in some areas of the country has indicated conservation tillage practices may increase movement of agricultural chemicals to surface and subsurface water sources (Scott, 1987). Long-term, well controlled field studies are needed to improve understanding of the effects and interactions of tillage and management practices on movement of agricultural chemicals to ground and surface water.

Research-based information appropriate for local conditions is needed to refine technical guidelines for recommending agricultural management practices that reduce or eliminate movement of chemicals to water reservoirs. To conduct meaningful research on the interaction of production management practices and the off-site movement of agricultural chemicals, it is necessary to control management over large land areas, preferably an entire watershed. Typical experiment station field plots are too close together to permit differentiation of the effects of various cultural practices on water quality. The Tennessee Agricultural Experiment Station has a unique resource at the Ames Plantation near Grand Junction. The Ames Plantation is a holding of some 18,000 acres available to the University of Tennessee for research purposes.

The Watershed

Within the Ames Plantation is a 2500 acre watershed that is representative of thousands of acres of loess agricultural soils over the Holly Springs geologic formation of the Coastal Plain region of western Tennessee and Mississippi. The extent of this watershed and the opportunity to control management practices makes it possible to adequately separate research plots to permit differentiation of the impact of various agricultural production practices on water quality.

The water shed is located 60 miles east of Memphis and 10 miles north of the Tennessee-Mississippi border. An intermittent stream bisects the watershed and flows northwesterly into the North Fork of the Wolf River. Since the fall of 1990 cropland north of the stream has been in conservation tillage while that south of the stream has been conventionally tilled.

The Facility

Eventually 12 research sites will be developed within the watershed. Currently one, 25 acre site has been selected on each side of the watershed. The sites were selected to be as similar as practical with respect to soils and topography. Development of these two sites is complete and data is being collected to evaluate the effectiveness of the sampling scheme.

Within each of the 25 acre sites a square, one acre field test plot has been established. The one acre sites are surrounded by a low berm to exclude surface water from other parts of the field and to direct plot runoff into an H-flume for runoff measurement and automatic water sampling. Plot layout and instrument location is shown in Figure 1.

Sampling

To monitor and evaluate water, chemical, and sediment movement in the field test plot area provisions have been made to sample surface runoff water, water within the unsaturated soil region, and water in the ground water reservoir. Sampling locations are shown in Figure 1. Precipitation and runoff are measured and recorded by an ISCO® Model 3230 that also provides control for an ISCO® Model 3700 sampler which automatically collect runoff samples.

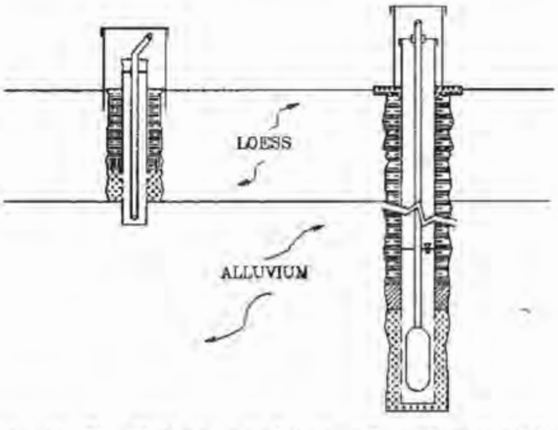

Figure 2: Cross-section of ground water and perched water sampling wells.

Water in the unsaturated soil region, the vadose-zone is sampled by tension-free pan lysimeters, by vacuum lysimeters, and by shallow wells screened at the depth of the loess-alluvium interface. In each one acre field plot three pan lysimeters are installed at a depth of three feet and collect an integrated water sample over an area of 5.0 ft^2. Adjacent to each pan lysimeter location a cluster of vacuum lysimeters are installed to collect water through porous ceramic cups at depths of 6, 12, 18, 24, and 36 inches. Also, installed at each lysimeter location is a neutron gage access tube and a bank of tensiometers. The tensiometers are installed at the same depths as the suction lysimeters.

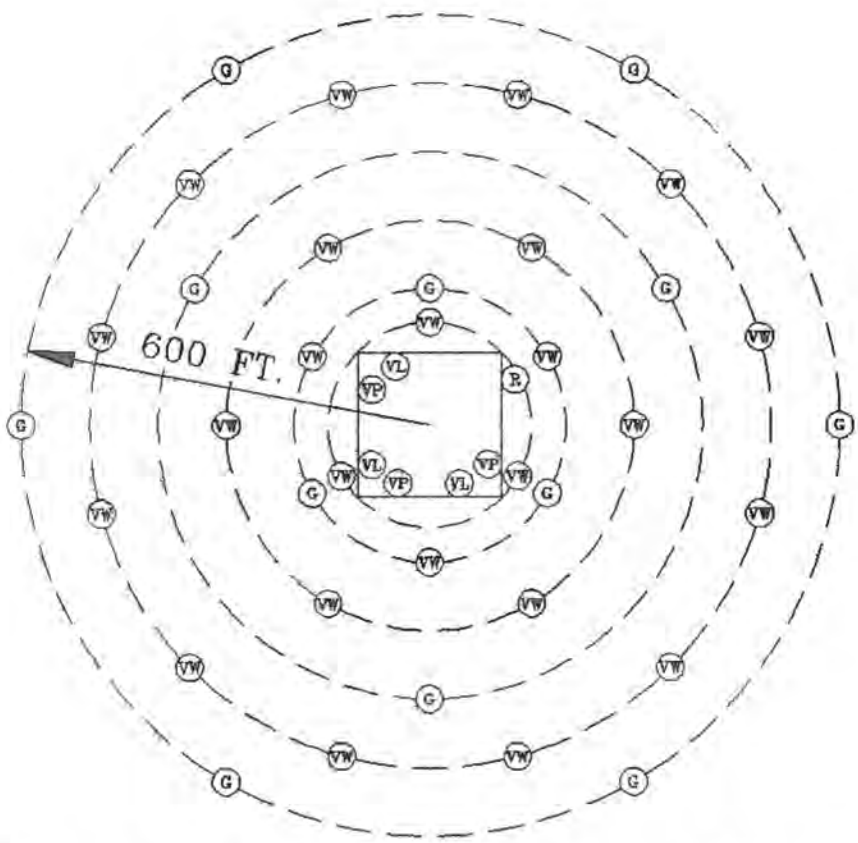

Figure 1: Locations of shallow vadose-zone wells (VW), ground water wells (G), vadose-zone lysimeters (VL), vadose-zone pans (VP), and runoff flume (R) around one acre field test plot.

Outside the one acre field plot are 24 shallow wells installed with a 6 inch screen located at the interface of the loess and the underlying alluvium to collect perched water (Fig 2.). Water entering the screened segment of the well is collected in a reservoir at the bottom of the well casing. Samples are retrieved with a vacuum pump.

Outside the one acre field test plot water samples from the underlying aquifer are taken from 12 wells at each site. Additionally, there are two wells located near the upper and lower ends of the watershed. The ground water wells and perched water sample locations are arranged in a radial pattern around the centers of the one acre field plots (Fig. 1).

A sample schedule tied to precipitation events was begun September 1, 1992. Sampling is initiated when more than 0.5 inches of precipitation is infiltrated in one day, or when cumulative infiltration reaches 3.0 inches. Runoff samples are collected as soon as possible after an event. Pan lysimeter and perched water samples are collected two days after an event. Because ground water samples are likely not effected by individual precipitation events, these samples are collected on a regular biweekly schedule.

Facility Testing

A chemically conservative soil water tracer, probably bromide, will be applied in February 1993 to evaluate the current sampling installations. Tracer data will be used to evaluate the adequacy of the number and location of sample wells. This information will be used to determine the design of future sites on this watershed.

Future Work

After initial testing long term sample collection will continue. Comparisons of water, tracer, and sediment movement will be made between the conventional and conservation tillage sites. Pesticides with high leaching potential will be applied only within the field test plots and nowhere else in the watershed.

Information gathered from this test watershed will help identify agricultural cropping practices that reduce the migration of agricultural chemicals to surface and subsurface water. Completion of all 12 research sites will provide a facility that will enable Experiment Station researchers to conduct statistically defensible tests of various cropping systems.

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RESERVOIR INTERPOOL PLANT HABITAT DYNAMICS IV. APPROXIMATION OF RIPARIAN CARBON DETENTION AND DECOMPOSITION PROCESS ALTERATIONS

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Overview

Notable alterations of riparian system bio-dynamics have occurred with the engineered management of water resources in the upper Tennessee Valley watershed. Impoundments above Chattanooga inundate about 380 square miles (980 Km2) of former terrestrial habitat at normal pool elevations. About 40 percent of this area is exposed at winter pool (designated as mudflats). The objectives of this report are to point out major changes in the Carbon cycle due to the effects on areal primary productivity and implied restrictions of decomposer activity.

Data from various forest analyses, using Sycamore as a bottomland forest indicator, allow a habitat reconstruction. The historical annual production of forest for First-class soils now under water during the growing season has been estimated. Assumed conversion of these same soils to legume forage agriculture then yielded projected, annual crop biomass. Various sources report the carbon detained by these organic units, forest and field plants, as 45 to 50 per cent dry weight of annual biomass production.

Water quality monitoring (TVA) has provided information for extrapolation from extant aquatic habitats (Valley reservoirs) of carbon detained annually from in situ primary production and allochthonous inputs. Concurrent chlorophyll a measures can be areally estimated. We have collected several taxa of contributing algae.

Our exploratory investigations of drawdown zone substrates have found occasional concentrations of mudflat primary production during the winter months, but most such areas are barren of vascular plants. Our studies now show the decomposer compartment of the system is functionally depauperate. With a scarcity of in situ primary productivity, organic resources are generally external.

Anaerobic conditions beneath the exposed sediment surfaces occasionally preserve identifiable biogenic detritus, while crude microanalyses otherwise show very low organic content in fine-textured mineral alluviums. Winogradsky column analyses and literature reviews point to bacterial reduction of inorganic compounds as well as methanogenesis. Organo-toxic complex breakdowns are not yet studied in our projects, but have been examined elsewhere by UTK ecologists.

The aquatic (summer pool) surface area is increasing. Erosional encroachment is reducing the "new riparian" flood zone width. The nominal 9200 Km edge of the 26 detailed impoundments is lengthening. The areal carbon detention has decreased manyfold and this decrease will continue.

Mudflat Status

There are some 100,000 + acres (≈42,000 ha) of mudflats between summer pool and winter pool drawdown elevations on managed reservoirs upstream of Chickamauga Dam, not including flood zones between summer pool and top of gates (TVA, 1980). Mudflats have two distinctive substrates; hydrologically truncated residual soils on shoreline slopes and sediments without profile development on alluvial (and colluvial) bottoms.

Near-shore summer aquatic bed habitats are generally hydrologically unstable and often barren of submersed macrophytes. In very localized areas emergent non-woody perennials and occasional aquatic shrubs characterize this habitat. Planktonic algae abound at times; some 24 taxa have been identified by P.L. Walne (UTK). Short-term mosquito control fluctuations do not noticeably affect this vegetation.

Following continuous autumn drawdown exposure, late summer- early autumn weedy terrestrial annuals and some creeping shoreline perennials may develop on the newly exposed substrates (Webb, Dennis and Bates, 1988; Webb and Bates, 1989; Amundsen, 1989; with Bartlett, 1990; with Walker, 1991). This late growing season vegetation is usually sparse, clumped, and except in certain areas, of low cover and grazing value. As the mudflat drains and substrate aeration improves, heat transfer from the winter pool moderates the habitat. The seedbank may yield winter-periodic stands of generally scattered, but occasionally extensive, small-statured herbs and graminoids. Several kinds complete their life-cycle before the summer pool water level rise of the next spring season and restock the mudflat seedbank. The timing of the persistent drawdown and the length of the drawdown period determine the success of the periodically adapted flora.

Sightings, sign and scat indicate a rather uneven utilization of the drawdown zone by wildlife. Evidence of macroinvertebrates, as well as mammalian and avian species, may be conspicuous but is usually discontinuous. Cover and food sources are the obvious attractions, but the structural and physical conditions of the edge may entice and enhance behavioral choices as well (Amundsen and Walker, 1991). Livestock impact is severe in some areas.

Carbon Detention

The terrestrial landscape abutting the upper Tennessee River and its tributaries was almost entirely closed forest prior to European settlement. Several studies on hydromesic bottomland in southern forests can be interpolated to approximate expected annual carbon detention through biomass increment and measured litter fall (Rosson, 1992; Wells and Schmidtling 1990; Smith et al; 1975; McGinnis, 1958). Sycamore (Platanus occidentalis L.) presence was chosen as an indicator of bottomland forest stands represented by basal area measurements and demarcated by First-class soils (USSCS classification) for projection of carbon detention in the historically forested bottoms. This species has been characterized in appropriate stand records for this analysis by B. Hafer and J. Faulkner (UTK). Sycamore is reported to contribute 8 to 9 percent of the bottomland annual production totals used below (Smith et al., 1975).

Incremental productivity of mixed hardwood bottomland stands reported with sycamore can be estimated by computing the cubic biomass of the stand when age, height and basal area are available. Using the model of Smith et al. (1975), J. Faulkner (UTK) has translated (into BASIC) the equation for such stands:

$$\log_{10}\text{CU.BIOMASS}=C_1+C_2(1/\text{AGE})+C_3[(\log_{10}\text{HEIGHT})/\text{AGE}]+C_4(\log_{10}\text{BASAL AREA}).$$

where C_{1-4} are stand type coefficients from Smith et al.;

AGE is the stand age;
HEIGHT is the average tree height in feet; and
BASAL AREA is the square feet per acre average.

Annual litter fall in contemporaneous regional forests has been measured by McGinnis (1958). McGinnis's and similar studies show ≈33% more annual biogenic fall than intact tree, standing crop.

The arithmetic employed yields (Sycamore qualified stands plus mean litter):

Standing Crop/yr 1.5 tons/acre.
Litter/yr 2.0 tons/acre.
7000 lbs/acre x 2.47 acres/ha ÷ 2204.6 lb/metric ton = 7.84 metric tons/ha, annual production, bottomland forest.

Assuming the more recent, pre-impoundment conversion of valley bottom to agriculture, USSCS (1941) First-class soil areas now inundated by Douglas Reservoir were delineated (M. Finger, UTK) and alfalfa production compared for these soil types. Some 6000 acres of First-class soils have been removed from agricultural potential in Jefferson County TN by Douglas and the arithmetic across soil types yields:

Average First-class soil alfalfa yield/yr 3.03 tons/acre.
6060 lbs/acre x 2.47 acres/ha ÷ 2204.6lb/metric ton = 6.79 metric tons/ha, annual production, alfalfa.

Analyses of primary productivity variously reported in the literature (reviewed, Post et al. 1990) indicate the annual fixation of carbon (CO_2) as 45 to 50 percent of the increment of dry matter weight or biomass, in vascular plants. The average regional bottomland site (forest and/or alfalfa) is calculated to have a primary production of 7.3 metric tons/ha. A carbon detention of 45 to 50 percent of that biomass is 3.3 to 3.7 metric tons of photosynthetically fixed carbon/ha/yr.

Six reservoirs (Chickamauga, Watts Bar, Ft. Loudon, Cherokee, Douglas and Norris) have been sampled for organic carbon (Meinert, 1991). Calculating the volume by surface relationship of the sampled reservoirs and applying the volumetric carbon measurements reported shows a detention of 0.24 metric tons of carbon/ha across the six reservoirs. Meinert's (1991) data also yield a euphotic zone value of 0.36 Kg/ha of chlorophyll a. This chlorophyll is evidence of photosynthetic carbon fixation in situ. A large part of the aquatic carbon measured is from allochthonous sources.

The extant normal pool reservoir detention of carbon is 1:14.5 of the preimpoundment landscape potential (≈7%).

Decomposition

The producers of the mudflat system depend not only on photosynthetic processes, but also on nutrient resources. The mineralization of biogenic materials by decomposer organisms is an important facet of appropriate supply. Many consumers associated with the drawdown zone are not only in a grazing food chain (consumption of new photosynthate) but are involved in (or restricted to) a detritus food chain (consumption of non-living organic materials).

There are no definitive field studies on the specific microfloral (bacterial, fungal) decomposers of the mudflats. A preliminary survey of appropriate literature and consultations with others engaged in aquatic organo-toxicological research has allowed a general classification of microbial processes likely to occur in the sediments and the bacteria responsible for this activity (A-M. White, UTK). With the low level of within-system primary production, bacterial metabolic processes are largely dependent on allochthonous inputs. In the winter, the near-saturated condition of much of the fine textured alluvial sediment is responsible for anaerobic and high reducing conditions at very shallow depths. Allocthonous materials, including intact terrestrial plant parts, can be found entombed in the sediments, but are patchy. Surge currents, occasioned by local storms, boat waves, or drastic water level changes, contribute to the scouring of detrital inputs as well as they effect an instability of the rooting zone for plants in the aquatic bed of the near-shore.

Winogradsky column experiments with anerobic sediments (S. Wampler, LCHS) show an expected appearance of microfloral colonies, but developments are inconsistent and no dominance is detectable. Bacteria associated with reducing processes involving Sulfur, Iron, Nitrogen, Methane, Chromium and Manganese are indicated (by survey and/or column appearance). The methylation of Mercury and the degradation of polychorinated biphenyls (G. Sayler and others, UTK) have been demonstrated in Tennessee Reservoir sediments. The mudflat is a deficient system, requiring extensive nutrient and energy imports, whereas the historic bottomland forests likely contained a decomposer compartment more in balance with primary production. The decomposer compartment of the mudflat system needs comprehensive field investigations.

Consequences

The extensive mudflat ecological system is erratic and exists as an adjunct to adjacent and upstream ecosystems. Low carbon fixation and inhibited decomposition define and limit the consumers that can be supported. Duration of consistent water level is a controlling factor in any consideration of ecological succession towards a stable, discrete, aquatic or terrestrial system.

The siltation of reservoirs as the result of unrelated land usage in the watershed, accompanied by the retreat of shore lines, also noted as a consequence of human activity, is enlarging this disturbed habitat.

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NITROGEN REMOVAL FROM IN-LINE DETENTION BASINS

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Urban runoff presents a major sources of pollution loading, such as suspended solids, organic matter, nutrients, and heavy metals, to receiving waters. Suspended solids accumulates from litter, erosion processes, atmospheric fallout, decaying vegetation, and street pavement abrading (Horner et al. 1982). Organic matter may come from decaying vegetation, petroleum products, and animal droppings. Nutrients found in runoffs are primarily phosphates, nitrates, and Kjeldahl organic nitrogen that usually attribute from back-yard fertilizer and other commercial products (Wanielista, 1990). Heavy metals are form vehicle emissions (Shaheen, 1975).

The U.S. Environmental Protection Agency conducted a study of the removal effectiveness of detention ponds under the Nationwide Urban Runoff Program (NURP) in 1983. The results demonstrated that a detention pond is the most promising technique to control the runoff (Driscoll, 1983). It provides a temporary storage basin to prevent flooding after a rainfall event, and functions as a reactor to remove the pollutants in runoff. However, an in-line detention pond nodule was investigated (Yousef, et. al 1990). It concluded that although most pollutants in stormwater runoff can be removed in a detention pond by sedimentation, the total nitrogen removal was less than 30 percent.

The introduction of fertilizer and other commercial products in agricultural and residential areas produces high concentrations of nitrogen in runoffs and increases the oxygen consumption rate due to nitrification. On the other had, biological nitrification and denitrification processes generate nitrogenous acceleration of algal blooms in detention ponds. The increase in nitrogen removal and improvement in the performance of detention ponds was studied using Granular Activated Carbon (GAC) biofilms. Executing this operation was also suggested.

5 gallons of rainfall and 25 gallons of runoff were collected from an open channel flume in a medium density residential area of Memphis, Tennessee. Both water samples were carried through chemical analysis including TS, DO, temperature, pH, BOD, ammonia, nitrate, nitrite, and phosphorous. The procedure outlined in <u>Standard Methods for the Examination of water and Wastewater</u> (1989) was used. To assist the degradation kinetic study, the stock solutions of nitrate and ammonia nitrogen in stormwater runoff were spiked into the runoff sample. The resulting concentrations of nitrate and ammonia nitrogen in the runoff sample. The resulting concentrations of nitrate and ammonia nitrogen in the runoff were 13.85 mg/l and 16.47 mg/l, respectively.

5 gallons of prepared runoff was aerated for 24 hours. The runoff stayed in a quiescent tank for 5 days to generate the biomass sludge. The sludge was withdrawn, mixed with 28.78 grams of Granular Activated Carbon, and then incubated for 15 days until biofilms had grown on the surface of the gas. Once the preparation was completed, the composite was added to a 1.5 inch adsorption column. The runoff was pumped into the GAC column with 0.35 ml/min (0.5 L/day) flow rate. The effluent was collected and examined for nitrate and ammonia nitrogen analysis.

The in-line detention pond module consists of two tanks in a series. The schematic diagram is shown in Figure 1. The first tank functioned as an aeration (air stripping) tank. A 6 hour period was provided in this tank. The effluent form this tank was analyzed for nitrate and ammonia nitrogen. The second tank was a detente unit with a volume 10 times larger than the first tank. Under tranquil conditions, suspended solids and soluble solids can be removed in this module. The effluent from the second tank was analyzed for nitrate and ammonia nitrogen as well.

The water quality of rainfall and stormwater runoff showed the pollutants in the runoff were higher than those in the rainfall. The dry street, unpaved areas, and land use are the possible sources of the pollutants. During this study most of the nitrogen found in the runoff was in the form of nitrate and Kjekdahl organic nitrogen. Because the area selected is primarily a residential zone, the nitrogen loading that came for backyard fertilizers and pesticides was expected.

Based on the previous study the use of sedimentation to remove the total nitrogen in the runoff was insignificant. Biological nitrification and denitrification on GAC biofilms with recycled sludge was proposed. After 5 days of operation, effluent collected from the bottom of the GAC column showed that more than 70% of the ammonia and nitrate nitrogen in the runoff could be removed in GAC biofilms. The GAC biofilms were erratic in reducing the ammonia and nitrate nitrogen at the beginning. The percent of nitrate and ammonia remaining in the effluent vs operation days are plotted in Figure 2.

The nitrate and ammonia nitrogen remaining in the effluent of the GAC column entered the aeration module. This design system can strip nitrate and ammonia nitrogen in to the air. The effluent collected showed almost 50% of incoming ammonia nitrogen into the air. The effluent collected showed almost 50% of incoming ammonia and 30% of nitrate was removed in the first tank after a 6 hour period. IN the last module, the design attempted to remove nitrate and ammonia nitrogen in unsteady state by sedimentation and by augmenting the denitrification in the pond. As a result, a large amount of the total solids was found on the bottom of this module. The concentrations of nitrate and ammonia in the final effluent were 1.36 mg/l and 1.74 mg.l, respectively. The overall removal efficiency of ammonia and nitrate nitrogen in this system was improved, resulting in a reduction of those compounds by approximately 90%.

Detention ponds have been demonstrated as the Best Management Practice's (BMP's) for stormwater management. However, the previous study found that the hydrophilic pollutants, such as nitrogen and other compounds, are difficult to remove within detention ponds. The purpose of this study was to increase nitrate and ammonia nitrogen removal from detention ponds by using an aeration facility and GAC biofilms. The precursory result revealed that the removal efficiency of this operation can reduce approximately 90% of the investigated compounds. The stoppage in the GAC column and the dissolved oxygen control for the entire system will need to be carefully assessed during the scale-up operation.

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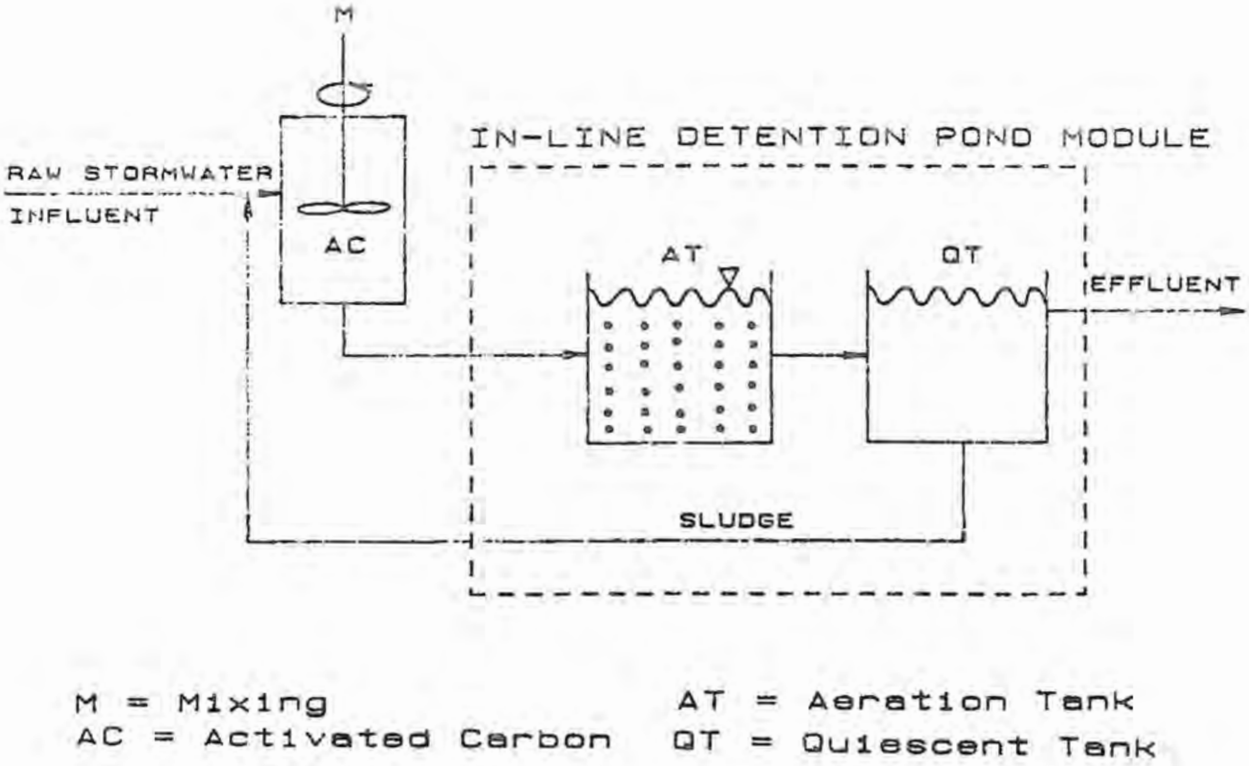

FIGURE 1. Schematic Diagram of Nitrogen Removal From In-Line Detention Basins

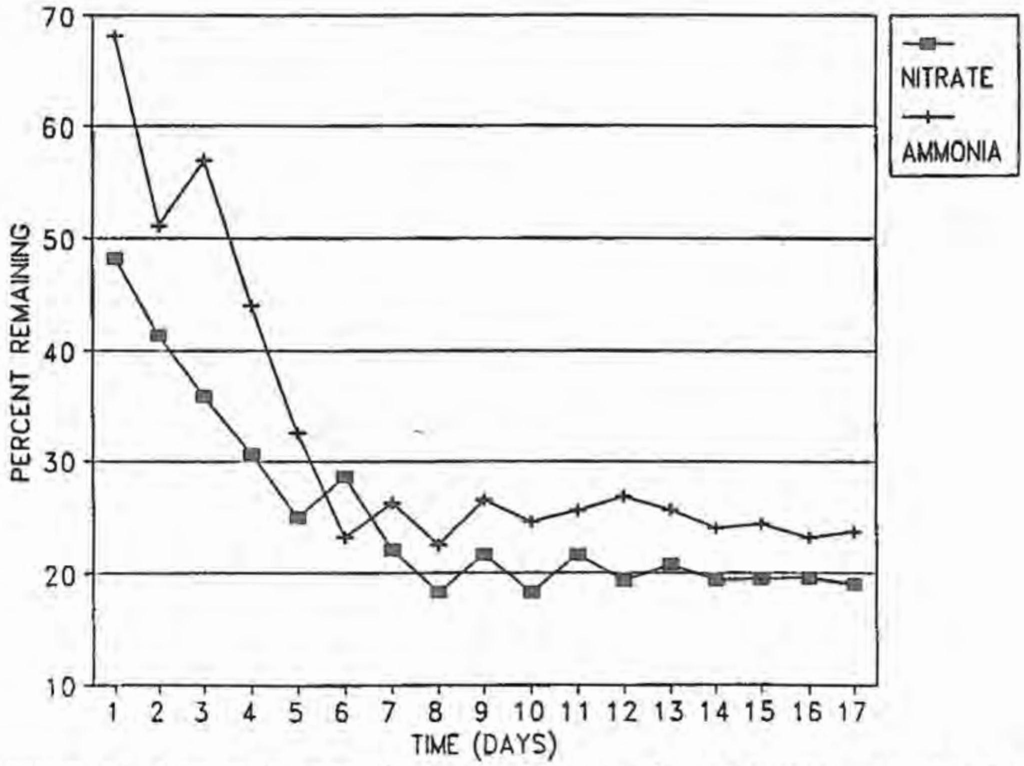

FIGURE 2. Percent Remaining of Ammonia and Nitrate in the Effluent of Granular Activated Carbon Column

HYDROGEOLOGY OF OUTCROPPING TERTIARY STRATA NEAR CEDAR GROVE IN SOUTHWESTERN CARROLL COUNTY, TENNESSEE

By John K. Carmichael[1] and Stephanie E. Johnson[1]

ABSTRACT

Test drilling was conducted during 1991 near Cedar Grove in southwestern Carroll County to obtain hydrogeologic information about the outcropping Tertiary strata in western Tennessee. Samples of cuttings and geophysical logs from four test holes at three locations were used to determine the lithology and stratigraphy at the drilling sites. The cuttings and logs confirmed the presence of a relatively continuous interval of fine- to very-coarse sand which composes the Memphis Sand of the Claiborne Group. The Memphis Sand is underlain by a relatively thick and uniform interval consisting mostly of clay and silt which compose undifferentiated units of the Wilcox and Midway Groups.

The Fort Pillow Sand of the Wilcox Group is absent in all of the test holes except possibly one of the two holes drilled at the westernmost site near Lavinia. In the deeper test hole, which was drilled to a depth of 435 feet, about 25 feet of fine sand was penetrated from a depth of about 333 to 335 feet in the clay interval beneath the Memphis Sand. This sand is in a stratigraphic position which indicates that it could be equivalent to the Fort Pillow Sand.

Two test wells were completed and tested to determine the potential yield and chemical quality of water in the Memphis Sand. Yields of the two wells were 275 and greater than 350 gallons of water per minute, and specific capacities were about 18 and 10 gallons per minute per foot, respectively. Water samples from the two wells were collected and analyzed for major dissolved and selected trace inorganic constituents, and scanned for organic compounds. Results of these analyses indicate that the water is soft, contains low concentrations of dissolved solids and iron, and is suitable for most common uses.

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STRUCTURAL AND STRATIGRAPHIC CONTROLS ON CAVE DEVELOPMENT IN THE OAK RIDGE AREA, TENNESSEE

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Introduction

The Oak Ridge Reservation (ORR) is located in the northwestern part of the Valley and Ridge province in east Tennessee. The Valley and Ridge province is the topographic expression of the southern Appalachian foreland fold-thrust belt, which formed during the late Paleozoic Alleghanian orogeny. In the Oak Ridge area, three major northwest verging thrust faults (Kingston, Whiteoak Mountain, and Copper Creek) imbricate and juxtapose carbonate and clastic stratigraphic units that range in age from the lower Cambrian to the lower Mississippian (Fig. 1). The carbonate stratigraphic units range in thickness from 1278 to 1748 m and include the Maynardville Limestone in the Conasauga Group (hereby included as part of the Knox Group), the Knox Group, and the Chickamauga Group. Stratigraphic relationships and repetition of units by thrust faulting has produced three northeast striking and southeast dipping carbonate bands bounded to the northwest and southeast by noncarbonate units (Fig. 1). Preliminary results indicate that within two of these carbonate bands, formations composed of mudstone and argillaceous limestone appear to further subdivide groundwater basins. Our efforts have focused on relating the stratigraphic and structural characteristics of these rock units with cave development in the region.

Understanding the relationship between conduit development and bedrock geology is important on the ORR because the presence of mature karst indicates the potential for rapid transport of contaminated groundwater from waste disposal sites. Various approaches are being used to examine this relationship. Because many wells have been drilled on the ORR, drilling logs are being used to infer the intensity of subsurface cavity and conduit development with respect to different stratigraphic units. Both recent and prebuilding construction topographic maps have been used to inventory surficial karst features above particular stratigraphic units. Once these karst features are identified, field work has involved describing known, as well as exploring for previously unrecognized surficial karst features. Finally, regional downcutting and karstification since the Pliocene has resulted in the preservation of sometimes large relict cave segments in resistant carbonate ridges of the Knox Group. For example, the strike oriented master conduit of Cherokee Caverns reaches approximately 45 m wide and least 23 m high, and contains features that record very slow fluvial erosion alternating with periods of rapid erosional dissection. Since the formation of these caves is similar to others beneath the ORR, information from them can, by analogy, be used to infer the characteristics of presently active karst systems. Information of this type is needed for developing groundwater testing and monitoring strategies, and for characterizing and conceptualizing the base and storm flow response of the karst systems.

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Stratigraphy and Karst Development

We are examining whether karst development in the Knox and Chickamauga Groups is affected by changes in: lithology (dolomite vs limestone), bed thickness, insoluble residue content, porosity, and grain size. The element of time, however, is so pronounced in the area that any potential discrepancy in erosional resistance between dolomite and limestone appears to be of little relevance. Although the major carbonate units are the focus of this study, it is important to note that cavities have been documented in carbonate beds of the Rome Formation and Conasauga Group (Moore, 1988). In fact, although the Rome Formation is composed of predominantly clastic rocks, a thick dolomite sequence does occur which has been associated with the development of a sinkhole.

The Upper Cambrian to Lower Ordovician Knox Group is the thickest unit within each carbonate band (700 to 1000 m) and contains the greatest abundance of surficial karst features (sinkholes, springs, sinking streams, and caves) (Fig. 1). Locally, dissolution within the epikarst has produced enlarged fractures and enterable caves to depths of 15 m, which indicate the minimum vertical extent of infiltration in the quick-flow zone. The stratigraphic characteristics of the Knox Group remain the same within each thrust sheet, which indicates that stratigraphic controls on karst development will be similar within each carbonate band. The Knox Group consists of medium to massively bedded dolomite of various grain sizes, with lesser amounts of limestone, chert, and calcite cemented sandstone. Chert varies from thin, discontinuous lenses and pods that parallel bedding in dolomite, to individual beds ranging in thickness from 2 to 30 cm. It is unknown at this time whether some of the bedded cherts act as insoluble barriers capable of pearching groundwater, but the discontinuous lenses appear to have no effect on cave development. For example, in Cherokee Caverns large phreatic tubes developed in the Copper Ridge Dolomite, which contains numerous horizons of discontinuous chert lenses and pods (Fig. 1). Cave mapping indicates that the development of the passages was not affected by the presence of either the chert horizons, slight changes in dolomite grain size, or changes in dolomite bed thickness.

Subsurface information on cavity development in the Knox Group (and Maynardville Limestone) attests to the intensely karstified condition of this unit. The term cavity will be used to describe any subsurface void encountered during drilling, although most cavities are expected to be integrated with the overall conduit system. Some of these cavities contain sediments, indicating groundwater flow through conduits and their relative connectivity. For example, in the Whiteoak Mountain thrust sheet more than 50% of the wells drilled intersect cavities. This is an extraordinarily large percentage when compared to the predicted percentage of 0.04 for karst terranes (Quinlin and Ewers, 1985). In addition, Moore (1988) studied 21 Knox wells from throughout the ORR and found cavities in all of them that range in size from 0.03 to 8.5 m. Because of the difficulty in determining individual formations in the Knox Group based on well logs, however, the relative percentage of cavities in each formation is unknown. The maximum depth of conduit development will be controlled by factors such as: (1) the presence of underlying predominantly noncarbonate units of the Conasauga Group; (2) the maximum distance between recharge and discharge points; and (3) local and regional baselevels. Maximum cavity depths encountered during drilling are at least 30 m below the invert of the Clinch River.

The Middle and Upper Ordovician Chickamauga Group comprises the remaining portion of each carbonate band (Fig. 1). Although composed primarily of limestone, the stratigraphic characteristics of the Chickamauga Group vary within each thrust sheet, because of sedimentologic facies changes. Within the Chickamauga Group are a number of formations consisting of thick bedded mudstone, calcareous siltstone, and argillaceous limestone, which may not be cave formers and may separate cave systems in adjacent units. For example, at the base of the Chickamauga Group in the Kingston thrust sheet is the Pond Springs Formation (Fig. 1). The lower part of the Pond Springs is approximately 50 m thick and consists of fine grained, thick bedded, micritic limestone. The upper part of the Pond Springs ranges from 50 to 100 m thick and is composed of mudstone with some micritic limestone and thin chert beds. Overlying primarily the lower part of the Pond Springs is a large, elongated sinkhole parallel to bedding strike that captures runoff from a large drainage area. The presence of the sinkhole proves the existence of subsurface conduits in the area, but the shape and position of the sinkhole appears to be influenced by the location of the mudstones in the upper Pond Springs.

The existence of an intensely karstified Chickamauga Group in the Kingston thrust sheet has been interpreted based on drilling and building foundation boring results at the K-25 site. Analysis of geologic logs from 74 carbonate wells in the area revealed that 34% of the wells intersected cavities. In addition, flowstone was found in two of the deep cavities indicating that they were formerly air-filled caves, which may still operate as exit pathways. The lack of detailed surface mapping and coring in the area, however, precluded an analysis of cavity development with respect to individual formations.

In the Chickamauga Group in the Whiteoak Mountain thrust sheet, the Rockdell, Benbolt, and Witten Formations are the purest and thickest limestone sequences (Fig. 1). The rest of the formations consist of mudstone, calcareous siltstone, argillaceous limestone,with minor amounts of micritic limestone and chert. A major potential barrier to downdip oriented conduit development is the Fleanor Shale, which is predominantly a 75 to 80 m thick mudstone and calcareous siltstone. Besides the presence of springs and a few sinkholes, however, data pertaining to the intensity of karst development in the Chickamauga Group are based on drilling results. Two across strike drilling transects at the X-10 site sampled every unit in the Chickamauga Group, but did not encounter any large conduits (Fig. 1; Lozier and Pearson, 1987). Although drilling results do not provide any information on large conduit locations, packer test results do provide information on the slow-flow zone. Groundwater in the slow-flow zone moves primarily in fractures, because of the low matrix porosity and permeability of the rock units. Core logs indicate that units comprised primarily of limestone are intensely weathered along bedding planes at all depths, but units composed of primarily mudstone appear more resistant to weathering. Highly weathered zones exhibit hydraulic conductivity values ranging from 10^{-5} to 10^{-6} cm/sec, whereas the weathering resistant zones exhibit hydraulic conductivities in the range of 10^{-8} cm/sec or lower (Lozier and Pearson, 1987).

The use of the aforementioned drilling results to interpret the intensity of karst development in the Chickamauga Group in this carbonate band is misleading, because drilling along strike towards the southwest intersected numerous cavities of various sizes. Investigations for the Clinch River Breeder Reactor site incorporated the acquisition of 24 coreholes over an area of approximately 0.16 km^2 (Fig. 1; Seay, 1973). The coreholes range in depth from 45 to 60 m and sampled the lower half of the Chickamauga Group. A total of 144 cavities were intersected in 22 of the 24 holes. Cavity heights ranged from 0.04 to 4.3 m, with 100 cavities smaller than 0.3 m, 30 cavities between 0.3 and 0.9 m, 10 cavities between 0.9 and 1.5 m, one 2.3 m cavity, and one 4.3 m cavity. In addition, during foundation construction a number of cavities were revealed with average diameters of 0.5 to 1 m. The largest cavities occur in the thick to massive limestone beds of the Rockdell Formation. A small scale tracer test conducted in an excavated cavity located in the Rockdell Formation indicates that the cavity is part of a conduit system with flow to the northeast parallel to bedding strike (Melroy, 1986). In addition, a surprising number of small cavities are present in the mudstone-rich Fleanor Shale (Fig. 1). The cavities are suspected to have formed in isolated, fractured limestone beds within the mudstone. These results (1) emphasize the variable results that can be obtained by drilling in a karst terrane, and (2) indicate that extensive cavity development may occur even in the very impure limestone units.

Structure and Karst Development

Map scale folds and thrust faults are responsible for the position and orientation of the carbonate bands across the ORR. One important aspect of the macroscopic thrust faulting is the change in stratigraphic characteristics of the Chickamauga Group in each carbonate band. A change in stratigraphy can lead to differences in karst development, and therefore the characterization of one carbonate band will not properly describe another. A second major influence folding and thrusting can have on cave trends is a result of local changes in the strike and dip of bedding (Palmer, 1991). In the K-25 area, complex bedding orientations are associated with the southwest hinge of the East Fork Ridge syncline and the development of the Whiteoak Mountain fault (Fig. 1). In general, both faulting and folding are responsible for a rotation in bedding orientation towards the northwest, which can affect the trend of vadose and phreatic cave components. Bedding orientations at depth are also expected to vary in this complex zone of deformation, although along strike away from K-25, bedding orientations maintain a fairly consistent northeast strike and southeast dip. In the Whiteoak Mountain thrust sheet carbonate band, the strike and dip of bedding is N50°E / 40°SE, and maintains a fairly constant orientation across the area. The consistency in bedding orientations in this carbonate band aids in the prediction of potential conduit pathways and discharge points. The less steep dip of bedding (10-15°SE) in the Copper Creek thrust sheet is responsible for the large width of the carbonate band. Bedding in this carbonate band maintains a fairly consistent northeast strike, but subtle changes in bedding dip towards the southeast may influence cave trends. For example within Cherokee Caverns, three superposed large phreatic passages are oriented parallel to the strike of bedding and appear unaffected by bedding dip (Fig. 1). On the other hand, Copper Ridge Cave is a large vadose passage that meanders in a downdip direction. Minor vadose infeeders in this cave also meander downdip with dip-parallel segments locally following a near vertical, northwest striking fracture set, and strike-parallel segments tending to follow bedding strike. Another important result of folding and thrusting is that dipping bedding exposes numerous bedding planes to weathering. Exposures in the Knox Group commonly contain weathered bedding planes that appear to be a primary source of surface water infiltration.

The fracture system in the area consists of both systematic and nonsystematic fracture sets comprised of extensional, hybrid, and shear fractures (Price and Cosgrove, 1990). The systematic fractures are considered to influence cave development because they are planar, have relatively long lengths, and maintain a fairly consistent orientation. The major systematic fracture sets are normal to bedding, strike northeast and dip moderately northwest, (referred to as strike-parallel) and strike northwest and dip steeply to the northeast or southwest (referred to as strike-perpendicular). The orientation of these two fracture sets suggests that they may serve to guide the initial development of both strike-parallel and downdip cave passages. For example, within Cherokee Caverns, a strike-parallel, left-lateral shear fracture zone can be traced for 200 to 300 m along the ceiling of the cave before being concealed by cave formations. The fracture zone consists of a set of fairly continuous shear fractures, with a local increase in minor fracturing associated with the shear fracture tips and stepover zones. Unfortunately, whether the position of the cave only aided recognition of the fracture zone or whether the increased fracture frequency associated with shear fracture development guided the initial trend of the cave cannot be determined. Solutional enlargement of fractures, however, is clearly evident in surface and cave exposures. Furthermore, faults observed in exposures of the Knox Group are often associated with a local increase in the frequency of fracturing, which appear to develop as preferred zones of dissolution.

In the Oak Ridge area, outcrop fracture spacing is partly a function of rock elastic moduli (Young's Modulus and Poisson's ratio) and the thickness of the fracturing unit. If either the thickness of the fracturing unit or value of the elastic moduli increases then the fracture spacing also increases. The size of a fracturing unit is closely related to bed thickness in interbedded clastic rock types. In carbonates, bedded sequences of similar lithologies tend to deform as one thick unit, which will result in a wider fracture spacing, but also tends to produce very long fractures. Therefore the development of long fractures intersecting a number of bedding planes can enhance surface water infiltration and serve as avenues for solutional enlargement. Furthermore, cherts commonly have a very close fracture spacing, because they tend to be thin bedded and are more brittle then the surrounding carbonates. The highly fractured characteristic of the chert beds may cause them to be easily breached and prevent them from being insoluble barriers. In addition, the intense fracturing of the chert beds will increase their effective permeability and enhance infiltration, which may cause preferential solutional enlargement in the adjacent carbonates.

In summary, karst development in the Oak Ridge area is primarily within the Maynardville Limestone, Knox Group, and Chickamauga Group. Specific formations within the Chickamauga Group (e.g., Pond Springs and Fleanor Shale), however, appear to have fewer karst features and may act as insoluble barriers to conduit development. The combined effects of bedding dip, faults, and fractures in the carbonates act as important infiltration pathways and sites for initial cave development. Groundwater flow is constrained to the southeast and northwest by noncarbonate units, resulting in strike-parallel cave systems. Future studies of the karst systems in the Oak Ridge area will include: (1) definition of groundwater basins; (2) continuous monitoring of hydrographic and chemical response in conduit wells and springs; (3) tracer tests; (4) geophysical surveys; and (5) drilling of predicted subsurface conduits.

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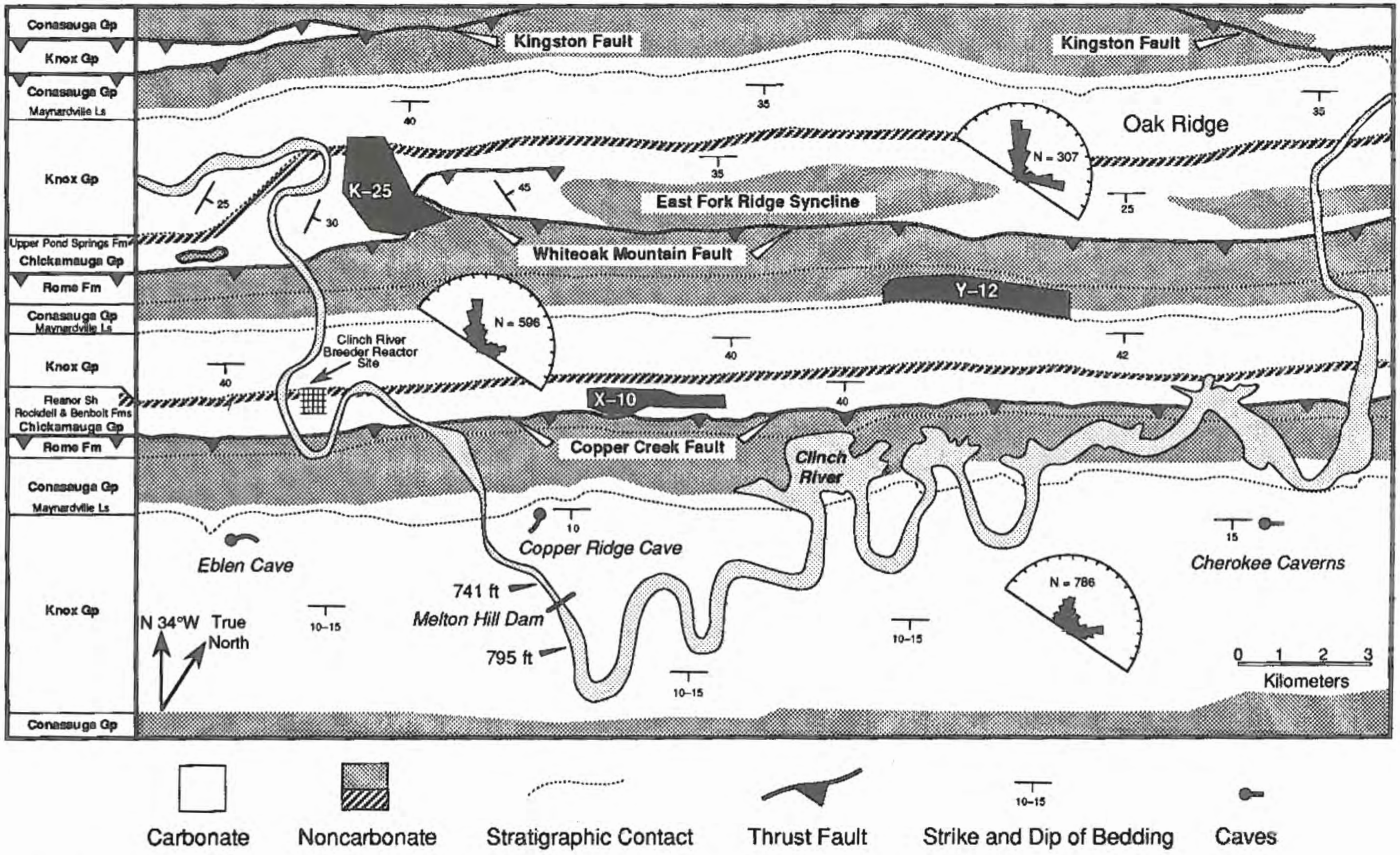

Figure 1 Generalized geologic map of the Oak Ridge area, with place names referred to in the text, and associated carbonate and noncarbonate groundwater flow systems. The Maynardville Limestone, Knox Group, and Chickamauga Group are the stratigraphic units comprising the carbonate bands in each thrust sheet. Individual formations discussed in the text are of smaller type size and listed adjacent to their approximate map position. Measured strikes of the systematic fracture sets in each thrust sheet are plotted on rose diagrams, and indicate that the dominant fracture sets strike to the northeast and to the northwest.

TENNESSEE IN-FIELD SPRAYER MOUNTED RINSE SYSTEM (TISMRS)

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One of the primary issues facing agricultural producers today is proper application of crop protection chemicals. Beyond proper application, producers are faced with increasingly rigid guidelines for disposing of unused chemicals and/or rinsate from sprayer clean-up operations. Dumping or draining of unused concentrated chemicals which have been diluted with water or crop oils is illegal and can present a serious threat to ground water supplies and the environment.

To address the needs of producers using crop protection chemicals, the Tennessee In-field sprayer Mounted Rinse System (TISMRS) was developed to allow in-field triple rinsing of the sprayer system. This system allows the operator to distribute clean-up rinsate in the field where it is both safe and legal. The diluted rinsate from the rinsing process is placed on field borders or back over the crop as long as label application rates are not exceeded. By rinsing the sprayer system in the field, the amount of concentrate returned to the on-farm rinse-pad can be reduced. Typically rinse-pads are located near drinking water resources such as wells. This reduces the potential for localized will contamination resulting from sprayer clean-up operations.

Data collected on clean-up efficiency of the TISMRS, using a 10,000 ppm aqueous potassium bromide (KBr) solution, indicate that triple rinsing with a rinse water volume equal to ten percent of the sprayer tank capacity produces a final rinsate with less than 10 ppm KBr residual concentration.

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HYDROGEOLOGY OF THE CASCADE SPRINGS AREA NEAR TULLAHOMA, TENNESSEE

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The U.S. Geological Survey, in cooperation with the town of Wartrace, conducted an investigation to delineate the recharge area and describe the hydrogeology of the Cascade Springs area near Tullahoma, Tennessee. Cascade Springs, located on the Highland Rim escarpment, discharge from the cherty Fort Payne Formation just above the Chattanooga Shale.

Three locally important aquifers, which might supply water to the springs, have been identified in the area. The aquifers, in descending order, are (1) the shallow aquifer, (2) the Manchester aquifer, and (3) the Fort Payne aquifer. The shallow aquifer consists of clays and chert gravels. The Manchester aquifer is composed of unconsolidated chert gravel with minimal clay content and the upper, well-fractured interval of the Fort Payne Formation. The Fort Payne aquifer consists of dense, bedded, cherty limestone with few fractures, which are concentrated along horizontal bedding planes just above the Chattanooga Shale.

The three aquifers are moderately interconnected. However, in places where the upper Fort Payne Formation is relatively unfractured, the cherty limestone impedes the downward flow of water from the regolith. Near the escarpment this creates 35- to 60-foot differences in pressure heads between wells completed in the regolith and those completed in rock. Wells located farther from the escarpment, where the Fort Payne Formation is assumed to be well fractured, show little change in pressure heads with increased well depth.

The primary recharge area for Cascade Spring is located southeast of the springs. Recharge water travels toward the springs through the cherty regolith of the Manchester aquifer or through the fractures in the Fort Payne Formation. The boundary of the recharge area cannot be fully delineated, however, because few wells are located south of Cascade Springs.

LOW-FLOW AND FLOW-DURATION CHARACTERISTICS FOR STREAMS IN TENNESSEE

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Low-flow and flow-duration data are critical for the effective management and utilization of the surface-water resources in Tennessee. Several key regulatory programs within the Tennessee Department of Environment and Conservation depend on these data for day-to-day operations. City and county governments, utility districts, consulting engineers, and many others also use these data.

The U.S. Geological Survey, in cooperation with the Tennessee Department of Environment and Conservation and the Tennessee Valley Authority, began a study in 1991 to update the low-flow and flow-duration data for streams in Tennessee. Data were collected at three types of gaged sites: (1) long-term continuous-record sites, (2) short-term continuous-record sites, and (3) partial-record sites.

Low-flow characteristics for long-term continuous-record sites were based on the log-Pearson Type III frequency distribution, and were computed for 1, 3, 7, 14, 30, 60, and 90 consecutive days for recurrence intervals of 2, 5, 10, and 20 years. Flow-duration characteristics for long-term continuous-record stations were calculated by statistical analysis of the period-of-record daily mean flows.

Low-flow characteristics for short-term continuous-record sites and partial-record sites were estimated by correlating base-flow discharges at these sites to daily-mean discharge values at long-term continuous-record sites with similar basin characteristics. Low-flow values for the short-term continuous-record stations and partial-record stations were estimated for 1, 3, and 7 consecutive days for a recurrence interval of 10 years; and 3 consecutive days for a recurrence interval of 20 years.

HYDROLOGIC AND HYDRAULIC ANALYSES AT AKIN BRANCH AND CAYCE VALLEY BRANCH IN THE LITTLE BIGBY CREEK WATERSHED, COLUMBIA, TENNESSEE

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Local flooding due to inadequate drainage affects many communities in Tennessee and in other States. The development and filling of flood plains in urban areas can increase runoff rates beyond the design capacity of older culverts and bridges. Such conditions are present within the Little Bigby Creek watershed of Maury County, Tennessee, and particularly in the urban reaches of two tributaries, Akin Branch and Cayce Valley Branch, in the City of Columbia.

To determine the local conditions that contribute to flooding along these streams and to evaluate the effects of possible flood-control measures, the U.S. Geological Survey (USGS), in cooperation with the City of Columbia, conducted a flood study of Akin Branch and Cayce Valley Branch during 1990-91. Objectives of the study were to estimate discharge and water-surface profiles along these streams during storms having recurrence intervals of 5-, 10-, and 25-years under present drainage conditions, and to make similar estimates for several flood-control alternatives, in which the culvert and bridge openings were enlarged. The study is one of several urban hydrology investigations being conducted by the USGS in Tennessee and other States.

Akin Branch and Cayce Valley Branch drain small urban watersheds of 1.69 and 1.04 square miles, respectively. Flood discharges having recurrence intervals of 5-, 10-, and 25-years were estimated at the mouths of these streams using flood-frequency relations developed for small urban streams in Tennessee. For each stream, flood discharges at points upstream from the mouth were estimated by subdividing the watershed and assigning a percentage of the discharge at the mouth to each subarea.

Water-surface profiles corresponding to estimated flood discharges were simulated for current conditions at Akin Branch and Cayce Valley Branch using a computer model for water-surface profile computations. The model was used to predict changes in floodflow characteristics that might result from possible flood- control alternatives, primarily enlarged culvert and bridge openings. Results of the model analyses indicate that increasing the size of openings in some culverts and bridges would reduce existing flood depths and flow velocities in the study reaches.

NASHVILLE WATER QUALITY MONITORING AND MODELING

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In 1991, the City of Nashville engaged Consoer, Townsend & Associates and Vanderbilt University's Department of Civil and Environmental Engineering to implement a dynamic water quality model for use as a planning and management tool for the Cumberland River. The information obtained through intensive sampling and modeling during 1990 and the late 1980s indicated that there was a need for a dynamic water quality model capable of simulating short-term fluctuations in water quality, and the intermittent nature of the release from the Old Hickory and Cheatham Dams.

After an evaluation of several dynamic models, CE-QUAL-W@, a two-dimensional model developed by the U.S. Army Corps of Engineers Waterways Experiment Station, was selected as the model of choice for this application. To determine the magnitude and frequency of changes in water quality, automatic dataloggers were placed in the river at several locations and different depths. A meteorological station was also installed near the river to obtain data required by the model. Two intensive four-day water quality surveys were conducted with the participation of several agencies to collect data for calibration and validation. A comprehensive water quality data base that incorporates hourly data gathered by all participating agencies has also been developed. The model is capable of accurately predicting the effect of point and non-point sources on the river's water quality.

This paper describes the implementation of a mathematical model for the Cumberland Rive, its calibration and validation, and the results obtained under different organic loading scenarios. The successful efforts of several local, state and federal agencies to collectively gather necessary data and to improve the model are also presented.

GROUND WATER INSTITUTE
Herff College of Engineering
Memphis State University

Dr. John W. Smith

Conceived by non-academicians and given birth by a visionary University president, the Ground Water Institute was created in November, 1991, as an externally funded research- service-education entity within the Herff College of Engineering. Dedicated to the study of the unique ground water resource of West Tennessee, the Institute utilizes faculty and students as well as research specialists at Memphis State University to work toward the following overall goals:

A. To become a nationally recognized center of excellence in the area of ground water studies and to develop a program which recognizes the importance of tangent areas of study which are associated with, affected by and complimentary to the study of ground water aquifer systems and recharge basins.

B. To maintain professional standards and dedication (collectively and individually) to research, service, and education in the management, use, and protection of our ground water resources.

C. To promote the mission of the Institute through communication with all levels of government, industry, private, and public organizations through meetings, professional contacts, seminars, workshops, short courses, reports, publications, teaching, and other involvement evolving from association with ground water research and related areas of study.

D. To provide educational development and support for both graduate and undergraduate students.

E. To become a repository for ground water data, reports, publications, and related information in West Tennessee.

F. To provide a cadre of trained people to enter the professional ranks who have expertise and training to help solve our local, regional, and national problems in the ground water resources area.

Integral to the functioning of the Institute is the cooperative attitude and assistance of the financial supporters of the Institute who form the Planning Advisory Committee. The Institute represents a unique concept to deal with a unique resource. The organizational structure, on-going projects, and plans for the future are briefly discussed in the following paragraphs.

UNIQUE CONCEPT

The Institute is dedicated to the study of the ground water resource serving Memphis/Shelby County and in a larger context the Mississippi Embayment. Emphasizing ground water research and data accumulation/manipulation, the Institute is organized around the concept that the Institute must be responsive to the needs of the region and those who are financially supporting the Institute while at the same time maintaining technical integrity and academic objectivity.

The organization of the Institute is illustrated by the attached chart. The emphasis throughout the Institute is education of students in ground water related areas. Faculty, drawn primarily from the Civil Engineering Department but potentially from diverse disciplines, will assume the responsibility for research priorities defined by the Planning Advisory Committee and utilize undergraduates as well as graduate students (masters and doctoral) in addressing those research needs.

Each of the entities funding the ongoing operation of the Institute provides a member for the Planning Advisory Committee (the exception being a limited number of industrial representatives). The Committee annually reviews the proposed research projects to be funded from the ongoing funds by the Institute staff and members and prioritizes the research projects. The Committee meets quarterly with the Director to receive updates relative to ongoing research activities and to relay to the Institute staff the ground water needs (studies, data accumulation, etc.) which need to be addressed by the Institute.

With members selected in accordance with their background, education, and experience, a Technical Advisory Council will be formulated to review the progress and products of the Institute and to provide input to the Director to maintain the highest quality research productivity. Annual meetings will be held with the Director and staff on the MSU campus. The Council will be available to the Director at other times for advice and recommendations.

The Institute serves a key role in the activities of the Memphis/Shelby County Ground Water Quality Control Board. Given broad regulatory and planning authority from all elected governmental units in the county by common ordinance, the Board relies on the Institute for data on which to implement their strategic plan. The Institute is also called upon to provide information on site specific issues which appear to negatively impact the ground water of Shelby County. While the Board is limited to the geographical boundaries of Shelby County, the Institute can go beyond those geographic boundaries thus providing additional data to the Board.

UNIQUE FUNDING

Conceived and given birth at a time when the University was under severe budget limitations, the Institute is supported almost entirely from external funds of local water users. The University provides limited space and some release time for the professional staff. Accordingly, the Institute does not have the potential bureaucratic mandate to perpetuate itself because of state tax support. From the initial conception, the Institute will live only as long as a need exists which is often not the case for programs which are supported from the tax roles.

Funding for the Institute is derived from users of the ground water on a pro-rated use basis. Considering the ground water as a resource common to all in Shelby County (and the Mississippi Embayment), the concept of users paying for the protection and long-term management of the resource is reasonable. While the Institute will not become a regulatory agency, the data and data manipulating techniques required by regulatory units are out puts of the Institute. The budget for the Institute is set annually by the PAC based on the approved research program and the estimated cost of executing that program from the Institute staff. Once this budget is set, the cost to each participating entity is based on the previous year's water production. The cost for municipalities includes the allowance for industrial water extracted by the municipality and sold to industries. Several large industries operate their own wells for industrial process water and are participants in the funding and direction of the Institute. All "off-system" industries with an average daily usage of >0.5 MGD will be invited to participate in the support of the Institute.

As will any academic program, the faculty or staff are encouraged to solicit and compete for external funding from private and governmental sources. Funding from the Institute is intended to provide support for the operation of the Institute and specific mission oriented research defined by the PAC. Faculty and staff are encouraged to seek funding for ground water related research which may have more of a long-term application to the functioning and purpose of the Institute.

UNIQUE RESOURCE

The ground water resource in the Shelby County region is truly a unique resource which has been millions of years in the making because of its quantity and quality. Development of civilization in the Mississippi Embayment from the earliest times has depended on the abundance of water in the region. Life style and economic growth in West Tennessee has resulted in part from the abundant ground water resource which is available. This dependence has developed to the point where the entire region is almost totally dependent on ground water even though there are tremendous quantities of surface water available in the region.

The Institute will be come a unique resource as the staff and facilities are developed and ground water users in the region recognize the wealth of ground water information which will be available at one location. With input from the Planning Advisory Committee, the Director will develop annually the research projects, seminars, short courses, and other activities to be undertaken by the Institute staff and members. A partial listing of such activities which could be undertaken as part of the ongoing research activities of the Institute is as follows:

> Conduct research on ground water occurrence
> Assimilate ground water information using ARC/INFO and GIS
> Conduct research on natural ground water quality
> Develop computer models of ground water flow
> Develop computer programs for water well management
> Conduct research on influence of surface water on ground water
> Conduct research on the flow through porous media
> Develop and conduct education activities associated with ground water development and use
> Conduct seminars and short courses on well head protection.

In addition, the Institute would:

> Provide a forum for interchange with regulating agencies
> Form a ground water resource data repository
> Support undergraduate/graduate ground water education
> Seek funding for support of ground water research from outside agencies
> Develop an awareness focus on ground water as a natural resource
> Provide expertise to respond to specific needs of the region (contamination, excessive demands, etc.)

Although in its infancy (being less than one year old), the Institute is active in the following areas:

> 3-Dimensional flow and contaminant model development for the shallow and first water production aquifer at two MLGW well fields. Work is progressing on a county wide flow model.
> Development and maintenance of a ground water geographic information system.
> Determination of the permeability of the loess overburden and the confining layer to water and organic solvents.
> Development of a zoning impact study correlating ground water critical areas with present and future zoning.
> Establishment of a link with other utilities in the region as a beginning of a regional ground water association.
> Establishment of the location and attributes of all under ground storage tanks in Shelby, Fayette, and Tipton Counties in the GIS for well head protection analysis. The center of the above activities is the latest version of ARC/INFO geographic information software and seven Sun SPARC workstations.

In addition to the director, four faculty, 12 students, and one research engineer form the Institute staff at this time. Fiscal year 1993 will see the addition of two doctoral students as well as additional studies related to ground water remediation and neuro network analyses. The 1993 budget will include funds for undesignated or non-mission oriented ground water research.

PROGRAM ACTIVITIES AND RESEARCH PRIORITIES OF THE TENNESSEE WATER RESOURCES RESEARCH CENTER (TNWRRC)

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The Tennessee Water Resources Research Center (TNWRRC) is one of 54 federally designated state and territorial water institutes, established by Congress in 1964 and presently administered by the U.S. Geological Survey. The primary mission of the institutes is to serve as a link between the academic community and water-related personnel in federal and state government and in private-sector organizations, for the purpose of mobilizing university research expertise in addressing high-priority water problems and issues in each of the respective states and regions.

TNWRRC is supported by the USGS under provisions of PL 101-397, by the University of Tennessee, and by other government agencies, industry and private organizations.

In supporting the federal mandate the TNWRRC is committed to fulfilling these major goals:

- To assist and support all academic institutions of the state, public and private, in pursuing water resources research programs ofr addressing problem areas of concern to the state and region.
- To provide information dissemination and technology transfer services to state and local governmental bodies, academic institutions, professional groups, businesses and industries, environmental organizations and others, including the general public, who have an interest in water resources matters.
- To promote professional training and education in fields relating to water resources and to encourage the entry of promising students into careers in there fields.

The TNWRRC fulfills these goals through the support of water resources-related research at the various colleges and universities in Tennessee; coordination and support of workshops, conferences and professional training programs; technical information clearinghouse services to university faculty and students, consultants, state and federal agencies, private organizations; general public; and other miscellaneous activities.

Highlights of TNWRRC program activities will be presented, including a progress report on current efforts to survey and identify water resources research needs and priorities important to Tennessee.

AUTHORS INDEX