EXTENDED ABSTRACTS FROM

SIXTH TENNESSEE WATER RESOURCES SYMPOSIUM

Nashville, Tennessee
February 12-14, 1996

Sponsored by

U.S. Geological Survey, Water Resources Division • Tennessee Valley Authority
Oak Ridge National Laboratory • Environmental Consulting Engineers, Inc.
Tennessee Department of Environment and Conservation • U.S. Army Corps of Engineers
The University of Tennessee, Knoxville

In Cooperation with

Tennessee Section of the American Water Resources Association

GLOSSARY OF ACRONYMS:

USGS - U.S. Geological Survey
TVA - Tennessee Valley Authority
ORNL - Oak Ridge National Laboratory
ECE - Environmental Consulting Engineers, Inc.
TDEC - Tennessee Department of Environment and Conservation
USACOE - U.S. Army Corps of Engineers
UT - The University of Tennessee, Knoxville

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Maxwell House Hotel
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Compiled and Edited by

Rita O. Wadlington
Michael A. Eiffe
and
Michael J. Sale

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PREFACE

This proceedings represents the sixth gathering of water resource professionals in Tennessee under the sponsorship of the Tennessee Section of the American Water Resources Association. The purposes of these symposia are: 1) to promote communication on water research and management, and 2) to encourage cooperation among the diverse range of water professionals in the state. The first five Water Resources symposia have been very successful, demonstrating the important role of these gatherings.

As always, it has been a real pleasure to work with the dedicated group of people who have been responsible for this year's symposium. Janet Herrin, TVA, and Jess Weaver, USGS, are the President and President-Elect of the State Section. They provided the overall leadership that made this year's symposium possible. Paul Craig, ECE, and Susan Hutson, USGS, serve as the Section's Secretary and Treasurer. Larry Richardson, now with the Corps in Nashville, Tim Gangaware with the Tennessee Water Resources Research Institute, Barbara Balthrop, USGS, and Louis Buck with the Tennessee Department of Agriculture, also played critical roles on the Steering Committee this year. Mike Eiffe, ECE, led the organization of papers into the agenda you see here. Last but not least, Rita Wadlington at ORNL did a great job in pulling together this proceedings publication. Please search these people out and give them your thanks, because we would not be here without them.

Now, on to the future. The pressures of change that are sweeping all of our organizations are all too well known and do not need to be repeated here. But with all these changes, the need for solid communication and interagency cooperation has never been greater. Our opening plenary session with state agency representatives is designed to give us one view of where we are going. Throughout the other contributed papers and poster sessions, you will find many more indications of new directions and exciting accomplishments.

In the years since this symposium was first organized in 1987, we have seen a number of changes in the leadership. The transition in leadership is continuing as Jess has moved on to new opportunities in Alabama. It is time for new leaders to come forward. Being the Volunteer state we are, I'm sure that they will come, that the State AWRA Section will continue a premier professional organization in interdisciplinary water resources, and that the Tennessee Water Resources Symposium will be a regular focus of our accomplishments. Although our organizations may evolve, the tremendous human and natural resources of Tennessee will always be here -- therein lies my confidence in a bright future.

I for one can't wait to see what the future will bring.

Michael J. Sale, Co-Editor and Past-President, AWRA Tennessee Section

6th Tennessee Water Resources Symposium

Time	*Scheduled Activities*		
	Monday, February 12		
6:30 pm	Registration Desk Open		
7:00 pm	Opening Reception and Poster Session		
	Tuesday, February 13		
8:00 am	Registration Desk Open		
8:30 am	***Keynote Address*** -- Bud Gilbert, Tennessee State Senator		
9:00 am	***Panel Discussion*** -- Tennessee Regulators and Resource Managers		
10:00 am	**Coffee Break**		
10:30 am	***Session 1A*** -- GIS Mapping	***Session 1B*** -- Other Issues	***Session 1C*** -- Karst
Noon	**Lunch**		
1:00 pm	***Session 2A*** -- Sediment Yield Issues	***Session 2B*** -- Stormwater Runoff	***Session 2C*** -- Modeling Issues
2:30 pm	**Refreshment Break**		
3:00 pm	***Session 3A*** -- Sediment Transport	***Session 3B*** -- Waste Water Management	***Session 3C*** -- Wellhead Protection
4:30 pm	**Adjourn Concurrent Sessions**		
5:00 pm	***Reception and Poster Session***		
6:00 pm	***Tennessee Section AWRA Business Meeting***		
	Wednesday, February 14		
8:30 am	***Session 4A*** -- Reservoir Management	***Session 4B*** -- Agricultural Land Use	***Session 4C*** -- Groundwater Hydrology I
10:00 am	**Coffee Break**		
10:30 am	***Session 5A*** --Watershed Management	***Session 5B*** -- Water Quality	***Session 5C*** -- Groundwater Hydrology II
Noon	**Lunch**		
1:00 pm	***Session 6A*** -- Surface Water Monitoring	***Session 6B*** -- Nutrients	***Session 6C*** -- Groundwater Modeling
2:30 pm	**Refreshment Break**		
3:00 pm	Session 7A -- Water Supply and Demand	Session 7B -- Biomonitoring	Session 7C -- Groundwater Quality
4:30 pm	**Adjourn Concurrent Sessions and Symposium**		

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Poster Sessions

ECOREGION DELINEATION AND POTENTIAL REFERENCE SITE IDENTIFICATION IN TENNESSEE

Joy I. Broach[1]

Emphasis on ecosystem management has resulted in a need to develop a framework to identify ecological systems on a regional basis. One method of locating these regions is through the use of map that takes into account the biotic and abiotic components of the environment. An ecoregion map identifies geographical areas of relative ecological similarity that are reflected in regional patterns of these components. In 1987, Omernik developed a national map of ecoregions by synthesizing information on land surface form, potential natural vegetation, geology, soils, and land use. The framework grew out of an effort to classify streams for more effective water quality management. The approach, however, is based primarily on patterns of terrestrial applications (Omernik, 1987, 1995; Omernik and Gallant 1989). The ecoregion map can be used to characterize stream water quality because water quality is predominantly influenced by the characteristics of the land it drains. An ecoregion framework developed from landscape characteristics can be used to stratify the naturally occurring variations in water quality, flow regime, habitat structure, and food source which directly affect the structure and composition of aquatic communities (Hughes and Larsen 1988; Larsen et al. 1988).

Although the national ecoregion map reduces the variability in factors such as soils, geology, hydrology, physiography, vegetation, land use, and land cover, many state agencies have found that the resolution of the national map does not provide the detail or accuracy to meet their needs. This has led to more collaborative efforts for the refinement of ecoregions and definition of subregions at a larger scale (Griffith et al. 1994; ADEM and MDEQ 1995; and projects completed or in progress in Oregon, Washington, North Dakota, Indiana, Ohio, Pennsylvania, Massachusetts, and Florida). The Tennessee Department of Environment and Conservation, Division of Water Pollution Control, has contracted with the U.S. Environmental Protection Agency, Corvallis Laboratory, to refine ecoregions and delineate subregions in Tennessee at 1:250,000 scale. In a collaborative effort with other state and federal agencies, including the U.S. Department of Agriculture's Forest Service and Natural Resources Conservation Service, a draft map of the "Level III and Level IV Ecoregions of Tennessee" has been produced with the final map due in 1996.

In the summer of 1995, there was a multi-agency cooperative effort to identify potential stream reference sites in Tennessee. Streams that are representative of the ecoregion characteristics and are minimally disturbed and least impacted from point and nonpoint source pollution may serve as suitable reference streams. The water quality of these reference streams represents some of the highest quality that can reasonably be expected in a region, and can serve as benchmarks to compare similar but more disturbed streams in the same ecoregion (Larsen et al. 1988; Griffith et al. 1994). Within the ecoregions, the Division of Water Pollution Control intends to identify and sample least disturbed stream sites to show what is representative in water quality and aquatic community structure. By measuring the water quality and health of the stream community in these reference sites, a baseline can be established against which the quality and condition of other, more impacted streams can be measured. Data collected at reference sites can be used to assess attainable conditions, develop biological criteria, and establish water quality standards that correspond to the natural background conditions. Streams that compare poorly with the reference condition suggest that improvement should be possible, while those that exceed the reference condition may be worthy of special

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[1]Environmental Specialist 5, Tennessee Department of Environment and Conservation, Division of Water Pollution Control, Planning and Standards Section, 6th Floor, L & C Annex, 401 Church Street, Nashville, TN 37243-1534, Phone (615) 532-0701

protection. The ecoregion/reference site process augments the watershed management approach, provides a scientific basis for assessing the health of streams, and aids in the development of regional criteria that are attainable and protective of aquatic ecosystems (Hughes and Larsen 1988; Omernik and Griffith 1991).

Copies of the draft map of Tennessee ecoregions can be obtained by contacting:

Glenn Griffith
US EPA
200 SW 35th St.
Corvallis, OR 97333
Phone: (503) 754-4465;
email glenn@mail.cor.epa.gov.

An ARC/INFO export file of the coverage can be obtained by anonymous FTP:

ftp morpheus.cor.epa.gov
name:anonymous
password: <your email address>
cd pub/WB/sandi
filename: tn_subeco.e00

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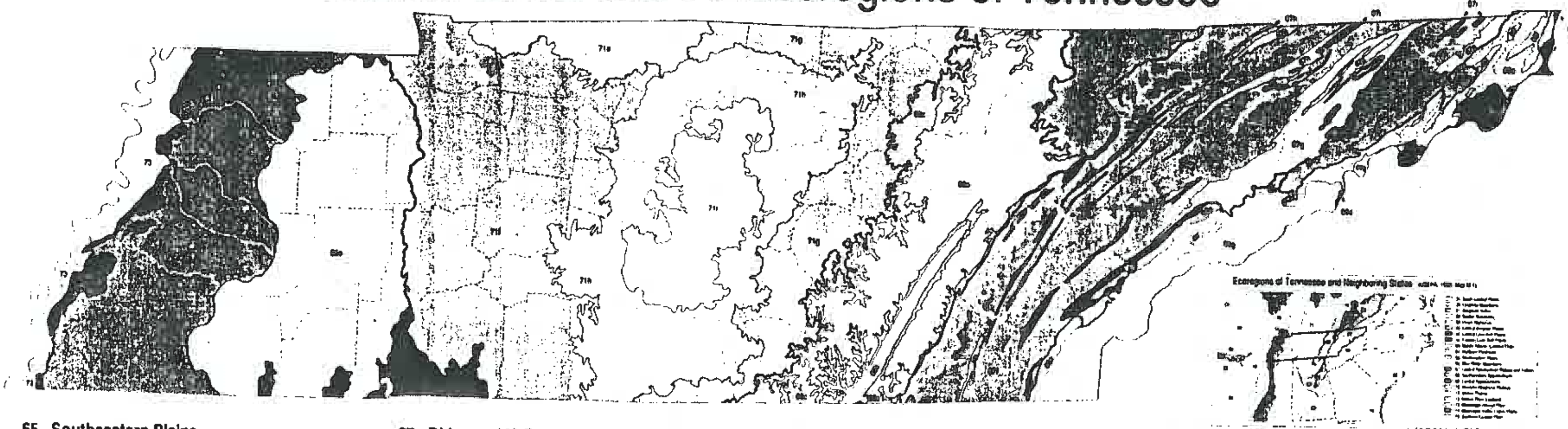
Draft Level III and IV Ecoregions of Tennessee



65. Southeastern Plains
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66. Blue Ridge Mountains
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- 66e. Southern Sedimentary Ridges
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20 0 mi 20 40
40 0 km 40 80
Albers Equal Area Projection

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Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. This draft map depicts revisions and subdivisions of ecoregions, compiled originally at a relatively small scale (USEPA 1995; Omernik 1987). Compilation of this map, performed at the larger 1:250,000-scale, is part of a collaborative project primarily between the United States Environmental Protection Agency (EPA) National Health and Environmental Effects Research Laboratory (NHEERL) - Corvallis, OR., and the Tennessee Department of Environment and Conservation (TDEC). Collaboration and consultation is also occurring with other state and federal agencies, including the U.S. Forest Service and Natural Resources Conservation Service, in an effort to obtain consensus regarding alignments of ecological regions. The ecoregions and subregions are designed to serve as a spatial framework for environmental resource management. The most immediate uses by the State of Tennessee are for selecting regional stream reference sites and identifying high-quality waters, developing ecoregion-specific chemical and biological water quality criteria and standards, and augmenting TDEC's watershed management approach.

The approach used to compile this map is based on the premise that ecological regions can be identified through the analysis of the patterns and the composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Wiken 1986; Omernik 1987, 1995). These phenomena include geology, physiography, vegetation, climate, soils, land use, wildlife and hydrology. The relative importance of each characteristic varies from one ecological region to another regardless of the hierarchical level. A Roman numeral scheme has been adopted for different levels of our ecological regions to avoid confusion with the meanings of other hierarchical terms such as zones, divisions, provinces, subregions, etc. Level I is the coarsest level, dividing North America into 15 ecological regions, with Level II dividing the continent into 52 regions. At Level III, the continental United States contains 98 ecoregions (US EPA 1995). Explanation of the methods used to define the EPA's ecoregions are given in Griffith et al. (1994; 1995), Omernik (1995), and Gallant et al. (1989). The draft map is being circulated for comments and suggestions which should be addressed to James Omernik, U.S. EPA - NHEERL, 200 SW 35th Street, Corvallis, OR 97333, (503) 754-4458; or to Glenn Griffith, U.S. EPA - NHEERL, 200 SW 35th Street, Corvallis, OR 97333, (503) 754-4465, FAX: (503) 754-4617, email: glenn@heart.cor.epa.gov.

The principal author of this map is Glenn Griffith, US EPA. Contributors and collaborators include James Omernik, US EPA; John Jenkins and Richard Livingston, USDA-NRCS; James Keys USDA-FS; Phil Stewart and Greg Russell, TDEC-WPC; and Glendon Smalley. Cartographic and GIS development provided by Sandra Azevedo, Ogden Professional Services.

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DEMONSTRATING A HOLISTIC APPROACH TO IDENTIFYING AND COSTING NEEDS ON A WATERSHED BASIS

C. J. O'Bara, D. B. George, Y. R. Clark, P. P. Piszczek, J. A. Weeks, and M. T. Davidson[1]
E. Bunting[2]

The provision of optimal user benefits is the ultimate goal of any water resources management or planning program. The derivation and use of proper management tools facilitates the decision-making process. Our study on the Richland Creek watershed in south-central Tennessee is an example of a comprehensive tool which aids managers and local citizens in determining the cost-effectiveness and environmental impacts of various land management practices. This project commenced with the distribution, return, and analysis of a public opinion survey concerning the current and future status and quality of Richland Creek and its tributaries. This survey illustrated the major concerns for maintaining high quality water for potable, recreational, agricultural, and industrial uses. The multitudinal uses of the water resources prompted the need to develop a management tool capable of handling the diverse situations. Four physical and mathematical simulation models provided the quantitative evaluation of pollution potential in the watershed: (1) agricultural overland flow, (2) urban runoff, (3) instream dynamics, and (4) groundwater dynamics. Results from the computer simulations were integrated with a multi-layered ARC/INFO Geographic Information System (GIS); this provided the spatial analyses which allowed planners to identify critical areas. An economic evaluation (cost-benefit analysis) of the influence of various land management practices on the quality of water resources was performed after completion of the modeling process. The transfer of information from a technical to nontechnical standpoint concluded the project; this included educational seminars pertinent to the use and interpretation of overall model results.

A firm understanding of natural resources is the key to successful management. The knowledge of Richland Creek and its tributaries was gained from extant databases and informative reports provided by such agencies as TDEC, TVA, USGS, and NRCS. Cooperative efforts among state and federal agencies alleviates the stress which knowledge "gaps" exert on natural resource issues.

[1]Center for the Management, Utilization, and Protection of Water Resources, Tennessee Technological University, Cookeville, Tennessee 38505-0001

[2]Tennessee Department of Environment and Conservation, Division of Construction Grants and Loans, Nashville, Tennessee 37243-1534

SEDIMENT MODELING STUDY-HOTOPHIA CREEK WATERSHED

R. H. Smith[1], B. E. Johnson, S. S. Sunkara, R. L. Hunt

For most watersheds, extensive rainfall, streamflow, and sediment discharge data are not available for calibration of hydrologic models. However, land use, topographic, edaphic, and meteorological information are generally available. Spatial and physical attributes of a watershed that affect water quality and sediment yield can be assembled into a geographic information system (GIS) data base. This information can then be used to generate synthetic water quality data or estimate sediment yield by a simplistic approach. An important problem, particularly in the watersheds located in North-Central Mississippi that are part of the Demonstration Erosion Control (DEC) Project, is how to estimate the benefits (i.e., reduction in sediment yield) due to the construction of channel grade control drop structures. This study focuses on the development and testing of a synthetic watershed sediment routing model (GISSRM) that can be integrated with the GRASS GIS.

GISSRM is a traditional lumped sub-basin parameter model based upon (a) SCS rainfall-runoff techniques; (b) construction of the storm runoff hydrograph using a gamma distribution; (c) channel routing by a Muskingum method for ungaged streams; (d) modified universal soil loss equation (MUSLE) for computing wash load or sediment delivery from a sub-basin; and (e) Yang Stall method for computing bed material load or sediment transport in the main channel reaches. Hotophia Creek is a tributary of the Little Tallahatchie River located east of Batesville and west of Oxford, Mississippi with a drainage area of approximately 36 sq. Mi. Channel surveys dated 1985 and 1992 were used to represent before and after the DEC grade control drop structure conditions. The watershed was subdivided into 30 sub-basins and routing reaches for the GISSRM model. Sediment yield predicted with the model compares favorably with observed data recorded at the USGS gage (5 years record 1987-1992) as shown below. Bed material load reduction due to the drop structures varied from 16 to 100% depending upon the reach relative location. A 2.7 mile reach (stations 180+00 to 322+00) has steepened during the time period 1985-1992 and additional drop structures are needed to prevent the continued degradation and increased bed material load.

	USGS GAGE	GISSRM
Annual total load (tons)	135,140	137,522
Annual bed material load (tons)	61,000	68,700
Average % sand in suspended sediment samples = 35%		
Calibration storm 3-17-87:		
total load (tons)	9,987	9,537
bed material load (tons)		3,422 (36%)
Verification storm 5-8-89:		
total load (tons)	17,182	14,096
bed material load (tons)		4,359 (31%)

[1]Associate Professor, University of Memphis, Memphis, Tennessee 38152

RUNOFF CONNECTIVITY ZONES: PRELIMINARY RESULTS OF A FIELD-BASED STUDY IN A TRIBUTARY CATCHMENT OF SECOND CREEK, KNOXVILLE, TENNESSEE

Carol P. Harden[1]

INTRODUCTION

The processes by which contaminants move toward and into streams are poorly represented by watershed models, which typically generalize land surface characteristics and omit details of the spatial linkages between the land surface and stream channel. In most cases, however, runoff is generated over small portions of catchments (Anderson and Burt, 1978) and the sediment yield of a watershed is a small percentage of the sediment eroded within the watershed (Roehl, 1962). An improved understanding of the linkage between land surfaces and stream channels is needed to better interpret sediment yield data and provide insight into sources of "non point source" pollution (Walling, 1990). Spatially-explicit details can be critical to modeling and mitigating rainfall runoff and contaminant movement. For example, while a strip of vegetation or a high infiltration zone adjacent to the channel can buffer the movement of surface water and filter out suspended particles, the same strip elsewhere in the watershed could be of much less hydrological importance.

To begin to grapple with the issue of how to incorporate spatial relationships in watershed modeling, I have started to examine rainfall runoff and sediment discharge patterns of a small, ephemeral tributary of Second Creek in Knoxville, Tennessee. The primary objective of this study is to determine patterns of rainfall runoff and sediment transport in order to identify portions of the tributary catchment that are relatively more or less important contributors of runoff and conveyors of particulate material to the stream system. The preliminary study discussed here is a first effort to study the catchment as a functional unit and quantify its rainfall runoff patterns. I was particularly interested in becoming familiar with the dimensions of storm hydrographs of the tributary and of Second Creek at Inskip Park, and I hoped to identify threshold values of rainfall required to generate runoff on surfaces other than pavement.

Second Creek was selected for its convenient location, good access and local multi-agency interest. The Second Creek drainage area is well mapped by the City of Knoxville, but neither Second Creek nor the ephemeral tributary are gaged. The tributary has a drainage area of 91 hectares (225 acres) that includes commercial, residential, recreational and transportation land uses. The tributary channel pre-dates development in the area but has been manipulated (realigned, partially culverted) in the urbanization process.

METHODS

Field-based research was begun in June 1995 in the upper reaches of Second Creek in Knoxville, Tennessee, to observe and monitor runoff in a first-order urban tributary catchment and to characterize the spatial relationships between runoff and sediment source areas and the channel system. Discharge of Second Creek at Inskip park and the unnamed tributary stream were monitored in June, 1995, using a MJP current meter when flow was sufficient. Otherwise, any flow exiting a culvert in the tributary was captured and measured. Water samples were taken and analyzed for turbidity and conductivity. Runoff detectors,

[1]Associate Professor and Head, Department of Geography, University of Tennessee, Knoxville, TN 37996-1420, email: charden@utk.edu

fashioned from plastic film canisters were emplaced on catchment surfaces prior to rain events. An open plastic rain gage was mounted on a fence at the Inskip baseball field and monitored during the month.

RESULTS AND DISCUSSION

Small daytime rain showers occurred on June 19 and June 20, 1995. Data in Table 1 demonstrate the flashy response of the tributary to the approximately 2 mm rain that fell on June 20. Rainfall runoff arrived at the gaging site 35 minutes after the onset and 8 minutes after the end of the rain.

For comparison, the discharge of Second Creek at Inskip Park increased from 0.05 cms (cubic meters per second) before the shower to at least 0.10 cms by 11:30 AM. Runoff from the shower reduced the conductivity of Second Creek from 454 to 370 μs. High conductivity of Second Creek water is attributed to the fact that the stream's base flow emerges from a series of springs in the 340 meters upstream from the mouth of the unnamed tributary. High conductivity of tributary waters represents the flushing of soluble materials from paved surfaces. Tributary conductivity was relatively high, but flow was down to a trickle in the morning of June 20 because the light shower (less than 1 mm caught in rain gage at mouth of tributary) on June 19 had been the first rain in seven days.

Runoff detectors on grassy surfaces near the tributary stream were dry following both the June 19 and June 20 showers. Observations during the rain events showed that runoff was not produced on unpaved land surfaces at Inskip Park and that runoff was only being generated on paved surfaces in the watershed. During the month of June, the rainfall threshold required to generate runoff on pavement was observed to be highly variable and primarily a function of surface temperatures and rainfall intensity. Low intensity rain landing on hot surfaces evaporated quickly.

The most important contributing areas for sediment and runoff were those along the immediate banks of the stream channel and at sites linked by drainage and/or paved surfaces to the channel network. Rainfall in June was not sufficient to generate runoff on unpaved watershed surfaces. The next phase of monitoring is scheduled for the early spring of 1996 when heavier rainfall, wetter antecedent conditions and greater runoff are expected.

TABLE 1. Runoff in the Inskip Tributary of Second Creek, June 20, 1995.

Time	Turbidity	Conductivity	Discharge
0900 hours	13.6 NUT	360μs	0.1×10^{-3} cms
1005	*RAIN*	*BEGINS*	
1032	*RAIN*	*ENDS*	
1034	12.2 NTU	365 μs	0.1×10^{-3} cms
1048			0.078 cms
1051	113.2 NTU	248 μs	
1235	37.2 NTU	177 μs	1.5×10^{-3} cms

RUNOFF CONNECTIVITY ZONES

Although light showers generate flashy runoff from paved surfaces in the watershed, the higher infiltration capacities of vegetated surfaces in its older residential neighborhoods were not exceeded in June. Nor was June rainfall sufficient to generate saturation-based overland flow. Reconnaissance of the watershed reveals some sectors in which surface runoff would be more likely to pond them to make its way to the channel. In part, this reflects a complication introduced by the fact that the watershed is in a karst area; in part, it reflects a complication introduced by the fact that the watershed in a karst area; in part, it reflects the inefficiency of this fluvial system, especially because the landscape has been reshaped by human activity.

Spatially-explicit relationships in watersheds are highly site-specific. To examine the potential of the land surfaces in the study watershed for delivering rainfall runoff and particulate constituents to the stream channel, I divided the area into three Runoff Connectivity Zones. These zones are characterized by the set of factors that affect runoff initiation and movement: topography, infiltration characteristics and surface roughness (Table 2).

In the study watershed, Zone 1 includes paved surfaces and roofs adjacent to paved surfaces. Pavement is well connected to the stream, either by other pavement or by storm sewers. Zone 2 comprises rougher surfaces, with higher infiltration capacities. Exemplified by the vegetated areas that did not generate runoff in June 1995, land surfaces in this zone would generate and deliver runoff only in times of heavy rain and/or high antecedent moisture, when the advantage of better infiltration would be lost. Zone 2 could be further subdivided to reflect differences in slope or proximity to the channel. Zone 3, the zone that "never" or "nearly never" contributes surface runoff to the stream applies to places in the watershed with no slope or with barriers to the movement of surface water. These are "sinks" in the watershed where surface water will pond rather than flow. Because Zone 3 areas do not transport sediment to the stream, they do not serve as sediment sources in the watershed. Zone 2 areas would be infrequent sediment sources.

TABLE 2. Characteristics of Runoff Connectivity Zones

Factor	Zone 1	Zone 2	Zone 3
Surface roughness	smooth	rougher	rougher
Infiltration capacity	very low	higher	higher
Topography (slope)	sloping	sloping	barrier or no slope
Connectivity	well-connected	potentially connected	not connected

Although this work is preliminary, some early results are relevant to questions of sediment sources in upper Second Creek. Runoff at the site of construction activities in a new subdivision in the upstream end of the watershed is connected to the stream by one storm sewer that passes under Clinton Highway. While a major movement of debris would be unlikely to successfully cross the highway, smaller amounts of construction sediment will persist and move into the channel system slowly over a longer time. Particulate matter from Clinton Highway and from the large parking lot at Clinton Plaza is very effectively delivered to the stream. For this reason, a gully located on the south edge of the parking lot (behind the grocery store) is an active and important source of sediment in the watershed. The Inskip recreational ball fields do not have enough slope for water to flow to Second Creek, so water ponds in low points on the fields. Gusty winds preceding thunderstorms would play a more important role than rainfall runoff in delivering ballfield sediment to the stream if a large mound of dirt had not been positioned right at the edge of Second Creek. Its position in Zone 1 guarantees sediment delivery to the Creek every time rain falls.

Understanding and mapping the connectivity of runoff-prone surfaces in a catchment is a key step in targeting land surface areas for more cost-effective management and in developing models that are more sensitive to site-specific problems and remediation efforts. Although these preliminary observations come from a sewered, suburban drainage, the concept of Runoff Connectivity Zones also has relevance to watersheds with other land uses.

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APPLICATION OF MAGNETIC SUSCEPTIBILITY AND RADIONUCLIDE ANALYSES OF LAKE SEDIMENT TO SEDIMENT YIELD STUDIES IN A SMALL APPALACHIAN CATCHMENT

P. Daniel Royall[1]

Short-term (less than 5-year) suspended sediment monitoring programs are critical for understanding event-based dynamics of sediment transport, but suffer from several shortcomings with respect to sediment yield studies. Problems include the measurement of bedload, the restriction of measurements to only a few (often large) catchments selected for gauging, and the difficulty of extrapolating short-term measurements over longer periods of time. These difficulties have prompted the advocacy of lake sediment analysis as a means of augmenting short-term data.

Lake sedimentation surveys have been used for a long time to document change in lake sediment volume. In contrast, the detailed analysis of sediment cores is a relatively recent approach to sediment yield studies, particularly for small catchments. Detailed analysis of cores can provide a means of discerning and dating lake sediment strata in sequences that may otherwise appear homogeneous (Oldfield, 1977). For appropriate sites therefore, this stratigraphic approach may provide information on changes in sediment yield through time, in the absence of costly and time consuming continuous sediment monitoring.

In this study I present preliminary results of a lake sediment stratigraphy study from a site in the Blue Ridge Mountains of northern Virginia. The ultimate goal of this project is to determine the relative importance of different flow magnitudes with respect to the mass of sediment moved in this and other small (1st - 3rd-order) mountain catchments.

SITE AND METHODS

The study site is the Thompson Lake / Crooked Run watershed (38° 57'25"N, 77° 59'40"W) located along the eastern flank of the Blue Ridge Mountains east of Front Royal, Virginia. Crooked Run upstream of Thompson Lake is a 3.83 km^2 2nd-order catchment draining steep, rocky and forested slopes along 1st-order tributaries and is incised into weathered debris train deposits along the 2nd-order channel downstream. Thompson Lake was constructed in 1965-66 and impounds Crooked Run drainage in a roughly circular 3.64 ha basin to a maximum depth of 9 meters. Normal capacity is 200,000 m^3 and outflow is through a single vertical riser at the deep (downstream) end. The choice of this study site is based on several criteria. In addition to being located in an area suited to the research question, lakes must have undisturbed sediment deposits, and ideally be as old as possible, have high sediment trap efficiency, be small enough to easily obtain cores from, and be reasonably accessible. In my search for ideal study sites in the Blue Ridge Mountains, finding sites that were both undisturbed and old proved difficult. Thompson Lake meets all requirements, although it is still a relatively young site.

I extracted sediment cores from locations distributed across the lake representative of major depositional environments. At three strategically located "master" core sites I extracted three cores to provide material for multiple analyses. All cores were extruded and sliced into 1-cm thick discs. After air drying these slices, I measured the mass-specific magnetic susceptibility of each slice using a Bartington Instruments magnetic susceptibility meter and single sample sensor. Magnetic susceptibility is generally interpreted to reflect the concentration of ferrimagnetic minerals in a sample, which in turn is related to the amount and

[1]Geography Department, Univ. of Tennessee, Knoxville, TN 37996; e-mail:ROYALL@UTKVX.UTK.EDU

source area of incoming sediment (Thompson and Oldfield, 1986). I used the down-core variation in magnetic susceptibility to define sediment strata and correlate these strata between core sites in the spatial array. I estimated the mass of mineral particulates in lake sediment using a loss-on-ignition procedure and adjusted this mass for trap efficiency based on Heinemann's (1981) curve. Airborne particulate influx is likely insignificant and preliminary estimates of biogenic silica in lake sediment samples are low; measurements to quantify these inputs are in progress. I attempted to estimate the ages of strata by obtaining measurements of Cs-137 content at 1-cm increments through one master core and comparing the resulting profile to the record of fallout in the northern hemisphere. I compared resulting magnetic, Cs-137, and sediment yield data to nearest available precipitation and discharge records, looking for potential relationships.

RESULTS AND DISCUSSION

Lake areas near the inflow delta and in the deepest portion of the lake have the thickest sediment sequences (33 cm and 24 cm respectively), whereas the littoral zone is characterized by thin or no accumulations. The total volume of reservoir sediment is approximately 5200 m^3. Based on estimates of average mineral particulate concentration (156 kg(dry) m^{-3}(wet)) and trap efficiency (82%), total sediment accumulation is ~800 metric tons (dry) and average 30-year sediment yield is ~5.8 t km^{-2} yr^{-1}. This value is similar to values estimated by Wolman (1967) for fully forested catchments in the Maryland Piedmont. Correction of individual samples for down-core variability in organic content at a number of core sites would refine these estimates. One potentially significant input not accounted for in these figures is sediment derived from lake shore erosion. Measurements to quantify this input are underway.

Although all cores have not yet been analyzed, magnetic susceptibility profiles suggest the presence of at least three and possibly four strata. Not surprisingly, best correlations (non-statistical) appear to occur between cores from similar depositional environments. Highest total susceptibility values occur close to the stream inflow, presumably reflecting higher mineral to autochthonous organic component ratio. Characteristics of the magnetic zones for deep water cores are: Zone 1: (uppermost) ~3.5 cm thick, low susc.; Zone 2: ~4 cm thick, high susc.; Zone 3: ~7 cm thick, low susc.; Zone 4: (basal), ~2.5 cm thick, below an initial peak.

The single Cs-137 profile obtained so far (from 8.5 m water depth) shows a decline from highest concentrations (~1.3 pCi g^{-1}; uncorrected for decay) consistent with high but rapidly declining fallout in the 1960s, to levels found in recent sediments (possibly around 1970) within early Zone 3. If this chronological marker is reliable, sedimentation rate in the basal zone (4) should be nearly double the post-1970 rate. A 1970 marker at this level suggests that a susceptibility peak sometime just up-sequence might be expected due to increased mineral input associated with the Hurricane Agnes flood (precip.= 19 cm) in 1972. No large increase in susceptibility value is identifiable at this level. Alternatively, this high flow event, and succeeding events in the 1970s may not have produced large amounts of sediment with respect to more frequent moderate events. Another possibility is that magnetic susceptibility is responding to influences other than mineral sediment input like redox conditions at the lake bed (Thompson and Oldfield, 1986). Clearly, other time markers are needed to clarify the sedimentation history. The use of Cs-137 fluctuations to place more recent time markers is problematic because the most useful markers are associated with high fallout between 1954 and 1965, and because bioturbation and topsoil erosion inputs complicate direct comparisons with later fallout levels. In the absence of reliable dating, magnetic stratigraphy may be more important as an indicator of changes in sediment source area over time (in conjunction with other sediment properties; e.g. Hutchinson, 1995), and in the destination of eroded sediment once in the lake.

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ANALYSIS OF MEANDER RESTORATION ON THE MIDDLE FORK FORKED DEER RIVER, TENNESSEE

Roger A. Gaines[1]

INTRODUCTION

The Middle Fork Forked Deer River (MFFDR) has a drainage area above its mouth of 489 square miles and forms its headwaters near Lexington, TN. The river flows from its source northwestwardly until it joins the North Fork Forked Deer River approximately twelve miles upstream from the City of Dyersburg. Historically, the river had a meandering channel and wide floodplain. The existing Middle Fork channel is a relatively straight canal constructed during the early part of the 20th century to reduce flooding along the river. The canal has experienced bank and bed adjustment in recent times due in part to changes in hydrology caused by land use changing from woodland to agriculture and degradation of downstream channels. Banks tend to be steep with slopes from 1V:1.5H to near vertical. Channel bed material is predominantly fine to medium sands. Channel profile adjustment has typically been degradational with some alternating periods of local deposition occurring over time. Overbank deposition appears to occur frequently with numerous sand layers and deposits located throughout the floodplain. Historic channels meandered across the floodplain, changing planform to reach an equilibrium between sediment loads, hydrology, and hydraulic conditions for the watershed land use and basin topography. Construction of the canal early in the century severed these meanders. Subsequent to canal construction, the abandoned meander channels have under gone varying degrees of deterioration, with some channels being filled completely by deposition. Some areas along the meander channels still exhibit some of the historic characteristics such as top width, while other areas have become ponded where the present canal thalweg is actually perched above parts of the floodplain. Where the abandoned channels were completely filled, or nearly so, locating the historic meander path was difficult. Aerial photography taken in the 1960s, 1980s and 1994 in conjunction with USGS quadrangle maps assisted in estimating the historic channel locations. Aerial and field reconnaissance also aided in evaluation of historic channel condition and location.

Channelization by locals in the early 1900's sought to reduce flood stages and durations. Various improvements to the channels have been proposed in the past. A recent proposal to improve drainage and overall floodplain functionality was developed by a committee established by the Governor of Tennessee. This proposal (referred to as the State Mission Plan) consists of restoring the previously severed meander channels for low-flows and maintaining some capacity in the present canal for higher flows.

RESTORATION PROPOSAL

The State Mission Plan consisted of reconnecting seven meander loops (nine cross-over points with the present channel) between RM 2 and RM 15.7 of the Middle Fork, constructing low-level diversion weirs across the present main channel to re-establish low flows to the restored meander channels, and modifying levees at three locations. Use of HEC-2 in computing water surface profile elevations required several iterative steps. First, levee modifications at the three identified locations were evaluated to determine the

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[1]Research Civil Engineer, U.S. Army Corps of Engineers, Memphis District, 167 North Main Street, Room B202, Memphis, TN 38103-1894, (901) 544-3391

extent of modification necessary to effectively remove hydraulic effects of the levees. This was accomplished by consecutive trials of levee removal/ setback (or floodplain restoration). Once the amount of lateral levee modifications had been established, historic meander channel locations were estimated from aerial photography, surveyed cross-sections, and USGS 1:24,000 quadrangle maps. Historic meander geometry was estimated from surveys of remnant meander channels. The third and fourth steps required an iterative process. Where remnant meander channels had filled with sediment deposits, a channel "template" was estimated. Surveys of the relatively intact remnant meander channels, in conjunction with top widths scaled from aerial photographs, were used as a basis for this estimate. Bottom elevations of each meander loop were estimated from plotted thalwegs along the abandoned meanders and the present channel such that net gradients between cross-over points were consistent (not always a positive slope). Channel bankfull capacity was used as a check on meander channel geometry-- bankfull discharge in the remnant meander channels was estimated using normal depth and studies conducted by the USGS to determine historic channel capacities or dominant discharges for the abandoned North Fork meanders near the Middle Fork confluence. After the projected meander channel geometry and dominant discharge had been estimated, a low-level diversion weir was sized for placement in the present channel to divert all flows up to the dominant discharge (estimated to average around 300 cfs for all seven loops) to the restored meander channels. For discharges greater than the dominant discharge, flows would be conveyed by both the restored meander channel and the present channel. Little change in distribution of overbank discharges would result. In the fifth step, existing condition HEC-2 model geometry was modified to reflect the diversions weirs and the restored meander channels. The Manning's roughness values were modified using "NH" records to subdivide the floodplain into strips. The roughness for the meander channels was input for cross-section stations between the meander top banks. The remaining overbank roughness was adjusted, as necessary, to maintain the original composite roughness factor. To validate performance of the proposed restoration, sediment routings for a 50-year period were conducted using HEC-6T to evaluate the splitting and recombining of flow through the restoration reach. Results of the sediment routings were used to check stability of the meander channels and the present channel and whether the dominant discharge was maintained throughout the routing simulation; stability was defined as neither scouring or depositing. Slight refinements were made to the model to ensure the desired system stability; these adjustments included optimizing the diversion weir crest elevations. Diversion weir elevations were set based on diverting all discharges to the restored meander channel up to the meander's bankfull capacity at each crossover point while maintaining the required flow distributions.

SEDIMENTATION ANALYSES

The purpose of these analyses was to determine the degree and location of channel aggradation and/or degradation that may be expected after the proposed project has been completed. Sedimentation must be an essential component of any meander restoration proposal. Since any channel modification constitutes a change in regime, it is logical to assume that the channel (or channels with meander restoration) will undergo an adjustment to changed hydraulic and hydrologic conditions over a period of time after project completion. The time period necessary for channel restabilization is variable and is dependent on the degree of stability of the original channel, extent of channel modification, type of soil in which the channel is bedded, and intensity, duration, and frequency of channel-forming discharges.

Data collected for sedimentation analyses consisted of bed material samples obtained at specified cross-section locations. Bed material consisted primarily of sand sizes in the Middle Fork channel. No suspended sediment or bedload measurements were available in the basin. Sediment inflows for the main channel and several major tributaries were estimated using empirical equations. Historic cross-section data were available for 1960 and 1979 conditions. Calibration of the HEC-6 model was accomplished using the

1960 to 1979 time periods. Model confirmation was accomplished using the 1979 to 1994 time period. Hydrology was developed for a 50-year period at locations where sediment inflow was estimated. The 50-year hydrology was modified to reflect conditions as appropriate. The same inflowing sediment loads were used for all model simulations except Buck-Davis and Stokes Creeks for the State Mission Plan proposal; sediment production for Buck-Davis and Stokes Creeks is reduced by changes in watershed land treatment practices with the State Mission Plan. Sediment routings for the State Mission Plan proposal required use of a modified version of HEC-6, HEC-6T "Sedimentation in Stream Networks", developed by William A. Thomas. This program has the capability to calculate flow distribution, hydraulic parameters, and sedimentation in networks with closed loops; each restoration reach of the old meanders comprises one loop. Each loop consists of an upstream and a downstream junction and two segments or branches; one was the main canal and the other was the restored meander.

Hydraulic and hydrologic conditions resulting from State Mission Plan implementation for the Middle Fork were incorporated into HEC-6T. This included adjusting the sediment inflow from Buck-Davis Creek to enter the restored meander instead of the main canal. Flow distribution between the main canal and the restored meander channel was evaluated by an iterative procedure until the desired flow distribution, diversion weir elevation, and channel stability was attained. The desired flow distribution was to divert discharges up to 300 cfs to the meander (the meander "dominant" or "channel forming" discharge) while minimizing scour or deposition in the main canal or the restored meander. Additionally, after the sediment routing period, it was desired that the flow distribution would not vary significantly from the original distribution. Flow distributions were compared to HEC-2 model results to aid in adjustments of the HEC-6T model. Early in the sediment routing analysis the need for a sediment trap at the upstream end of the restoration reach was identified. Routing results without a sediment trap indicated that the upper most restored meander channel would aggrade during the first 5 years of simulation causing flow to redivert to the main canal even with the diversion weir. Inclusion of a sediment trap, with associated trap maintenance, maintained the meander channel capacity throughout the 50 year simulation. The necessity for constructing a sediment trap at the upper end of the restoration reach was identified because of excessive sediment deposition in the upper meander loop. Without a trap and associated maintenance the meander channel filled and flow could no longer enter After excessive deposition in the meander channel had been minimized, general trends in the average bed elevations were analyzed. Typically, scour occurred near the upstream end of each meander loop and deposition occurred near the downstream end. This is because during moderate to large flows, the meander channel loops have a capacity of only about 300 cfs and most of the water, with its sediment, goes into the overbank areas where the sediment deposits. As the water returns to the canal and crosses over to the next downstream meander, it is sediment depleted and causes scour at it enters the meander. Just downstream of the confluence of the meander and Buck-Davis Creek severe scour occurred. The scour resulted partly because sediment yield from the Buck-Davis Creek watershed was reduced 39 percent with conservation practices applied under the State Mission Plan and partly because the Buck-Davis Creek channel previously entered the main canal which had a higher conveyance than the meander.

CONCLUSIONS

In alluvial river systems it is expected that banks will erode, sediment will be deposited and/or scoured, and floodplains and side channels will undergo modification with time. The North and Middle Forks of the Forked Deer River have experienced a slow progressive degradation process in response to changed watershed land use and outlet improvements. The improvements included with the State Mission Plan will restore low flows to the meander channels along the historic alignments established through this study. Intermediate and higher discharges will be conveyed by both the restored meanders and present canal. The floodplain will continue to be the predominant conveyance for flood discharges. Meander restoration and levee modification will slightly reduce flood stages and also restore a more natural drainage pattern for existing ponded areas and the floodplain in general. Impacts to the existing channel morphology will consist of a decrease in overall sediment transport capacity through the restoration reach due to reduced slopes and channel conveyance (total conveyance is increased slightly for near canal bankfull stages) and an increase in floodplain storage. Stream morphology will be restored to a more natural condition as a result of the State Mission Plan. A sediment trap will be required near the upstream limits of meander restoration to maintain meander integrity over the project life. The sediment trap will require maintenance on a frequent, as needed basis as presently designed. Grade stabilization measures will be required at several meander cross-over points to guard against scour. The anticipated stability problems under State Mission Plan conditions will be similar to prevailing conditions experienced in most meandering, alluvial river systems. The greatest problems will probably consist of sloughing banks on outside bends associated with the development of point bars and deflection of the thalweg. Generally, the restored meander channels should be reasonably stable and return their natural tendencies to slowly migrate through the floodplain.

USE OF NONLINEAR OPTIMIZATION TECHNIQUE AND CONCEPT OF EXPERT SYSTEM FOR CALIBRATION OF WATERSHED HYDROLOGIC SIMULATION MODEL

Yixing Bao[1], Roger B. Clapp, and Michael J. Sale

Over a period of 50 years, the waste disposal activities at ORNL have resulted in an accumulation of cesium-137 (^{137}Cs) and other radionuclide contaminants that are bound to sediments distributed along the floodplain of the White Oak Creek (WOC) basin. A comprehensive, continuous watershed model, Hydrologic Simulation Program-Fortran (HSPF), has been applied to the WOC basin to simulate various hydrological processes, sediment transport, and movement of ^{137}Cs. Because a large number of parameters are required in HSPF modeling, a major effort in the modeling processes is adjusting calibration parameters to make simulation results and measured values agree as closely as possible. This paper presents a model (OPTCALI) that we developed for calibration to improve results and efficiency in calibrating the model.

OPTCALI incorporates a nonlinear optimization technique and concepts of expert system. HSPF was linked to OPTCALI as a submodule. OPTCALI runs an iterative scheme. In each iteration, the expert-system component determines which parameters should be calibrated, and the nonlinear optimization module is then called to determine the optimal values of the parameters selected. The iterative scheme continues until all calibration parameters are calculated. The expert system component represents a collection of experiences of HSPF modeling and watershed characteristics. The nonlinear optimization component automates the process of determining values of calibration parameters by minimizing the absolute difference in streamflow between the observed and simulated values.

In applying HSPF, the White Oak Creek basin is represented by four pervious land segments that are connected through seven channel reaches. The major calibration parameters are lower zone storage, infiltration capacity, groundwater recession rate, upper zone storage, interflow, interflow recession, and lower zone evapotranspiration. Because the previous conventional trial-and-error calibration used equal parameter values for all land segments, the OPTCALI was first run to calibrate model with the same assumption. Initial parameter values were those that resulted from the previous trial-and-error calibration. OPTCALI improved the annual water balance at the White Oak dam (outlet of the basin) by 400% over the best results from previous trial-and-error approach.

A close examination of stream flow simulated at each land segment, however, indicated that the overland runoffs at land segments 1, 2 and 3 did not match with the observed flow. The main reason is that the assumption of the uniform parameter value for all land segments is not valid. Therefore, the HSPF model was recalibrated by OPTCALI to consider the parameters for each land segment and channel reach separately. In the first iteration, only lower zone storage's were considered as calibration parameters (control variables in optimization model). Optimal solution was reached after 17 one-dimensional searches and 104 gradient calls. The resultant annual water balance was improved by 29.2%. In the second iteration, the remaining calibration parameters were control variables with updated lower zone storage's as constants. The optimal solution was after 18 one-dimensional searches. The annual water balance was further improved by 21.5%. Because the annual water balance, in this approach, was calculated not only at the basin outlet but

[1]Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6036. Oak Ridge National Laboratory is managed by Lockheed Martin Energy Research Corporation for the U.S. Department of Energy under contract number DE-AC05-96OR22464.

also for individual land segment runoff, the actual enhancement of model results is much better than the percentages indicated above.

The combination of optimization and expert system dramatically reduces the time required for calibration process and improves the modeling results significantly. OPTCALI provides a cost-effective tool especially for modeling a basin with multiple land segments. The expert-system component is still relatively simplistic in its current form and needs to be extended. The same principle that combines expert system with optimization can be applied to other water resources models to improve model calibrations.

COMPARISON OF WATER QUALITY OF A CHANNELIZED STREAM AND A NON-CHANNELIZED/WETLAND STREAM IN THE BEAVER CREEK WATERSHED, WEST TENNESSEE

Herbert H. Cochrane[1] and Shannon D. Williams[2]

The water quality of a channelized stream and a non-channelized stream that flows through a 250-hectare bottomland hardwood wetland was examined in the Beaver Creek watershed, West Tennessee. Both streams receive agricultural runoff from drainage basins of similar size (about 3,000 hectares), land use, and topography. Suspended sediment and nutrient samples were collected during three storms, one prior to the planting of row crops and two during the summer growing season. Major differences in concentrations and loads of suspended sediment and nutrients were observed between the two streams. The channelized stream generally had higher concentrations and loads of suspended sediment and nutrients, even when the channelized stream received less rainfall and had less storm runoff that the non-channelized stream.

[1]Graduate Student, Department of Geography, University of Memphis, Memphis, Tennessee 38152

[2]Hydrologic Technician, U.S. Geological Survey, 7777 Walnut Grove Road, Suite LLB2, Memphis, Tennessee 37120; email: swilliam.er.usgs.gov; phone: (901) 766-2977

PRECIPITATION VALIDATION STUDY IN THE TENNESSEE RIVER BASIN

Robert C. Beebe[1], Bill C. Arnwine[2], L. Wayne Hamberger[3]

The Tennessee Valley Authority (TVA) River System Operations (RSO) operates a 243 rain gage network in a 40,250-square-mile area for the multipurpose management of the Tennessee River watershed. With a rain gage density of approximately one gage per 165 square miles, runoff is not always accurately determined from the rain gage network for some precipitation events. This occurs more often in the mountainous regions of Eastern Tennessee and Western North Carolina where orographic effects on precipitation can be significant.

The Precip product of the WSI Virtual Rain Gage provides rainfall estimates at a frequency of once every five minutes and a density of one virtual rain gage every 2.6 square miles. This represents between one and two orders of magnitude more rainfall information than is obtained from the rain gage network.

For the last two years, RSO has been receiving and comparing the 24-hour Precip values computed at the TVA rain gage locations with the corresponding observed rain gage measurement.

Two basic types of analysis between the Precip product and the observed gaged measurements compared area averages for rain events greater than 0.5 inch and case studies detailing the larger rainfall events. First, the unweighted rain gage area average is compared with the Precip area average for rain events exceeding 0.5 inches across the watershed. Figure 1 illustrates the cumulative area average rainfall totals for rain events occurring between December 1993 and September 1995. This time interval is divided into three periods. The first period between December 1, 1993, and December 1, 1994, is prior to the National Weather Service (NWS) acceptance of the NEXRAD radars that provide most of the coverage in the Tennessee River watershed. The period between December 1994 and March 1995 involves post-NEXRAD acceptance data. The final period from April 1995 through September 1995 reflects an adjustment to the algorithm used in Precip to improve the conversion of radar reflectivity to precipitation during convective precipitation events.

For the pre-NEXRAD acceptance period, the difference between the cumulative total for the five rain events in the watershed was 6.65 inches measured by the observed gages compared with 3.30 inches estimated by Precip for the same events. If it is assumed that the observed gage values are accurate, then Precip underestimated rainfall on average by 102 percent.

During the next period following NEXRAD acceptance in the area, five rainfall events recorded 3.22 inches observed versus 2.85 inches from Precip. The difference between the cumulative total measured versus Precip values dropped to 13 percent. For the most recent period involving the adjusted Precip algorithm, the difference between three observed gaged events which averaged 2.45 inches and the Precip average of 2.50 inches was two percent.

The next type of analysis involved performing more detailed case studies of the larger rainfall events. Two events have been selected for review that are representative of the relationship between gage

[1]Data Collection Specialist, River System Operations, TVA, WT 10B-K, 400 W Summit Hill Dr, Knoxville, TN 37902-1499 (423)632-4203

[2]Civil Engineer River System Operations, TVA, WT 10B-K, 400 W Summit Hill Dr, Knoxville, TN 37902-1499 (423)632-6932

[3]Meteorologist, Engineering Services, TVA, TVA, WT 9C-K, 400 W Summit Hill Dr, Knoxville, TN 37902-1499 (423) 632-4222 ; whamber@mhs-tva.attmail.com

measurements and Precip values determined during the two-year period. One event has been selected from the pre-NEXRAD acceptance period and one from the post-NEXRAD acceptance period using the VRG upgrade with the most recent Precip algorithm. The following is a summary of the individual storms, statistical analysis of the data, and conclusions for the two events.

STORM OF JANUARY 25-28, 1994

Precipitation from the storm of January 25-28, 1994, ranged from an inch in the northeast portion of the Tennessee River Basin to six inches in northeast Alabama and south central Tennessee. High pressure centered to the southeast of the Tennessee River Basin on the 24th-26th brought southwest flows with steady increases in temperature and moisture. The air mass was warm and humid for January. Stratiform precipitation fell on the 25th and showers and convective precipitation occurred with a squall line in the western part of the Basin on the 26th. The region continued to be in the warm, moist sector of a west-to-east advancing cold front on the 27th and 28th triggering heavy rains, showers, and squall lines ahead of the front.

The Precip data for this storm is derived from pre-NEXRAD acceptance period data, and an earlier version of the Precip algorithm.

The rainfall frequency distribution graph plots the number of gages in one-half inch bin increments (Figure 2). A comparison of the distributions shows Precip reported many more gages under 1.5 inches, was within four gages of the observed at the 2.5 inch point, and reported no gages over five inches. The observed precipitation is a positively skewed normal distribution; however, the Precip distribution does not appear normal.

The Precip versus gage measurements (observed) scatter graph shown in Figure 3 plots the individual stations using the x-axis for the observed gage totals and the y-axis for the Precip totals. If the gages matched, the points would draw a straight line with a slope of one. Most of the points fall below the ideal line, indicating the Precip values did not report as much rain as observed by the gages. A few outliers show differences as much as five inches between Precip and observed rainfall.

Descriptive univariate statistics were used to quantify the central tendency and variability of the distribution. For example, the mean and median Precip values when compared to the observed values were lower by 0.84 inch for the mean and 0.73 inch for the median. The variability of the observed range was 6.46 inches compared to Precip's 4.8 inches. Individual gage comparisons ranged from Precip overestimating the observed by 3.47 inches to Precip underestimating the observed by 5.31 inches. The observed measured variability has two-thirds of its observations within 1.12 and 3.32 inches, whereas the Precip has two-thirds of its observations within 0.43 and 2.33 inches. The kurtosis indicates Precip has fewer observations near the center than the observed and the skewness indicates a positively skewed observed rainfall distribution. Using the sum of the storm total in inches, and assuming the rain gages measured only 90 percent of the precipitation total due to 10 percent sampling error, Precip measured 56 percent of the precipitation.

The co-variance statistic quantifies the ranges by averaging the product of deviations of rain gage totals from the respective observed or Precip means. The co-variance between the observed and the Precip was 0.49, which is relatively weak compared to the observed variance of 1.21 and the Precip variance of 0.90.

The correlation statistic quantifies the degree of one-to-one relationship between the observed totals and the Precip totals. The correlation between the observed and the Precip was 0.46 compared to a perfect correlation of one. This implies larger observed values relate positively to larger values of Precip, but the relationship is weak. The outliers on the Figure 3 scatter graph weaken the correlation.

The ranked difference statistic takes the rainfall difference (observed-Precip) for an individual station and ranks the station differences. This statistic indicates Precip was within plus or minus one inch of the observed totals 62 percent of the time. Precip underestimated 84 percent of the observed station totals including 35 percent underestimated by one inch or greater.

The contours in Figure 4 show where Precip underestimated the observed totals. This map indicates pronounced Precip underestimates in northern Alabama and the mountains of North Carolina. Perhaps one explanation for the Precip underestimates is the relatively poor radar coverage in these two areas.

STORM OF APRIL 19-20, 1995

The storm of April 19-20, 1995, produced rainfall of less than an inch in the east and northeast to five inches in the southwest corner of the Tennessee River Basin. Rainfall was as a result of convective thunderstorms.

The April 20, 7 a.m. EST, weather maps showed a stationary front across the northern part of the basin leaving most of the basin in the warm, moist air sector. A surface cold front was moving into the region from the west. Ahead of the cold front was a squall line. The strong converging flow at the surface and diverging flow aloft ahead of the squall line provided continued thunderstorm development for the rest of the day. Afternoon surface heating and the approaching cold front provided enough energy to produce the largest rainfall totals in the late afternoon and early evening.

Precip data for this storm is derived from post-NEXRAD acceptance data and the revised Precip algorithm.

The rainfall frequency distribution graph, Figure 5, shows the observed distribution with approximately 70 gages indicating between zero and 0.5 inch and gradually decreasing to one gage at 5.5 inches. The Precip distribution also shows about 60 gages between zero and 0.5 inch with 55 gages between 1.5 and 2 inches. Comparing the distributions, the observed had more gages under an inch than the Precip, both had the same number of gages in the 1 to 1.5 inch bin, and the largest difference was in the 1.5 to 2.0 bin where the Precip had a secondary peak of 55 gages compared to the observed of about 28. Neither distribution appears normal.

The scatter graph, Figure 6, shows even scatter about an inch wide around the ideal line indicating most of the observed and Precip rain gages compared well. Precip underestimated all observed values above four inches, although the sample size of six is small. The outliers resulted from Precip overestimating the observed totals, just the opposite of the January 1994 storm.

The Precip estimates when compared to the observed, were higher by 0.14 inches for the mean and 0.30 inches higher for the median. The observed range was 5.03 inches compared to the precip estimate of 4.6 inches. Individual gage comparisons ranged from the Precip overestimating the observed by 2.95 inches to the Precip underestimating the observed by 1.60 inches. The observed variability has two-thirds of its observations within 0.22 and 2.26 inches, whereas the Precip has two-thirds of its observations within 0.37 and 2.39 inches. The skewness and kurtosis are difficult to interpret because the distributions are not normal. Using the sum of the storm total in inches and assuming the gage network measured only 90 percent of the precipitation total due to a 10 percent sampling error, the Precip measured 101 percent of the precipitation.

The co-variance between the observed and the Precip for the entire storm was 0.81 which is relatively strong compared to the observed variance of 1.05 and the Precip variance of 1.02.

The correlation between the observed and the Precip for the entire storm was 0.77, compared to a perfect correlation of one. This implies larger observed values relate positively to larger values of Precip totals and a strong relationship.

The ranked difference statistic indicates Precip was within plus or minus one inch of the observed totals 86 percent of the time.

TRENDS, CONCLUSIONS, RECOMMENDATIONS

A reduction in the differences between the observed gage network and Precip estimated rainfall occurred from the January 1994 storm to the April 1995 storm which is probably due to NEXRAD data plus an improvement in the precip algorithm. Two statistics that best describe this are (1) the correlation improvement to 0.77 in the April 1995 storm and (2) the storm totals where the Precip went from measuring 56 percent of the total gaged rainfall in the January 1994 storm to 101 percent of the total rainfall in the April 1995 storm.

Precip underestimated all observed totals greater than five inches during all storms. A skewness factor adjustment could be installed to adjust these differences if this trend continues.

There are areas in the Tennessee River watershed where Precip tends to underestimate rainfall. These are also areas where NEXRAD coverage is limited radially (north Alabama) or vertically (Appalachian Mountains). The NWS has scheduled to install a NEXRAD radar in north Alabama in the next two years.

ACKNOWLEDGMENTS

The authors wish to acknowledge the excellent work of TVA Engineering Services staff members Jerry Foust and Betty Watkins for the data set development and graphical figures.

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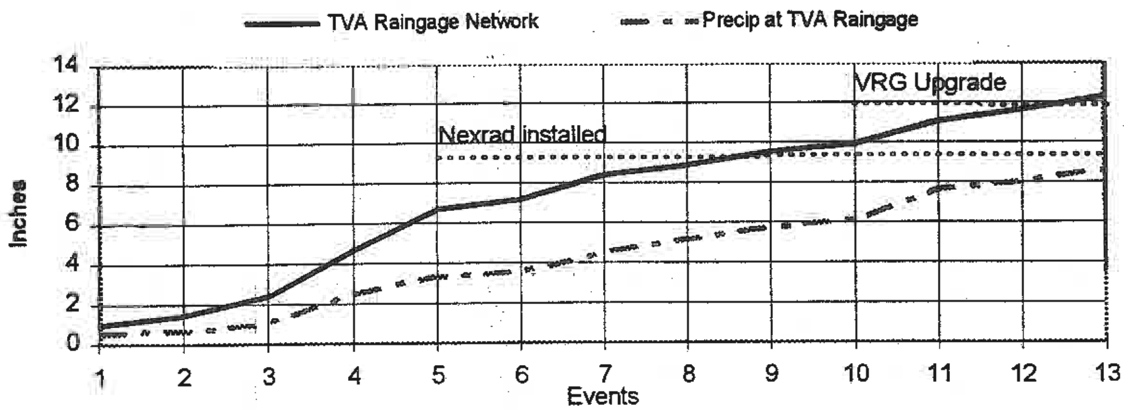

Figure 1. Cumulative rainfall totals for events from December 1993 - September 1995 in the Tennessee River Basin

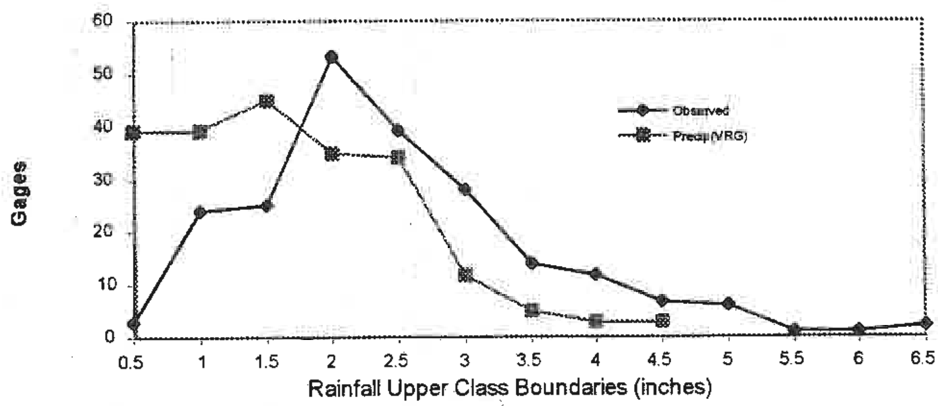

Figure 2. Rainfall frequency distribution in the Tennessee River Basin, January 25-28, 1994

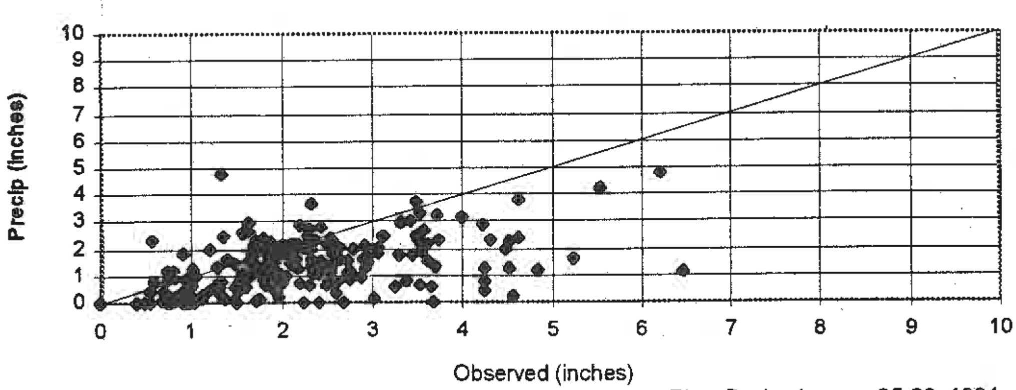

Figure 3. Rainfall scatter for individual stations in the Tennessee River Basin, January 25-28, 1994

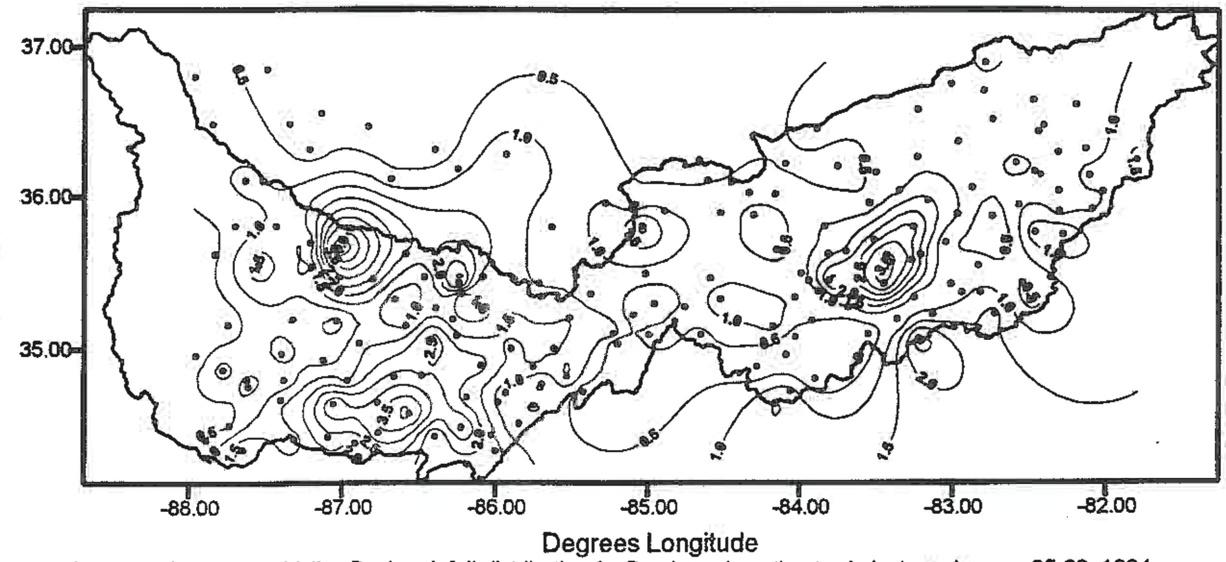

Figure 4. Tennessee Valley Basin rainfall distribution for Precip underestimates in inches, January 25-28, 1994

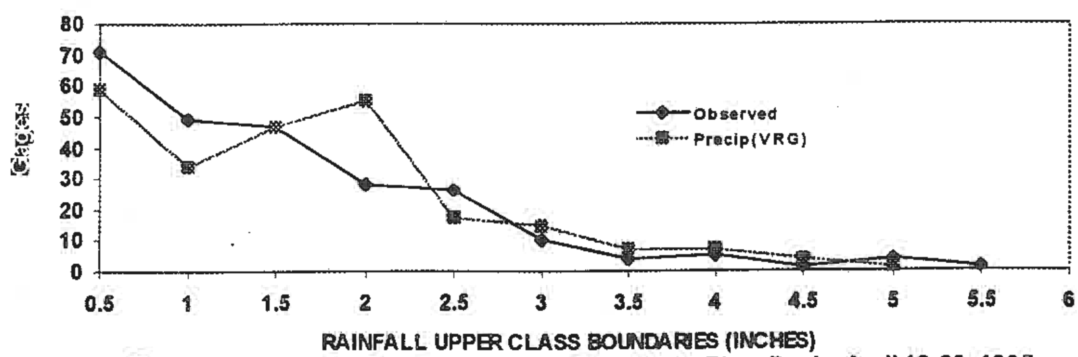

Figure 5. Rainfall frequency distribution in the Tennessee River Basin, April 19-20, 1995

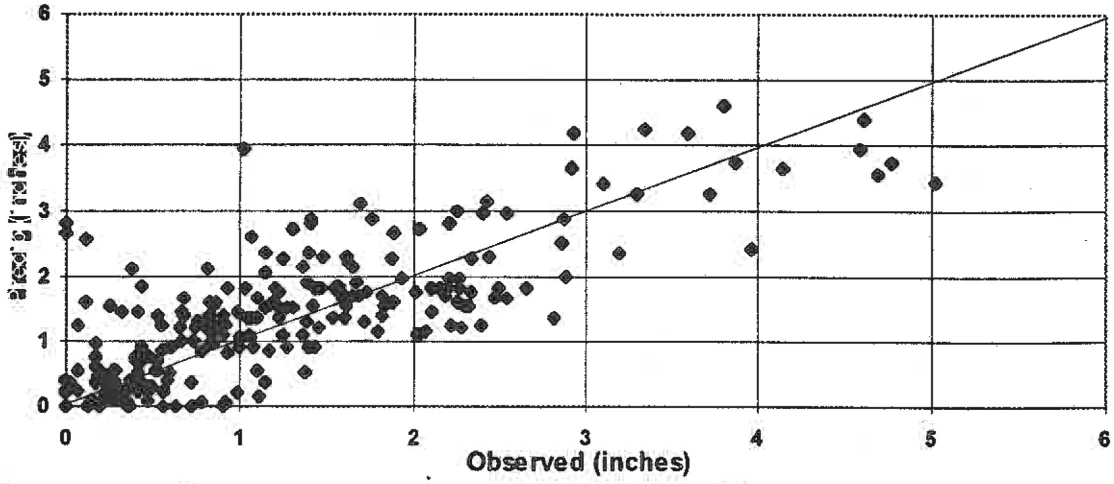

Figure 6. Rainfall scatter for individual stations in the Tennessee River Basin, April 19-20, 1995

GOVERNMENT PROGRAMS AND THE REGULATION OF DYE TRACING: THE FUTURE

Albert E. Ogden[1]

INTRODUCTION

Until recent years, ground water tracing was conducted in karst areas nearly exclusively by cavers to establish hydrologic connections between sinking streams or cave rivers to springs for the purpose of aiding exploration and discovering new caves. For a long time, karst hydrogeologists have tried to convince federal and state environmental agencies that ground water flow in carbonate rocks is very different than in porous media and tracing techniques must be used for such endeavors as establishing monitoring points and defining spring drainage basins. Well that time has come, but the unexpected result is that government agencies are beginning to regulate, control, register, and even decide who is qualified to conduct a ground water trace. For the ground water cleanup industry this is probably a good idea. Many facilities, such as Superfund sites, have a number of responsible parties. Often, neighboring facilities with ground water problems hire different consultants who usually keep their investigative techniques and cleanup strategies held in confidentiality until becoming public through the state agencies. If two facilities were to conduct dye traces during the same time period, the results could cause false positives. This could be economically disastrous for a company that gets blamed for pollution they did not cause.

In addition to the above concern, ground water tracing activities are now more frequently being conducted within soil aquifers where ground water flow velocity is commonly slower and dye absorption is a major problem. Thus, much larger quantities of dyes are being used. In these hydrologic settings, a tracing agent may reside in the subsurface for months or even years thereby eliminating future tracing at the facility or neighboring facilities potentially for a long time. These situations require significant prior research into the broader ground water problems of an area, good field reconnaissance, and excellent coordination among all government agencies and PRP's.

The primary purpose of this paper is to inform the hydrogeologic community as to which organization must be contacted (if any) before conducting a ground water trace. Since at least one state has already fined someone for discoloring a stream without giving prior notification, this is important. The information presented in this paper was gathered by conducting a phone survey to eight states that have large areas of karst. Besides state agency personnel, several people who routinely conduct dye tracing in the United States were contacted.

SURVEY RESULTS

In Tennessee, a permit must be completed and submitted to the Underground Injection Control Program (UIC) prior to conducting a trace. Their address and telephone number is Tennessee Department of Environment and Conservation-UIC Program, 11th Floor, L & C Tower, 401 Church Street, Nashville, TN 37243, (615) 532-0169. The permit application is lengthy having been developed for the injection of contaminants down a well. Placement of tracers into a sinkhole or well is considered injection of the Class V variety. The permit application is lengthy and not totally appropriate. In addition to the numerous non-

[1]Department of Geography and Geology, Middle Tennessee State University, Murfreesboro, Tennessee 37132, phone: (615) 898-4877

applicable questions asked, it is required to give specifics as to location, geology, amount and type of tracer to be used and location of water wells within the AOI (area of influence) as found through a search of well driller logs. There is a charge for obtaining a printout of the water well data. The results of the tracing is then expected to be supplied to the State which can be a problems regarding client confidentiality. The Solid Waste Program in Tennessee is unofficially requiring dye tracing as part of new landfill applications in karst areas so that springs hydrologically connected to the proposed landfill can be established as monitoring points. Also, as part of the new Tennessee Wellhead Protection Program, ground water tracing must be used by larger water utility districts that supply drinking water from spring and some wells in karst. Tracing required by the Solid Waste or Wellhead Protection programs must still be approved by the UIC Program.

Kentucky requires advance notification of dye tracing through the KY Division of Water, Field Operations Branch, 14 Reilly Road, Frankfort, KY 40601; telephone (502)564-3410. The notification may be completed by telephone and simply requires the principal investigator's name and telephone number, proposed date of injection, likely recovery period, dye colors to be used, and potentially affected county area or body of water. This information is then supplied to the appropriate Regional Field Office. With this knowledge, state officials are prepared to reduce the alarm expressed by concerned citizens should surface waters or wells be discolored. The Division's Groundwater Branch encourages but does not require ground water investigators to review locations of water wells and previous dye traces result kept on file before conducting the tracing. Mr. Joe Ray of the KY Groundwater Branch-Division of Water states "designed tracer tests are not presently prohibited in Kentucky. However, Section 2 of 401 KAR 5:031 states: Surface waters shall not be aesthetically or otherwise degraded by substances that produce objectionable color, odor, taste, or turbidity."

The Division of Water has authority to issue a Notice of Violation to any person discoloring the waters of the Commonwealth. The offender may be liable for a civil penalty and for costs incurred by state personnel during the investigation" (written communication, July 11, 1994).

The Arkansas Department of Pollution Control and Ecology (DPC&E) requires preparation of a study plan before conducting a ground water trace. The study plan has no specific format, but most be approved before a "short-term authorization" is given to conduct the tracing. This approval is reported to take any where from hours (fax reply) to months. To obtain a short-term authorization to conduct a dye trace contact the Arkansas DPC&E at P.O. Box 8913, Little Rock, Arkansas 72219 (501) 562-7444.

To conduct ground water tracing in Missouri, a person must obtain a form from the Missouri Division of Geology and Land Survey, P.O. Box 250, Rolla, Missouri 65401 (314) 368-2100 and detail the work plan, including the latitude and longitude of injection points and sampling stations. After completion, the results must be submitted back to the State. In some cases, this can be a problem since it possibly could endanger consultant/client confidentially. If a ground water trace is being planned in the Springfield, MO area (Greene Co.), the county Resource Management Department, 833 Boonville, Springfield, MO 65802 office must also be contacted.

Virginia does not have a permitting process for conducting ground water tracing at this time, but the issue has become a recent matter of serious discussion. In general, the Virginia Department of Environmental Quality-Water Division, 629 E. Main St., P.O. Box 10009, Richmond, VA 23240 (804) 762-4000 considers the random use of dyes for tracing a degradation of water quality. One reliable source in the State government said that State agencies are routinely conducting dye tracing as part of their job as well as consultants where pollution issues are involved. In some cases where the sinkholes are considered Class V injection wells, another source said that the matter is referred the U.S. EPA Region 3. To help resolve the controversy over the use of dyes as tracing agents, Terri Brown of Virginia's Department of Conservation and Recreation, VDCR New River Valley Field Office, P.O. Box 1506, Dublin, VA 24084, (540) 831-4008 has initiated a voluntary "Dye Registry Program" in cooperation with the regional offices in karst areas of the

Virginia Department of Health and the Virginia Department of Environment and Quality. Standards of the National Sanitation Foundation for dyes are being investigated to gain statewide approval for their use.

Government officials were contacted in four other southeastern states containing significant karst areas and none regulated or registered ground water tracing. Similar to Virginia, tracing was commonly being performed in the states by agencies personnel and consultants. In all of these states, discoloration of the water is considered an environmental offense with potential legal ramifications. Therefore, a prudent individual would inform the local environmental field office of the chance that a spring or creek could become red or green and thus prevent the waste of valuable state resources investigating a citizen's perceived pollution problem.

CONCLUSIONS AND PERSPECTIVES

The growing recognition of the uniqueness of karst and the need for dye tracing by state agencies has long been desired by karst researchers. The need to coordinate dye tracing efforts in the ground water industry is irrefutable. Unfortunately, with government control there are many questions to be asked. Will there soon be fees required as part of the permitting process? Will a person wanting to conduct a dye trace have to establish his qualifications with the state, take tests, have special degrees, or pay professional fees? Will one or more people in a state agency be able to prevent a person from performing a dye trace simply because they do not get along? And what about the cavers who have conducted most of our nation's dye traces? Will they be stopped from conducting our most basic karst hydrologic research? Who is to say that their work may not some day help in solving pollution problems or provide information necessary to prevent ground water pollution from future development? These are tough questions that need to be resolved through forums between State officials and karst hydrogeologists before final regulations are made.

LOCATING DISTURBED GROUNDS USING REMOTE SENSING IMAGERY: PRELIMINARY RESULTS OF GROUND TRUTHING AT SWSA-4, ORNL

Norman A. Zehms, Jr.[1] and Thomas K. Evers[2]

INTRODUCTION

During 1993-1994, several ORNL divisions participated in the Strategic Environmental Research & Development Program (SERDP) to assess the utility of national classified remote sensing assets as applied to environmental restoration activities. SERDP utilized data analysis and data fusion techniques on a combination of historical imagery (1942 to present), 1992/1994 thermal and multispectral remote sensing data, and limited ground truth data to develop a trench map of Waste Area Grouping (WAG) 4. Ground truthing of remote sensing imagery involves comparison to measured in situ parameters. The primary result of this project was time-continuous in situ data for both trench and non-trench areas. Remote imagery for the period of this study was of limited utility for comparative use in ground truthing.

BACKGROUND

At WAG 4, Solid Waste Storage Area (SWSA) 4 covers approximately 23 acres. From 1951 until 1959, SWSA 4 received a variety of low- and higher-level radioactive wastes, including transuranic wastes, all buried in trenches or auger holes. A fire destroyed most burial activity records. Surface water sampling data indicate that a substantial quantity of contamination (^{90}Sr) is being released from the burial trenches in SWSA 4. These trenches have contributed 25% of ^{90}Sr release observed at White Oak Dam from 1987-1994 and about 14% of the total ORNL off-site risk via the drinking water pathway.

WAG 4 contained unknown trench areas and was on a fast track for interim remedial action. The SERDP trench map was based on historical and current remote sensing and aerial survey information. The trench map was used by the WAG 4 technical managers to direct other ground-based characterizations to further delineate the trenches. The SERDP trench map was then the key in allowing a precise sampling study to pinpoint localized ^{90}Sr sources feeding the major seeps.

As a result of this successful experience at WAG 4, ORNL participated in the follow on study, "Application of National Remote Sensing Capabilities for Burial Waste Identification and Assessment of Contaminant Migration," through the auspices of the Government Applications Task Force (GATF) Pilot Project. In addition to ORNL (and several DOE offices), Los Alamos National Laboratory and Savannah River Technical Center joined this collaborative effort.

The primary aspect of the GATF project involved conducting a detailed ground truth experiment to assist with the evaluation of remotely sensed data. The ground truth experiment has focused on three primary parameters of interest: soil surface temperature, soil moisture content, and infrared (IR) signatures. In addition, IR radiometers were also positioned over the trench and outside the trench.

[1]Environmental Consulting Engineers, Inc., P.O. Box 22668, Knoxville, Tennessee 37933; phone: (423) 691-3668; email: nzehms@ece.com

[2]Computing Physics Applications Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee 37831; phone: (423) 574-8704; email: evt@ornl.gov

METHODS AND RESULTS

Analysis of remote sensing data from the SERDP study indicated strong thermal signatures throughout the year near the vicinity of WAG 4 Trench TT19. TT19 was therefore selected as the candidate ground truth study area. The suite of ground truth sensors include the following:

- 24 soil surface temperature thermistors,
- 10 surface soil moisture blocks,
- 2 infrared temperature transducers,
- 1 rain gauge; and
- and corresponding data logging/storage support equipment.

The ground truth experiment collected continuous in-situ data (five minute sampling interval) from sensors at depths of from 1-10 inches, from September 16 through November 27, 1995. A variety of meteorological sensors were also available both locally at the WAG 4 site and at a nearby meteorological tower (ORNL MT2) located less than 2 kilometers from the site, measuring precipitation data, solar radiance, air temperature, wind speed, and relative humidity.

On the basis of previous field investigations at WAG 4, topography, direct field observations of surface subsidence, and differential grass growth, boundaries for trench TT19 were roughly delineated and several points flagged at the site. From these location points, the axis of the trench was determined on the land surface. Based primarily on the field observations of denser vegetation (longer, healthier grass, and slight subsidence within the main body of the trench), two transects parallel to the trench to locate instruments were staked out. Sensor locations along the transects are separated by a variable distance of approximately 4 m (13 ft) in the non-trench area and 11.3 - 15.5 m (37-51 ft) in the trench area. There is approximately 14 feet of elevation difference between the up-slope non-trench sensors and the down-slope in-trench sensors.

From more than 10 weeks of ground truth data, two consecutive weeks were selected for qualitative and quantitative analysis. All sensors were sampled and recorded every 5 minutes (2016 data points per sensor per week). The first data set selected was October 16 - 22, 1995. General weather conditions during this week: four days of essentially clear/sunny weather followed by two days of clouds, including a relatively short rainstorm with total precipitation of 0.24 - 0.27 inches. The second data set was October 23 - 29, 1995. General conditions for this period: mostly mixed, sunny and partly cloudy days, two days of mostly cloudy skies, and a single day of precipitation (beginning 10/27/95 0745 hours) with total precipitation of 1.28 - 1.33 inches.

As expected, a strong diurnal effect (considerable spread in high/low peak temperatures) is noticeable. Influxes of surface soil moisture during rain events cooled all temperature sensors, however, differences between trench and non-trench temperatures during evening hours were much more pronounced as compared to differences between trench and non-trench temperatures during daylight hours. Analyses of the ground truth data, to date, show that, in general, soil temperatures are slightly cooler and soil moisture greater within the waste trench. Both in-situ sensors and thermal infrared measurements from the IR radiometers, confirm this temperature difference. Data analyses continue in an effort to both qualitatively and quantitatively assess the magnitude of temperature differences and determine factors that influence those temperature differences. Unfortunately, a legitimate ground truthing from the collected data is unlikely as coincident satellite imagery for the project was limited in both quantity and quality.

MANAGEMENT OF HIGHWAY STORMWATER RUNOFF IMPACTS TO GROUND WATER IN KARST AREAS—A STATUS REPORT

J. Brad Stephenson, Barry F. Beck, and Zhou Wanfang[1]
James L. Smoot[2], and Anne M. Turpin[3]

INTRODUCTION

Stormwater runoff transports hydrocarbons, heavy metals, and other contaminants from highways, contributing to the pollution of surface water and ground water. Ground water is particularly vulnerable in karst areas, where soils may be thin or nonexistent and where ground water recharge occurs directly through fractures, sinkholes, and sinking streams. P.E. LaMoreaux & Associates, Inc. (PELA) and the University of Tennessee (UT) are addressing the issue of ground water contamination resulting from highway stormwater runoff in karst areas. This research is being supported by the Federal Highway Administration (FHWA) and Departments of Transportation (DOTs) in fifteen states: Arkansas, Florida, Illinois, Indiana, Kentucky, Maryland, Minnesota, Missouri, New York, Oregon, Pennsylvania, Tennessee, Texas, Virginia, and Wisconsin. A major goal of this study is the development of practical remedial methodologies for treating highway runoff in karst settings.

Batch and column experiments are being conducted in the laboratory to aid in the design of a runoff treatment system. Potential locations for field testing have been visited in each state participating in this study. Following evaluation of more than 125 sites, a sinkhole draining a high-traffic interstate highway interchange in Knoxville, Tennessee, has been selected as one of two locations where the contaminant removal effectiveness of a prototype treatment system will be assessed. The average daily volume of traffic at the site exceeds 76,000 vehicles. It is anticipated that the pilot treatment system installed in the sinkhole will involve the use of peat and/or other materials to remove suspended and dissolved pollutants by sedimentation, filtration, and adsorption. Preliminary results of laboratory and field studies will be presented.

BACKGROUND

Investigations of the quality of highway runoff and management practices for its treatment have been conducted by the FHWA, the U.S. Environmental Protection Agency, and the U.S. Geological Survey. These studies have demonstrated that highway runoff is an important contributor of pollution to surface water and groundwater. It has been shown that stormwater runoff transports suspended and dissolved solids, heavy metals, nutrients, bacteria, road salt, herbicides, and hydrocarbons from highways. These materials collect on highways as a result of normal operation and maintenance activities. Pitt and Amy (1973) and Shaheen (1975) suggest that road runoff has a greater impact *per capita* than sewage for total suspended solids and some metals. Reviews of the extensive literature on highway runoff are included in Barrett and others (1993), Burch and others (1985), Dupuis and others (1985), Gupta and others (1981), Kobriger and others (1981,

[1] P.E. LaMoreaux & Associates, Inc., 106 Administration Road, Oak Ridge, Tennessee 37831, (423) 483-7483, E-mail: *pelaor@usit.net*.

[2] Professor, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, Tennessee 37996-2010, (423) 974-7718, E-mail: *smoot@utkvx.utk.edu*.

[3] Graduate Research Assistant, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, Tennessee 37996-2010.

1984), and Yu (1993). Novotny and Olem (1994) and Wanielista and Yousef (1993) present overviews of stormwater management, including highway runoff quality. Hamilton and Harrison (1987) present the proceedings of international symposia on highway-related pollution.

Hydrocarbon contamination in highway runoff results from the incomplete combustion of gasoline, oil dripping onto road surfaces and parking areas, and disposal of waste oil at storm drains (Latimer and others, 1990). Pavement wear and right-of-way erosion contribute to highway runoff pollution, as do highway deicing and right-of-way maintenance activities (Gupta and others, 1981). Nitrogen and phosphorus may be derived directly from automobiles (Driscoll and others, 1990). Pollution is also derived from exhaust emissions, fluid leaks, and the normal wear of tires and other auto parts (Gupta and others, 1981). According to Shaheen (1975), less than 5 percent (by weight) of traffic-related deposits originate directly from automobiles. However, he notes that vehicle-derived pollutants are likely the most significant because of their potential toxicity.

Harrison and Wilson (1985) report that about 50 percent of the metals in highway runoff are associated with dust, even though it constitutes only 6 percent of the total weight of the solid materials. Similarly, Hewitt and Rashed (1992) note that the particulate phase contains more than 90 percent of the inorganic lead, approximately 70 percent of the copper, and approximately 56 percent of the cadmium. On the other hand, some PAHs in stormwater runoff appear to be correlated with rainfall intensity rather than suspended solids concentrations. The concentration of aliphatic hydrocarbons in runoff decreases with each consecutive flush from high intensity rainfall (Asplund and others, 1980), suggesting that their solubility limits their association with suspended solids. Data presented by Zawlocki and others (1980) also indicate that most hydrocarbon compounds remain in solution in highway runoff.

Data from numerous studies (e.g., Wada and Miura, 1984) have suggested that the majority of pollutants are discharged during the beginning of a storm and that the pollutant load decreases with time. This is known as the "first-flush" phenomenon. However, when rainfall events occur close together with few dry days for pollutant accumulation, the highway surface may be clean enough to minimize the first-flush effect (Gupta and others, 1981). Hewitt and Rashed (1992) report a highly significant correlation between the length of the antecedent dry periods and the quantity of dissolved lead and copper removed from highway surfaces by runoff events. Balades and others (1983) conclude that a few short-duration rainfall events may introduce 30 percent of the annual highway-related contaminant load.

Smith and Lord (1990) note that impact on water quality is minimal from highways with average daily traffic (ADT) of less than 30,000 vehicles per day. However, surrounding land use has been shown to have a more significant influence on runoff quality than traffic volume (Gupta and others, 1981). Highway construction effects have been noted by numerous researchers, including Yew and Makowski (1989), who address an area along the Tennessee-North Carolina border where highway construction exposed a pyritic shale, releasing acidic runoff to nearby streams.

The most significant metals in stormwater runoff with respect to groundwater contamination are aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc (Pitt and others, 1994). With the exception of zinc, most are associated primarily with particulate materials and can be removed by sedimentation or filtration. Studies of recharge basins have shown that most heavy metals are removed in the basin sediment or in the vadose zone. Particulate metals are filtered out at the soil surface, and dissolved metals are removed by adsorption onto the near-surface particles in the vadose zone during infiltration. Studies of recharge basins have shown that lead, zinc, cadmium, and copper may accumulate at the soil surface with little downward movement over many years.

The effects of highway runoff on groundwater depend on such factors as sorption processes of the aquifer material and groundwater velocity. Pollutants may also be immobilized at the ground surface and within the vadose zone. In areas with thick soil, natural processes may attenuate contamination in highway runoff before it recharges the aquifer. However, in karst areas significant groundwater recharge occurs through features such as sinkholes and sinking streams. Flow of surface water into sinkholes and sinking streams provides rapid, direct recharge of underlying karst aquifers with little or no attenuation of any transported contaminants.

The primary objective of highway stormwater runoff pollution management is the reduction of total pollutant loads entering groundwater or surface water. Although all highway runoff contains pollutants, low concentrations may not always constitute a problem for the receiving waters. Therefore, runoff treatment should be applied to that portion of the runoff with the highest contaminant concentration. In some cases, this may be achieved by treating only the "first flush."

Numerous techniques exist for treating highway stormwater runoff. Effective methods, which may be implemented individually or in combination, include the use of the following: curb elimination, vegetated swales, French and Dutch drains, checkdams, sedimentation ponds, detention basins, and filtration. Keith and others (1995) discuss the contaminant removal efficiency of rock and peat filters in sinkholes receiving highway runoff. Preliminary findings indicate that one peat filter has been removing approximately 80 percent of suspended particulate materials and about 50 percent of the dissolved copper and zinc.

EVALUATION AND SELECTION OF FIELD TESTING SITES

During the initial phase of this investigation, site visits were conducted to evaluate locations where highway runoff potentially impacts groundwater in karst areas. More than 125 sites were visited in fifteen states. Additional information was obtained from DOT personnel and others with recognized knowledge of the karst areas in each state or region. These data were used to assess the suitability of each site for use during field testing of the runoff treatment method.

Two sites have been selected for field testing of runoff treatment methodology. They are located at the I-40/I-640 interchange in eastern Knoxville, Tennessee, and adjacent to I-70 in Frederick, Maryland. The Knoxville site provides high ADT; right-of-way location with sufficient work area; large proportion of highway-derived runoff; direct recharge of a karst aquifer with minimal natural filtration; and documented groundwater flow routes and monitoring locations.

INVESTIGATION PLAN

The primary objective of this project is to design and test a method for improving the quality of highway runoff draining into karst aquifers through sinkholes. The treatment methodology will involve a combination of sedimentation, filtration, and adsorption designed to treat the first flush of stormwater runoff. The first phase of testing consists of laboratory experiments to determine the most effective combination of filter media, thickness, and compaction. These batch and column tests are being conducted by the UT Department of Civil and Environmental Engineering.

Pilot treatment structures will be installed and tested in the selected sinkholes. Their hydrologic function will be monitored in the field. Water samples collected before and after treatment will be analyzed to evaluate water quality improvement. The hydrologic performance efficiency will also be monitored to assess the long-term viability of the structures and projected maintenance requirements.

The pilot structures will be designed to treat the first flush. To prevent flooding at the site, the structure will be designed to permit subsequent runoff to bypass the treatment process and flow directly into the sinkhole. It is anticipated that runoff water will be pretreated in a preliminary detention basin to promote settling of coarse sediment and removal of floating debris. The treatment media will probably be placed in the flat bottom of a large, shallow retention basin. A perforated drainage pipe beneath the media will collect treated drainage and conduct it into the sinkhole. The surface of the treatment media area will be designed to minimize clogging and to facilitate maintenance.

The drainage conduit from the treatment structure into the sinkhole will be designed to permit sampling of the treated runoff as it recharges the karst aquifer. Contaminant loads of treated runoff will be compared with loads measured upstream of the treatment structure to test its effectiveness. Because of the time lag resulting from detention and treatment of the runoff, the total load of each contaminant before and after treatment will be compared. Samples will also be collected at the spring.

CONCLUSIONS

Stormwater runoff is a significant source of ground water contamination, especially in karst areas. Most pollution is transported during the "first flush" of runoff from a storm event, and impacts to water quality are more significant from highways with traffic in excess of 30,000 vehicles per day. Other factors include amount of impervious area, pavement type, drainage mechanisms, right-of-way vegetation, precipitation characteristics, and construction activities.

The effects of highway runoff on groundwater quality depend on local hydrogeologic conditions. Particulate metals may be filtered out at the soil surface, and dissolved metals may be removed by adsorption onto soil particles during infiltration. However, highway runoff can have a more significant impact on groundwater quality in karst terranes, where soils may be thin or nonexistent and where groundwater recharge may occur directly through fractures, sinkholes, and sinking streams. Although hazardous materials releases present the greatest risk of acute groundwater impacts in karst areas, chronic and periodic impacts have been documented from highway-related pollutants. Whenever possible, highway alignment and other engineering controls should be designed to minimize the runoff of highway stormwater drainage into karst aquifer recharge features (sinkholes). Runoff treatment methods should be used only in areas where there is no feasible alternative to subsurface disposal of stormwater.

Because most contamination in highway stormwater runoff is associated with particulate material, sedimentation and/or filtration should be included in any treatment system design. However, because dissolved hydrocarbons also appear to be a significant component of highway runoff, adsorption or other measures should also be considered.

Following field visits to fifteen states, suitable sites for field testing of the runoff treatment methodology have been located in Knoxville, Tennessee, and Frederick, Maryland. At each of these sites, a karst aquifer receives recharge directly from high-traffic highways and related surfaces. Ground water flow routes have been determined by previous dye-tracing investigations at each site.

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STORMWATER ORDINANCE FOR CITY OF KNOXVILLE, TENNESSEE

Brently J. Johnson, P.E.[1], James L. Smoot, Ph.D., P.E.[2], and Bruce A. Tschantz, Ph.D., P.E.[3]

Due to the increase in development in the Knoxville area in the last 20 years and the 1987 amendments to the Clean Water Act, the need existed for the City of Knoxville to revise their ordinances. Presently, the ordinances are fragmented and very weak.

The 1987 amendments to the Clean Water Act required the City to obtain a National Pollutant Discharge Elimination System permit (NPDES) for the discharge of stormwater into Waters of the State. The City committed to the following management programs during the application process: (1) residential and commercial areas, (2) illicit discharge and proper disposal, (3) industrial facilities, and (4) construction sites.

In addition to this, the lack of well-organized neighborhood groups and a perceived need for economic development without overburdening the developers with expensive regulations, had in the past, resulted in inadequately controlling the impacts of new development on existing neighborhoods.

Upon recognizing the administration's desire to accommodate the neighborhoods need for eradicating problems created by new development, we put together a program to present to the Mayor's cabinet for discussion. After a series of five meetings lasting approximately two hours, we had direction to proceed.

This ordinance is a result of both the NPDES requirements and the City's desire to eradicate adverse effects of new development from the surrounding property owners. It is divided into five Articles. Article I, titled In General, Article II, titled Control of Rate of Stormwater Discharge, Article III, titled Water Quality Control of Stormwater Discharge, Article IV, titled Illicit Connections and Illegal Dumping, Article V, titled Water Quality Requirements for New Development. The most significant technical aspects of the ordinance are contained in Articles II and V.

Article II defines the design standards for detention ponds and the method of hydrologic and hydraulic computations. One significant item is that we are no longer requiring only a single staged outlet sized for release of the discharge which would have been created by the 10-year pre-development storm under AMC-I conditions. We are now requiring the outlets to be staged such that the discharge for a two-inch precipitation event, two-year, five-year, and ten-year storm post-development discharge not exceed the pre-development runoff from these respective storms. Additionally, we are now sizing the pond volume for the difference between the AMC-II pre-development inflow and the AMC-II post-development inflow.

Article V discusses water quality requirements for new development which will be the retention of the first one-inch of rainfall captured and attenuated over 48 hours. One significant finding which effects infiltration as well as runoff was the relationship of the hydrologic soil grouping to the textural classification.

As HR961 passes through the legislative process, Section P of the federal law could be deleted; therefore, the NPDES permit for municipalities would be deleted and delegation for water quality programs would be returned to the states. This may have an effect on our ordinances.

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[1]Stormwater Engineer, City of Knoxville, Knoxville, Tennessee 37901; phone: (423? 521-2148; FAX: (423) 521-2631

[2]Associate Professor, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, Tennessee 37996; phone: (423) 974-7718; FAX: (423) 974-2669

[3]Condra Professor, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, Tennessee 37996; phone: (423) 974-7721; FAX: (423) 974-2669

ESTIMATING THE IMPERVIOUS AREA IN AN URBAN WATERSHED FOR USE WITH POLLUTANT LOAD MODELING: SECOND CREEK, KNOXVILLE, TENNESSEE

Martha Castle[1]

INTRODUCTION

Poor water quality in surface streams in urban areas has become an increasingly serious problem. In recent years, water quality problems associated with urban streams have gained the attention of the federal government, and in 1990 the U.S. Environmental Protection Agency issued minimum water quality standards for urban stormwater runoff and surface streams (US EPA 1990). In order to comply with these federal mandates, urban areas must perform baseline and followup studies. However, since monitoring the dynamics of urban watersheds is difficult, especially considering the pervasiveness of nonpoint source pollutants, models must be used. These pollutant load models require, among other factors, the area of impervious surfaces. As this parameter is not directly measurable (except, possibly, in the tiniest watersheds, and then with difficulty), a number of estimation methods have been developed. One commonly used technique is "averaging-by-land-use," whereby an average percentage imperviousness is applied to the area of each of the land use types in the watershed. The result is a weighted mean for the whole watershed. While this method is relatively simple and cost-effective, it may not be accurate enough for use in the determination of runoff load calculations. This project examines the averaging-by-land-use method in the Second Creek watershed of Knoxville, Tennessee, and evaluates its accuracy by comparing it to GIS and air photo analysis techniques.

BACKGROUND

Surface runoff, defined as precipitation that travels over the ground surface to streams (Chow 1964), can occur in a number of ways, two of which are directly relevant. The first, Horton overland flow, occurs if the precipitation rate exceeds the infiltration capacity of the soil, and is dominant in zones with large areas of reduced infiltration capacity, such as urban lands. The second runoff-producing mechanism, saturation overland flow, occurs when precipitation continues beyond the point of soil saturation (Dunne 1988). By definition, saturation overland flow can only occur on pervious areas.

There are a number of methods for estimating runoff flow rates. The Rational Method, which was introduced in the late 1800's (Chow 1964; Lazaro 1979; Stephenson 1981), is possibly the most widely used, and has an equation of the form: $Q = C\ I\ A$, where Q = the peak discharge (in cubic feet/sec); C = the runoff coefficient; I = the rainfall intensity (in in/hr); and A = drainage area (acres).

The runoff coefficient C is expressed as the proportion of precipitation that contributes to runoff peak, assuming no infiltration or storage en route to the stream (Stephenson 1981). It must account for climatic, physiographic and soil characteristics, and it is assumed to be the same for: 1) storms of various frequencies and 2) all storms on a given watershed (Chow 1964). The runoff coefficient is subject to judgment. Without prior knowledge and information about the watershed, it is difficult to estimate useful and accurate values of C. Values of the runoff coefficient range from 0.05 for flat, sandy areas to 0.95 for impervious areas such as roofs and pavement.

A simple definition of an impervious surface is one whose infiltration capacity is zero (Lazaro 1979). Shaw expands on this definition (Shaw 1978), stating that impervious areas exist in urban and industrial

[1]University of Tennessee , Dept. of Geography, 408 G & G Building, Knoxville, TN 37996-1420

areas where there are many roofs and paved surfaces. On such areas there is little or no ground surface into which rainfall can infiltrate, so 100% rainfall can be assumed to become runoff.

The effects of impervious areas on urban watersheds are well documented. Runoff rates tend to increase with increased imperviousness, and lag time to peak rates is shortened (Lazaro 1979). There is very little depression storage on impervious surfaces (Chow 1964; Novotny, et. al. 1985), and transmission losses (for example, due to infiltration or detention storage) tend to decrease as imperviousness increases (Milligan, et al. 1984). Additionally, pollutant loadings also tend to be higher in watersheds with a higher percentage of impervious area (Milligan, et al.1984).

Camp, Dresser & McKee, an established environmental consulting firm, and the main contractor for Knoxville's National Pollutant Discharge Elimination System (NPDES) Permit Application, employed a method that can be termed "averaging-by-land-use" (for lack of a more official designation). The percentage of impervious area for each land use category was calculated by multiplying an assumed percentage imperviousness (which was based on Nationwide Urban Runoff Program (NURP) and TVA data) by the percent of total area of the watershed. The average for the entire watershed is simply the sum of the land use percentages. That is, total % imperv. = x(% area)(assumed % imperviousness) 100. There are a number of potential problems associated with this method, mostly resulting from inaccurate land use designations. First, small differences in category designation can result in drastically different impervious coefficients (for example, in Knoxville's NPDES permit application "public housing" is quite a different land use than "public land" (City of Knoxville, 1992). Second, it is important to make sure that the land is actually being used in the way it is designated, and has not changed with time. Third, the extent of imperviousness can vary greatly within each land use category. Each of these can cause error in determining imperviousness, and eventually, nonpoint source load estimates.

THE STUDY AREA

The Second Creek watershed in Knox County, Tennessee is one of eight urban watersheds in the city of Knoxville. Second Creek originates in north Knoxville, flows south more or less parallel to I-75/275 through the central part of the city, and empties into Fort Loudoun Lake (Tennessee River). It drains residential, commercial, and industrial areas, as well as portions of the University of Tennessee and downtown Knoxville. Although Second Creek is the smallest of the Knoxville watersheds (draining approximately seven square miles), its central location and wide variety of included land uses have created complex water quality problems. Urban runoff and nonpoint source pollution play a significant role, with additional problems thought to be brought about from possible groundwater exchange from other areas since the watershed lies in a karst area (Kung 1980; Milligan 1986).

To address these problems, raise public awareness of urban watersheds in general, and develop a model that can be used to assess and restore any urban watershed in the state, the Second Creek Restoration Demonstration project was created. Although the primary organizations are the Tennessee Department of Environment and Conservation Nonpoint Source Pollution Program (TDEC-NPS), and the Tennessee Water Resources Research Center, University of Tennessee (TNWRRC), thirteen other organizations are participating, including various independent, city, state, and federal agencies. This is a multidisciplinary, multi-year project whose long-term goal is to develop a practical assessment model that can be applied to any urban watershed.

Camp, Dresser & McKee performed a study of the Second Creek Watershed for the City of Knoxville's NPDES Stormwater Application (1992). To estimate annual runoff volume in the Second Creek watershed, they used an equation in the Watershed Management Model (WMM) that is similar to the Rational Method: Annual Runoff = C* (annual rainfall) for each of sixteen established land use types in the watershed. In Knoxville, the average annual rainfall average is 46.08 inches/year. To compute stormwater runoff coefficients (C), impervious areas were assumed to have a runoff coefficient of 0.95, and pervious areas a runoff coefficient of 0.15. For each land use, the equation is:

$$C = (\%\ \text{impervious area} * 0.95) + (\%\ \text{pervious area} * 0.15).$$

METHODS AND RESULTS

Since time constraints precluded the processing of the entire watershed, a sample subwatershed was chosen. Subwatershed 6 (Sub6), has an area of approximately 425 acres, and lies in the central, urban, portion of the watershed. Thirteen of the sixteen land uses are represented, with exceptions being mining, public parks, and private recreation.

Air Photo Technique. Aerial photographs of the Sub6 area were obtained from Knoxville/Knox County GIS (KGIS) and enlarged to 1" = 100'. The photos were edgematched, a clear plastic sheet was laid over them, and the pervious and impervious areas were manually traced with a marker. Then the plastic sheet was cut into 7.5x10" pieces and xeroxed onto graph paper, so that each square on the paper represents 100 square feet.

Areas of pervious and impervious regions were calculated directly, using a combination of four different methods: simple square-counting, a template for rectangular areas, a polar planimeter, and basic geometry for those areas that were easily divided into polygons. The total time involved was approximately sixty-five hours. This technique yielded results of 46.2% pervious area and 53.8% impervious area.

GIS Technique. An Intergraph line file containing Sub6 road, parking lot, building and sidewalk outlines was provided by KGIS. This file was first converted to an Arc/Info coverage, then "cleaned up" (dangles fixed and polygons closed), and each polygon given either an "impervious" or "pervious" notation. Then a database query was run to determine the total pervious and impervious areas in square feet. This phase took about sixteen hours, the vast majority of which was dedicated to cleaning up the linework and assigning tags. This technique yielded results of 40.3% impervious area and 59.7% pervious area.

Averaging-by-Landuse Technique. Since Camp, Dresser & McKee used Knox County tax records to determine the sixteen categories of landuse and their subsequent areas, KGIS agreed to duplicate this procedure for Sub6 only. They provided the percent of landuse for each of the sixteen categories in Sub6, which were then multiplied by the respective coefficients to get a weighted mean (see Table 1).

However, KGIS was unable to provide an exact duplication of categories on its first run. Notably missing are the categories of Vacant (over 10 acres), Rural Residential, Churches, Institutional, and Major Roads & Highways. In addition, two extra categories were added, Under Construction/Other Uses, and Unknown Land Uses/Not Loaded. While the addition of two categories is likely not significant, especially considering their low land use (both less than one percent), the omission of the others may be highly significant. In particular, Major Roads & Highways carries a percent imperviousness of .95, and since the subwatershed is in an urban area, it follows that the area covered in roads is likely relatively large. Likewise, the Churches and Institutional categories, while not as impervious as Roads & Highways, would have some effect in raising the impervious percentage. At the writing of this abstract, KGIS is making a second run on the data, attempting to determine the area covered by the missing categories. With the data currently available, this technique yielded results of 27.8 % impervious area and 72.2% pervious area.

CONCLUSIONS

The primary focus of this project was to determine the validity of the average-by-landuse method by comparing it to GIS and air photo techniques. While the latter two techniques were fairly consistent, their results for impervious area were about 20% higher than those obtained using preliminary results derived from the averaging method. The similarity of GIS results to those obtained by air photo analysis demonstrates the potential for using pre-existing GIS files to achieve good results in much less time. However, for the GIS method to be applicable to a given watershed, fairly comprehensive outline files must exist, This assumption is becoming more valid as municipalities are implementing GIS systems. The substantial difference in results between air photo analysis and averaging-by-landuse based on the first run of KGIS data underscores the need to have all of the relevant parameters included in GIS data. Averaging-by-landuse based on data that includes the area covered by the missing coverages is expected to yield results that more closely resemble those of other methods.

TABLE 1

LAND USE CATEGORY	%IMPERVIOUSNESS	%LAND USE	%IMPERV
Agric., forestry, vacant	1	14.81	0.15
Public Parks	1	0	0
Vacant (over 10 acres)	5	np1	0
Rural Residential	20	np1	0
Single Family Resid.	25	67	16.75
Private Recreation	35	0	0
Public Land	35	3.45	1.20
Multi-Family Residential	40	5.05	2.02
Churches	40	np	
Institutional	50	np	
Mining	60	0	0
Offices & Services	60	1.6	0.96
Manufacturing & Wholesale	72	1.09	0.78
Commercial	85	4.97	4.22
Transp. Util. & Communication	85	1.01	0.85
Major Roads & Highways	95	np	
Under Construction/Other Uses	90	0.76	0.69
Unknown Land Uses/Not Loaded	50	0.5	0.13
TOTAL	27.75		

np: not provided by KGIS
1 considered 0, since this is an urban area

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INVESTIGATING DAIRY LAGOON EFFLUENT TREATABILITY IN A LABORATORY-SCALE CONSTRUCTED WETLAND

B.L. Benham[1]

Dairy lagoon supernatant treatability was evaluated using ten laboratory-scale (1.5 m by 0.5 m) constructed wetlands. Select design and operational variables were examined. Tested treatments were combinations of three organic loading rates (waste strength levels; high, medium, and low) and three types of microbial attachment sites (vegetated, plants; inert, wooden dowels; and none, no attachment site). Five combinations of organic loading rate and microbial attachment site were tested. Removal efficiencies were based on analysis of influent/effluent waste constituent levels. Dominant nitrogen removal mechanisms were determined from an examination of influent/effluent nitrogen speciation. And, an analysis of waste utilization kinetics provided insight as to the applicability of a widely used design model.

Results showed consistently high nitrogen removal efficiencies (65 to 81 percent) for all treatments. Nitrogen speciation results indicate that nitrification/denitrification was the dominant nitrogen removal mechanism. Carbon removal was less efficient (6 to 39 percent) and varied with influent strength. Kinetic-rate constants from the five treatments were not statistically different ($\alpha = 0.05$). The evaluated design model uses microbial attachment site parameters like specific surface area to modify a base reaction rate-constant (i.e., a rate-constant for a system with no microbial attachment sites). In this case, the rate-constant for the control (treatments with no microbial attachment site) was not statistically different from either the vegetated or inert treatments. This result illustrates shortcomings with the evaluated design model.

[1]U.S. Geological Survey, 1013 North Broadway, Knoxville, Tennessee 37917, Phone: (423) 545-4140; Fax: (423) 545-4227

THE STATUS OF WATERSHED MANAGEMENT WITHIN THE TDEC's DIVISION OF WATER POLLUTION CONTROL

Pat Patrick[1]

ABSTRACT

After nearly two years of examining the Division's operation and various approaches to watershed management, the Division of Water Pollution Control implemented a Watershed Management Approach to Permitting in January, 1996.

WATERSHED MANAGEMENT CYCLE

The approach can best be illustrated by a five year cycle (see attachment) which starts with a planning workshop of stakeholders. This workshop is to gather concerns from the stakeholders within the watershed. The information available and the additional information needed to adequately evaluate the water quality of the watershed, to develop protective discharge permit limits, and to recommend source management strategies are evaluated and data gathering efforts are planned during this phase.

The Division is currently in this phase in a small group of watersheds. The cycle will be initiated in additional groups of watersheds each year.

The second and third years will be devoted to gathering the information needed to define the water quality within the watershed and to allocate the stream's capacity to assimilate waste. Another workshop will be held at the end of the third year to share the information with the stakeholders.

During the fourth year the information and data will be examined, the water quality will be evaluated, and the causes and sources of stream impacts will be determined. Discharge limits will be drafted for all dischargers within the watershed to address those sources of impacts which the Division regulates. Recommendations for correction of those sources not regulated by the Division are to be developed. The evaluations, impact causes and sources, discharge limits and non-point recommendations will be contained in a Watershed Management Plan. It is hoped that the Watershed Management Plan will serve as a catalyst to other agencies and organizations in correcting some of the impact causes.

In the fifth year the Watershed Management Plan is to be presented to the watershed's stakeholders in another public meeting. Discharge permits will also be drafted based on the Watershed Management Plan. These permits will be issued in the sixth year of the cycle, which is also the first year of the next cycle.

DEFINITION OF WATERSHEDS

Other states in the Southeast have divided their study areas into relatively large, continuous watersheds which might comprise one fifth of the state. They have monitoring teams that are reassigned every year or two to the watershed under study. Tennessee is different in that we have six field offices staffed with technical personnel who do the inspections, monitoring and stream surveys. In order to more evenly utilize this manpower, sub-watersheds are based on the Hydrologic Units defined by USGS's eight digit code (HUC's) and then grouped into five groups with as near an even number of permitted dischargers in each

[1]362 Carriage House Drive, Jackson, Tennessee 38305-2222; (901) 661-6201

group. Each field office has watersheds in each of the five groups and those watersheds shared by two offices are in the same group. By utilizing the watershed approach, the field offices can better target their monitoring and survey efforts to those streams where information is needed for multiple dischargers.

WATERSHED MANAGEMENT SECTION

A new section has been created in the Division with the duties of coordinating the stakeholder workshops, compiling the gathered information and drafting the Watershed Management Plans. It is headed by Dr. Sherry Wang, formerly with the Planning and Standards Section and the Natural Resources Section. It is staffed by professionals with expertise in groundwater monitoring, habitat restoration, wasteload allocations and GIS.

PERMITS

The keystone to such an approach is to have all of the discharge permits within a watershed expire at the same time. Currently the permits' expiration is random due to the initial random submittal of permit applications. The Division's three permitting sections - Municipal Facilities, Industrial Facilities and Mining - will use a combination of issuance of short term permits and revoke and reissuance of permits to adjust the expiration dates of the permits. This process should be completed within six years, the same time that the first group of watershed based permits are to issued.

WATERSHED COMMITTEE

The Watershed Management approach implemented by the Division was developed by a committee of Division employees: Dr. Sherry Wang, Manager of the new Watershed Management Section; Ms. Saya Qualls, PE., Municipal Facilities Section; Ms. Pat Patrick, Manager of the Jackson Field Office; Mr. Arup Bandyopadhyay, Industrial Facilities Section; and Mr. Greg Denton, Manager of the Planning and Standards Section.

IMPACTS OF MANURE APPLICATIONS IN SILAGE CORN ON SUBSURFACE AND SURFACE WATER QUALITY

M. D. Mullen[1], D. D. Tyler, G. V. Wilson, P. G. Gale, and D. C. Yoder[2]

An experiment was initiated in May 1991 to investigate the impacts of surface applied dairy manure on subsurface and surface water quality. Tension-free pan lysimeters were installed at a depth of 90 cm in 18 plots to collect leachate. Six treatments were imposed: a O nutrient control; 168 kg N ha^{-1} as ammonium nitrate plus P and K fertilizers; and 4 rates of N as dairy manure, 112, 252, 378, and 504 kg N ha^{-1}. Nitrate-N concentrations in leachates rarely exceeded 4 mg of NO_3-N L^{-1}. However, cumulative losses of N from the root zone were significantly higher at the 504 kg N ha^{-1} manure rate. For 1994, over 45 kg of nitrate-N ha^{-1} leached from the root zone compared with less than 25 kg N for all other treatments. The data indicate that the continued application of 504 kg manure-N/ha is causing an accumulation of mineralizable N, resulting in greater leaching losses over time. Runoff volumes from the 168 kg N ha^{-1} treatments has generally been greater than from the 504 kg manure-N plots. Phosphorus concentrations in runoff from the manured plots was usually greater than from the non-manured plots, but lower amounts of runoff resulted in few differences in P export. Losses of P were less than 300 g P ha^{-1} per runoff event in 1994. Based on water quality data and yield data to date, we would recommend that producers in the loess soil region of west Tennessee apply no more than 300 kg manure-N per hectare yearly.

[1]Associate Professor, Dept. Of Plant and Soil Science, P.O. Box 1071, University of Tennessee, Knoxville, TN 37901-1071

[2]University of Tennessee, Knoxville, Tennessee

HYDRAULIC CONDUCTIVITY ESTIMATES FROM SLUG TESTS IN A KARST TERRANE, OAK RIDGE, TENNESSEE

Allen Motley[1] and Loren K. Demaree[2]

INTRODUCTION

During the summer of 1994, slug tests were conducted at monitoring wells throughout the K-25 Site, near Oak Ridge, TN. More than 200 existing groundwater wells at the K-25 Site provide access to bedrock and unconsolidated hydrogeologic units. Values of hydraulic conductivity were obtained at 187 well locations (ECE 1994b).

BACKGROUND

Prior to 1994, hydraulic conductivity values were available for only 46 wells at the site (Geraghty & Miller 1989). K-25 Environmental Restoration Division's Groundwater Program requires groundwater data that is accurate and representative of site conditions, which will improve aquifer characterization. This project is a part of ongoing efforts to determine human health and environmental risks from contaminated groundwater at the K-25 Site (ECE 1994a).

These slug tests were performed to provide order of magnitude estimates of hydraulic conductivity for a geographic distribution of wells across the K-25 Site. Variations within a geologic formation and between formations were also identified (ECE 1994b).

FIELD METHODS

Electronic data loggers and 10 PSI pressure transducers from In-Situ, Inc. were used. This equipment was chosen for its field durability, ability to provide industry standard accuracies in water level measurements (±~0.01 feet @ 15 deg C, with a resolution of ~0.003 feet), and sufficient variability in programming modes of data acquisition and retrieval.

Pressure transducers were placed about 7-12 feet below static water levels to allow complete slug submergence and to maximize the representativeness of the collected data. Solid PVC slugs (3.5 in/8.89 cm x 5.00 ft/1.5239 m for 4 in/10.16 cm ID casing and 1.5 in/3.81 cm x 5.00 ft/1.5239 m for 2 in/5.08 cm ID casing) were used to stress the aquifer, providing the 4 inch ID and 2 inch ID wells with ~3 feet and ~2 feet, resp., of initial water level displacement within the well casing.

A subset of wells completed in bedrock are paired with vertically nested wells completed in unconsolidated material overlying the bedrock. Water levels in the paired well were monitored during these slug tests to evaluate hydrologic connection between the paired wells.

Test data were collected until well levels recovered at least 90% of the initial change in water level, until precipitation or other influences significantly perturbed the recovery response, or until at least 12 hours

[1]Lockheed Martin Energy Systems, Inc., P.O. Box 2001, Oak Ridge, TN, 37830; Phone: 423-576-5782; Email address: motleyca@ornl.gov

[2]Environmental Consulting Engineers, Inc., P.O. Box 22668, Knoxville, TN 37933; Phone: 423-691-3668; Email address: ldemaree@ece.com

had elapsed. Step-logarithmic data frequency was used, beginning at ~3 data points per second and utilizing a maximum of 15 minutes (after 100 elapsed minutes of a test). Manual measurements were typically collected during the first several minutes of each test as both a backup and a Quality Assurance measure of the electronic data logging systems.

The Bouwer And Rice method of slug test analysis (Bouwer and Rice 1976) was used to calculate estimates of hydraulic conductivities for all tests (see report for well UNW-36). The Bouwer and Rice method is stated as applicable to fully and partially penetrating wells, unconfined and confined aquifers, rising head tests, and, with some restrictions, falling head tests (Bouwer 1989). Data downloading and analysis in the field allowed efficient determination of completion and validity of the tests.

RESULTS

The results of slug tests conducted in wells at the K-25 Site indicate that hydraulic conductivity values generally fall within the expected range for the geologic materials present at the site. Domenico and Schwartz (1990) report a range of 1.0x10-7cm/sec to 2.0 cm/sec for limestone and karst aquifers. The hydraulic conductivity values obtained from the wells at the K-25 Site ranged from 2.97x10-7 centimeters/second (cm/sec) to 7.77x10-2 cm/sec.

The data show a wide range of hydraulic conductivity values between wells and geologic formations. A high degree of variability also exists within both the unconsolidated zone and the bedrock. Although there are differences in hydraulic conductivity between individual bedrock formations and the unconsolidated zone, the mean values determined for the bedrock and the unconsolidated zone materials are quite similar. Detected paired well responses were produced in very few of the paired well tests, were small (<~0.02 feet), and of short duration (seconds).

Geographic distributions of hydraulic conductivity values are shown graphically (from Energy Systems 1994). Explanation of formation names can be found in ECE, 1994a. This map shows top-of-bedrock geology with superimposed hydraulic conductivity range symbols, while the K-25 Hydraulic Conductivity by Formation graph refers to the formations in which the wells are completed (screened section).

Hydraulic conductivity in the bedrock ranged from 5.72x10-7 cm/sec to 7.77x10-2 cm/sec. Hydraulic conductivity in the unconsolidated zone ranged from 2.97x10-7 cm/sec to 7.45x10-2 cm/sec. The means of the hydraulic conductivity for the bedrock and the unconsolidated zone were quite similar at 4.27x10-3 cm/sec and 1.25x10-3 cm/sec, respectively.

The highest hydraulic conductivity value was obtained at a bedrock well completed in what is interpreted to be limestones of the Pond Spring Formation (Lemiszki 1994). The lowest value was obtained at a well completed in clays of the unconsolidated zone. The greatest range in minimum and maximum hydraulic conductivity values occurs in the shallowest depths (0-50 ft) and this range becomes slightly more constrained with depth. However, in some instances, the lowest hydraulic conductivity for a given formation was obtained at shallow depths.

The spatial distribution of hydraulic conductivity across the site also is highly variable. Within a given geologic formation, the range of hydraulic conductivity values may span up to five orders of magnitude (ECE 1994b). This high degree of variability is not unexpected given the complex hydrogeologic conditions at the K-25 Site. In addition, there are inherent limitations in the use of slug tests for determining hydraulic conductivity and these limitations are only amplified by the high degree of karst development underlying the site.

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Bouwer & Rice Calculator (Ver 1.0)

Run Title

07-18-1994 Rising Head Test for UNW-36

Input Data

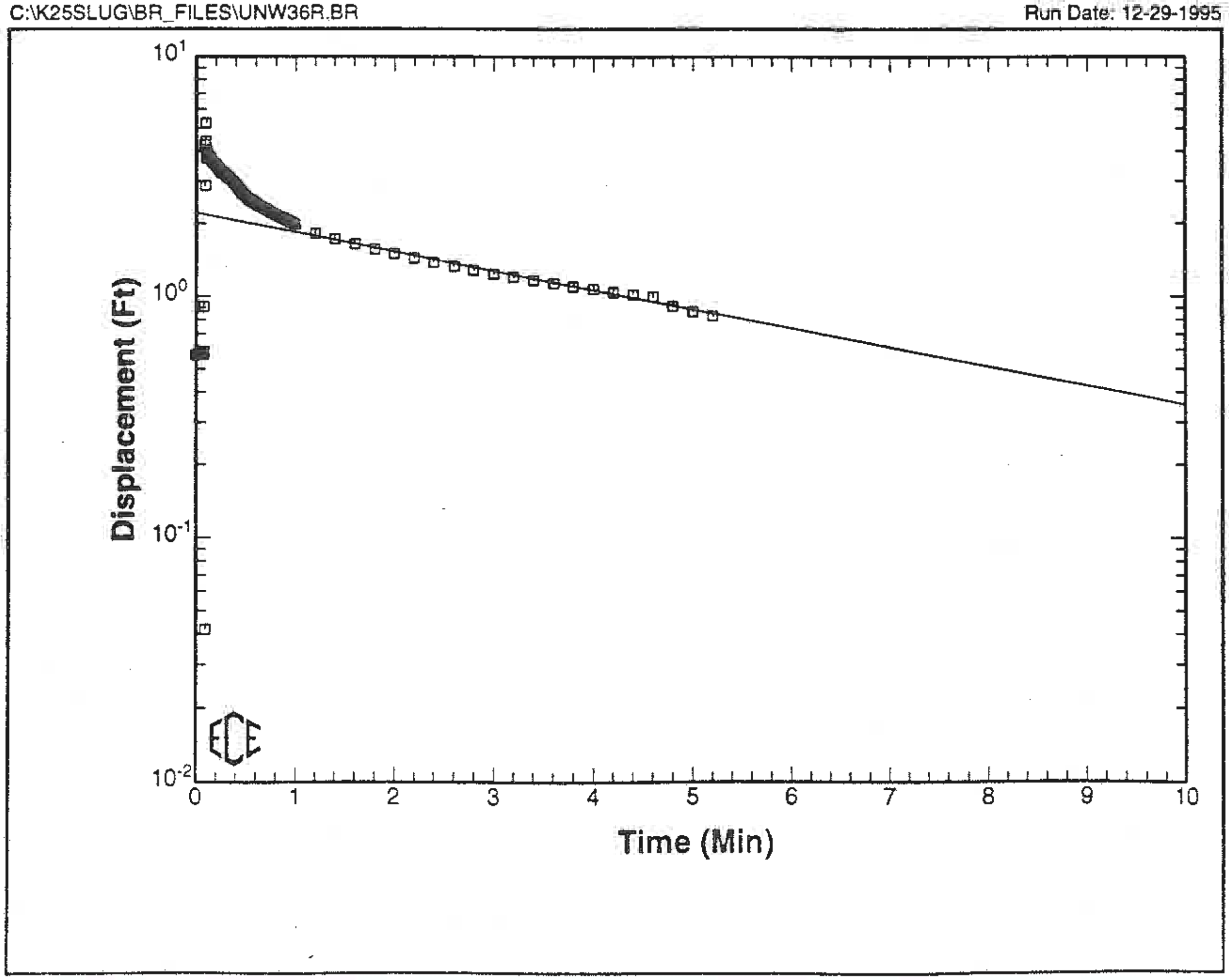
Well ID:	UNW-36R	Sat Thickness (H):	100 Ft
Casing Radius:	.167 Ft	Sat Penetration (Lw):	6.65 Ft
Boring Radius:	.375 Ft	Screen Length (Le):	10.4 Ft

Valid Data Points: Starting: 1, Ending: 162

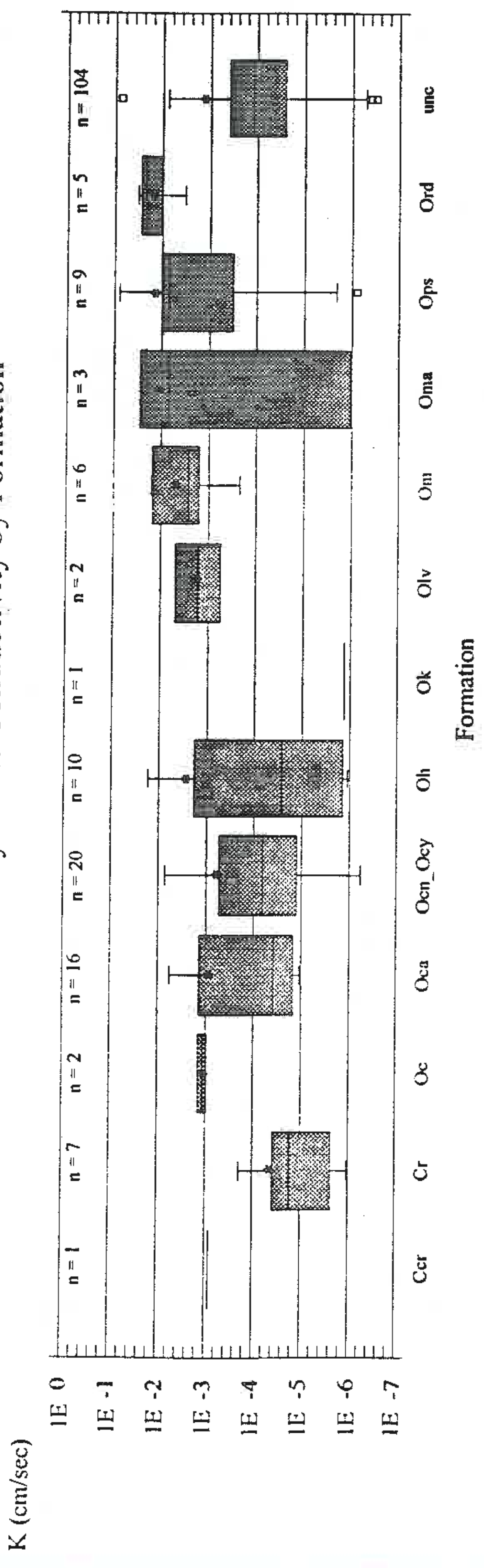
Summary of Results

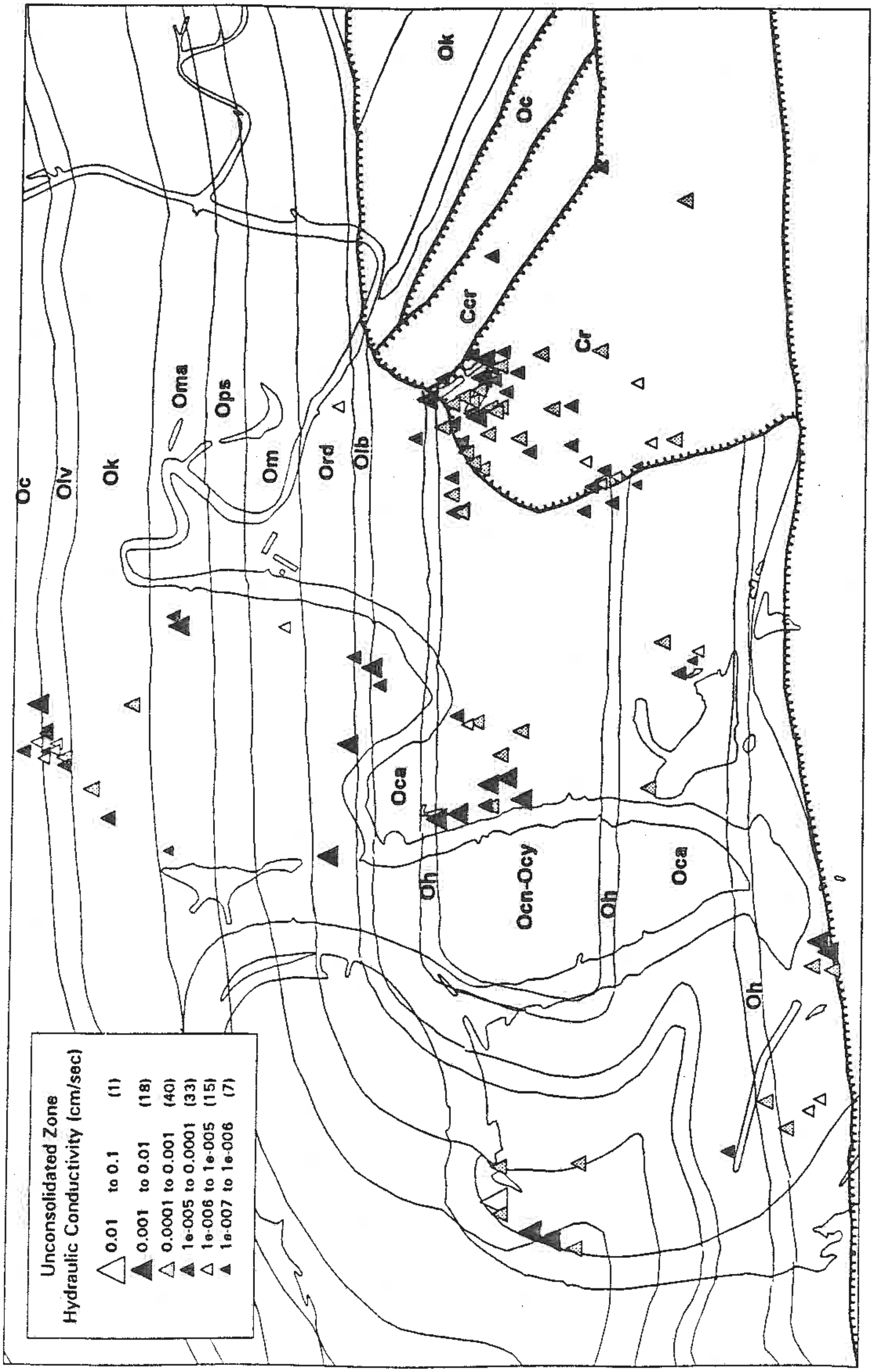
Hyd. Conductivity:	2.32E-04 Cm/Sec	Pick1 X:	1.33 Min
Y0:	2.21 Ft	Pick1 Y:	1.74 Ft
Effective Radius (Re):	2.41 Ft	Pick2 X:	5.09 Min
Maximum Displacement:	5.22 Ft	Pick2 Y:	.67 Ft

C:\K25SLUG\BR_FILES\UNW36R.BR Run Date: 12-29-1995



K-25 Hydraulic Conductivity by Formation





Unconsolidated Zone Hydraulic Conductivity at the K-25 Site

CONTINUOUS MONITORING OF WATER LEVELS, CONDUCTIVITY, AND TEMPERATURE IN A KARST TERRANE, OAK RIDGE, TN: FIELD METHODS AND PRELIMINARY RESULTS

Loren K. Demaree[1] and Robert S. Poling[2]

INTRODUCTION

Continuous monitoring of water levels in wells within and around the Department of Energy K-25 Site near Oak Ridge, Tennessee is being conducted by Environmental Consulting Engineers, Inc. (ECE) for Lockheed Martin Energy Systems. Field data collection began in February of 1995 and is projected to extend through most of 1996. More than 200 existing groundwater wells at the K-25 Site provide access to bedrock and unconsolidated hydrogeologic units. A subset of wells that are believed to be completed in solution cavities ("karst" wells) are also monitored for specific conductivity and temperature. Presentation and discussion includes methods used, graphical data, preliminary results, and associated technical aspects of time-continuous data collection.

PURPOSE

K-25 Environmental Restoration Division's Groundwater Program requires groundwater data with temporal and spatial variability that is accurate and representative of site conditions, which will improve aquifer characterization. This is a part of ongoing efforts to determine human health and environmental risks from contaminated groundwater at the K-25 Site.

These data should show the varied responses of and relationships both between geologic units and between wells to a variety of influencing factors. These factors include precipitation events, short-term (days to weeks) sub-regional hydrologic trends, and both anthropogenic and tidal influences. Potential uses of the data are determination of hydrologic connectivity, groundwater flow path determination, determination of karst influence on the groundwater system, to aid groundwater monitoring and sampling, and groundwater flow and contaminant transport modeling (ECE 1995).

FIELD METHODS

The spatial and lithologic variability of monitoring points is determined by the locations of existing monitoring wells and piezometers at the K-25 Site. Wells monitored simultaneously are typically in close geographic proximity to one another, allowing evaluation of heterogeneities and other properties over short distances (meters to hundreds of meters).

Electronic data loggers, pressure transducers, conductivity probes, and temperature probes from In-Situ, Inc. were selected and procured. This equipment was chosen for its proven field durability, ability to provide industry standard accuracies in water level measurements (±~0.01 feet for standard 10 PSI transducers), and sufficient flexibility in programming modes of data acquisition and retrieval.

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[1]Environmental Consulting Engineers, Inc., P.O. Box 22668, Knoxville, TN 37933; Phone: 423-691-3668; Email address: ldemaree@ece.com

[2]Lockheed Martin Energy Systems, Inc., P.O. Box 2001, Oak Ridge, TN, 37830; Phone: 423-576-5493; Email address: polingrs@ornl.gov

Pressure transducers, as well as conductivity and temperature probes for designated "karst" wells, are placed in the wells at depths selected to maximize the representativeness of the collected data. Data loggers are programmed to record simultaneously at fifteen minute intervals. Periodic service visits are performed to ensure data collection accuracy and continuity, and to transfer data from the data loggers.

A subset of wells completed in bedrock are each paired with a vertically nested well completed in unconsolidated material overlying the bedrock. These paired wells are monitored simultaneously to evaluate hydrologic connection between the paired wells.

A subset of wells completed in bedrock are monitored for water levels using a packer and reducer pipe system. Use of this system is required by that well having any historic water level measurement greater than 25 feet above the midpoint of the screened section of the well (ECE 1995). The time and expense of this requirement is needed to ensure that any potentially large inertial effects will be minimized, and that short duration groundwater responses can be adequately monitored.

PRELIMINARY RESULTS

Preliminary analysis of the data reveal varying degrees of influence by precipitation events, changes in level of surface water bodies (primarily Poplar Creek), tidal and barometric variations, and anthropogenic events. Wells positioned closely, by spatial and formation relationship, generally show very similar responses, but often have responses that are significantly dissimilar.

The influence of precipitation events on "karst"-designated wells, which are monitored for specific conductivity and temperature, in some instances show hydrograph-type responses of increasing specific conductivity and temperature, while some instances show responses of decreasing conductivity and temperature (see graph of BRW-68). Examples of continuous data for some wells show tidal influences in "daily" and lunar monthly cycles, both in bedrock and unconsolidated material. Paired (bedrock/unconsolidated) wells monitored to date have exhibited a variety of precipitation response/behavior characteristics. These include identical water level elevations, identical scale of response at different water level elevations, and either the bedrock or the unconsolidated well responding while the other shows little or no response.

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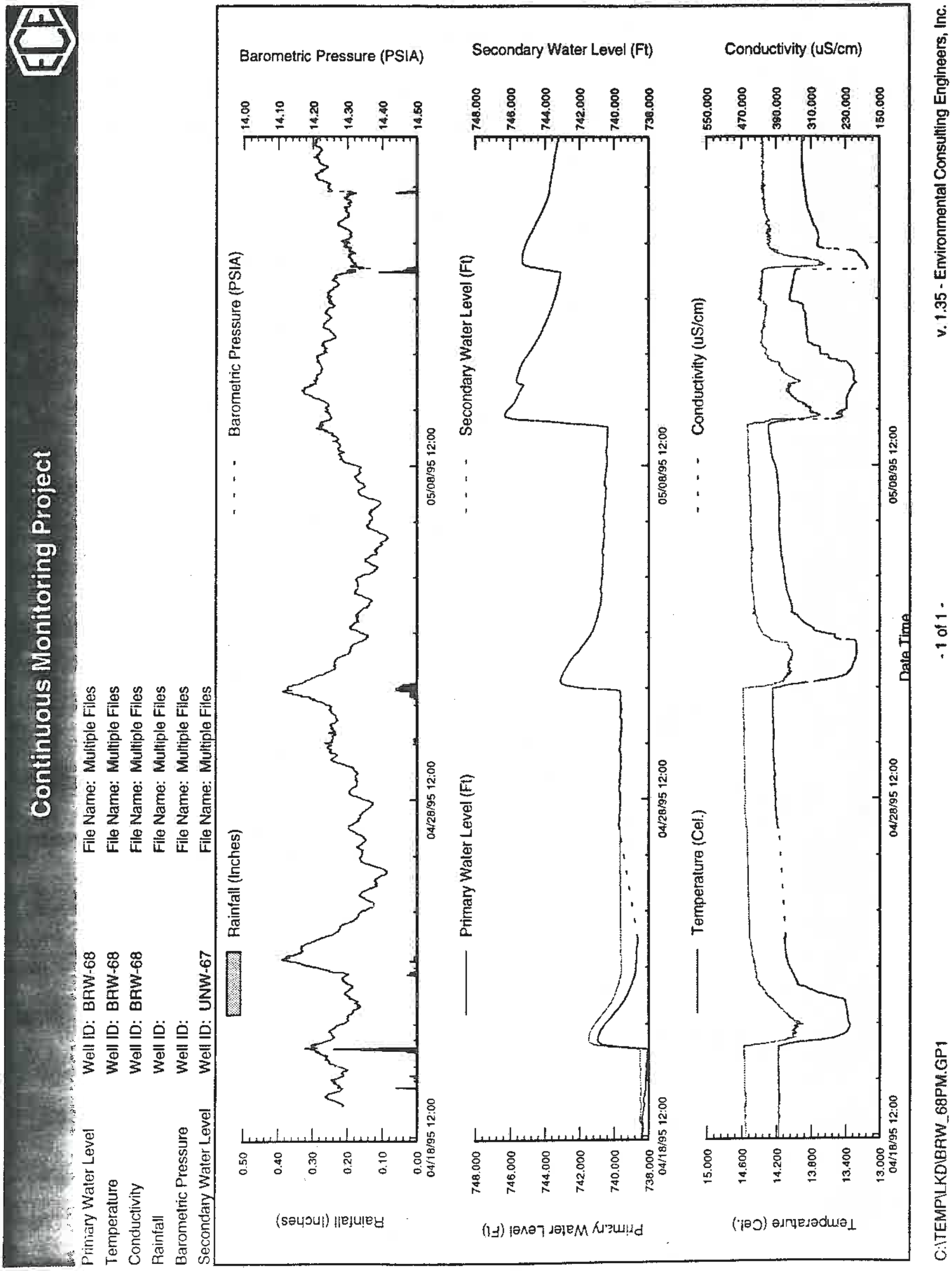
Continuous Monitoring Project
Primary Water Level Well ID: BRW-68 File Name: Multiple Files
Temperature Well ID: BRW-68 File Name: Multiple Files
Conductivity Well ID: BRW-68 File Name: Multiple Files
Rainfall Well ID: File Name: Multiple Files
Barometric Pressure Well ID: File Name: Multiple Files
Secondary Water Level Well ID: UNW-67 File Name: Multiple Files
Rainfall (Inches)
Barometric Pressure (PSIA)
Primary Water Level (Ft)
Secondary Water Level (Ft)
Temperature (Cel.)
Conductivity (uS/cm)
0.50
0.40
0.30
0.20
0.10
0.00
14.00
14.10
14.20
14.30
14.40
14.50
748.000
746.000
744.000
742.000
740.000
738.000
15.000
14.600
14.200
13.800
13.400
13.000
550.000
470.000
390.000
310.000
230.000
150.000
04/18/95 12:00
04/28/95 12:00
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Date Time
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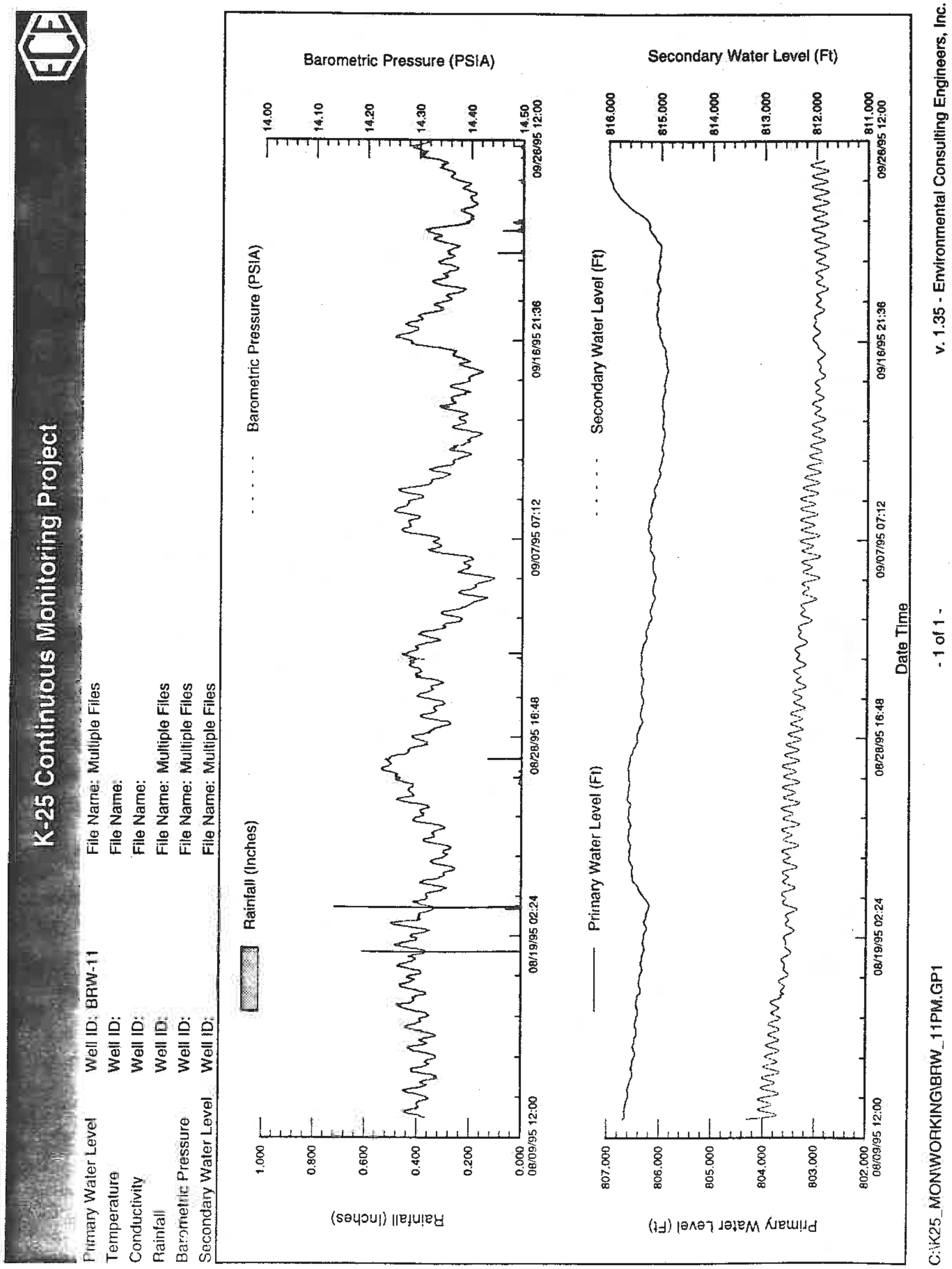
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Primary Water Level Well ID: BRW-11 File Name: Multiple Files
Temperature Well ID: File Name:
Conductivity Well ID: File Name:
Rainfall Well ID: File Name: Multiple Files
Barometric Pressure Well ID: File Name: Multiple Files
Secondary Water Level Well ID: File Name: Multiple Files
Rainfall (Inches)
Barometric Pressure (PSIA)
Primary Water Level (Ft)
Secondary Water Level (Ft)
1.000
0.800
0.600
0.400
0.200
0.000
14.00
14.10
14.20
14.30
14.40
14.50
807.000
806.000
805.000
804.000
803.000
802.000
816.000
815.000
814.000
813.000
812.000
811.000
08/09/95 12:00
08/19/95 02:24
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09/07/95 07:12
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09/26/95 12:00
Date Time
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IDENTIFYING THE SOURCES OF WATER-QUALITY IMPAIRMENT IN AN AGRICULTURAL KARST TERRANE

Tom D. Byl[1] and Brad Hazlett[2]

The North Fork - Fall Creek Hydrologic Unit Area is an agricultural watershed located in Bedford County, Middle Tennessee. Land use in the watershed includes agricultural production (poultry, cattle, riding horse operations, and row crops), forestry, and residential and commercial developments. The watershed is situated on a karst terrane with thin soils, sinkholes, caves, and conduit-type subsurface flow. The ground water and surface streams are well connected through these conduits. Concern about nutrient enrichment and fecal pollution prompted efforts to identify and mitigate sources of contamination. In 1994, the U.S. Geological Survey in cooperation with the Tennessee Department of Agriculture, Natural Resources Conservation Service, and Bedford County Soil Conservation District, began to characterize surface-water quality throughout the watershed. The objective of the study was to determine the origination of nonpoint-source pollution in the watershed. Stream nitrate-nitrogen concentrations ranged from 0.1 to 10 milligrams per liter. Fecal bacteria concentrations exceeded 1,000 colonies per 100 milliliters in 14 of 16 tests. Optical brighteners, which are indicative of septic systems, were detected in four of seven tributaries. Cattle were commonly observed in some of the streams. The results indicate that both humans and agricultural animals contribute to the impaired water quality.

[1]U.S. Geological Survey, 810 Broadway, Suite 500, Nashville, Tennessee 37203; tdbyl.er.usgs.gov; (615) 736-5424

[2]Bedford County Soil Conservation District, 709 E. Lane St, Shelbyville, Tennessee 37160

AN APPLICATION OF THE SWMM MODEL USING GIS TECHNIQUES AND A WINDOWS INTERFACE

Gerald A. Burnette[1]

INTRODUCTION

The U.S. Department of Energy (DOE) wanted to assess the effects of a predetermined, theoretical storm event on the storm drain system at one of its large facilities. Environmental Consulting Engineers, Inc. (ECE) was hired to gather field data and develop a computer model to evaluate the system. After evaluating several models, ECE chose the Environmental Protection Agency's (EPA) Storm Water Management Model (SWMM) for the project. Detailed descriptions of the structures and conduits that make up the system were supplied by the facility operator (client), while ECE provided watershed delineation as well as descriptions of all open channels affecting the system. During the course of the project, several computer programs were developed to assist in the analysis. Most notably, a geographic information system (GIS) was developed for displaying components of the storm drain system. Additionally, a front end for the SWMM model was developed, which allowed the model to be run in the Microsoft Windows environment. This paper describes some of ECE's efforts on this project and highlights the custom programs developed.

THE STORM DRAIN SYSTEM AND THE MODEL

The storm drain system analyzed in this study consists of six networks of subsystems; the subsystems are determined by geographic proximity. Each subsystem is composed of a single discharge point (outfall) and all of the pipes, open channels, structures, and areas that route water to that point. Because SWMM models the response of a single set of connected structures, the model needed to be run independently for each of the more than 150 outfalls in the system. This need to generate a large number of input data sets was the primary motivation for developing a Windows front end for the model. Also, the subsystems are often tightly spaced (and sometimes interlocking), making it difficult for field crews to properly identify the outfall associated with a particular structure or area. This arrangement motivated the development of a GIS-based tool for producing maps of specific outfalls and their subsystems.

The client initially provided ECE with design drawings of the storm drain system. The age of the system, though, necessitated field verification of all the conduit and junction data. The client hired another contractor to perform this service and used the results to build an electronic database describing the system. Several components of the system (e.g., roof drains) channeled water through small pipes to larger structures. For various reasons, it was agreed that these small conveyances would be omitted from the model. As a rule, only pipes 12" or larger in diameter were included. While the other contractor was gathering pipe and structure data, ECE's field crews delineated the area that drained to each catch basin and manhole. ECE also determined the characteristics of each open channel that was to be included. These elements were also entered into an electronic database, so that all the parameters needed to physically describe each subsystem could be read automatically by a computer program.

[1]Environmental Consulting Engineers, Inc., P.O. Box 22668, Knoxville, TN 37933; Phone: (423) 691-3668; e-mail: burnette@ece.com

THE DATA AND THE PROGRAMS

Analysis of the first versions of the data supplied by the client indicated some problems. The most common problems were missing data and elevation data that were inconsistent between the pipes and structures records. The first programs written for the project, then, were ones that performed quality checks of the client-supplied data. These included programs that performed the following functions:

- filled in key missing data in the pipes table. The pipes table, as supplied by the client, did not include upstream and downstream structures or coordinates. These items were discernible from the pipe designation, though, so a program was written to perform this function. Also, the surface roughness for each pipe was inserted using a standard for the material and construction of each pipe.
- compared the pipe invert elevations listed in the structures and pipes tables. The pipes table contained invert elevations at each end of the pipe, while the structures table contained invert elevations for each pipe connected to the structure. The program compared the elevations in each table, filled in data found in one table but missing from the other, reported data missing from both tables, and reported cases where the two tables showed different elevations for the same pipe.
- checked for potential SWMM errors. SWMM will not allow the invert elevation of any incoming pipe to be lower than the invert of the outgoing pipe for a given structure. The program checked for this condition and, when it was found, adjusted the incoming pipe invert to 0.1 ft above the outgoing pipe invert. These changes were noted in a comments field of the table.
- traced the connectivity of a system to supply all records with the appropriate outfall number.
- imposed artificial ground elevations when the true elevation was missing. As a rule, the elevation entered was 2 ft above the crown of the highest pipe.

These program provided ECE with a high degree of confidence in the completeness and consistency of the pipes and structures data.

The next programming effort for the project involved the development of a GIS-like tool for displaying all the structures and pipes associated with a particular outfall. This effort was designed to support ECE's field data gathering activities. Early work in the delineation of drainage areas was hampered by questions as to whether particular collection structures were connected to the system via 12" or larger pipes, insuring inclusion in the pipes table. The GIS program was developed specifically to address these situations.

The program was developed for use with MapInfo, a desktop mapping package for Windows. A base map of the facility, which included layers for roads, buildings, and water (rivers and streams), was imported into MapInfo. The structures table was imported and geocoded, and the pipes table was imported. A program was then developed in MapBasic that would prompt the user for an outfall number, then display all the structures associated with that outfall and draw lines representing the pipes connecting the structures. During the course of the project, features were added to this program until it became a very valuable tool. In the end, the program drew lines for pipes and open channels in any style and color selected by the user, displayed different types of structures in different symbols, and labeled the structures automatically. This program was used by the field crews for identifying structures and determining connectivity, by the modelers for verifying model input, and by the project engineers for producing maps of outfalls for inclusion in the report. See Figure 1 for an example of a map produced by the program.

THE WINDOWS INTERFACE

The largest amount of programming time for the project went into the development of a Windows-based interface to the SWMM model. As previously mentioned, the need to quickly generate input data sets (many of which would be very similar) was the primary motivation for developing this interface. The resulting program is not generally applicable—it was designed specifically for this project and therefore has some limitations. First, input data can be generated for only two of SWMM's blocks: RUNOFF and EXTRAN. Second, some assumptions were made regarding all the input data sets; the corresponding sections of the input files were hardcoded instead of allowing for user options. The most important of these assumptions were

- only the predefined rainfall event would be modeled;
- no base flow would be indicated;
- initial depth of water in all junctions would be zero;
- all manholes were assumed to be 4 ft in diameter;
- all structures except outfalls, pipe junctions, and sealed junctions were allowed to store water; and
- all outfalls were modeled as elevated discharges.

The main dialog for the interface is shown in Figure 2. As can be seen from this screen, the focus of the interface is on identifying various data sources and other files. The user can specify the names of database files containing each type of modeled element, the name of the SWMM input file to be generated, and the names of the various SWMM output files to be generated. The user also specifies which SWMM blocks to generate and selects the network and outfall to be modeled. Of particular interest here is the "SWMM Control Center Configuration File." This file saves all the settings made in a particular session in a standard Windows initialization file format, allowing later restoration using a single file selection process. This feature provided must helpful in generating input files quickly because the user could load a configuration file for a similar outfall and change only a few options. Also from this main dialog, other dialogs can be launched that allow the user to purposely omit selected pipes and structures from the model input data set.

The next most important screens in the program are the ones that set the parameters used by each of the model blocks. The "Runoff Block Controls" dialog allows the user to set the starting date of the simulation and the start time of the storm event. The length of the simulation can also be varied, although the duration of the actual rainfall event cannot. The RUNOFF Block uses three different time steps according to conditions that vary during the simulation, and these can be controlled here as well. During operation, SWMM runs each block successively and independently. The time steps used in each block do not, therefore, have to match. The "Extran Block Controls" dialog allows the user to control the time steps used in the EXTRAN Block, but also includes a routine that will calculate the number or duration of steps needed to match the EXTRAN time to the RUNOFF storm duration. The user enters either the number of time steps desired or the duration of each step, and the other parameter is calculated and inserted. Several other parameters can be controlled fro this dialog. Most notably, a maximum iteration count can be attached to surcharge calculations in order to prevent the model from hanging.

After the appropriate files have been selected and options have been set, the interface provides a dialog that tracks the building of the SWMM input file. This dialog displays a general status indicator that identifies each section of the input file as it is constructed. There are also indicators that identify the specific elements being read from each table. After the input file is constructed, the model can be run directly from the interface. When the model is run, a DOS shell is launched so that the normal SWMM messages are displayed. After termination of the model, control returns to the interface program. Results of the model run can be viewed within the program. The "Modeling Results" dialog shows a quick summary of the run by indicating whether or not any of these key conditions occurred: junction flooding, junction surcharging, or pressurized flow in a pipe. Complete details of the run can be viewed by selecting either the "Junctions" or "Conduits" menu items.

Some fine tuning of the model is possible by using the interface to alter certain parameters. Pipe diameter and surface roughness can be changed for any given pipe. This allows for more realistic modeling by taking into account situations where, say, a pipe is partially blocked. The other alteration that is possible through the interface affects open channels. By default, channels that are downstream of any pipe are modeled in EXTRAN, while all others are modeled in RUNOFF. The interface allows the user to select any open channel and explicitly identify the block in which it should be modeled. Varying the open channel modeling or the pipe parameters allows the user to explore the impact of various scenarios on the system.

CONCLUSION

The programs developed during the course of this project provided valuable assistance to ECE for data quality assurance, field data collection, model control, and presentation of results. The Windows interface to the SWMM model allowed quick generation of model data sets and model runs, as well as some degree of "what if" analysis. The programs allowed ECE to describe the response of the storm drain system to the defined rainfall event in a more cost effective manner.

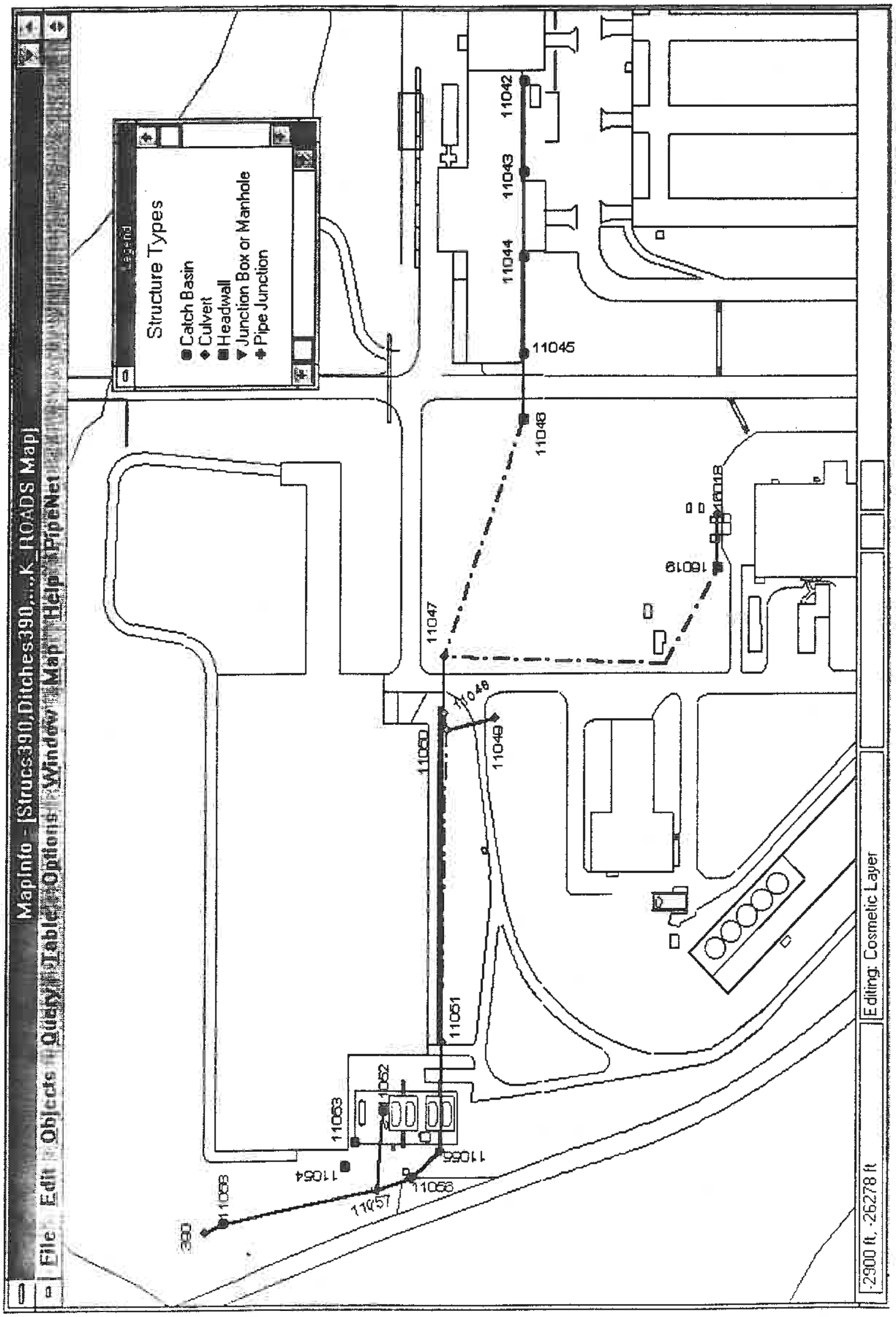


Figure 1. An example map showing pipes, structures, and open channels for one outfall. The map was generated by the GIS application.

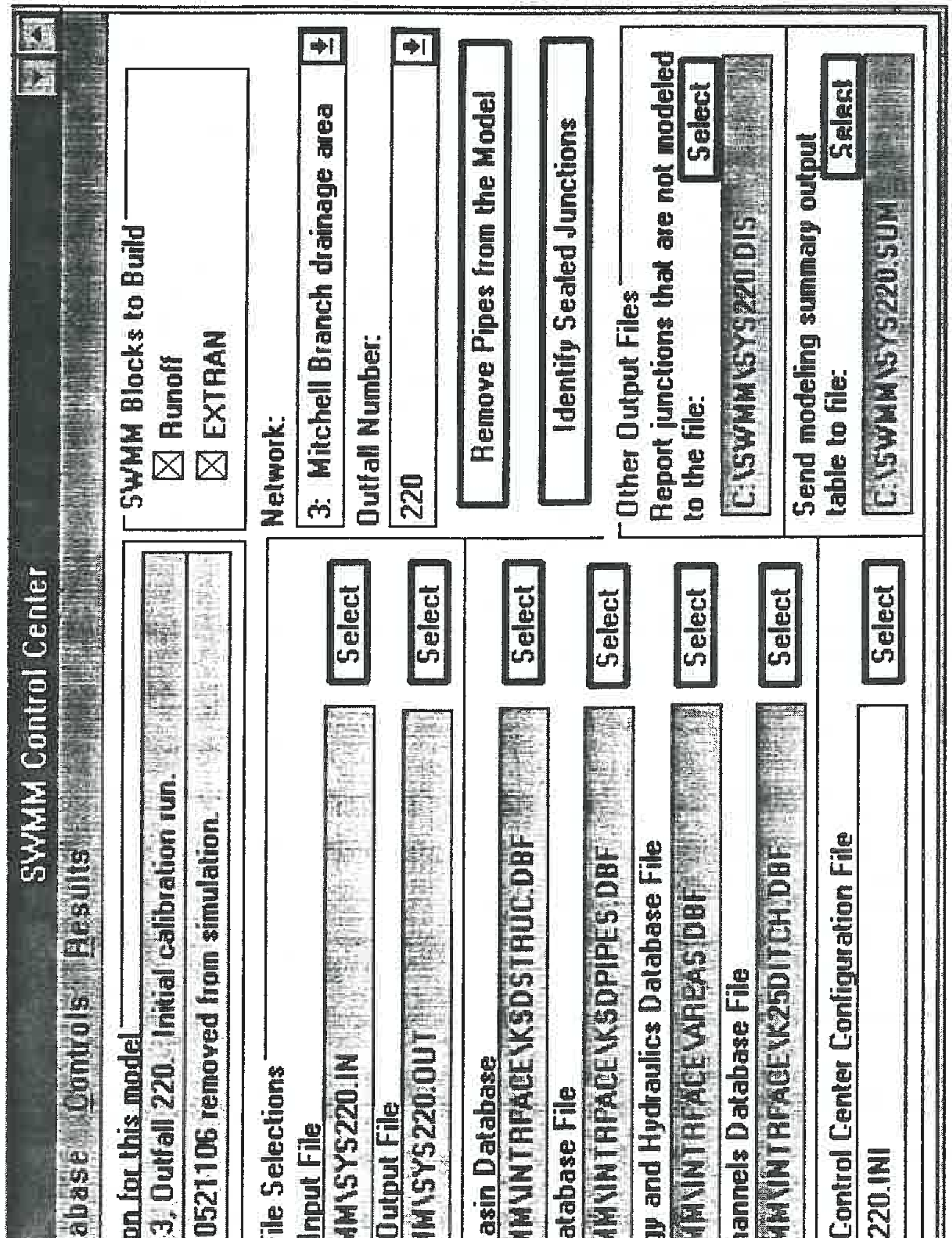


Figure 2. The main dialog of the Windows interface for SWMM.

DEVELOPMENT AND CALIBRATION OF A THREE DIMENSIONAL SATURATED-UNSATURATED FLOW MODEL FOR A HETEROGENEOUS FLUVIAL AQUIFER AT PORTSMOUTH, OHIO

N. J. Williams[1], S. C. Young, D. H. Barton, and B. T. Hurst

INTRODUCTION

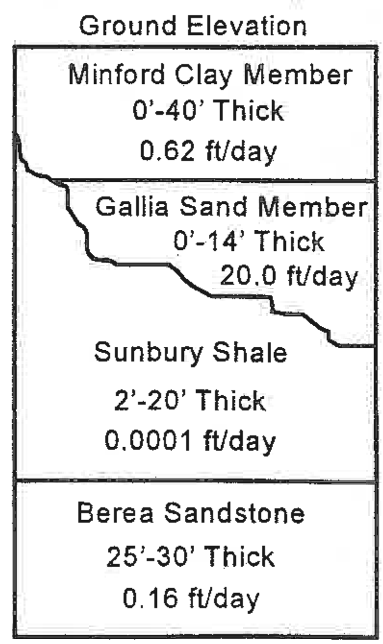
Portsmouth Gaseous Diffusion Plant (PORTS) lies within the abandoned valley of the Portsmouth River in Southern Ohio. An analysis of approximately 300 subsurface boring logs from the southern portion of the site suggests that contiguous deposits of relatively clean silts and sands are associated with a former river channel. Piezometric contours of quarterly water table measurements from 70 wells show large-scale diverging and converging flow patterns consistent with the location of silts and sands inferred from the boring logs. The sedimentological model developed for this site includes a transgressive/regressive marine cycle that formed sandstone and shale bedrock units, a transition from meandering to lacustrine environments that formed the overburden materials, and the erosional and redepositional effects of recent streams and drainage channels [1].

The development of a calibrated 2-D and 3-D groundwater flow model was needed to evaluate optimal methods for capture of a TCE plume. The 2-D model was used to demonstrate that horizontal wells would be more effective for plume capture than a 'funnel-and-gate' option. The 'funnel-and-gate' model consists of using two subsurface impermeable barriers to funnel groundwater to a vertical extraction well. The 3-D model focused on optimizing the location of the horizontal well and quantifying its performance under several scenarios. The groundwater flow models were based mainly on the sedimentological model of the site and were adjusted for recent construction related impacts on the aquifer.

SITE STRATIGRAPHY

The stratigraphy consists of two bedrock formations and four overburden materials. Figure 1 shows a simplified stratigraphy column at PORTS with approximate thicknesses and estimated hydraulic conductivities (K). The oldest bedrock formation consists of a fine-grained sandstone with shale laminae and thin shale beds and is referred to as the Berea. The Sunbury formation is a black, fissile, highly carbonaceous shale and was heavily eroded in certain areas by the ancient Portsmouth River. The Berea Sandstone and the Sunbury Shale are considered relatively homogeneous because they consist of oceanic deposits.

Figure 1- Stratigraphy



The unconsolidated deposits are divided into two major units: Gallia sand member and Minford clay member. The Gallia has the most transmissive and heterogeneous deposits at PORTS. It consists of the floodplain, point-bar and channel lag deposits of the ancient Portsmouth River. The Gallia is considered the main aquifer at the site. For this

[1]Environmental Consulting Engineers, Knoxville, Tennessee; phone: (423) 691-3668; FAX: (423) 691-0661; E-mail: nicolas@ece.com

reason considerable emphasis was placed on dividing the Gallia deposits into textural facies that could help define large-scale patterns in the hydraulic conductivity field. The facies classification scheme was limited to Sand, Gravelly Sand, and Gravelly Mixture. The Sand Unit consists of mostly sand and/or sandy silt and has the highest hydraulic conductivity. The Gravelly Sand Unit consists of mostly sandy gravels or gravels, and it was limited to about 15% clay. When the sandy gravels or gravels had more than 15% clay, it was classified as Gravelly Mixture. The Minford clay member deposits are primarily associated with lacustrine deposits and cut-and-fill activities. The deposition of the Minford occurred as a result of a glacier partially blocking the Teays River resulting in the formation of Lake Tight [2]. The transition between the Minford clay member and the Gallia sand member is not easily defined due to the continuum of deposits characterized by the gradual transition from a fluvial to a lacustrine environment.

CONSTRUCTION RELATED IMPACTS ON THE AQUIFER

There are many construction related impacts on the aquifer. Several manmade trenches and subsurface barriers shown in Figure 2 affect groundwater flow at PORTS. Along the northern and eastern boundaries of the X-749 Landfill and in the southern portion of the site are bentonite subsurface barriers. The estimated K of these barriers are 10,000 times lower than that of the K associated with the Gallia deposits, so the barriers can be approximated as impermeable barriers in the numerical model. Along the southeastern and western boundaries of the X-749 Landfill, permeable trenches have been installed, with an estimated K of 280 ft/day [3]. The permeable trenches were installed to enhance drainage to two extraction wells. Three trenches associated with storm pipe drains at the model site could act as preferential channels for groundwater flow due to the coarse-fill associated with the trenches. Across much of the site, construction and grading has changed the topography. More fill than cut has occurred in the X-749/X-120 area. A stream and its tributaries on the western side of the model was filled with compacted clay. Fill thickness up to 20 feet reside in the model domain, and portions of the thick fill have low permeability which will reduce recharge. Additionally, the fill may extend into the Gallia Sand layer and thus affect the K distribution of the Gallia Layer.

GROUNDWATER FLOW MODEL

The groundwater flow model consisted of a finite-element, saturated-unsaturated flow model using FRAC3DVS [4]. An accurate delineation of the site's stratigraphy is a keystone to an accurate model at PORTS, because highly variable K's are assigned to the stratigraphic units. These are some of the features of FRAC3DVS: delineation of complex geology with fully deformable finite elements having 8 nodes, simulation of variably saturated conditions, proper treatment of flow boundary conditions along well screens in heterogeneous media, and the use of an adaptive time-stepping procedure. The model grid is shown in Figure 2 and consists of five element layers with 21,500 elements, and 26,400 nodes.

HYDRAULIC CONDUCTIVITY DISTRIBUTION

The K's assigned to the different model layers are summarized in Table 1. The K of the Berea Sandstone was based on the review of hydraulic test results. Due to lack of hydraulic tests in the Sunbury Shale, the Sunbury Layer was assigned a K which has been used in previous groundwater models at PORTS [5, 6]. In regions where local streams have eroded the Sunbury Shale, a weathered shale material type was used. To use the Gallia textural units to help map the Gallia K field, a K was assigned to each Gallia unit by performing a multiple regression analysis on slug test results. Two key assumptions were included in the multiple regression analysis. The first assumption was that both the K of the Minford layer and the underlying bedrock were low enough to have a minimal effect on the calculated transmissivity for the Gallia. The second assumption was that for a Gallia unit to affect the calculated transmissivity, the Gallia unit had to be intersected by the well screen. The assignment of a K for each Gallia textual unit permits the calculation of a continuous transmissivity field for the entire Gallia layer. For each unit, a transmissivity is calculated as the product of the unit thickness at each element and the unit-specific K. The Gallia transmissivity for each element is determined by summing the transmissivities for the three units. To calculate the Gallia K for each element, the Gallia transmissivity is divided by the total Gallia's thickness at that element. Figure 3 shows the hydraulic conductivity for the Gallia layer.

Table 1 - K values assigned to the stratigraphic layers

Unit	Kx and Ky (ft/day)
Minford Layer - Layer 5	
Overburden	1.4
Alluvium	0.7
Low-K Channel	0.1
Gallia Layer - Layer 3 & 4	
Gravelly Mixture	1.4
Gravelly Sand	3.4
Silty Sand	25.7
Alluvium	0.7
Low-K Channel	0.1
Weathered Shale	0.01
Sunbury Layer - Layer 2	
Sunbury Shale	0.0001
Weathered Shale	0.01
Berea Layer - Layer 1	
Berea Sandstone	0.1

An alluvium material type was included around Big Run Creek, Holding Pond No. 1, and a small stream on the southern boundary to account for floodplain and stream alluvial deposits. In the Northwest, the Gallia K field was modified by including a Low-K zone. This K zone represents a former drainage channel that was filled with compacted clay during the plant's construction. This low-K channel's effect can be seen in the water table plots for the sites, dry wells in the vicinity, and the very low K from pumping tests in this area [1]. The low-K channel played a very important role in the study. The Minford clay member includes layers of fine silts, lacustrine clays, and compacted fill and is likely moderately heterogenous, but it is considered homogeneous. A uniform K for the Minford layer can be justified, given the lack of reliable pump test results for the Minford. The importance of the Minford layer is its control of recharge to the Gallia. For steady-state flow models, the most important impact of the Minford on the groundwater flow system is determined by the spatial distribution of recharge.

The barriers installed around X-749 Landfill and to the south of the landfill were represented as no-flow boundary planes. These no-flow boundary planes were simulated by selectively decoupling nodal connections in the numerical model. Figure 4a and 4b shows how the nodal connections were decoupled to represent a no-flow condition. This required the addition of extra nodes and changing the nodal connections of certain elements. The gap was set to three feet wide but could also be accurately represented with zero width. The permeable trenches at the X-749 Landfill were represented by 6 foot wide elements with K's of 100 ft/day. The trenches associated with the three storm drains (pipe 1, 2, & 3 in Figure 1) were represented as 6 foot wide elements with K's of 40 ft/day.

BOUNDARY CONDITIONS

The boundary conditions imposed on the groundwater model simulation consist of no-flow and constant head conditions as shown in Figure 5a, 5b, and 5c. The no-flow boundary conditions were based on either a topographic divide or a hydraulic divide from a two-dimensional flow net analysis. Constant head values from stream data were calculated from the topographic elevation. Constant head values for the Berea and the Gallia water table were calculated from the measured head at approximately 50 monitoring wells in April 1995. The boundary conditions for Minford layer are identical to the Gallia's boundary conditions due to the lack of data in the Minford.

The recharge distribution selected for model calibration consists of a low rate of 0.01 in./yr. over the capped area at the X-749 landfill, the area beneath buildings, and the area above the low-K channel in the northwest model domain. The area east of the X-749 Landfill which has topography sloping toward Big Run Creek and which has a relatively thick unsaturated zone was assigned recharge rates of 0.17 and 0.1 in./yr. Recharge across the rest of the model varied from 1.0 in./yr. to 3.0 in./yr. based on the thickness of the overlying Minford

Snapshot water table measurements were assumed to represent steady-state conditions. This assumption mandates that an average recharge rate be used. Within the physical system, however, recharge is controlled by rapid transient changes in the unsaturated flow system which cannot be accurately represented by a steady-state system. Relatively simple unsaturated properties were used for the Gallia and the Minford layers for this reason. The saturation was assumed to vary linearly between 100% saturation at a pressure of 0 ft or greater and 10% saturation at a pressure of -5 ft or smaller. The value for $K_{unsaturated}$ in the horizontal direction was assumed also to vary linearly between $K_{saturated}$ at 100% saturation and $0.1*K_{saturated}$ at 10% saturation.

MODEL CALIBRATION

Conventional groundwater flow model calibration involves adjusting model parameters to improve the match between measured and simulated water table elevations. Without adequate consideration to flow constraints, a groundwater model can appear calibrated but it might not accurately predict groundwater flow. Thus, proper model calibration must include data beyond hydraulic head values. The model calibration and validation were based on hydraulic heads and base flow in Big Run Creek. The hydraulic head data set used for calibration is from the April 1995 snapshot. This data set represents the average water table values measured during April 1-4 and April 18-20. The hydraulic heads calculated by FRAC3DVS for the Gallia layer is contoured in Figure 6. The model residuals are shown in Figure 6 at the 80 monitoring wells in the Gallia. Fourteen other measurements were located in the Berea, and four more measurements were in the Minford, giving a total ninety-eight wells used for model calibration. The root-mean-square error was 1.39 ft while the arithmetic mean was -0.41 ft. Given that 1.39 ft is less than the seasonal variations observed at the majority of the wells and is small compared to the nearly 50-ft head differential across the model domain, the calculated residuals suggest that the groundwater flow model is adequately calibrated.

The fluxes from the upper five layers of the nodes on the eastern boundary of the flow model represent the contribution of the model domain to the base flow of Big Run Creek. To estimate the base flow of Big Run Creek, two weirs were installed and monitored for approximately two months. To estimate base flow, only regional groundwater flow should be contributing water to Big Run Creek. The average difference between the downstream and upstream weirs is about 14.4 gpm. Using the gross assumption that both sides of Big Run Creek contribute the same base flow amounts, the estimated base flow contribution to Big Run Creek is 7.2 gpm [1]. A summation of the fluxes at the appropriate eastern boundary nodes gives a total flow of 5.1 gpm. The favorable agreement between the predicted and measured base flows suggests that the groundwater flow model is adequately calibrated. The fluid mass balance for the model domain is excellent as the model error between total inflows and outflows is less than 0.01%.

MODEL APPLICATION

The primary focus of the 2-D model was to demonstrate that horizontal wells would be more effective for plume capture than a 'funnel-and-gate' system. The evaluation of alternative collection systems was primarily based on their ability to extract groundwater. The purpose of the numerical simulations is to demonstrate the feasibility of passively collecting groundwater and then to determine the best conceptual design for the collection facility. The 705-ft barriers were implemented as no-flow boundaries by selectively decoupling nodal connections. Table 2 provides the predicted groundwater flow rates for 24 different groundwater collection scenarios. The model results indicate that the horizontal well is more effective for collecting groundwater than the impermeable barriers with vertical extraction wells. The combination of a horizontal well and barriers produces less than a five percent increase in groundwater collected for all simulations compared to a horizontal well without the barriers. These results suggest that barriers are not a cost-effective option for collecting groundwater in the X-120 region if a horizontal well is to be part of the groundwater collection system [7].

Table 2 - Modeled Groundwater Collection Systems

Type of Collection Facility	Presence/ Absence of Barrier	Water Table Elevation (ft MSL)	Groundwater Collected (gpd)
Funnel-and-Gate with Vertical Well at Location A	Present	646	762
		648	464
	Absent	646	736
		648	433
Funnel-and-Gate with Vertical Well at Location B	Present	646	833
		648	482
	Absent	646	799
		648	429
Funnel-and-Gate with Vertical Well at Location C	Present	646	209
		648	100
	Absent	646	181
		648	42
192.0 ft of screened horizontal well	Present	646	1558
		648	976
	Absent	646	1527
		648	938
384.5 ft of screened horizontal well	Present	646	1909
		648	1171
	Absent	646	1877
		648	1114
624.0 ft of screened horizontal well	Present	646	1964
		648	1189
	Absent	646	1943
		648	1152

The 3-D model focused on optimizing the location of the horizontal well and quantifying its performance under several transport scenarios. Key design criteria for the horizontal well are its location, length, and head losses. As might be expected in a fluvial aquifer, the most dominant feature affecting the well's performance was preferential high and low K zones. For maximum flow withdrawal, the well performance was simulated with a hydraulic head of 645-ft MSL. The 645-ft elevation represents the lowest head that could be maintained without desaturating the Gallia deposits. The mean flow rate of 2.9 gpm and 1.86 gpm is predicted for well heads of 645-ft MSL and 647-ft MSL, respectively [1].

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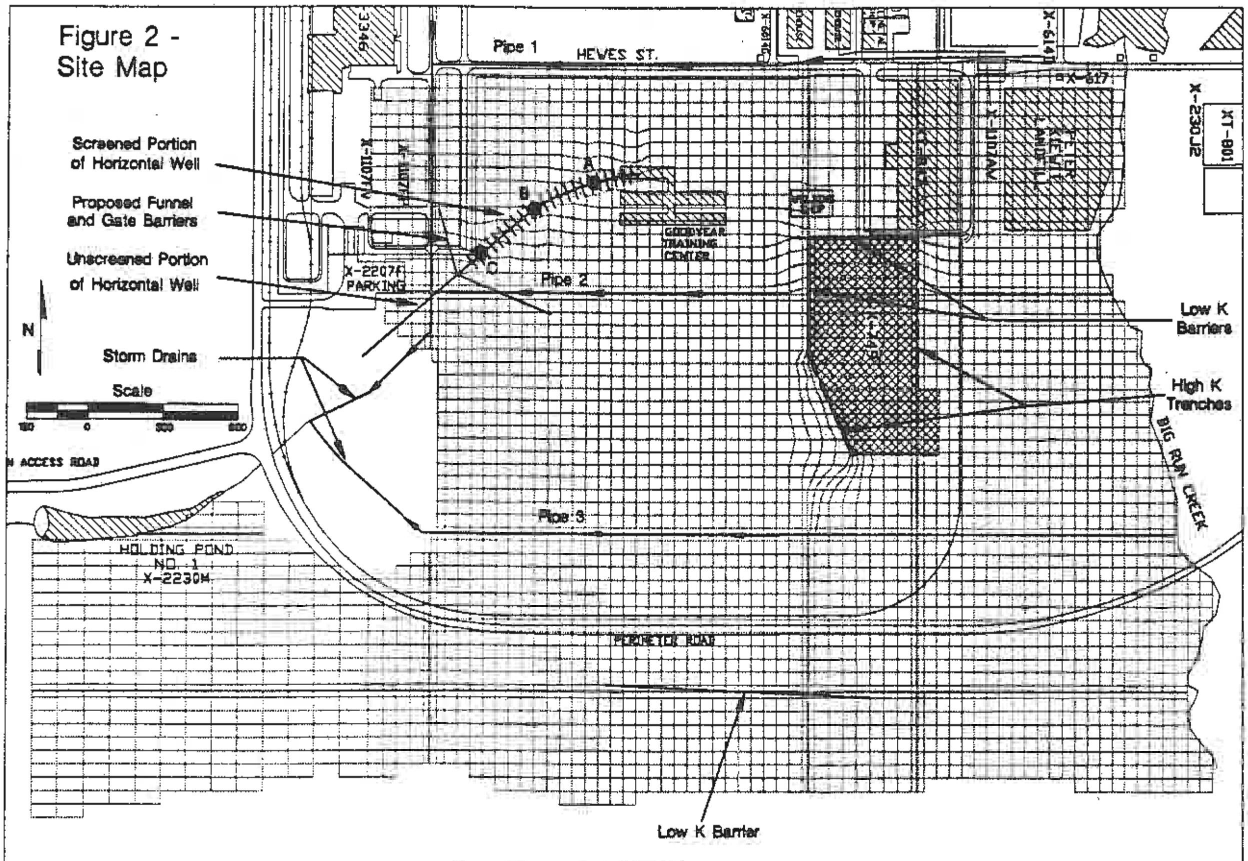

Figure 2 - Site Map

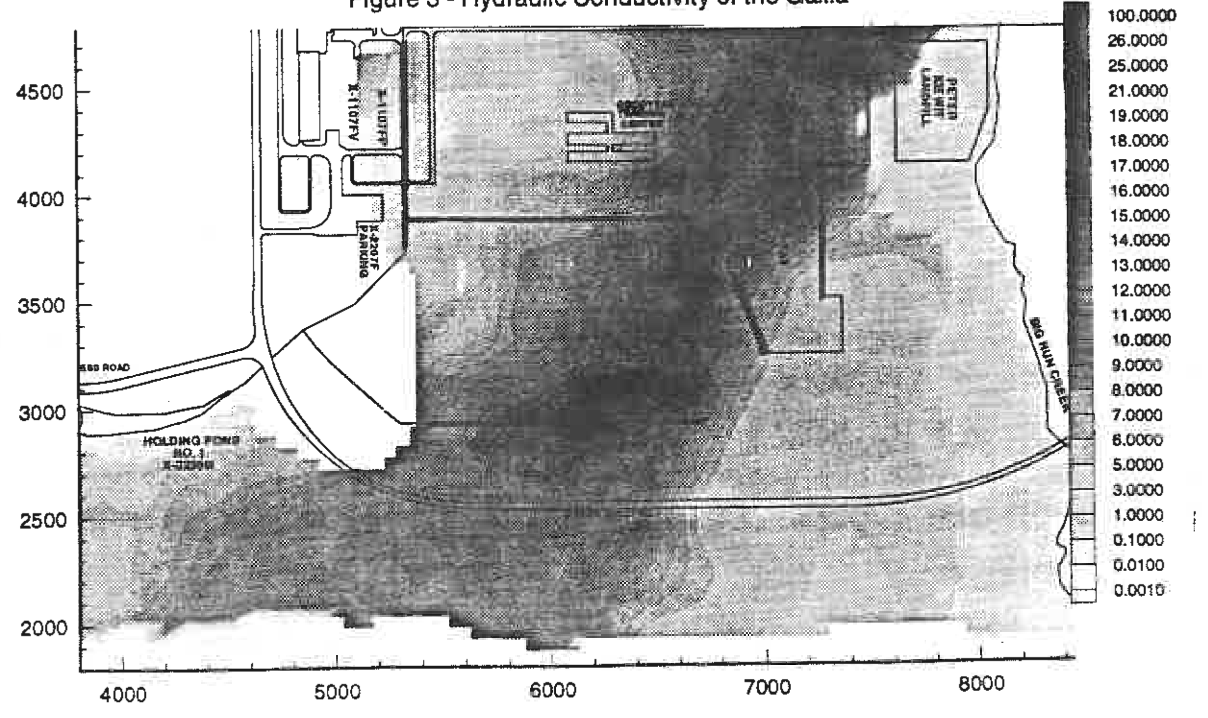

Figure 3 - Hydraulic Conductivity of the Gallia

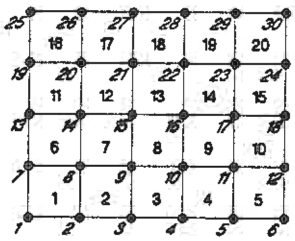

Figure 4a
Grid without a No-Flow Slurry Wall

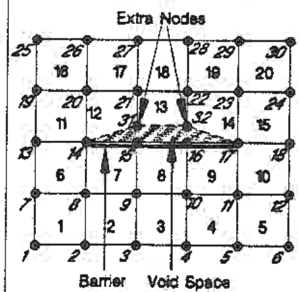

Figure 4b
Grid with a No-Flow Slurry Wall

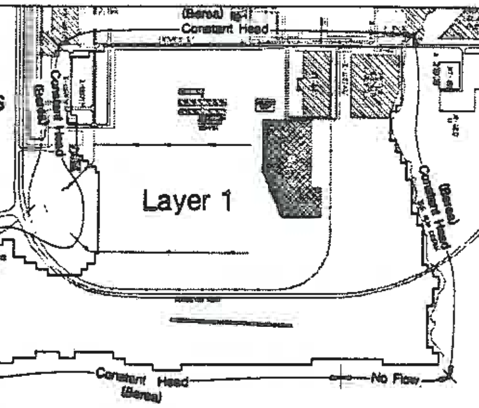

Figure 5a
Boundary Conditions

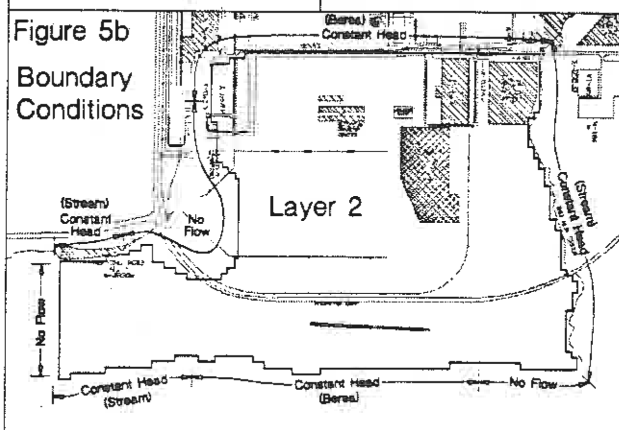

Figure 5b
Boundary Conditions

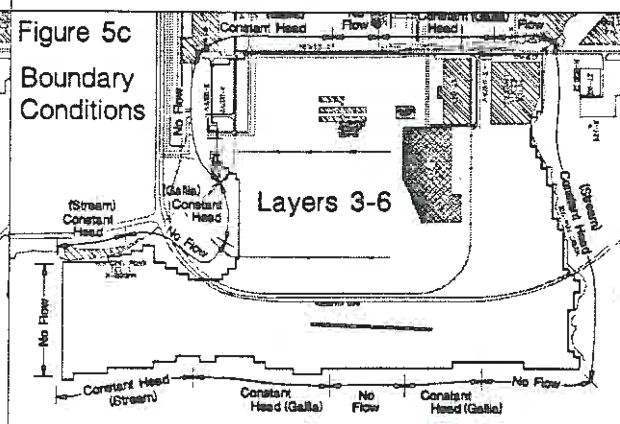

Figure 5c
Boundary Conditions

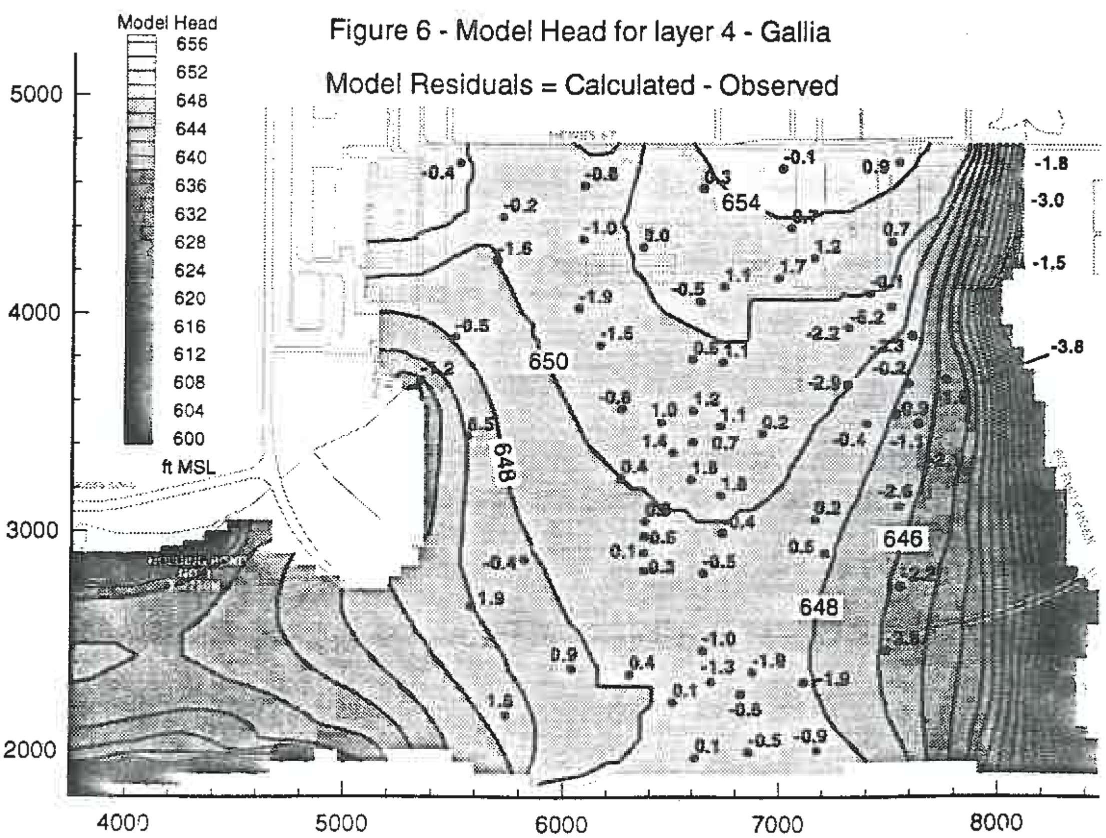

Figure 6 - Model Head for layer 4 - Gallia
Model Residuals = Calculated - Observed

EVALUATION OF PLUME CAPTURE ALTERNATIVES FOR A HETEROGENEOUS FLUVIAL AQUIFER AT PORTSMOUTH, OHIO

B. T. Hurst[1], S. C. Young, N.J. Williams, D. H. Barton, and D. J. Benton

INTRODUCTION

A three-dimensional groundwater model was developed for predicting the migration of the X-120 and X-749 TCE plumes at the Portsmouth Gaseous Diffusion Plant (PORTS). The model consisted of FRAC3DVS to predict groundwater flow and PTRAX, which couples to FRAC3DVS output, to predict groundwater solute transport. Model calibration and verification were based on hydraulic heads, base flow in Big Run Creek (the major local stream), and trichloroethylene (TCE) concentration data. The model was used to simulate the capture of TCE-contaminated groundwater by the X-120 horizontal well for six possible scenarios. The simulations suggest that the horizontal well will deliver a steady flow of approximately 3 gal/min, with an initial TCE concentration between 140 and 200 ppb. After approximately one and three years, the TCE concentration is predicted to decrease to less than 50 ppb and 10 ppb, respectively.

GROUND WATER SOLUTE TRANSPORT MODEL

To simulate contaminant transport at PORTS, a numerical ground water flow model was constructed using FRAC3DVS (Williams *et al.*, 1996) using K-zonations based on a sedimentological model. Solute transport was simulated using the particle tracking code PTRAX with the velocity field generated by the 3-D flow model to accurately model dispersivities in the range of 0.01 - 6.0 ft. There are two main purposes for performing solute transport at the X-120 and X-749 sites. First, the solute transport model is useful to predict the migration of the TCE plume through the ground water system and to determine when the plume will enter an environmental media that will facilitate public exposure to TCE. Second, this model will assist in selecting an effective remediation alternative for the site.

There are two major geologic features in the X-120/X-749 area that greatly effect the ground water flow, and thus the migration of the TCE plume. Construction activities have removed a significant amount of overburden material and used it to fill a drainage channel that was produced by a western stream and its tributaries in the X-120 area. Presumably, because the topography was leveled as part of preparations for future construction, the fill material was compacted during its installation. This produced the first major geologic feature of a low hydraulic conductivity channel in this portion of the model domain. The second geologic feature is a relatively high hydraulic conductivity zone in the central portion of the model domain, which is the resultant of a sand unit and a gravelly sand unit. The sand unit represents the sands and silts primarily associated with overbank deposits/levees and upper point bar deposits. The gravelly sand unit covers the largest area and likely represents a mixture of channel lag lower point bar deposits.

The ground water flow was calibrated with the April, 1995 water table survey composed of 95 water table measurements. The root-mean-square for the differences between the observed and predicted heads is 1.39 ft. The estimated base flow contributions to Big Run Creek, which runs along the eastern boundary of the model domain, was also used for model calibration. Weir data measured base flow contributions to equal

[1]Environmental Consulting Engineers, Knoxville, TN , USA Phone: 615-691-3668; Fax: 615-691-0661; E-mail address for Mr. Hurst is "bhurst@ece.com".

7.2 gal/min which corresponds with the model predicted value of 5.1 gal/min. Results from both data sets suggest that the ground water flow model is properly calibrated.

PTRAX is a fast, three-dimensional particle tracking code capable of two- and three-dimensional simulations for grids based on an assortment of element types. After reading in a velocity file, PTRAX can delineate flow paths and/or simulate groundwater transport. Because its mathematics are based on triangles and tetrahedra, PTRAX can couple with virtually any velocity field. This capability is particularly valuable where a non-layered finite-element grid has been used to simulate flow through complex stratigraphy. In addition, because it uses distance as the variable of integration, PTRAX can simulate particle movements significantly faster than conventional particle tracking codes.

To ensure that PTRAX could accurately predict the migration of the TCE plume, it was necessary to perform history matching. Because of the limitations of the site characterization data and the TCE data base, history matching will focus on the general trends associated with the bulk movement of the TCE plumes during the last 39 years and on the TCE breakthrough curves from 1988 to 1995 for selected wells.

Because the distribution and the amount of spilled TCE is unknown and the plume sampling did not begin until 1988, there is insufficient data to realistically evaluate a numerical simulation of the evolution of the TCE plumes. Although the TCE data is insufficient to accurately characterize the three-dimensional structure of the X-120 and X-749 plumes, the data is sufficient to characterize the general configuration of the plumes. To evaluate the solute transport model, the assumption is made that the current plume configurations were caused by TCE spills that began 39 years ago at the Goodyear Training Center (X-120 area) and at the X-749 Landfill.

Appropriate FRAC3DVS and PTRAX runs were performed to simulate the evolution of the X-120 and X-749 plumes from January 1988 until September 1994. Simulations of the breakthrough curves began and ended with the plume as shown in Figure 1. These plumes are similar to the ones used for the Corrective Measures Study (CMS) study. The simulations included two flow fields in order to account for the installation of the low-K barriers and cap at the X-749 landfill in September 1991. As shown in Figures 2, the simulated and measured breakthrough curves for X-749-13G have consistent trends and have similar magnitudes. Overall, the results suggest that PTRAX provides a realistic and credible simulation of the transport processes at PORTS.

TCE PLUME CAPTURE ALTERNATIVES

Several remediation alternatives were studied to determine which one would remove the TCE plume, as shown in Figure 1a, from the X-120 and X-749 sites. Currently, a passive ground water collection system utilizing a horizontal well, placed in a natural ravine, that intercepts the X-120 branch of the TCE plume is being recommended for removal for this portion of the contamination. The collected contaminated ground water will be passed through a reactive media that will facilitate the breakdown of the TCE by reductive dehalogenation. If this media proves to effectively treat the ground water, then this media will in a large-scale in-situ funnel and gate system to remediate the X-749 plume. Two major geologic features in this area greatly effect the ground water flow, and thus the TCE migration.. These features are important in the decision making process because they, as well as the current position of the TCE plume, are major factors in selecting the location and type of remediation alternative to be implemented.

REMEDIATION OF X-120 TCE PLUME

A horizontal well, which is a passive ground water collection system, has been recommended for removal of TCE contaminated ground water in the X-120 area (ECE, 1995b). It is passive because the ground water flows into the well only due to the hydraulic gradients produced in the surrounding ground water system. Key design criteria for the horizontal well are its location, length, and head losses. Head losses need to be minimized to maximize the available hydraulic head to drive the ground water flow through the treatment facility. The length of the horizontal well affects the amount of ground water flow, which determine the amount of plume capture and the volume of contaminated ground water available for passing through the treatment media. The location of the horizontal well is important because it greatly impacts the ground water flow and TCE concentrations delivered to the testing facility.

Among the two most important variables required to properly design the well is delineation of the X-120 TCE plume and the hydraulic conductivity, K, field of the Gallia deposits near the TCE plume. Prior to the evaluation of the horizontal well's performance, the selection of the X-120 looked promising based on the high K values presented in Geraghty & Miller, 1989 and the plume configuration. Geraghty & Miller reported K values from 45 to 62 ft/day and previously depicted X-120 plumes like that in Figure 4 suggest a rather large and Gaussian-shaped plume with a midsection of about 1000 ppb.

As discussed in Williams *et al.*, 1996, the high-K values within the X-120 area are significantly lower than indicated by previous three-dimensional models. A crucial issue to the horizontal well performance is its location relative to the low-K channel. Given the relatively low Gallia K values, the horizontal well was designed to be as long as possible (1200 ft) without extending far into regions where TCE concentrations were less than 100 ppb. For maximum flow withdrawal, the well performance was simulated with a hydraulic head of 645 ft MSL (mean sea level). The 645 ft elevation represents the lowest head that could be maintained without desaturating the Gallia deposits.

Three TCE plume configurations were utilized for plume migrations simulations. The TCE plume utilized in the CMS study is the maximum possible plume based on the current TCE data summaries for the X-120/X-749 area. The ECE plume was developed based on a review of all TCE monitoring data (ECE, 1995a), a consideration for the low-K channel in the Gallia, and numerous TCE measurements from mini-piezometers installed via cone-penetrometers in April 1995. The Conservative ECE plume is a modification of the ECE plume based on the possibility that the X-120 TCE plume is not contiguous but a piecewise accumulation of several smaller TCE plumes caused by the spreading of contaminated soils by cut-and-fill activities at PORTS. All three plumes were assumed to reside uniformly throughout the Gallia layer. No DNAPL source terms were associated with any of the plumes.

The predicted performance of the horizontal well for the case of 645 ft hydraulic head and three points in time (0, 10, 30 years) is illustrated in Figure 3. The three scenarios have similar values for the removal of TCE plume's mass. After five years, all scenarios show a TCE removal percentage between 40 - 55%. After 30 years, all scenarios show a TCE removal percentage between 60% and 80 %. However, because of the almost 10 fold difference in the TCE mass among the plume configurations, the three scenarios have considerable differences in the predicted TCE concentrations for the X-120 treatment facility. As predicted, the majority of the residual TCE after 30 years resides in the low-K channel.

REMEDIATION OF X-749 TCE PLUME

One objective of the CMS was to evaluate various remediation technologies to determine which one would be best to remove the TCE plume from the X-749 area. Five alternatives were modeled using the 3-D groundwater solute transport model. Each alternative supplemented the current remediation efforts with use of a variety of containment and removal systems. The alternative chosen to implement at the X-749 site had to have a high removal efficiency of the TCE plume and be cost effective.

The alternative currently being pursued for implementation at the X-749 area is a funnel and gate collection system. This system is similar to the horizontal well being recommended for the X-120 in that it passively diverts the ground water. The funnel and gate terminology describes a system of barriers that will be used to alter the current flow of the ground water and direct it into treatment media. This treatment media, placed at several locations along the system, is designed to absorb the TCE. The media can be removed and disposed once it has reached its saturation limit or the plume has been remediated to acceptable limits.

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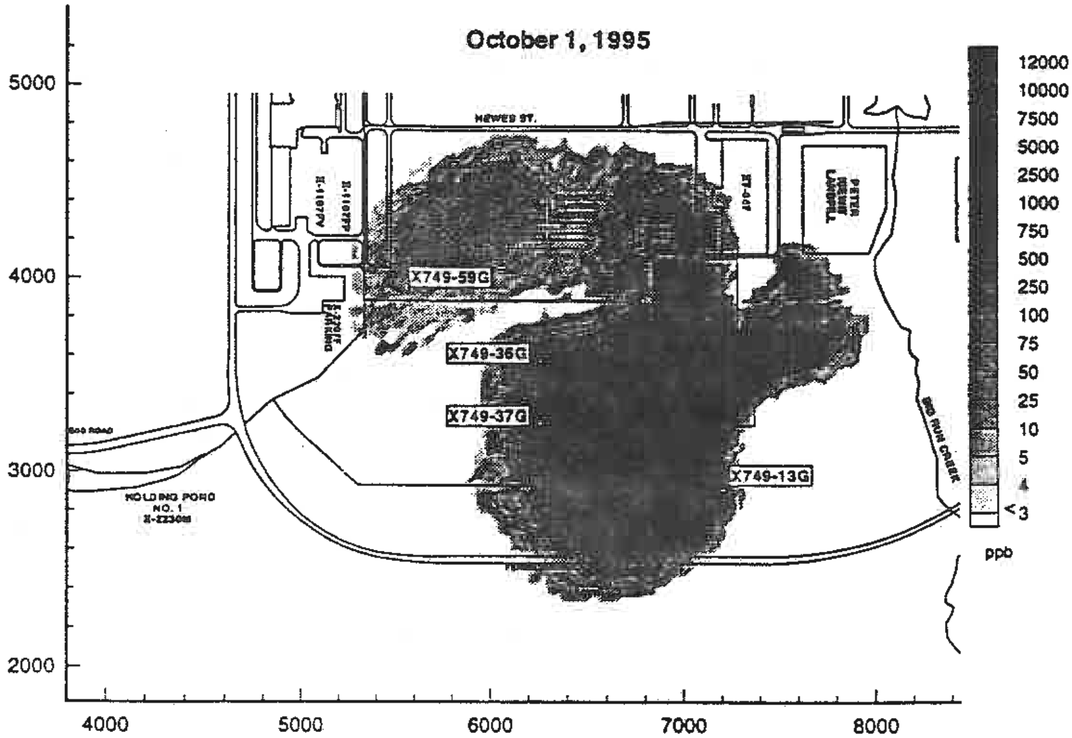


Figure 1. Final plume configuration for the simulated period of 1988 to 1994.

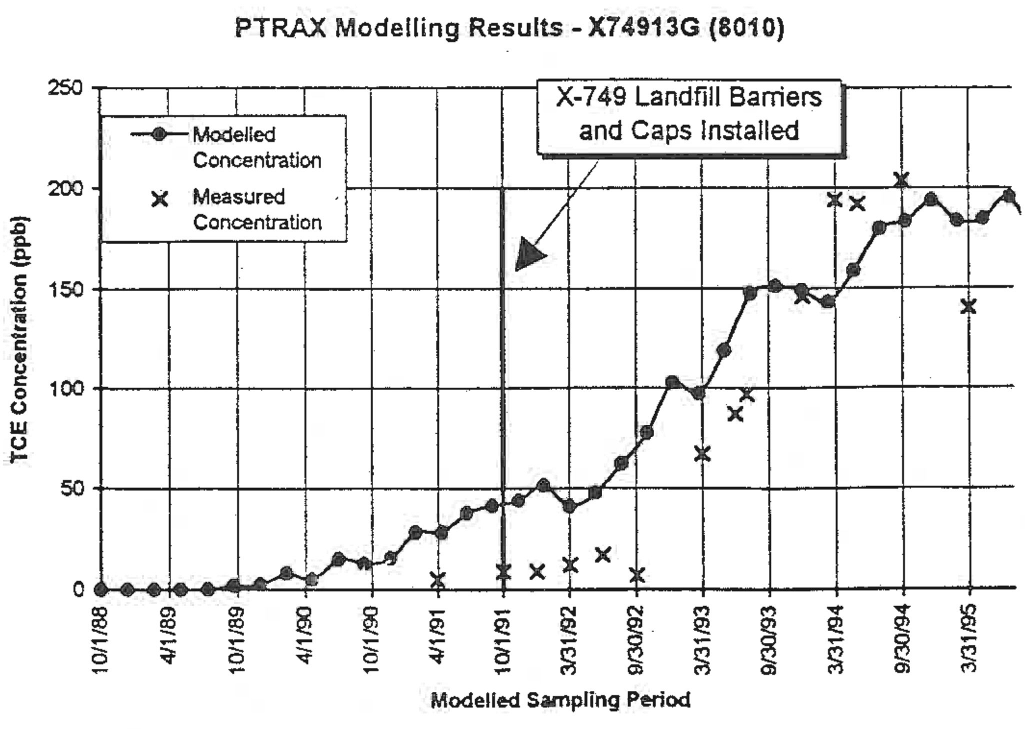


Figure 2. Simulated and observed breakthrough curve for X-749-13G.

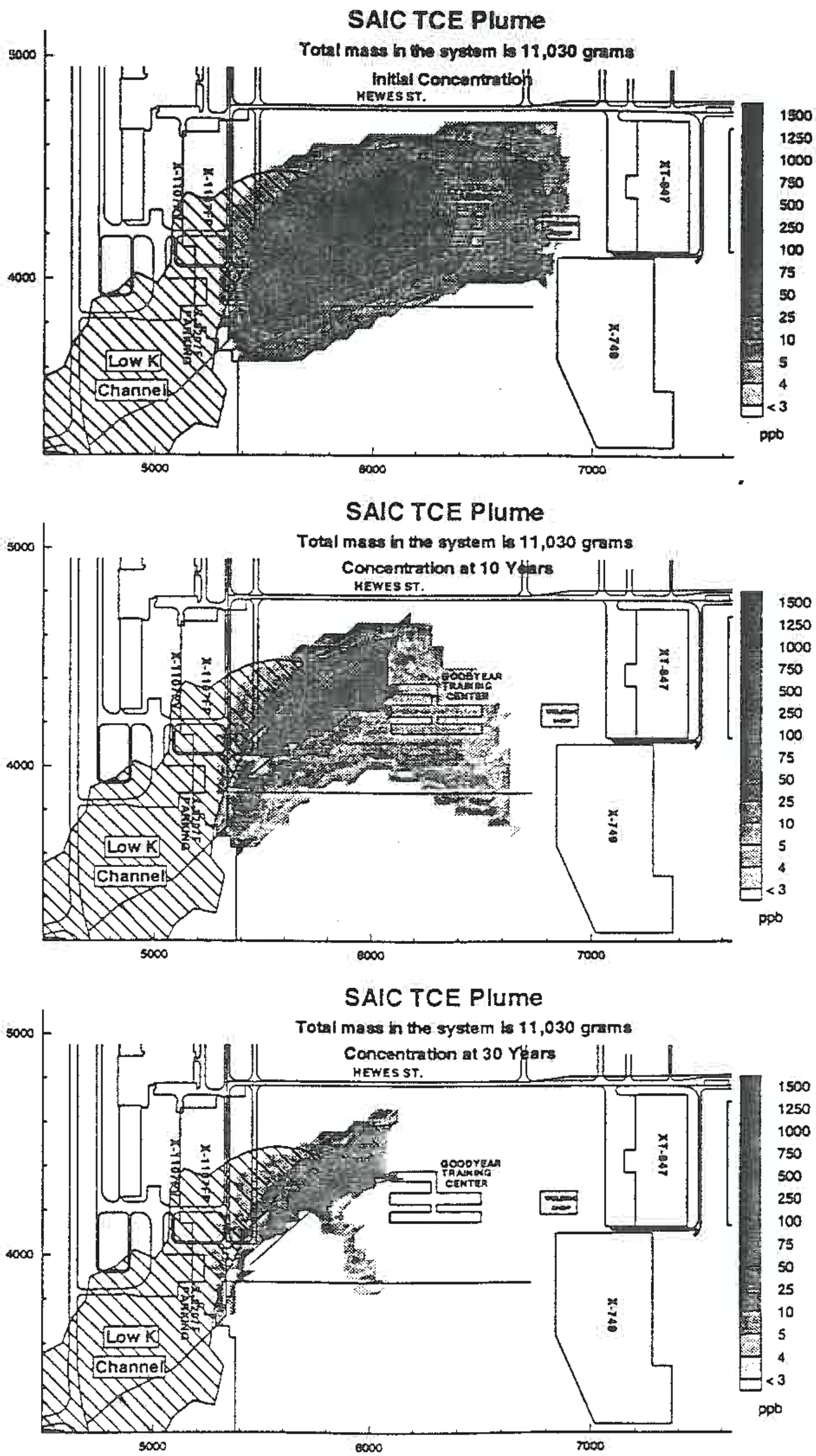


Figure 3. X-120 plume configurations for time periods 0, 10, and 30 years after installation of horizontal well.

WELLHEAD PROTECTION: AN INTEGRATED APPROACH FOR THE PROTECTION OF TENNESSEE'S PUBLIC WATER SUPPLIES

Thomas A. Moss, P.G.[1]

Over 1.8 million Tennesseans rely on public water systems that use a ground water source. Tennessee has had a limited number of incidents of contamination of public water systems, but Tennessee cannot rely on continued good fortune. It is critical that Tennessee's citizens continue to have safe public water supplies at a reasonable cost.

The ultimate success or failure of Tennessee's Wellhead Protection Program will depend on the development and implementation of good local management plans for every designated wellhead protection area in the state. It is extremely costly to develop new water supplies, remediate contaminated ground water, or add additional treatment at the Public Water System (PWS). Wellhead Protection is a focal point in the overall goal to develop a Comprehensive State Ground Water Protection Plan for Tennessee, with an emphasis on preventing ground water contamination. Tennessee's Wellhead Protection Program will require the cooperation of state and local government, private industry and the general public.

The official designation of wellhead protection areas provides valuable input and emphasis to government agencies in the siting of facilities and the prioritization and cleanup of contamination sites. Wellhead protection also makes good business sense -- it is in an industry's best interest to pay attention to good housekeeping practices if they are located within a wellhead protection area. Substantial spills or leaks from an industry's sloppy housekeeping practices within a wellhead protection area could culminate in their being a National Priority List Superfund Site.

ARDMORE SUCCESS STORY

The Tennessee Department of Environment and Conservation is currently involved with a multi-agency effort in the identification and remediation of a contaminant source that has impacted a small community water system in south central Tennessee. The city of Ardmore straddles the Tennessee/ Alabama line in Giles County, Tennessee and Limestone County, Alabama just east of Interstate 65 (see Figure 1). To date, the following agencies have provided assistance in the investigation:

TN Division of Water Supply, Drinking Water and Ground Water Management Sections
TN Division of Superfund
TN Division of Water Pollution Control
TN Division of Solid Waste Management
AL Department of Environmental Management, Ground Water Branch
EPA CERCLA Site Assessment Section.

The Ardmore project sets forth a valuable precedent and is a prime example of interagency cooperation in a wellhead protection scenario. Such cooperation on the part of various state and federal agencies can be a valuable tool in the protection of public water supplies both in the cleanup of existing sources of contamination and in the prevention of future contamination.

[1]Manager, Ground Water Management Section, Division of Water Supply, 401 Church Street, 6th Floor, Nashville, Tennessee 37243-1549; (615) 532-0170

In the case of Ardmore, a major portion of the success can be attributed to:

1) The willing cooperation between the Tennessee Department of Environment and Conservation and the Alabama Department of Environmental Management
   A) Alabama's Ground Water Branch's help in the contaminant source search.
   B) The Ground Water Branch's support through the Field Operations Division, without whose assistance in purging and sampling area wells the investigation would have been impossible.
2) The willingness of the Division of Water Supply to pay for the initial sampling costs of the investigation owing to Superfund's statutory limitations requiring an identified source.
3) The Ground Water Management Section's capabilities to assist/perform ground water investigations from within the Division of Water Supply.
4) Upper management and technical staff support from within the Department of Environment and Conservation, foremost of which is the Division of Superfund's willingness and persistence to pursue contaminant sources and require timely cleanup and the innovation of figuring in treatment costs for the public water system as a part of remediation requirements/ natural resource damages.
5) The willingness of the site assessment coordinator in EPA's CERCLA Site Assessment Section to provide the assistance of an EPA contractor.

The City of Ardmore has three wells, with the highest yielding well in Tennessee and its two other wells in nearby Alabama. Ardmore's city well # 3 in Tennessee tested above primary drinking water standards for 1,1 dichloroethylene in April of 1994. At that point, the city was required by the Tennessee Division of Water Supply to either develop a new uncontaminated water source or add a treatment system to remove the contamination. Ardmore's Water Department requested the Division of Water Supply's help in the determination and elimination of the source of the contamination and installed an air stripper unit to deal with the contamination.

The Ground Water Management Section in the Division of Water Supply contacted the Ground Water Branch in the Division of Water, its counterpart in Alabama, for assistance as well as the Division of Superfund in Tennessee. Owing to the unique location of Ardmore on the Tennessee/ Alabama state line, there was a substantial possibility that the contamination source(s) might be in either or both of the two states. With the help of Ardmore's Water Department, abandoned wells were located in the area for sampling purposes.

During part of the early field investigation, Ground Water Management Section staff also performed a ground water elevation survey with the use of GPS units to aid in the construction of a potentiometric surface map for Ardmore. The shallow aquifer into which all of the wells are drilled is comprised of Fort Payne residuum, with ground water flow essentially following surface topography. The apparent ground water flow pattern is to the south/southwest toward the city wells. The upgradient area to the north includes an industrial facility which had reported a TRIS release of solvents in the past (see Figure 2).

Sampling of area wells with the invaluable assistance of Alabama Department of Environmental Management Field Operations Division yielded trace levels of contamination from tetrachloroethylene in a hand dug well on the property of an industrial facility upgradient of the city wells. Tetrachloroethylene was also present in the city well. Two other abandoned wells between the facility and the city wells showed 1,1 dichloroethylene; trichloroethylene; and 1,1,1 trichloroethane, which might be indicative of a plume emanating from the facility (see Figure 3). City well #1 across the road in Alabama from well #3 had also begun to show low levels of contamination.

The Division of Superfund was able to use the chemical information collected and information provided by the facility in their investigation to justify assistance from an EPA contractor for EPA's CERCLA Site Assessment Program to take onsite samples at the facility on May 22 - 25, 1995. Ground Water Management staff were present to provide assistance to the Division of Superfund. Onsite soil samples provided the constituent matches of 1,1 dichloroethylene; tetrachloroethylene, 1,1,1 trichloroethane with city well #3. The soil samples showed significant levels of 1,1 dichloroethylene; 1,1,1 trichloroethane; tetrachloroethylene; 1,1-dichloroethane; 1,2 dichloroethane; 1,1,2 trichloroethane; trichloroethylene; and cis 1,2 dichloroethylene.

The Division of Superfund has subsequently had meetings with the responsible party and is currently negotiating an agreed order for cleanup under the voluntary compliance program. A key element of the requirements from the Division of Superfund is that of paying for Ardmore's treatment unit as well as the additional monitoring and maintenance costs due to the contamination. The Division of Superfund is also insisting on an early soils removal to reduce further contamination of the aquifer. Superfund has made the payment to Ardmore a required demonstration of willingness to voluntarily proceed under a consent order. If the responsible party is recalcitrant, the payment to Ardmore will be pursued as a recovery of natural resource damages in conjunction with a commissioner's order.

DEPARTMENTAL COORDINATION

The Department of Environment and Conservation has created an Enforcement Coordinator position at Bureau level in the Bureau of Environment to expedite multi-agency cases requiring enforcement. The Department of Environment and Conservation had several tools at its disposal in dealing with Ardmore's contamination problem, the most viable of which was through the Division of Superfund. There are also provisions within the Tennessee Safe Drinking Water Act that couple it with the Tennessee Water Quality Control Act in dealing with the contamination of a public water system, as well as Part I of the Hazardous Waste Management Act (Tennessee's RCRA law) and Underground Injection Control Regulations under the Tennessee Water Quality Control Act. The Federal Clean Water Act regulates surface water and ground water shown to have a connection with surface water. Tennessee's Water Quality Control Act (WQCA) is the basic equivalent, but goes considerably beyond with respect to ground water. The WQCA specifically addresses and protects ground water as "waters of the State."

Public water systems have limited tools at their disposal in protecting their water supply. State agencies with ground water regulatory roles play a valuable role in the protection of public water systems. Public water systems are also required to work with county, local government and local planning agencies in efforts to protect their wellhead protection areas. A significant portion of the Ground Water Management Section's responsibilities is that of coordinating regulatory activities in the wellhead protection areas with the help of the State's Ground Water Advisory Committee as well as overall ground water protection efforts. The Ground Water Advisory Committee is made up of state agencies with ground water regulatory/ assistance roles and includes the divisions within the Bureau of Environment in the Department of Environment and Conservation as well as other agencies within the Department and the Divisions of Plant Industries and Agricultural Resources in the Department of Agriculture. The Ground Water Management Section is also charged with the development of Tennessee's Comprehensive State Ground Water Protection Plan.

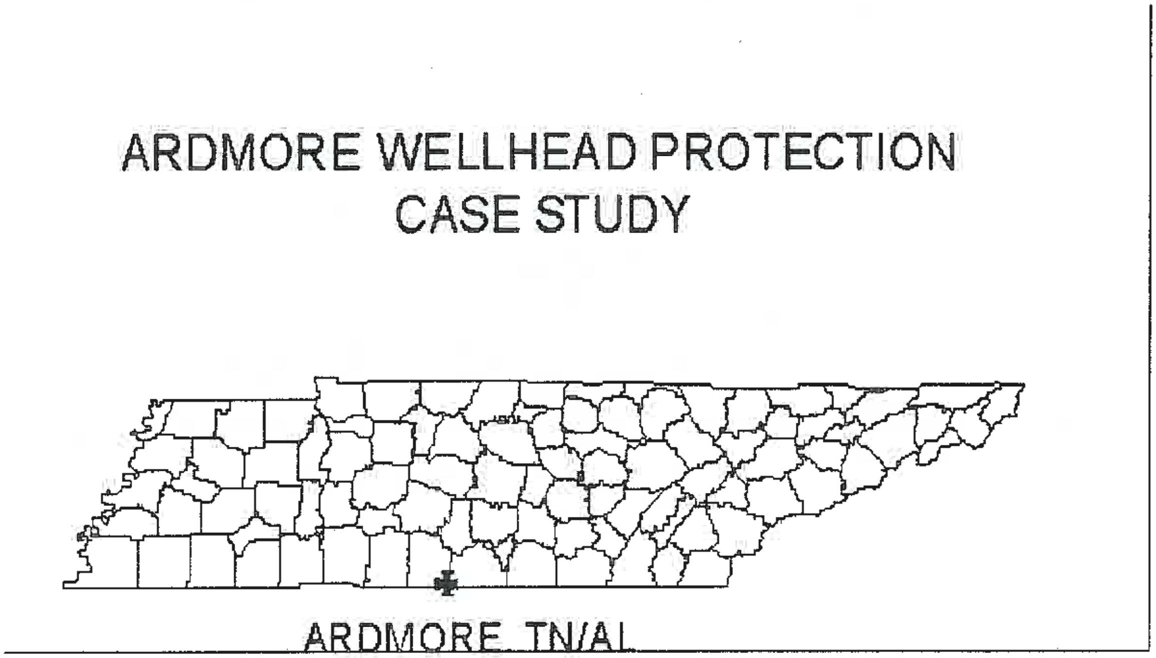


FIGURE 1

ARDMORE WELLHEAD AREA

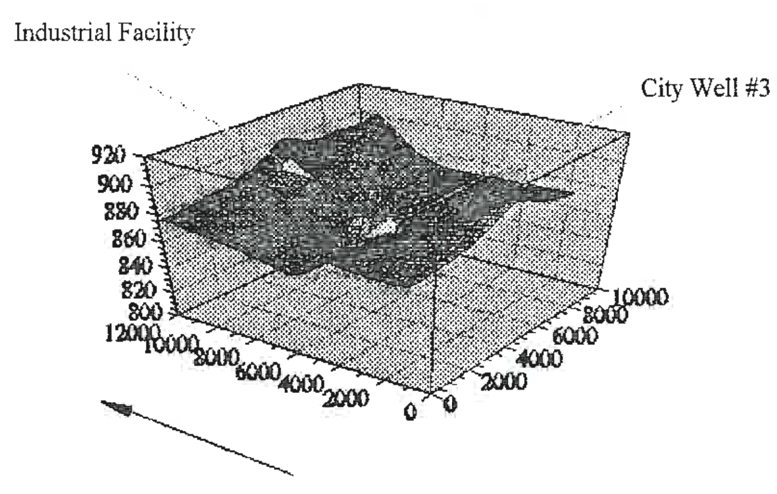


FIGURE 2

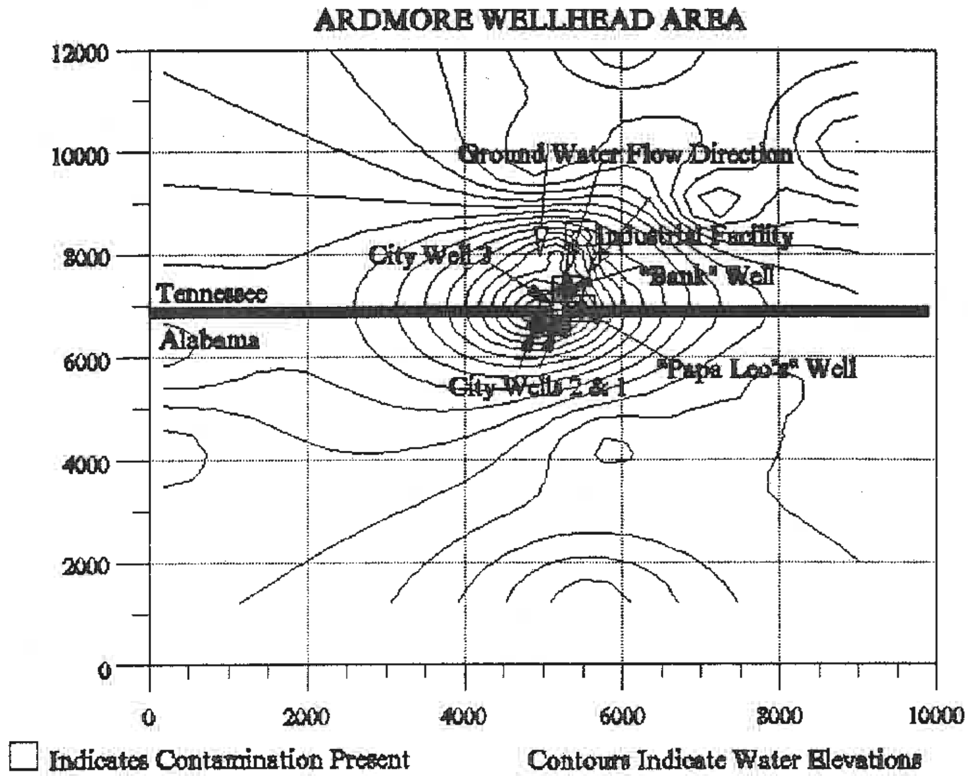

ARDMORE WELLHEAD AREA
12000
10000
8000
6000
4000
2000
0
0
2000
4000
6000
8000
10000
Ground Water Flow Direction
Industrial Facility
City Well 3
"Bank" Well
Tennessee
Alabama
"Papa Leo's" Well
City Wells 2 & 1
Indicates Contamination Present
Contours Indicate Water Elevations

FIGURE 3

DELINEATION OF WELLHEAD PROTECTION MANAGEMENT AREAS

James Outlaw[1]

INTRODUCTION

Under Rule 1200-5-1.34, the Tennessee Department of Environment and Conservation (TDEC) has developed regulations for mandatory state-wide Wellhead Protection Programs (WPP) to protect the various public water systems (PWS) that utilize ground water as a source of drinking water. For the East and Middle Tennessee area, this regulation covers PWS that utilize springs and karst aquifer systems. Municipalities that utilize surface water reservoirs for drinking water are excluded from this regulation. In West Tennessee, virtually all of the PWS utilize ground water as a source of drinking water and, as a result, must comply with the Wellhead Protection (WHP) Regulation.

There are three basic requirements under the WHP regulation: delineation of two zones of protection; an inventory of all potential contaminant sources within the protection areas; and the implementation of a management plan. The Zone 1 Area may be either a fixed radius around the production well or it may be based on the 8 week capture zone for the well. Larger water systems in West Tennessee (productions of more than 1 million gpd) are encouraged to use the 8 week capture zone as the basis for their Zone 1. This area is meant to be a zone of prohibition. No new activities will be allowed within this protection area. The Zone 2 Area must, as a minimum, be based on the 10 year capture zone. Within this area, landuse restrictions and facility monitoring will be required. It is left to the municipality to develop an implementation scheme for both management areas. Once the two protection areas have been delineated, an inventory of all potential contaminant sources within the zones must be developed. The risk of ground water contamination of each potential source must also be evaluated. The final step in the development of a WPP, is the implementation of a management plan.

DEVELOPMENT OF GROUND WATER FLOW MODEL

As required by the WHP regulations, the capture zones for production wells in West Tennessee may be delineated using numerical flow models. For larger systems, the use of a flow model is required. Two different models are acceptable, the WPA WHPA model and the USGS MODFLOW model coupled with MODPATH. The WHPA model uses a semianalytical technique to delineate time-related capture zones. MODFLOW uses a modified finite-difference technique to determine a solution to ground water flow equations. MODPATH uses a semianalytical particle tracking technique to delineate capture zones from a steady-state MODFLOW simulation.

Within Shelby County, Tennessee, all municipalities use ground water as their sole source of drinking water. The primary aquifer used by most municipalities in Shelby County, including Memphis, is the Memphis Sand aquifer. Millington uses the Fort Pillow Sand aquifer exclusively. The number of production wells currently totals around 200 (including municipal and major industrial). Consequently, it is almost impossible to simulate the operation of an individual well or wellfield with any sort of accuracy. In order to delineate the required capture zones for wells in Shelby County, a regional ground water flow models

[1]Research Associate, Ground Water Institute, The University of Memphis, Memphis, Tennessee 38152; Phone: (901) 678-4315, Fax: (901) 678-3078; E-mail: jamie@ce5.gwi.memphis.edu

was developed using MODFLOW. The model was a refinement of two previously-developed regional flow models developed by the Ground Water Institute and the USGS.

The geology of the area was defined using information contained in the GWI GIS database. A collection of around 400 geophysical logs were used to define the extent and thickness of confining layers and the Memphis Sand and Fort Pillow Sand aquifers. Hydraulic characteristics were determined from pump tests performed on many of the production wells in the area. The hydraulic characteristics were adjusted during calibration of the ground water flow model. The model was calibrated to water level measurements in several monitoring wells located throughout the county.

Once a calibrated flow model was developed, it was run to a steady-state solution and the required capture zones were delineated using MODPATH. The capture zones were delineated under the assumption that all of the production wells in the county were operating at their rated capacity. Although this is not a realistic assumption, it will produce a conservative estimate of a capture zone and is adequate for purposes of wellhead protection. Also, several of the suburban municipalities have opted, at the recommendation of the GWI, that a 40 year capture zone be used as the basis for the Zone 2 area as opposed to the 10 year capture zone. The larger capture zone provides a longer planning horizon that is important in rapidly-growing areas like the suburban municipalities around Memphis.

The 8 week capture zone for each production well in Shelby County was delineated using the EPA WHPA model. The hydraulic parameters required by WHPA were taken from the calibrated MODFLOW model. WHPA was used because it allows for the exact location of wells. In a MODFLOW model, the wells are placed at the center of a finite difference cell. Depending on the size of the cell, this may introduce a large error in the capture zone. This error is minimized in larger capture zones (i.e. the 10 year capture zone).

DELINEATION OF MANAGEMENT AREAS

Once the capture zones were determined, the Zone 1 and Zone 2 areas were delineated. Using the GIS program, ARC/INFO, the capture zones were converted to polygons and compared with a digital parcel map of Shelby County. The capture zones were modified to conform to parcel boundaries, based on both the size of the parcel and the amount of the parcel within the capture zone. If the parcel was less than 1 acre in size and more than 50% of it fell within the capture zone, then the capture zone was modified to include all of the parcel. For parcels between 1 and 5 acres, the requirement was 60% and for parcels greater than 5 acres, the requirement was 75%. For parcels that did not meet the above criteria, the capture zone was unmodified. This technique was used to make the development of a management plan easier. The Zone 2 areas for the Towns of Collierville and Arlington, and the Cities of Germantown and Millington have been delineated using this method and submitted to the state for approval. As of November, 1995, the submittal for the Town of Arlington had been approved by TDEC.

MANAGEMENT PLAN

Once the required protection zones have been delineated, the municipality must develop a management plan. In Shelby County, the management of WHP areas is complicated by the fact that the capture zones cross municipal boundaries. For example, one of the Memphis Light, Gas and Water wellfields has about half of its wells and a majority of the capture zone within the limits of the City of Bartlett. Germantown has one wellfield whose capture zone extends into both Unincorporated Shelby County and into the Town of Collierville. The Town of Collierville's Zone 2 areas extend into both Fayette County, Tennessee and also Marshall County, Mississippi. The problems with the Zone 2 areas crossing county and state boundaries have not been solved as yet. However, within Shelby County, a uniform WHP management plan should solve the multijurisdictional problems.

It is proposed that the planning commissions for the various municipalities in Shelby County as well as the Memphis/Shelby County Office of Planning and Development adopt the Zone 1 and Zone 2 Areas as a zoning overlay similar to the existing flood plain overlay. No new development would be allowed within the Zone 1 Area. It is recommended that the PWS delegate the Shelby County Ground Water Quality Control Board (GWQCB) with the responsibility for the management of the Zone 2 area. The management plan would require that developers obtain a "Certificate of Conformance" prior to obtaining a building permit. The proposed management plan is shown in Figure 1.

The GWQCB will review the developers plans and determine whether the developer has taken the necessary steps to ensure ground water protection once the development has been completed. For example, with in the Zone 2 area, all new service stations will be required to comply with the State Underground Storage Tank Regulations and install double-walled tanks and pipes. A leak detection device will be required between the walls of the tanks. If the plans meet the requirements of the GWQCB, then the Certificate of Conformance will be issued and the developer may apply for a building permit. If the plans are rejected, the developer will be allowed one appeal before the board and if the issue is not resolved, then the developer may appeal to the courts. This management plan does not place any restrictions on existing facilities, however, if an existing facility desires to expand, then the owner must comply with the wellhead protection regulations. It is also recommended that copies any monitoring reports prepared by facilities within the Zone 1 and Zone 2 areas be submitted to the PWS for review.

The Memphis/Shelby County Office of Planning and Development is agreeable to the proposed implementation plan as are the Towns of Collierville and Arlington and the Cities of Millington and Germantown. As of November, 1995, Memphis is undecided. The enforcement of the conformance to the WHP requirements will be the responsibility of the Codes Enforcement Department of Each municipality.

The proposed implementation plan provides a solution to the problem of multi-jurisdictional control of Wellhead Protection Areas. Placing the responsibility for enforcing the WHP management plan on the GWQCB will ensure a uniform WHP management strategy across Shelby County.

BACTERIA RESULTS AND WELLHEAD CHARACTERISTICS FOR PRIVATE DRINKING WATER WELLS IN MIDDLE TENNESSEE

Tim Thompson[1]

INTRODUCTION

The presence of fecal bacteria, fecal coliform bacteria and fecal streptococcus bacteria, in groundwater pose a serious threat to human health, due to the potential for contraction of a disease or virus. Fecal bacteria indicate the presence of animal and/or human waste. Fecal bacteria can originate from surface runoff from pastures, feedlots, dairy loafing areas, poultry growing operations, animal waste lagoons, seepage into groundwater from manure spreading, and from septic tank systems. In middle Tennessee the potential for fecal bacteria contamination of groundwater is compounded by the presence of karst terrain, shallow bedrock, and nonpoint source (NPS) pollution. Since the upstream limits of the Duck River and all its tributaries are being impacted by NPS pollution, it is suspected that the groundwater is also impacted by NPS pollution.

STUDY AREA

The study area is a 77,000 acre hydrologic unit which lies in the northwest corner of Bedford County, Tennessee and the southwest portion of Rutherford County, Tennessee (Figure 1). The unit lies within the upper Duck River system and is composed of 760 farms of diversified uses. Twenty-five Grade A diaries are present in the study area. Less than half of these have adequate waste storage and management systems. There are also 25 poultry growers with 58 poultry houses that have the problem of proper dead bird disposal and litter application. Other problems include unfenced or unprotected streams (and stream banks) and sinkholes, in grazing and pasture areas, from livestock. Sinkholes act as a direct channel to the groundwater.

A large percentage of people in northwest Bedford County, Tennessee depend on groundwater for all their needs, ranging from domestic water supply to irrigation and livestock watering. A number of wells within the study area have been previously tested, and high levels of fecal coliform bacteria fecal streptococcus were detected in some wells. Fecal bacterial pollution of groundwater is suspected to result from improperly installed and/or malfunctioning septic systems for domestic waste disposal, the potentially improper usage of manure as fertilizer, and from confined animal operations (dairy, swine, poultry, and beef operations).

Due to the shallow soil characteristics and karst terrain, septic systems are a potential source of fecal bacteria pollution. The shallow soil does not provide adequate buffering capacity for the drain fields, allowing more concentrated solutions to reach the groundwater, via existing fractures in the in the bedrock and/or fractures from blasting during septic tank installation, and sinkholes. Improper or malfunctioning septic systems, and the absence of a community septic system is a growing concern in Bedford County which is experiencing rapid development as a result of Nashville's growth. In karst terrain, the interconnection between surface water and groundwater increases the potential for groundwater contamination.

[1]Tennessee Department of Environment and Conservation, Division of Water Pollution Control-Watershed Management Section, 7th Floor L & C Annex, 401 Church Street, Nashville, TN 37243-1534; (615) 532-0688

METHODOLOGY

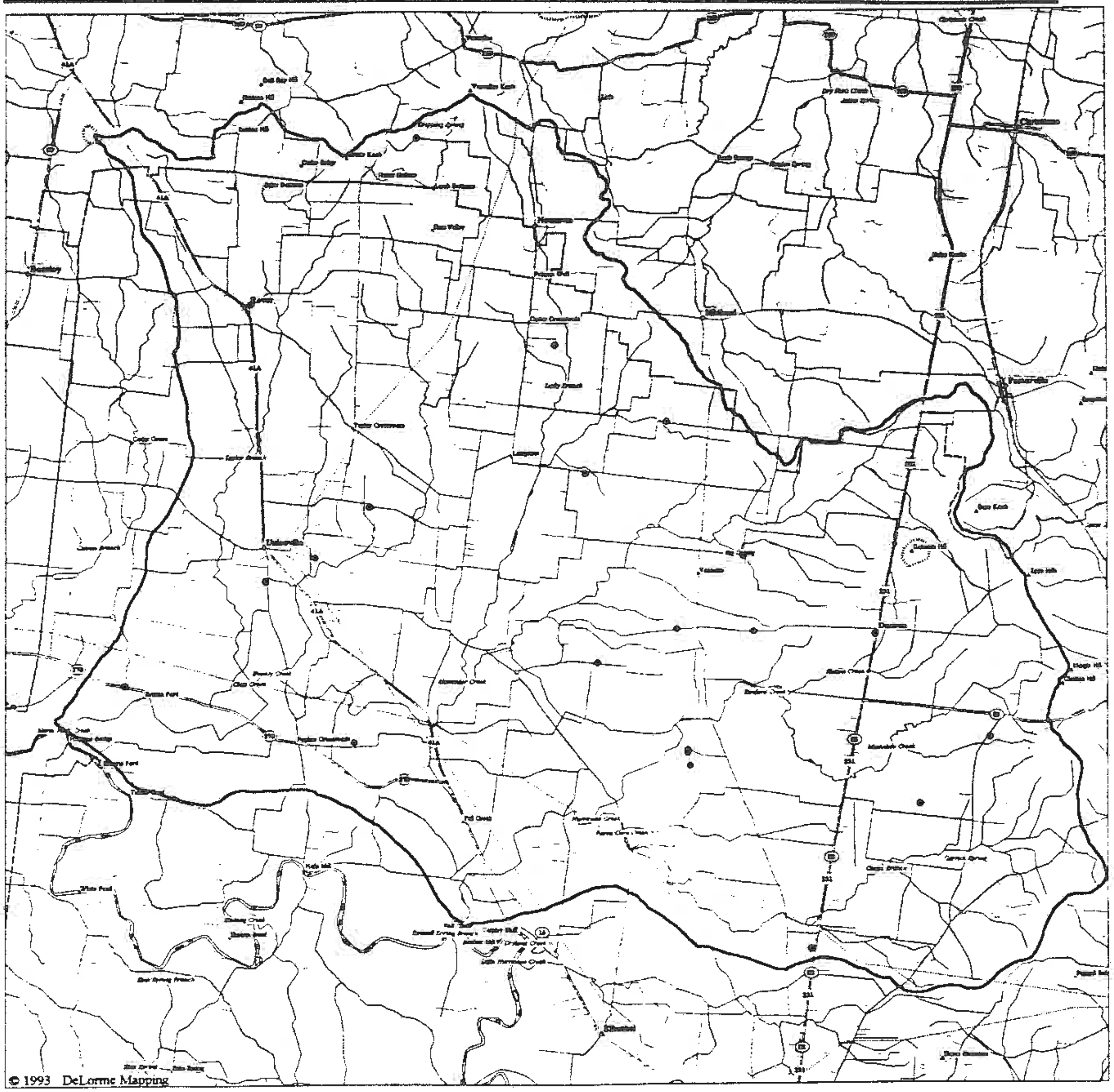
A detailed reconnaissance of the watershed was conducted, and all potential NPS pollution sources, land use types, available water wells, bedrock fracture and strata pattern, and sinkhole location were placed on a map. Water wells were selected based on potential NPS pollution sources, fracture and strata orientation, historical water quality data, and accessibility via the well owner. Due to the sensitivity of this issue, at the request of some well owners, and the discretion of the author, well owners names will be kept anonymous. A total of 20 private drinking water wells were selected.

Samples were collected six times; February, 1994 (winter); May 1994 (spring); August 1994 (summer); November 1994 (fall); February 1995 (winter); and May 1995 (spring). All samples were analyzed for fecal coliform bacteria and fecal streptococcus bacteria, at the Tennessee Department of Health, Environmental Laboratory. Wellhead survey parameters included: water use; well system filtration; year well was constructed; total well depth; casing height above the ground surface; cap on well; soil type around casing; surface slope; distance to septic tank; and distance to animal feedlot/confinement areas.

RESULTS

Only four of the 20 wells tested, consistently yielded results of non-detect. The remaining 16 wells yielded fecal coliform results ranging from non-detect to 23,000 colonies per 100 milliliters, and fecal streptococcus results ranging from non-detect to 16,000 colonies per 100 milliliters. At this time, preliminary statistical analyses show that as distance between the potential pollution source (animal feedlot/confinement area or septic tank) and the wellhead increases, colonies of fecal bacteria decrease. More detailed statistical analyses will be conducted.

High bacteria counts are attributed to a combination of poor wellhead protection practices, karst terrain, and NPS pollution from agricultural and domestic practices. Proper wellhead protection practices are critical in supplying water that is safe to drink and to use. The threat of fecal bacteria contamination of groundwater, ultimately drinking water for people without access to public water systems, indicates the need for greater awareness and protection of the wellhead. For people depending on private water wells for their needs, *they* are responsible for wellhead protection, better maintenance of the well, and for keeping potential contaminant sources at a safe distance from their wellhead.



LEGEND

State Route	Population Center	US Highway
Geo Feature	Street, Road	Railroad
Town, Small City	Major Street/Road	River
Hill	Street, Road	Airfield
US Highway	Variable Trails	Utility (powerline)
County Boundary	State Route	Land Mass

WELLHEAD SURVEY AREA
Mag 13.00
Wed Nov 08 07:10:28 1995

Scale 1:125,000 (at center)

2 Miles

2 KM

UPPER TENNESSEE VALLEY RESERVOIR RIPARIAN VEGETATION STUDIES I. PRIMARY PRODUCTION, HABITAT STABILITY AND EFFECTS ON AQUATIC ENVIRONMENTS

C.C. Amundsen[1], C.C. Loy, P.B. Inklebarger, R.A. Hanahan, S.L. Hammons, and J.M. Young

Alien habitats were imposed on the upper Tennessee River Valley with the impoundment of several main stream and tributary reservoirs, most of which are approximately one half century old. There were essentially no lentic bodies of water in east Tennessee before the construction of small, private impoundments begun around the turn of the century. An extensive (8400 km nominal length, some 9000 hectares) summer shoreline zone was altered from an area of topoedaphic mesic condition to seasonal, reservoir riparian zone as 15 major upstream impoundments constructed by the Tennessee Valley Authority (TVA) filled, beginning in the 1930's. The spring-summer pool levels of these extant (TVA) impoundments generally exceeds the highest known level of historic river floods. In essence, a new, hydrically adapted, forest flora has replaced the previously existing mesic, oak-hickory dominated expression. The reservoirs are managed for the production of hydroelectric power, navigation, flood control, water storage, and of increasing importance, recreational use.

This management has been manifested in a counterseasonal water regime, where the water levels influencing the terrestrial vegetation are now highest during the growing season and lowest during the season of vegetational dormancy, the converse of the riverine situation before impoundment. They hydrically displaced mesic vegetation has left a habitat suitable mostly for adaptable riparian flora migrating from upstream stream and river banks, and for alien plant introductions such as privet. This study focuses on the reservoir riparian vegetation of the summer shore of mainstream Watts Bar Reservoir (WB) in east central Tennessee in terms of the condition and composition of neohydric riparian aboreal stands. These stands, measured and evaluated on both the mainland shore and on small islands within the winter reservoir pool, show a composition similar to other hydrically influenced regional forests. The reservoir riparian forest is less productive in terms of basal area increment when compared to otherwise similar forests. The litterfall is relatively abundant. The development of the forest stands reflects the limits placed on the growth processes of the canopy dominant species by the presence of a saturated soil profile during the growing season. The reservoir riparian habitats studied are diminishing in extent due to shoreline erosion which compresses the hydric expression against a relic mesic habitat above present water level influence, and to continuing managed development of shoreline landscapes.

The objectives of the study have been to assess the changes in habitat characteristics from mesic to hydrically influenced, to characterize the composition and productivity of stands for comparison with empirically similar stands, to note the role of the reservoir riparian stands in the complex of upper Tennessee River Valley ecosystems including terrestrial components, allochthony and sediment contribution to the aquatic system and to predict as well the continued succession, progress toward expressed stability and the future of the reservoir riparian habitat with present conditions.

Methods involved in the study to date include standard techniques for floristic assessments, plot and plotless measurements for stand density and basal area, collection of litter, installation of simple wells for the monitoring of the saturated forest soils within the flood zone (top of reservoir gates contour), evaluation of

[1]Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, Tn 37996-1610. Telephone (423) 974-3065

erosion losses of the summer shore bank, and the determination of aquatic floral inputs (algae and macrophytic emergents) likely available to the nearshore aquatic communities.

Results to date show that through comparisons of empirically similar forests of the upland Tennessee-North Carolina area, the composition of the reservoir riparian forests studied along the TVA impoundments have relatively high coefficients of similarity (CCs = 2c/ sl + s2, SØrensen) to less actively disturbed stands of about the same longevity. Fewer than twenty consistently arboreal species at the specific level are common in hydrically influenced forest stands across the region. Smith et al. (1975) report 15 generic taxa in bottomlands noted for riparian proximity. Mann and Bierner (1975) list 12 and the Watts Bar mainshore transects completed to date show 14 (Amundsen, 1994). Recent plots taken exclusively on low islands entirely within the winter pool area of Watts Bar show 14 genera that appear in a least two of the aereal compilations compared. A relatively new Tellico Reservoir riparian zone (dam closed 1979) survey revealed 12 of the same common genera. The regularly encountered, hydrically adapted genera which contained reproductively successful species were maple, alder, birch, bluebeech, hickory, hackberry, dogwood, ash, sweetgum, blackgum, sycamore, oak, willow and elm. SØrensen quotients of similarity at the specific level for these compositions average 70% or better between and among stands compared.

Productivity measurements are not available for many of the riparian forest stands of the region compared, although Smith et al. (1975) do provide comprehensive data for stands which can be shown to be similar in age and taxal composition to the mainland reservoir riparian forests of Watts Bar. Data from Smith et al. (1975) show approximately 30 square meters per hectare of timber size individuals in the 50 year age class. Fifty year old Watts Bar stands show about two-thirds of that basal area (20 square meters per hectare). The Mann-Whitney non-parametric statistical test demonstrates that the WB stands do not have the same basal area values as those reported by Smith et al. (1975), Amundsen (1994), Loy (1994). A 15 year old Tellico Reservoir stand shows only 14 square meter basal area per hectare of riparian stands with comparable composition. The numbers from stands from which data are available indicate that age of stand is a factor in expected coverage, since composition coefficients are high, and within stands, basic habitat resources across the region were assumed to be similar in availability, an expected coincidence of riparian stands on now or once riverine substrates. The stands reported by Smith et al. however are not influenced by impounded pool rises and saturated soils during the growing season, and the WB and Tellico stands are.

The basal area increment of reservoir riparian stands appears to be limited in part at least by the measured (regularly in two transects of wells) saturation and poor oxygen levels at a shallow depth in the substrate. The critical depth to water appears to be in the neighborhood of 30 cm as determined from the wells and also from the scarp face at the shoreline which reveals the root zone profile. Litter collections in the Watts Bar reservoir riparian forest habitat however show more dry weight accumulations than those in abutting mesic forest zones upslope (the average slope limit is about nine percent within the Watts Bar flood zone or summer riparian habitat from summer pool elevation of 225.9 m to the flood pool contour at 227.1 m, the lowest level of consistent mesic expression). The riparian litter is more by a factor of five to three from current analyses. A compounded annual biomass increment shows the riparian forest approximates the productivity of an undisturbed mesic forest not subject to continued substrate flooding. Observations show the reservoir riparian forest to predominantly consist of fast growing, coarse crowned individuals which appear to lose apical dominance with height as allocations for growth (sensu David Tilman, 1988) shift from stem to leaf when root processes are restricted.

The aquatic habitat, nearshore, in proximity to the reservoir riparian forest communities, is usually normal in pH (rarely lower than 6.7 or higher than 7.3 over five years of weekly readings). The inshore waters are usually low in conductivity and low in light transparency due to a conspicuous mineral sediment load. TVA data (Meinert, 1991) show that the measured carbon content of the Watts Bar waters is low. Submersed macrophytes are not common, with only scattered occurrences of pondweed and the introduced watermilfoil noted. Emergent aquatic plants such as reed canary grass and willow leaf herb are locally conspicuous among others, but much of the 1240 km of the Watts Bar shore (TVA Operations 1980) show no vegetated transition between the summer shore and the winter mudflat (Amundsen and Walker, 1991). A preliminary study to identify the microphytic algae of Watts Bar which may be associated with characteristic shoreline conditions now reveals some 100 microphytic taxa in five phyla. Linkage of the compositional presence and abundance of indicator taxa awaits further analysis, but shallow summer cove waters and areas with direct shoreline organic resource inputs appear to show greater algal producer diversity and abundance.

The subject reservoir riparian forest stands, exemplified in a study at Watts Bar reservoir, the largest of the upper Tennessee Valley impoundments, are important, coincidental biotic expressions in the upper watershed of this major regional drainage. The communities which make up the reservoir riparian expression, in the area between the winter pool shore and above, particularly from the summer pool shore to the flood pool level of direct water influence, have shown, even in only some 50 years, a systematic interaction of biotic adaptation and physio-chemical adjustment to the imposed, counterseasonal inundation of substrates which has a long term mesic site genesis. There has been an establishment of a replacement floral resource supportive of a visible number of consumers of importance to the diversity of the areal faunal composition. The riparian strip, long and narrow in most expressions, is a habitat for hydorphytic plant establishment and persistence and consequent diversity within the valley flora. The terrestrial producer associations support both onshore and probably offshore secondary productivity of consumers and decomposers. Many of these faunal and microbiotic organisms are not adapted for either the terrestrial mesic habitat or for a fluctuating body of water which might otherwise show a decline in organic resources with age. Continued existence of the reservoir riparian habitat will likely allow an increase in the composition of flora, fauna and decomposers as migrants from similar, but geographically distant habitats become established or as other populations not now represented in the extant communities show genetic amplitude and adaptation which will allow their success. The future of the reservoir riparian habitat is however in jeopardy. The wave erosion of powerful pleasure boats is collapsing the banks and obliterating the lower islands. Continued development of the mostly privately owned mainland shorelines are replacing the forest species with open, designed and often exotic plantscapes. The value of the riparian strip as a filter for materials undesirable in the aquatic habitat is diminishing. The aesthetic appeal of a relatively unmanaged reservoir front is being compromised. There does not appear to be any answer to the inevitable loss of this relatively young, alien, but ecologically welcome habitat. Some delaying measures such as no boat wake zones near especially vulnerable shores and the plantings of native species which slow shoreline erosion (alder onshore, willowleaf herb offshore for example) may extend the life of the habitat. This compromise zone between wetland and swamp will be an ecological deficit when it is gone.

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APPLICATION OF CE-QUAL-W2 TO BARKLEY RESERVOIR

Bob Yager[1]

INTRODUCTION

Barkley Reservoir on the Cumberland River in north central Tennessee and central Kentucky is operated by the U.S. Army Corps of Engineers (COE) for flood control, navigation, hydroelectric power production, and recreation. Barkley dam located at Cumberland River Mile (CRM) 30.6 was completed in 1966. The reservoir is 118.1 miles long with the upstream end at Cheatham Dam at CRM 148.7. Near the downstream end Barkley Reservoir is connected to Kentucky Lake on the Tennessee River by a canal. The upper reaches of Barkley Reservoir are riverine with the lower reaches being more lacustrine. The average residence time for 1985 computed from daily data was 22.9 days. A 23-day moving average of daily residence time calculations varies between about 10 and 50 days with the lowest flows, greatest storage, and longest residence times during the early summer. In 1984, the average residence time computed from daily data was 12.8 days. A 13-day moving average of daily calculations for 1984 also varied from 10 to 50 days but was less than 20 days except for the month of September. Although there is little vertical temperature stratification, dissolved oxygen (DO) stratification does develop with occasional periods of low DO at depth.

WATERSHED DESCRIPTION

The drainage area of the Cumberland River at Barkley Dam is 17,598 square miles. The drainage area at Cheatham Dam is 14,163 square miles, leaving 3,435 square miles of local drainage into Barkley Reservoir. Major contributions to the local inflow include the Red River (1,465 square miles), Yellow Creek (175 square miles), Little River (601 square miles) and Eddy Creek (107 square miles), leaving 1,087 square miles of drainage area into small creeks and direct runoff to Barkley Reservoir. In addition to the inflow at the upper end of each of the three branches, additional inflows and outflows may occur through tributaries, withdrawals, discharges from Barkley Dam, local inflows, precipitation, evaporation, and seepage.

MODEL CONSTRUCTION

The largest inflows and outflows are at Cheatham Dam and Barkley Dam with significant flows through the Barkley-Kentucky Canal. Flows in the Little and Red Rivers, Eddy and Yellow Creeks, and local inflows are about an order of magnitude smaller. Flow into and out of the Cumberland Steam Plant ranges from approximately 10% to 100% of Barkley and Cheatham releases, but inflow equals outflow so there is no net flow into or out of the reservoir. Inflow temperatures and constituent concentrations were estimated from available data, which was often sparse. The Class 1 meteorological stations closest to Barkley Reservoir are in Paducah, Kentucky and Nashville, Tennessee. Since the downstream part of Barkley Reservoir is closer to Paducah, meteorological data from Paducah were used.

A branched version of the Corps of Engineers (COE) model CE-QUAL-W2 has been developed to help better understand the water quality dynamics of the reservoir. In addition to hydrodynamics and temperature, modeled constituents include nutrients, algae, detritus, dissolved oxygen, and CBOD. The final model grid consists of three branches with 93 segments and 23 layers; the Cumberland River is branch 1 and

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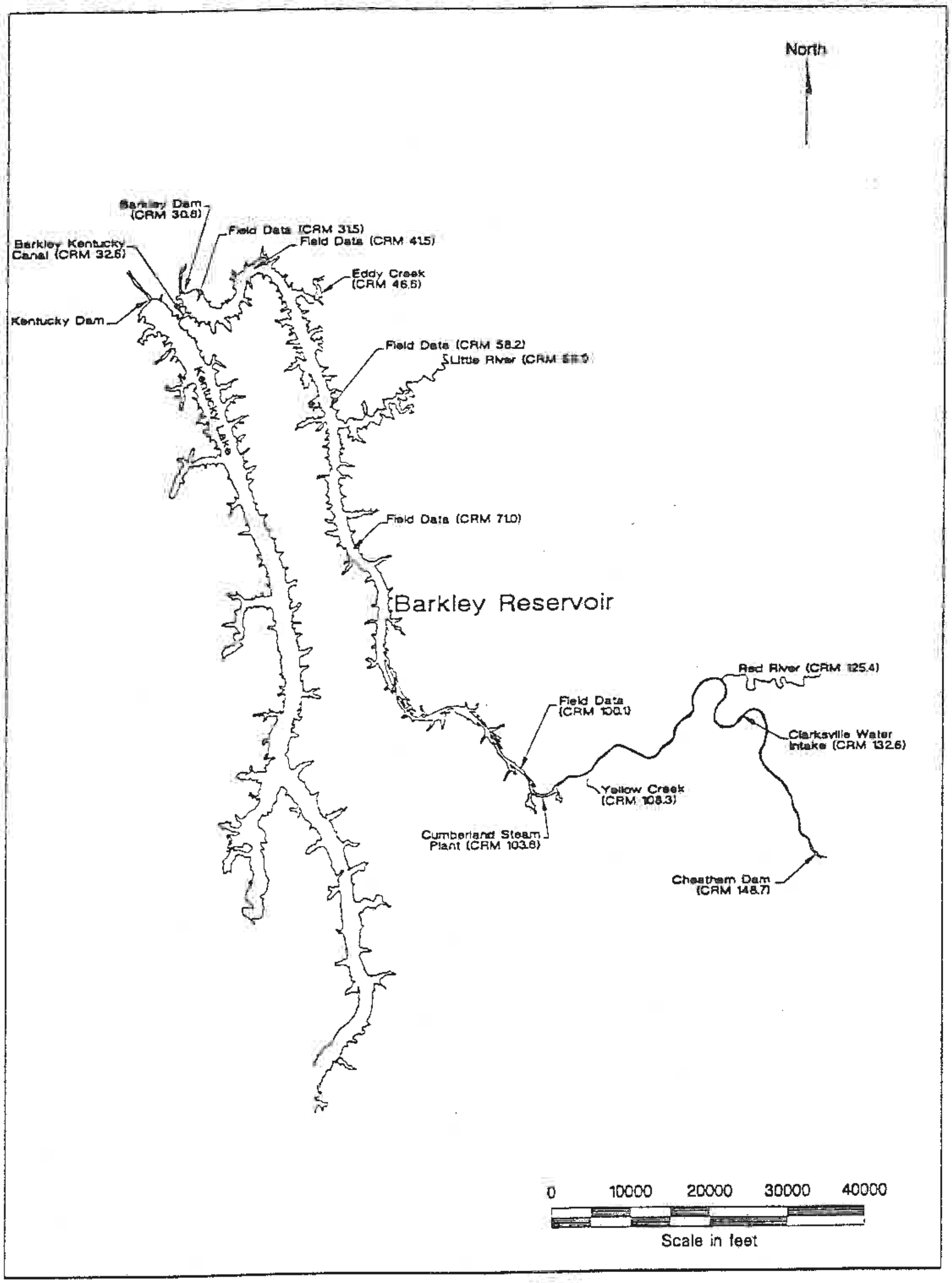
[1]Environmental Consulting Engineers, P.O. Box 22668, Knoxville, TN 37886; phone: (423) 691-3668; email: bobyager@ece.com.


North
Barkley Dam (CRM 30.8)
Field Data (CRM 31.5)
Field Data (CRM 41.5)
Barkley Kentucky Canal (CRM 32.5)
Eddy Creek (CRM 46.5)
Kentucky Dam
Field Data (CRM 58.2)
Little River (CRM
Kentucky Lake
Field Data (CRM 71.0)
Barkley Reservoir
Red River (CRM 125.4)
Field Data (CRM 100.1)
Clarksville Water Intake (CRM 132.6)
Yellow Creek (CRM 108.3)
Cumberland Steam Plant (CRM 103.6)
Cheatham Dam (CRM 148.7)
0
10000
20000
30000
40000
Scale in feet

the Little River and Red River are branches 2 and 3 respectively. Segment lengths are 3 km in branch 1 and 3.218 km (2 miles) in branches 2 and 3. All layer heights are 1.524 m (5 ft). The bottom of the lowest active layer (layer 22) in the model grid is at elevation 270.0 ft (82.292 m). Normal summer pool is elevation 359.0 ft (within model layer 6) and normal winter pool is 354.0 ft (within model layer 5).

The model has been calibrated to temperature and DO data collected by Murray State University in 1985 (King and Jarret 1988) and verified by simulating the reservoir with 1984 input data and comparing the results with 1984 field data. Selected calibration results are shown in the attached figures.

RESULTS

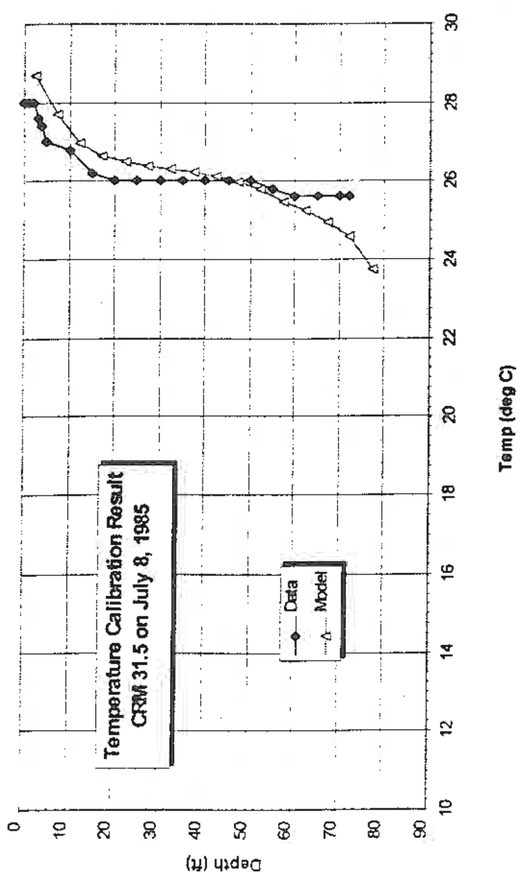
The calibrated model has been used to evaluate impacts of a proposed alternative headwater guide curve on water quality in the reservoir and in discharges from Barkley Dam. The effects of flows into and out of the reservoir through the Barkley-Kentucky canal and of the Cumberland Steam Plant at CRM 103.6 have also been investigated. Variations in the headwater guide curve produced only minor changes in predicted temperature and dissolved oxygen. The modeled effects of the Cumberland Steam Plant were as expected given the heat and DO introduced at that point in the model.

The predicted effects of varying the flow in the canal were somewhat less intuitive. The calibrated 1985 model was used to simulate an increase and a decrease of approximately 50% in canal flow into Barkley Reservoir. The only way to effect such variations in canal flow would be to modify the operations of Barkley and Kentucky Dams. In addition, canal hydrodynamics are complex and not well represented by the simplistic approach used in the model. Modeling this scenario was intended only to develop insight into the effects of canal flow on water quality in Barkley Reservoir. Effects in the forebay of Barkley Reservoir are fairly obvious. Since inflows from the canal were assigned warm temperatures and high DO as measured in the upper layers of the downstream end of Barkley Reservoir, hypolimnion temperatures in the reservoir near the canal were increased by about 0.2°C by increased canal flows and decreased slightly more by decreased canal flows. Varying the canal flows had a similar effect on modeled DO. Increasing the canal flow increased the hypolimnetic DO in Barkley by about 1 mg/L while decreasing canal flow lowered DO by a similar but somewhat greater amount. Effects in the upper layers were minimal since data from the upper layers of Barkley Reservoir were used to specify canal temperature and constituent concentrations.

A somewhat less obvious result is that effects extend tens of miles upstream of the canal. The attached figures show results at CRM 41.5, about 9 miles upstream of the canal. Variations in the canal flow changed the hydrodynamics of the entire reservoir, leading to changes in predicted temperature and water quality. Water and constituents are not being advected or otherwise physically transported upstream. A conservative tracer introduced into canal inflows in the calibrated 1985 model migrated only two to three miles upstream of the canal. Velocities at upstream stations do vary with canal flow, however. The slight warming of the hypolimnion with increased canal flow decreases vertical stratification and stability, allowing greater mixing of near surface DO deeper into the reservoir.

Increasing and decreasing canal flows also affect the temperature and DO of discharges from Barkley Dam. Predicted temperatures were about 0.5 deg warmer during the summer for increased canal flows and 0.5 deg cooler for decreased flow. Predicted DO concentrations in Barkley discharges were increased about 0.5 mg/L during the summer with increased canal flows and decreased 0.5 to 1.0 mg/L when canal flows were decreased in the model. This is most probably a direct effect of bringing in more or less oxygen rich water from the canal, which then is discharged in a relatively short time through Barkley Dam. Increases and decreases in temperature stratification also contribute to these effects.

The effects of the Barkley-Kentucky canal on the water quality of the downstream reaches of the reservoir are important but may not be well simulated by the model. Neither temperature nor constituent concentrations in the canal are routinely measured and were approximated by measurements from the surface layers of Barkley Reservoir at CRM 31.5. The model does indicate, however, that increasing or decreasing flow through the canal may have significant impacts on temperature and DO in the downstream portion of the reservoir and a noticeable effect on the water quality of reservoir outflows. Effects of canal flows are apparent tens of miles upstream of the canal through variations in the reservoir hydrodynamics induced by canal flows. Both better temperature and water quality data in the canal and a better understanding of canal hydrodynamics are necessary for a more complete understanding of the importance of the canal to Barkley Reservoir water quality.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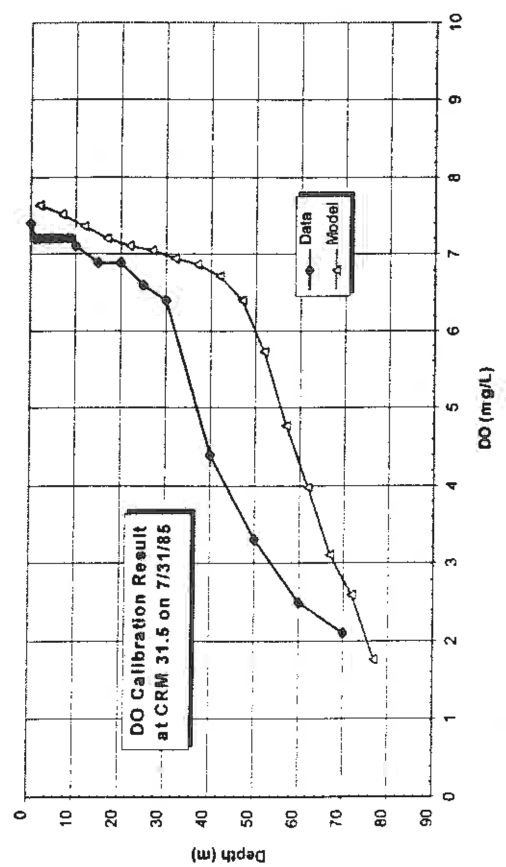
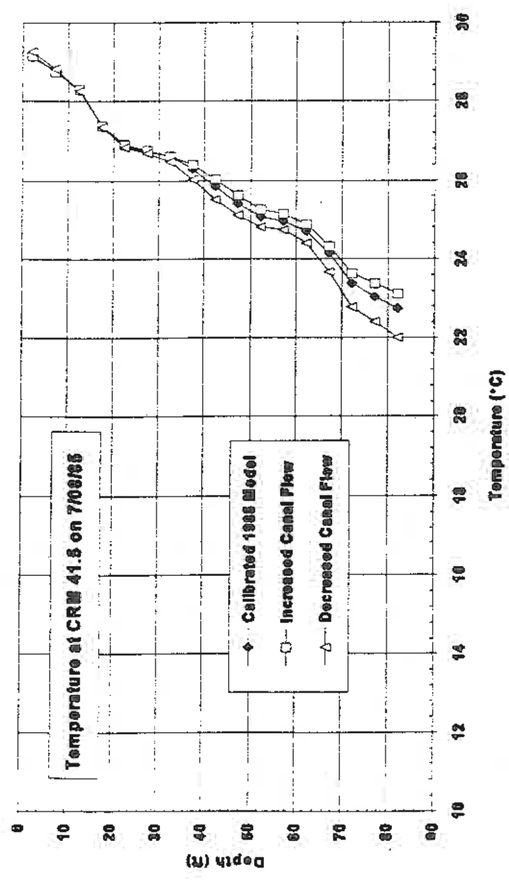
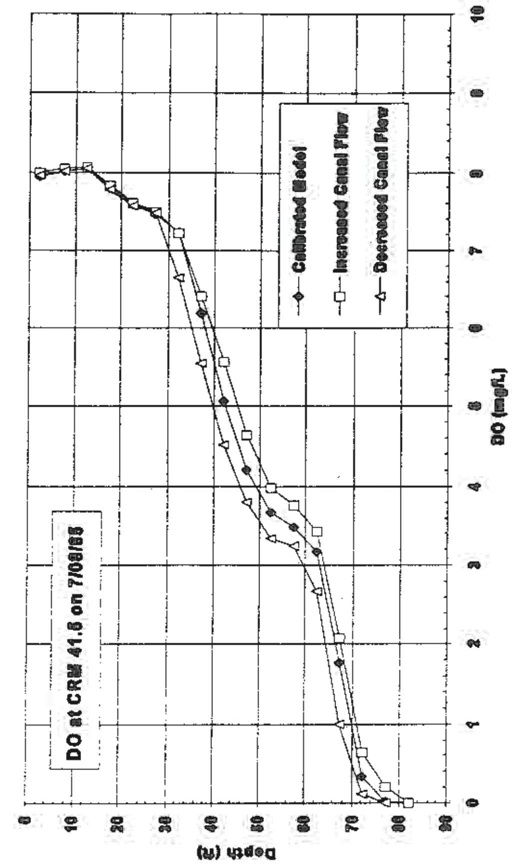
CRM 31.5 on July 8, 1985
Data
Model
Depth (ft)
Temp (deg C)


DO Calibration Result
at CRM 31.5 on 7/31/85
Data
Model
Depth (m)
DO (mg/L)


Temperature at CRM 41.8 on 7/08/85
Calibrated 1985 Model
Increased Canal Flow
Decreased Canal Flow
Depth (ft)
Temperature (°C)


DO at CRM 41.8 on 7/08/85
Calibrated Model
Increased Canal Flow
Decreased Canal Flow
Depth (ft)
DO (mg/L)

WATER QUALITY ISSUES RELATED TO THE OPERATION OF THE CORPS OF ENGINEERS CUMBERLAND RIVER WATER RESOURCE PROJECTS

Tim Higgs[1]

INTRODUCTION

The Nashville District of the Corps of Engineers operates a system of ten water resource projects in the Cumberland River of Tennessee and Kentucky. Water quality characteristics which develop in the lake are related both to watershed and operational effects. This paper discusses some of the more significant problems in the Cumberland River basin.

CUMBERLAND RIVER WATER RESOURCE PROJECTS

The Corps has constructed ten reservoirs in the basin and nine are operated as a system. These nine projects comprise a system which produces both regional benefits such as navigation, flood control, and hydropower, as well as regional and localized environmental effects due to alterations of natural flow regime and water quality.

The water resource projects can be broken into two general classes: mainstem Cumberland River projects operated primarily for navigation and hydropower and tributary storage projects operated primarily for flood control and hydropower. The mainstem navigation projects include, from upstream to downstream, Cordell Hull Lake, Old Hickory Lake, Cheatham Lake, and Lake Barkley. Tributary storage projects include Laurel River Lake and Lake Cumberland in Kentucky and Dale Hollow, Center Hill and J. Percy Priest Lakes in Tennessee. The tenth project is Martins Fork Lake in eastern Kentucky. This is a small reservoir built for recreation and has little effect on the basin as a whole.

ISSUES AT TRIBUTARY PROJECTS

The four large tributary reservoirs have similar problems, although they vary in severity. In this paper, Center Hill Lake is discussed specifically. Since the tributary dams are operated for peaking hydropower production, the tailwater sections are highly impacted from variable flow rates. Also, since these lakes seasonally develop strong thermal stratification, hydropower releases can be of poor quality, with respect to dissolved oxygen (DO) levels, during late summer and early fall periods. Figure 1 shows a typical seasonal pattern for temperature and DO levels in releases from Center Hill Dam. Releases from the other projects would follow the same general pattern. The depletion of DO in the reservoir is also dependent on watershed loadings. One major point to note is that dryer years generally show better water quality within the tributary lakes due to lower nutrient loadings.

The thermal stratification and deep hydropower withdrawals cause violations of State DO standards below the tributary dams. The tailwater of Center Hill Dam, the lower Caney Fork River, is the most significant impact since it is about 27 mile in length. The tailwaters of all the tributary projects, with the exception of J.Percy Priest Lake, are classified as coldwater aquatic habitat which has a DO criteria of 6.0 mg/l. In addition, fluctuating flow rates can impact water temperatures in the tailwaters as pulses of

[1]Environmental Engineer, U.S. Army, Corps of Engineers, Nashville District, P.O. Box 1070 (EP-H), Nashville, TN 37202-1070; (615) 736-7093

hydropower releases moved down the channel. This can lead to violations of coldwater maximum temperature criterion and thermal shocks if releases are curtailed for extended periods.

To improve aquatic habitat in the Caney Fork River, the Corps is currently designing a reregulation weir to be located about one and a half miles below the dam. The weir would be similar to the one built by TVA at Norris Dam and be designed to provide a continuous flow of 200 cfs. This flow rate was determined by evaluation of available wetted habitat at various flow rates. The reregulation pool would be filled by hydropower pulsing every 12 hours.

As mentioned earlier, DO levels from Center Hill Dam can be well below State standards. During recent years, levels below 2.0 mg/l have been observed. Alternatives to improve DO levels have been evaluated but to date funding for installing a "permanent" fix has not been obtained. At Center Hill Lake, it would be feasible to install a hypolimnetic oxygenation system due to the cold temperatures and water depth at the dam. A diffuser system would extend across the width of the lake channel and would be located upstream of the dam to allow some storage of oxygenated water within the pool. This is done to minimize the oxygen supply capacity needed by designing based on the average daily flow rate rather than instantaneous flow. The oxygenation system would be similar to those installed by TVA at Douglas and Cherokee Lakes. Rough costs for such as system would be about 2 million dollars.

Funding large capital expenditures has typically been a unresolvable problem for the Corps. The manner in which revenues of hydropower production are handled make it difficult to fund projects. This is a major difference between the Corps and TVA. Revenues resulting from hydropower generation at Corps projects goes to the federal pool rather than back to the operating agency. Each year a congressionally-approved budget is available for the Corps' project but this typically covers only routine operation and maintenance and cannot cover large expenditures. The true impacts of hydropower production are hidden since water quality standards are not met.

Previously, special operations were conducted at Center Hill Dam to see if operational adjustments to the turbine flow rates would improve release DO levels. This work showed roughly a doubling of DO levels by reducing flow rates by 50%. This operation curtail power production significantly. During 1994 and 1995, this special operation was implemented at Center Hill, Dale Hollow and Lake Cumberland to minimize the severity of low DO levels. During 1994, DO at Center Hill was raised from about 1.8 mg/l to about 3.5 mg/l. This operation does not met DO criterion but does reduce the severity of downstream impacts. During 1995, the costs associated with this operation have been scrutinized. Hopefully, this cost can provide some justification for constructing a "permanent" fix of the DO problems.

MAINSTEM SYSTEM OPERATIONAL EFFECTS AND MODELLING

The Corps must consider impacts resulting from the operations of the system of reservoirs on downstream areas. Probably the most significant regional water quality effects which can be controlled by operational adjustments is mainstem DO and temperatures levels. Releases from Old Hickory Dam are typically the control point for DO levels in the mainstem Cumberland River. In years past, DO levels dropped well below the State warmwater DO criterion each year. Through the use of two-dimensional water quality models, seasonal biweekly flow criteria, ranging from 7600 to 9400 cfs, has been developed to met the DO criterion below the mainstem projects. These models are calibrated with data from "real-time" water quality monitors operated by the USGS at critical points in the basin (mainstem tailwaters and Celina). These flows maintain low enough detention times to keep DO from depleting below 5.0 mg/l. Projections can be made based on typical conditions for water quality and meteorological conditions in the basin. These typical curves are adjusted based on data collected as the year progresses to consider year-to-year variability.

With this operation in place, the Corps has met the DO criterion consistently over the last several years, with the exception of some short-term episodes attributed to storm event loadings.

These models are also used to evaluate water temperature levels in the mainstem projects. Controlling limits are intake temperature requirements at the TVA Gallatin and Cumberland Fossil Plants. Water temperatures below maximum desirable intake temperatures are met by evaluating flow requirements through the system. This avoids violations of NPDES permit limits for temperature.

Recently, the Corps has evaluated potential operations to improve conditions for native mussels in the Cumberland basin. The US Fish and Wildlife Service approached the Corps with concerns about a long-term decline in native mussel populations which is primarily attributed to cold water temperatures in critical reaches. These depressed temperatures induce physiological stress on mussels preventing reproduction. Some reaches of the Cumberland no longer go through a natural seasonal thermal pattern as was present prior to the construction of the system of dams. The critical reaches include the upper riverine sections of Old Hickory Lake, the lower Caney Fork River, and the Cumberland River below Lake Cumberland. Model applications were made to see if limiting flow from the upstream projects would allow warming of sections of the river system to improve reproductive success. A 40-mile stretch of the Cumberland (upper Old Hickory Lake) was considered feasible to warm by limiting upstream releases. These operations would have some negative impacts associated with increased detention times through the reservoir system.

RECOMMENDATIONS/NEEDS

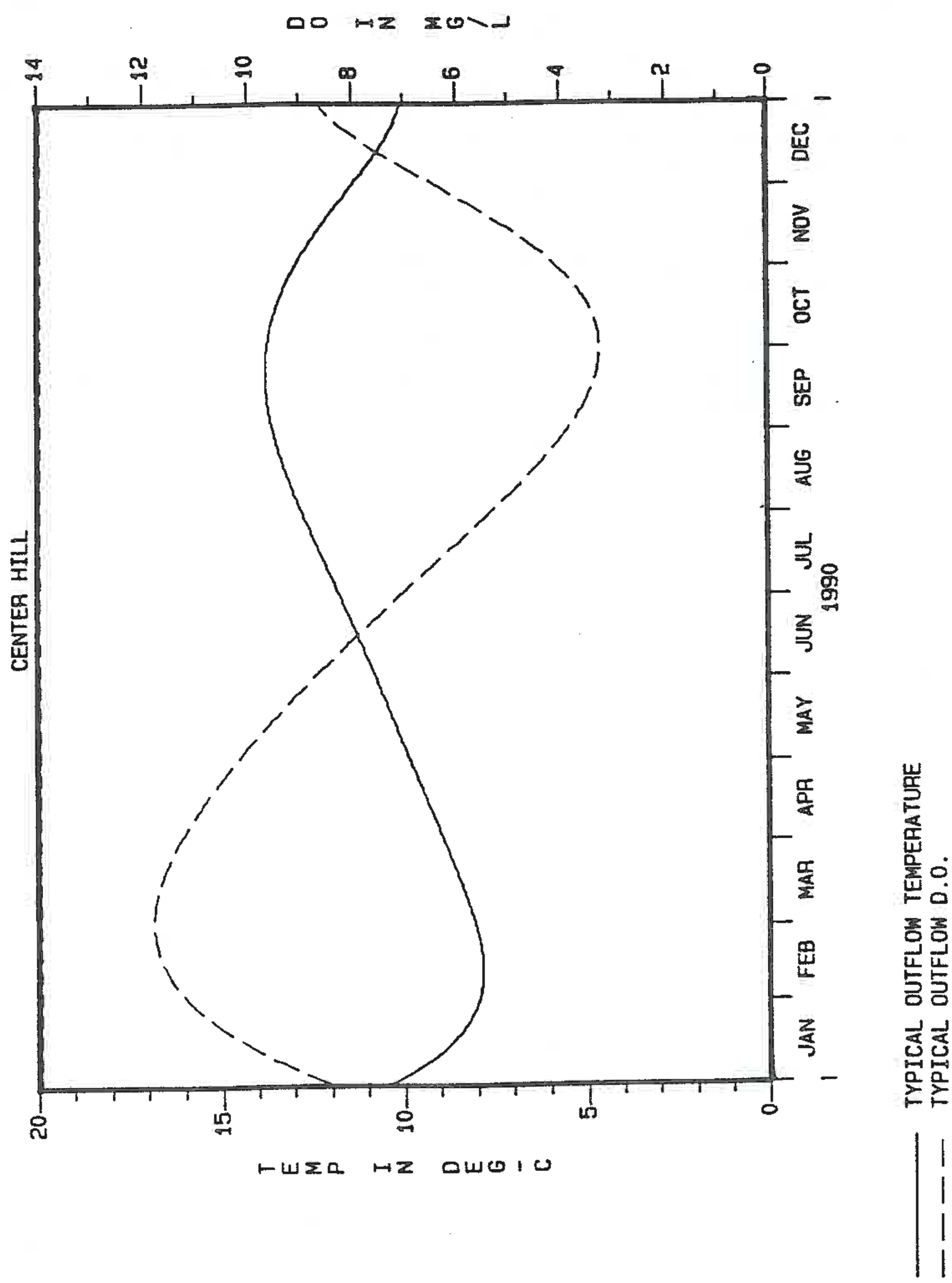
Recent data has shown a downward trend in water quality conditions in some Corps reservoirs. This paper has discussed potential solutions the Corps could implement to improve some problems. With continued growth in the region, nonpoint sources of pollution will likely increase. Increased control of construction activities and impacts from urbanization are essential to keep water resources from declining further. Operational and localized techniques at dams have limitations. Local governments must develop effective controls on residential development. Strong enforcement of NPDES permits for construction activities is an integral part of this program (county/city-level). Restoration programs driven by local residents are needed to cost-effectively improve riparian areas with the basin.

The Corps needs to improve funding mechanisms for addressing the impacts of hydropower production. Hypolimnetic oxygenation systems are needed to meet DO standards in a consistent manner. The current funding process does not provide the needed funding as environmental improvements are low on the priority list. With the current attitude in government, this situation is not likely to improve.

CONCLUSIONS

This paper summarized several water quality issues related to the operation of Corps of Engineers water resource projects. Many other important issues remain but were not discussed. Through the use of water quality models, various operational approaches have been evaluated and some implemented to improve conditions. Other structural techniques to improve conditions below Corps projects were discussed. These techniques need to be thoroughly evaluated and implemented in a manner that provides compliance with minimum water quality standards set by the Clean Water Act.

FIGURE 1


CENTER HILL
DO IN MG/L
TEMP IN DEG-C
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1990
TYPICAL OUTFLOW TEMPERATURE
TYPICAL OUTFLOW D.O.

A WATERSHED 'NEEDS ASSESSMENT' MODEL: RICHLAND CREEK WATERSHED, TENNESSEE

Elizabeth Bunting[1]

In September of 1994, the U.S. Environmental Protection Agency (EPA) selected the watershed of Richland Creek, tributary of the Elk River in south central Tennessee, as study area for a national pilot project. The goal of this project, a cooperative effort involving local citizens working with state and federal agencies, is to develop a computer model that will predict water quality management options for use by local communities. This model is multi-purpose, providing a planning tool specific to the Richland Creek watershed and a functional model for use in other watersheds. It will describe existing water quality conditions, identify various corrective options, and provide estimates of associated costs. This two-year study was funded by EPA to expand the Water Quality 'Needs Assessment' Program from the traditional wastewater treatment facility focus to a watershed scale for evaluating water quality needs.

There are two interrelated, but different, components of this watershed management model: one is the technology, the other the partnership among the different community interests and agencies. Technology of the watershed model combines a geographic information system (GIS) to compile data coverages describing various characteristics of the watershed with standard water quality models to predict changes given different conditions. The partnership of interests ensures an integrated perspective of the watershed community's values, perceptions, and needs for the future. Both are required for a functional watershed 'needs assessment.'

[1]Tennessee Department of Environment and Conservation, Division of Construction Grants and Loans, 8th Floor L&C Tower, 401 Church Street, Nashville, Tennessee 37243-1583; phone: (615) 532-0435; Fax: (615) 532-0614

INTER-ORGANIZATIONAL POLICY PLANNING FOR NATURAL RESOURCE ISSUES: LESSONS LEARNED FROM TWO STATE PLANNING ACTIVITIES

G. Dodd Galbreath[1]

Two different yet similar, state level planning activities resulting in the *Tennessee Wetlands Conservation Strategy* and the *Mission Plan for the Reformulation of the West Tennessee Tributaries Project* have yielded useful lessons about the process of policy planning that are fundamental to most inter-organizational planning efforts.

The development of the *Wetland Strategy* involved five state agencies, seven federal agencies and four private organizations in an iterative planning process to resolve disputes surrounding wetlands issues in Tennessee. The resulting plan has been supported by two administrations (one democratic and one republican), and has been successful at garnering $903,047 in EPA wetland grants. The implementation process has catalyzed several state and federal joint ventures and is proceeding on schedule. The plan is also recognized regionally and perhaps nationally as a model for other states. Tennessee is one of a handful states and the only state in the Southeast with a plan.

The development of the *Mission Plan* involved several private, state and federal litigants embroiled in a 20 year debate over river channelization in West Tennessee. A successful consensus resulted in a planning process partially facilitated by a federal mediator. The resulting solution to the debate has created a substantial public and private partnership to determine the feasibility, approach and success of a substantial river/watershed restoration/treatment project. The project has potential "win win" benefits for local landowners and policy stakeholders.

The presentation will identify fundamental characteristics of these two inter-organizational planning processes and differentiate between the varying but similar methodologies used to plan.

[1]State Policy Coordinator, Tennessee Environmental Policy Office, Tennessee Department of Environment and Conservation, 14th Floor, L&C Tower, 401 Church Street, Nashville, Tennessee 37243; phone: (615) 532-8545

SECOND CREEK WATERSHED RESTORATION DEMONSTRATION PROJECT KNOXVILLE, TENNESSEE

Timothy R. Gangaware[1], Kim Pilarski[2], James L. Smoot[3], and Bruce A. Tschantz[4]

Knoxville, Tennessee is situated near the headwaters of the Tennessee River approximately three miles downstream of the confluence of the Holston and French Broad Rivers. The metropolitan Knoxville area is the first major source of urban runoff to the Tennessee River as it flows past several other urban areas before its confluence with the Ohio River at Paducah, Kentucky. Water quality in the Knoxville area is severely degraded by urban runoff. Four of the eight major urban streams are posted against water contact recreation because of elevated coliform levels, and all of the urban streams are impacted by land development, riparian zone degradation, and urban nonpoint source runoff.

Activities for water quality improvement in Knoxville, Tennessee are now being coordinated through the Water Quality Forum of Knoxville, comprised of members of city, state, and federal agencies as well as private organizations who are responsible for, or interested in, addressing local water quality issues. The Forum's mission is to improve water quality conditions along the city waterfront on the upper Tennessee River and in the city's eight urban tributary streams, transforming these streams and their riparian zones into a valued community resource.

Second Creek has been selected as a pilot project for the Forum's long-range, city-wide goal of improving water quality in Knoxville's urban streams. Second Creek was selected because it typifies many of the problems seen in urban streams. The project involves a watershed-based approach to restore riparian zone and instream habitat, in conjunction with other water quality improvement activities in the Second Creek watershed. Project work is now coordinated through the Second Creek Task Force established by the Water Quality Forum. The Task force works to (1) develop a mechanism through which partner agencies and volunteers can work collectively to monitor, improve, and protect water quality; (2) increase public understanding of the human and ecological risks in the Second Creek watershed; and (3) inspire and guide community efforts to restore the stream and its riparian zones, and protect it from further degradation.

A diverse group of local, state, and federal agencies and other organizations have joined to form the Second Creek Task Force, including:

[1]Associate Director, Tennessee Water Resources Research Center, University of Tennessee, Knoxville, Tennessee 37996; Phone: (423) 974-2152; Fax: (423) 974-1838

[2]Environmental Scientist, Tennessee Valley Authority, 400 W. Summit Hill Drive, Knoxville, Tennessee 37902; Phone: (423) 632-4059; Fax: (423) 632-3188; email: kpilarsk@mhs-tva.attmail.com

[3]Professor of Civil & Environmental Engineering, University of Tennessee, Knoxville, Tennessee 37996; Phone: (423) 974-7718; Fax: (423) 974-2669

[4]Condra Professor of Civil & Environmental Engineering, University of Tennessee, Knoxville, Tennessee 37996; Phone: (423) 974-7721; Fax: (423) 974-2669

City of Knoxville
Ijams Nature Center
Knoxville Utilities Board
Knox County Government
Tennessee Valley Authority
Knoxville Community Action Corporation (CAC)
Metropolitan Planning Commission (MPC)
Tenn. Dept. Of Environment &Conservation (TDEC)
U.S. Army Corps of Engineers
U.S. Geological Survey
Oak Ridge National Laboratory (ORNL)
University of Tennessee
Knox County National Resource Conservation Service (NRCS)
Tennessee Wildlife Resources Agency (TWRA)
Tennessee Water Resources Research Center

The task force has two main objectives: (1) a short-term goal of reducing NPS pollution by identifying major pollution sources within the watershed, implementing best management practices (BMPs), restoring damaged riparian zones and streambanks, and increasing public awareness of water quality issues in urban watersheds; and (2) a long-term goal of developing a model or process that can be used by communities to assess and restore any urban watershed.

The Second Creek Task Force functions via a committee structure. A technical committee set up by the Task Force has responsibility for planning strategies to identify specific water quality problems and to monitor stream quality, as well as to develop projects that reduce and/or prevent nonpoint source pollution. Through qualitatively and quantitatively characterizing the current state of the watershed, specific locations, types, and extent of problems are being identified. KUB has been monitoring Second Creek for fecal coliform contamination at eleven sampling sites since 1990, attempting to detect and locate sanitary sewers which may be leaking into the stream. An expanded sampling program was initiated in 1991, including chemical analysis for heavy metals, BOD, COD, pH, and total suspended solids. An extensive sediment and organic chemical analysis of Second Creek occurred during the same time period. An Index of Biotic Integrity (IBI) method has been used to assess the ecological health of the stream. Rated "poor" based on IBI's conducted in 1992, as well as in 1994 and 1995, Second Creek exhibits significant degradation of its biological communities. The committee has also conducted field work to qualitatively assess the entire length of the creek utilizing EPA Streamwalk methodology. Quality and condition of the riparian zone, adjacent land uses, and condition/character of the streambed were recorded. This data will be used to prioritize areas for riparian zone and aquatic habitat restoration projects. The technical committee is also helping design a "green" parking lot, which will incorporate vegetated filter strips, pervious paving, and vegetated detention areas to minimize runoff impacts from a large parking lot located immediately adjacent to the creek.

An education committee has been set up to increase citizen awareness of urban nonpoint source pollution and to stimulate public involvement in the remediation projects. Working with watershed residents, the committee sponsors creek cleanups in the Second Creek watershed, and has developed several different educational programs regarding the creek and nonpoint source pollution. Members of the committee conduct educational outreach programs to schools and civic groups using videos, slide shows, and printed material they have prepared. The committee has also organized an annual water quality exposition highlighting water resources in the Knoxville area. Eight major cleanups have removed more than 5 tons of trash from the creek, and received extensive press coverage.

A government committee works to develop local regulations and incentive programs that will ensure participation of landowners in sound watershed management. The committee works with local and state decision-makers to ensure that policy decisions do not adversely affect the watershed. It has helped prepare guidelines and recommendations for riparian zone management for the Metropolitan Planning Commission, and City of Knoxville, and has worked on the formation of a non-profit land and water alliance that will work towards acquiring both sensitive riparian and wetland areas as well as funding for additional research and outreach activities.

University of Tennessee students and faculty have been extensively involved in the Second Creek project. Undergraduate and graduate level courses in various departments conducted research and class project focusing specifically on Second Creek, contributing valuable data to the technical knowledge base needed for a comprehensive watershed restoration. Graduate and undergraduate students in the UT Civil and Environmental Engineering Department were directly involved in the project through four courses in 1995. The courses taught by either Dr. Jim Smoot or Dr. Bruce Tschantz included Hydrology, Urban Stormwater Engineering, Water Resources Development, and Stormwater Modeling. Taking a team research approach, students addressed the following issues:

1. Identification of Hydrocarbon Hotspots in the Second Creek Watershed
2. Application of Structural BMPs to the Redevelopment of Brookside Mills Property along Lower Second Creek
3. Water Quality Assessment Study for Second Creek
4. Feasibility Study of Establishing a Stormwater Utility District in Second Creek
5. HEC-2 Water Profile Analysis Study for Lower Second Creek
6. Best Management Practices for the Second Creek Watershed
7. Modeling peak streamflows for several subwatersheds as well as the entire basin using the HEC-1, SWMM, and TR-55 models.

The findings and data of the students provided valuable technical insight and preliminary options to the Second Creek Task Force for future detailed work. For example, the team responsible for reviewing and making BMP recommendations research the feasibility, efficiency/effectiveness, and environmental and economic aspects of several innovative, non-traditional measures for improving water quality in Second Creek. These measures, including vegetative filter strips, porous pavements, infiltration trenches, and sand filter beds, will be incorporated into the "green" parking lot project the Technical Committee is working on.

At the end of each class term, team leaders presented their work to invited members of the Second Creek Technical Committee, who critiqued their work, offered recommendations for future work, asked questions, and participated in the student evaluation process. The Tennessee Water Resources Research Center and the UT Civil and Environmental Engineering Department sponsored the student effort with nominal funding, technical assistance, and in some cases, provided administrative assistance where the work involved student interaction with the public and representatives from different agencies.

Additional work conducted by UT students and faculty has provided not only valuable biological and hydrological data, but also provided tools for public outreach and education.

- Graduate level ecology classes assessed the total streamside corridor of Second Creek mapping types and condition of riparian vegetation.
- A botany/ecology class assessed specific forest composition and basal area in a forested wetland located in the upper part of the watershed.
- Agricultural engineering students developed a hydrologic water quality monitoring system for the Second Creek watershed, monitoring stream flow, rainfall, and water temperature. They also installed a weir in the headwaters of the creek that will be used to collect long-term flow data for a subwatershed of the creek.
- Planning students collected and assessed census data for areas of the watershed, characterizing socioeconomic status of the residents in those areas.
- Graphic arts classes developed a logo for the Second Creek project, "Give Second Creek a second chance."
- Communications students produced a 20 minute video for watershed residents, describing urban nonpoint source pollution and what citizens can do to improve water quality. The video has been used in various outreach programs and has also run on the local cable access television channel.

- Geography classes have catalogued plant species in several riparian zone areas of the watershed.
- A geography graduate student has conducted a survey of impervious and pervious surfaces in the watershed, using geographic information system and aerial photography information.
- Dr. Carol Harden, Department of Geography, has studied sediment transport into Second Creek during storm events.
- University of Tennessee students are also involved in helping with field work and collecting samples and have volunteered for various creek cleanups and outreach programs.

In September of 1995, six Americorps members were hired to work exclusively on Second Creek. Through their full-time efforts, public outreach and education will be expanded throughout the Second Creek watershed. Office space for the Americorps members is being donated by industry located along the creek, and Americorps members will be trained to provide outreach programs for the large homeless population living along the creek. Their efforts will also focus on increasing volunteer participation in the "Adopt-A-Stream" program, expanding the existing water quality monitoring effort, and educating land owners along the creek about the importance of bank stabilization and riparian zones.

The task force is also working with the Knoxville Greenways Coalition, a citizens group, to extend the greenway system along Second Creek. Further efforts during fiscal year 1996 will focus on riparian zone and aquatic habitat restoration projects. Grant money from Tennessee Department of Agriculture/Nonpoint Source Program will be directed toward the implementation of streambank stabilization techniques, reestablishment of a functioning riparian zone at several sites, and the restoration of instream aquatic habitat.

The goal of the Second Creek watershed restoration project is two-fold: (1) to improve the water quality and ecological integrity of the watershed, and (2) to develop a strategy for improving watershed quality that can be applied to other watersheds throughout the region. Technology transfer, including technical guidance documents, video and photo documentation, and workshops will document the process used for the urban watershed assessment and restoration that other communities can follow. The multidisciplinary, interagency approach of the Second Creek Task Force can be applied to not only other urban streams in the Knoxville area, but also in other urban areas of the country. The complex nature of water quality impacts today dictate that cooperative efforts of public and private organizations are necessary. To address the complex issues facing watershed restoration, a partnership approach builds a vital coalition of individuals, organizations, and public agencies who have a goal of not only improving water quality, but also of demonstrating the value of our rivers and streams as a natural resource to be protected and managed.

VERSATILE TECHNOLOGY FOR SOLUTIONS TO CHALLENGING STREAM MONITORING CONDITIONS: WHITE OAK DAM CASE STUDY

J. H. Johnson[1], A. J. Beal, and S. M. Gregory

INTRODUCTION

When collecting hydrologic data, knowledge of site conditions, along with well defined programmatic goals, should be taken into consideration when choosing field instrumentation. Often site conditions are less than ideal and present unique challenges. In addition, data collection requirements are sometimes specific and inflexible (regulatory compliance monitoring for example) and those rigid requirements present their own challenges. In meeting these challenges, commercially available turnkey monitoring systems may have shortcomings, which may or may not be acceptable. When turnkey systems fall short of meeting programmatic goals, either the goals must be adjusted, or more versatile instrumentation must be sought.

The Office of Environmental Compliance and Documentation (OECD) at the Oak Ridge National Laboratory (ORNL) was faced with several challenges in collecting discharge data and flow proportional samples at ambient stream monitoring locations and treatment facility discharge points. Therefore, a system-wide instrumentation upgrade project was undertaken. The decisions which led to selecting the instrumentation, and the way in which the instrumentation allowed site specific challenges to be met, can best be illustrated by looking at a case study, the instrumentation upgrade at ORNL's White Oak Dam (WOD) monitoring location.

WHITE OAK DAM OVERVIEW

From its beginning as a box culvert in 1941 to its present earthen structure, White Oak Dam has grown in its function as well as size. The dam is located on the Oak Ridge Reservation in Roane County, Tennessee, near the Oak Ridge National Laboratory.

White Oak Lake, which is formed by White Oak Dam, covers 15.7 acres at normal pool level and is fed by White Oak Creek. White Oak Dam is the final monitoring point for liquid effluent from ORNL and a monitoring site for ORNL's National Pollutant Discharge Elimination System Permit. Therefore, precise flow measurement and sample collection are required.

In 1983, the old effluent control coffer cell and gate were replaced with a new discharge channel, weirs and gates. One weir, used to monitor flows in the range of 0 to 14.6 cfs is a trapezoidal, sharp-crested weir with a three ft. Crest width and a 1.33 ft depth. Another weir, used to monitor flows in the range 14.6 to 2005 cfs, is approximately 45 feet upstream. It is a 120° truncated, triangular broad-crested weir with a width of 40 feet and a maximum rated head of 9 feet.

In 1992, a coffer dam was installed downstream of WOD at the confluence of White Oak Creek and the Clinch River. Its function was two-fold: (1) to retain contaminated sediment and (2) to raise the normal pool elevation of the White Oak Creek embayment to keep the seasonal mudflats covered.

[1]P.O. Box 2008, Oak Ridge, Tennessee 37831-6102; phone: (423) 574-7077. Oak Ridge National Laboratory is managed by Lockheed Martin Energy Research Corporation for the U.S. Department of Energy under contract number DE-AC05-96OR22464

CHALLENGES TO FLOW MONITORING AT WHITE OAK DAM

Site conditions and data collection requirements at White Oak Dam present several challenges to discharge measurement and sample collection. One challenge to sample collection at WOD is the large range between the volume of discharge occurring in the driest sampling period to the volume occurring in the wettest sampling period. The large range of flows, combined with a relatively large minimum sample volume requirement, makes it difficult to collect composite samples with flow proportionality over all ranges of discharge conditions. Another challenge is the integration of flow measurement, computing one flow rate and one flow total, from two weirs used for different ranges of flow. The large depth of the stilling wells at WOD presents another challenge to accurate discharge rate determination; accuracy of most stage measurement sensors is dependent on the range over which they operate.

Probably the biggest challenge to overcome at the WOD monitoring site is occurrence of submergence of both weirs. Since initial installation, there have been periods in which the sharp-crested weir has experienced submergence. Any degree of submergence of a sharp-crested weir will cause inaccuracy in discharge rate determination. The occurrence of submergence of the sharp-crest weir has become frequent since construction of the coffer dam downstream of the monitoring site. A broad-crested weir can tolerate moderate to high degrees of submergence with no significant impact to flow rate measurement. However, the broad-crested weir at WOD occasionally experiences submergence to a degree that discharge measurements are affected. When using a flow totalizer to drive a flow proportional composite sampler, it is necessary for the flow meter to make corrections for submergence if sample compositing is to be accurate.

GOALS OF THE INSTRUMENTATION UPGRADE PROJECT

To meet these challenges and to achieve other desired features, the following goals for the instrument upgrade were defined:

- hydraulic head measurement accuracy of ±0.005 ft
- head date recorded in machine-retrievable form
- improved representativeness in flow-proportional composite sampling
- computer system reliability of 99 percent uptime
- total system uptime of 95 percent
- integrated flow measurement
- real time submergence correction

SYSTEM DESCRIPTION

To meet the goals of the upgrade project, the chosen instrumentation had to be versatile. The Instrumentation and Control Division at ORNL designed a monitoring system to meet project goals, using microprocessor based and signal conditioning components. These components and other necessary hardware are commercially available off-the-shelf items, so the system designer need not invent his own hardware. The ORNL flow computer is comprised of a card cage with task specific plug-in printed circuit cards, sensor input/output modules, and user interface keypad and display. However, the system designer must develop his own system operating software routines according to the application. The ORNL flow computer was designed using components manufactured primarily by Octagon Systems Corporation and Analog Devices, Inc. The heart of the system is Octagon System's STD Bus 9600 processor card. The system operating software for t his product is written by the system designer using STD BASIC III™, Octagon's industrial version of the BASIC programming language. Once developed, the operating software is stored on the processor card in EPROM memory. The system can be configured to automatically restart after a power interrupt.

The ORNL flow computer is a monitoring and data acquisition system that provides a calculating flow meter with sample pacing and programmable data logging functions within a single instrument. It provides process monitoring and indication, data acquisition and storage, analog input and output, discrete input and output, and serial communications, as well as extensive calculation and logical functions. The front panel keypad and display provides menu selection, presentation of data, and the setting of operating parameters. Data is stored on a removable 1.44 MB floppy diskette for later retrieval using an IBM-PC or equivalent.

To improve head measuring accuracy, a magnetostrictive level gauge was selected. These devices have an accuracy specification of 0.025% of full scale or 1/32 inch (whichever is greater). The stilling wells at WOD are a minimum of 14 feet deep. Although the spans of the weirs being monitored are much less, in order to correct for submergence, the ability to track the head for most of the stilling well's depth is necessary. Also ASCII (EIA RS-485) interfaced and software controlled, the signal output to the flow computer is digitally interfaced, eliminating analog to digital signal conversion and improving system accuracy.

Because of the software and hardware versatility, there was a tendency to make the software too site-specific while the original intention was to produce a generic program that would work at all ORNL sites. However, remaining too generic takes away much of the versatility of the system. As a compromise, software was developed in which the core of the program deals with generic signal handling and instrumentation, and a portion of the program is left for the handling of site-specific conditions.

Hydrologic data is recorded on floppy disk with time and date stamps at user defined intervals. Additional disk data files include maintenance events performed on the system and daily minimum/maximum sample temperature extremes, an indicator of adequacy of sample preservation.

At White Oak Dam, the use of two primary flow devices to determine flow rate was handled by the development of an algorithm in which discharge conditions are evaluated by the computer based on three head measurements and the dimensions of the weirs. The three head measurements are (1) upstream head on the sharp-crested weir (which doubles as downstream head on the broad-crest weir), (2) upstream head on the broad-crested weir, and (3) downstream head on the sharp-crested weir.

The flow computer uses the downstream heads to monitor for submergence of the two weirs. If submergence of the sharp-crested weir is detected while flows are within the range of that weir, a correction is applied using an equation published in 1947 by Villemonte. The flow computer determines if the degree of submergence of the broad-crested weir is great enough to affect discharge measurement, and if necessary it applies a correction. Information on submergence correction for a triangular broad-crested weir can be found in reference 2.

The difficult in collecting flow proportional composite samples at WOD is choosing a sample collection rate that will collect the minimum amount of sample in the driest sample period, and at the same time, not overflow the sample container in the wettest sample periods. To meet this challenge, the flow computer was programmed to control multiple samplers, and extra samplers were installed at the site. Sample pacing rates for each sampler are different and they are coordinated to make maximum use of the storage capacities of the sample containers.

TESTING THE POSSIBILITIES

The versatility of this technology lends itself to almost limitless applications to solving unique monitoring requirements. Prior to the installation at WOD, the ORNL flow computer was installed and field tested at other ORNL sites. Units were installed at sites using bubbler tubes as the head measuring device and at sites using discharge rating tables for discharge calculations instead of rating equations. Effluent monitoring at one facility required sampling of batch discharges, requiring intermittent rather than continuous sampler pacing. The software was modified for this site and the sampler automatically samples when predetermined conditions are reached.

ADVANTAGES/DISADVANTAGES

Using off-the-shelf hardware reduces system development costs, such as hardware design and instrument reliability testing. It provides for easy part replacement or upgrades and offers hardware technical support from the vendor. The input/output device options, its "stand-alone" capability, and relatively low hardware cost give this unit an unlimited scope for helping with problem solving. The main disadvantage to this computer-based technology is the requirement for the system developer to be knowledgeable of programming and electronics. STD BASIC III™ is not difficult to master; however, the initial program development is time-consuming.

CONCLUSION

Versatility, capability and reliability are the key words in describing this technology. It can provide a solid platform for developing a solution to key problems, while retaining its ability to change as needs change or technology changes. When the problems require a one-of-a kind solution, the cost versus capabilities ratio makes the technology suitable for meeting the challenges of field monitoring conditions.

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ASSESSMENT OF MONITORING TOTAL DISSOLVED GAS AT TIMS FORD DAM

Helen G. Rucker[1]

Total Dissolved Gas (TDG) levels have become a major concern at Tennessee Valley Authority (TVA) hydro facilities and the tailraces from certain dams on TVA reservoirs due to the possibilities of major consequences to aquatic life. In some cases the water has become supersaturated with atmospheric gases during aeration in order to improve dissolved oxygen (DO) levels or while spilling operations were in effect for flood control. Fish kills at these locations have indicated gas bubble disease due to excessive uncompensated total gas pressure during some of these operations. Due to these conditions, an assessment for continuously monitoring TDG was conducted.

A TDG monitor was evaluated at Tims Ford Dam, which is located on the Elk River in middle Tennessee. It is a multipurpose dam and reservoir system which provides flood control, water supply, and hydropower generation. The hydroelectric plant has two units; a generating unit rated at 3890 cubic feet per second (cfs) and a small unit rated at 74 cfs, which is used to maintain minimal flows when the plant is not generating power. Due to reservoir stratification and biochemical oxygen demand processes, the historic DO values of the releases began to drop below 6.0 mg/L as early as mid-April and continue to decline to less than 1.0 mg/L by August and stay below 1.0 mg/L until late December. Initial testing at this site showed the target minimum DO content of the releases (6 mg/L) to be best achieved by the installation of air-oxygen injection equipment. Blower and compressor systems inject air at the large and small hydroturbine units, respectively. An oxygen injection system supplies oxygen to the penstock for the large unit and the sluice line for the smaller unit (Harshbarger, 1994). Because oxygen is relatively expensive and of a somewhat limited supply, this system was designed to be used only when target dissolved oxygen levels could not be met by the operation of the blowers and air compressors. A performance monitoring system installed to monitor the effectiveness of the aeration system, displays on-line data from unit discharges, oxygen flow rates, air flow rates, date, time, DO, and water temperature. This data is used to operate the aeration system to maintain a DO of at least 6.0 mg/L.

Tims Ford Dam was selected as the test site because the air injection increased TDG levels. TDG measurements made during small unit releases with the compressors operating ranged from 108 percent to 130 percent. Therefore, the oxygen system has been the primary aeration method during small unit releases or minimal flows to avoid TDG levels that would endanger aquatic life. Maximum efficient operation of the aeration system required more TDG data than the grab measurements made during weekly site visits and special tests. These grab measurements required manual operation and did not yield sufficient data for operation of the compressors on a routine basis. It is more practical to monitor TDG and adjust the aeration system than to determine operational policies derived from weekly measurements and predict TDG levels. Therefore, on-line TDG data was needed to operate the air compressors efficiently on the small unit to avoid supersaturation.

Also, a major reason for the selection of this site for the study is that the water discharged from the hypolimnion of Tims Ford Reservoir contains autochthonous slime material that occasionally clogs and fouls the DO sensor probe, thus giving erratic and erroneous results. Theoretically fouling of the TDG probe should have less effect on data because the fouling should not inhibit the gases from moving through the tubing. Therefore daily DO trends could be compared with the percent saturation trends for accuracy and minimize site visits for probe maintenance.

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[1] Environmental Scientist, Tennessee Valley Authority, P.O. Box 1010, Muscle Shoals, Alabama 35660; Phone: (205) 386-3435

In order to evaluate the reliability of a continuous TDG sensor, a six week study was conducted. Commercially available TDG monitoring equipment was assessed and a sensor was selected that could be integrated with the existing DO and water temperature monitoring system. Several factors were considered when selecting the sensor to be evaluated. The sensor would need to meet the following criteria:

- provide and record continuous TDG data unattended
- integrate with the current DO and water temperature monitoring system
- provide reliable data comparatively consistent with the existing TDG instruments used at the site to make grab measurements
- provide local barometric pressure (BP')
- provide an analog 4-20 milli-amp signal for integration into the performance monitoring system
- provide accurate data during slime build up on the sensors
- be consistent with the most commonly used and preferred technology, the membrane-diffusion method (Colt, 1983).

A six week time period for the study was selected that historically would include good operating conditions and also conditions for excessive fouling of the probe to evaluate performance. The membrane diffusion method has been determined as an accurate field method for measuring TDG, specifically the WEISS® saturometer (Fickeisen et al, 1975). As a result of a comparative field study between the saturometers and laboratory gas chromatography testing, field Quality Assurance (QA) procedures for measuring TDG with two WEISS® Saturometers were developed to ensure the accuracy of the instruments and the use by field personnel.

The system was installed on July 20, 1995 and integrated with the existing DO and water temperature monitoring system. Data was retrieved from the unit and comparison checks with the WEISS® saturometers were conducted on a weekly basis. The system was comprised of an Alpha Designs tensiometer, Campbell Scientific® data logger (CR10) and barometric pressure transducer, and a Hydrolab® Reporter with dissolved oxygen, and water temperature probes.

In situ measurements with the saturometers were not possible at the monitor location because the tailrace was inaccessible for direct measurements (the taildeck is 16' above the water surface). Therefore, prior to installing the system in the monitoring location, TDG measurements were taken downstream, where the two saturometers and tensiometer could be placed concurrently *in situ* to obtain benchmark readings. On August 21, 1995, a portable tensiometer of the same model was used to obtain more benchmark readings with the saturometers. During all comparisons, readings from both instruments were within two percent TDG percent saturation (see Figure 1).

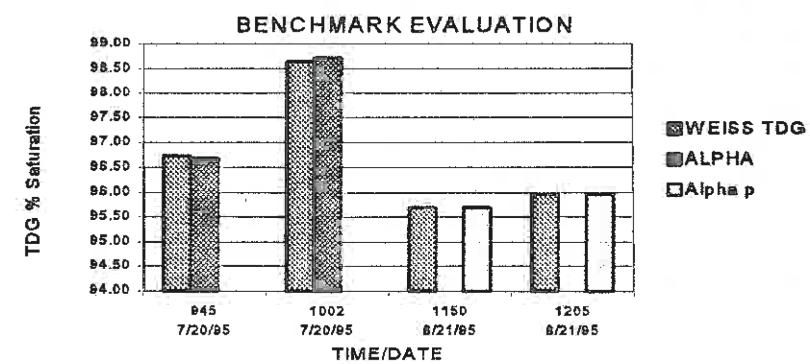

Figure 1. Benchmark Evaluation between Alpha Designs Tensiometer and WEISS® Saturometer.

During weekly site visits, the sensor was inspected for any physical damage, deterioration, and/or fouling. Data collected from the monitor included time, date, water temperature (°C), DO (mg/L), Delta P (mm Hg), and local barometric pressure (mm Hg). In comparing the DO values to the Delta P measurements, peaks indicating a change in DO are mirrored by a relative change in the Delta P as shown in Figure 2. The changes are contributed to the different operating conditions at the dam, e.g. the big unit generating with blowers injecting air into the discharge.

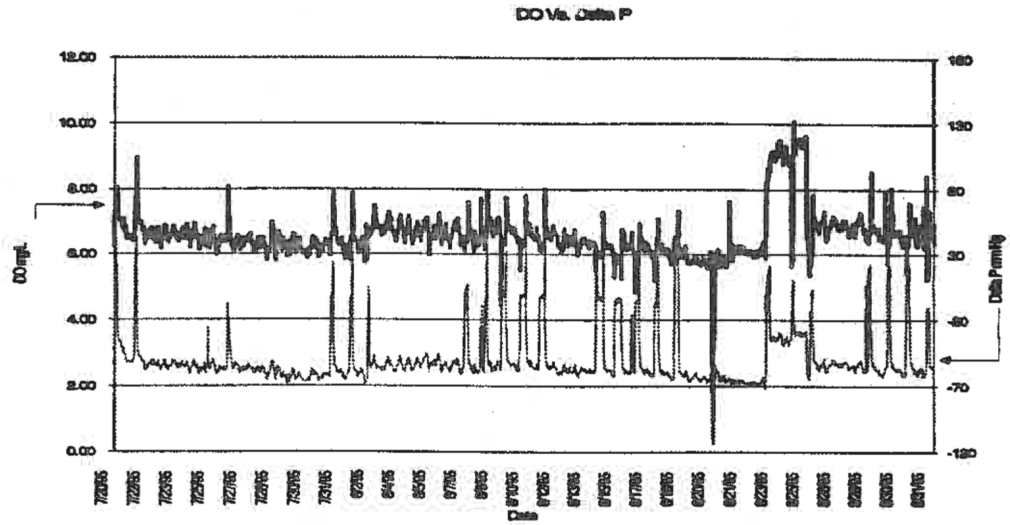

Figure 2. DO (mg/L) curve (top) compared to Delta P (mm Hg) curve (bottom). DO is plotted on the left axis with a scale of zero to twelve and Delta P is plotted on the right axis with a scale of -120 to 180 percent.

Data was imported into a spreadsheet, where TDG percent Saturation and N_2 + Argon (Ar) percent Saturation were calculated from equations using the water temperature, DO, and barometric pressure. The data is presented in line charts with each parameter of TDG percent Saturation, and N_2 + Ar percent Saturation plotted separately against the DO data curve for comparison (see figures 3 and 4). In comparing the DO curve to the N_2 + Ar percent saturation, the distinct peaks on the later curve represent the higher nitrogen values from the blowers during the big unit operation which inject air into the discharge (see Figure 4).

The excessive amount of fouling historically known at Tims Ford Dam was not present during the evaluation and therefore performance under these conditions were not evaluated during the study. It is believed that the fouling which dramatically affects DO readings would require a site visit before the tensiometer data would be affected. As long as the material did not become packed around the tubing, the gases should be able to move through the tubing. Based on the nature of the fouling material, if the probe is cleaned while on site for DO probe maintenance, the tubing should not be damaged. The tensiometer provided consistent data with the WEISS® saturometers within two percent of TDG percent saturation. The data logger recorded data unattended every thirty minutes and stored data which was retrieved weekly. An analog output module allows integration into the current performance monitoring system. Therefore, the Alpha sensor proved to be effective for monitoring TDG at Tims Ford Dam.

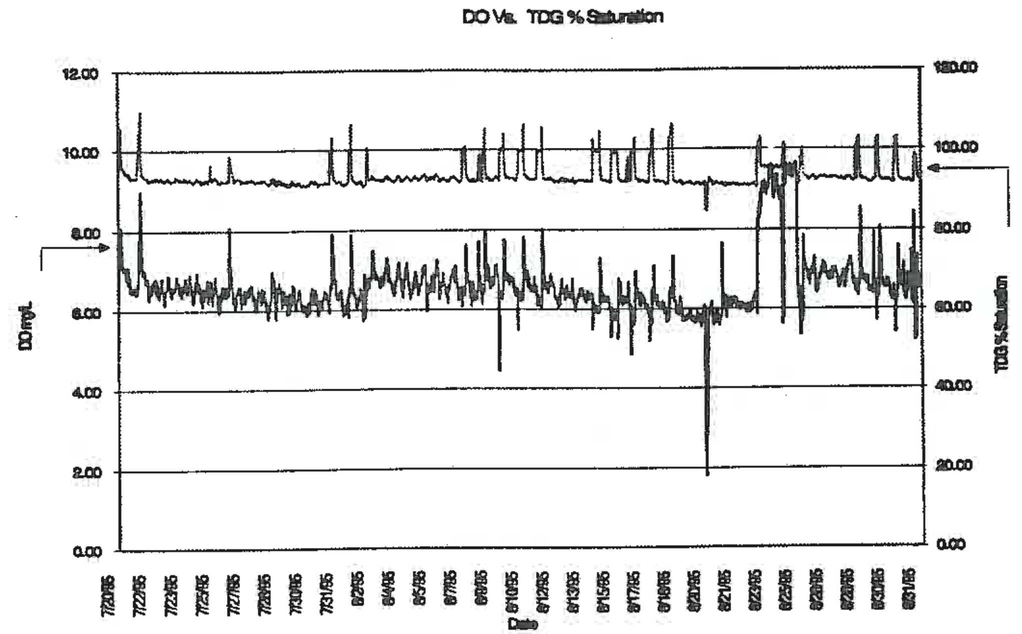

Figure 4. DO (mg/L) curve (bottom) vs. TDG % Saturation curve (top). DO is plotted on the left axis with a scale of zero to twelve mg/L and TDG % Saturation is plotted on the right axis with a scale of zero to one hundred-twenty percent.

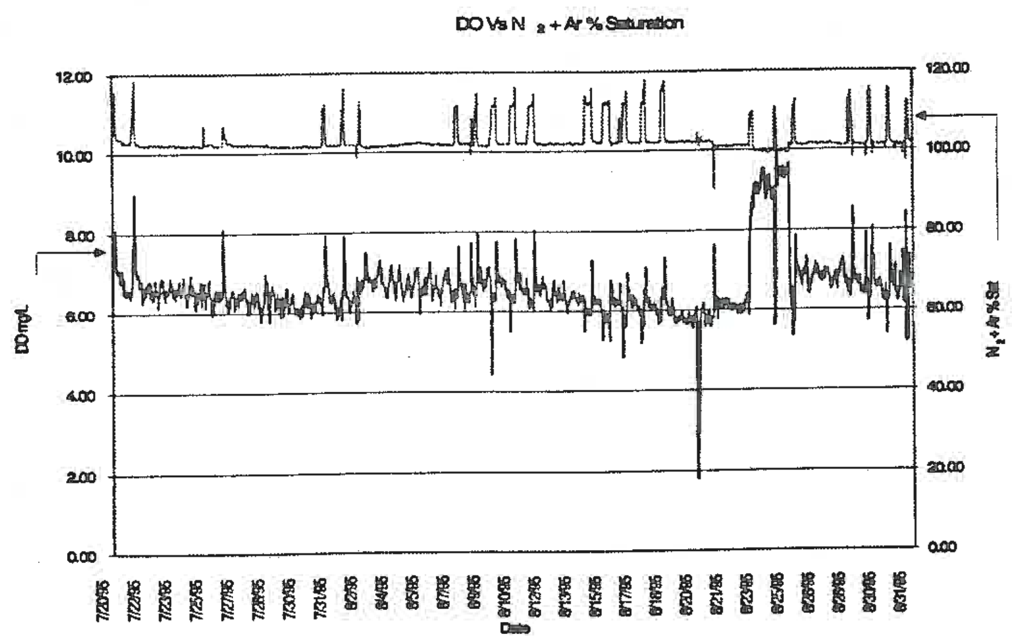

Figure 5. DO (mg/L) curve (bottom) compared to N_2 + Ar percent saturation curve (top). DO is plotted on the left axis with a scale of zero to twelve mg/L and N_2 + Ar percent saturation is plotted on the right axis with a scale of zero to one hundred-twenty percent.

SEASONALITY EXPORT OF NITROGEN AND SULFATE FROM A GREAT SMOKY MOUNTAIN SPRUCE-FIR WATERSHED

J. Shubzda[1] and S. C. Nodvin[2]

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 excitingly high deposition rate entering small catchments at high elevations causes adverse changes in stream export. In July of 1991, the Noland Divide Watershed study was initiated to monitor precipitation, soil solution and stream chemistry in order to assess the flux of N and S through the watershed. The Noland Divide site is one of the highest gauged watersheds in the eastern United States which includes 17 ha (40 acres) of old growth spruce-fir forest at 1695 m (5560 ft) elevation in GRSM. Samples collected from August 1991 to July 1995 indicate that high levels of nitrogen and sulfur are being deposited, leached below the rooting zone and exported from the watershed via the stream. Most of this export occurs during the non-growing seasons when conditions of high rainfall/snow and biological uptake of nitrogen within the ecosystem is low. However, even during the growing season, nitrate remains the dominate anion with concentrations generally above 35 μeq/L. Seasonal pulses of N and S can cause the pool of cations in the ecosystem to decline over time.

[1]Department of Forestry, 274 Ellington Plant Sciences, The University of Tennessee, Knoxville, Tennessee 37901-1071

[2]National Biological Service and Graduate Faculty in Ecology and Evolutionary Biology, The University of Tennessee, Knoxville, Tennessee 37901-1601

WATER DEMAND IN THE UPPER DUCK RIVER BASIN IN CENTRAL TENNESSEE FROM 1993 TO 2050

Susan S. Hutson[1]

Potential water demand was determined for selected water-service areas in the upper Duck River basin in central Tennessee. The Duck River is the principal source of water in the area and supplied 15.6 million gallons per day (Mgal/d) in 1993 to the cities of Lewisburg, Shelbyville, Columbia, part of southern Williamson County, and several smaller communities. Municipal water use, including water from ground-water sources, increased 19 percent from 1980 to 1993 (from 14.5 to 17.2 Mgal/d). Demographic and economic data and projections for development in the basin indicate that water demand will continue to increase through 2050.

Econometric and unit-requirement models contained in the Institute for Water Resources-Municipal and Industrial Needs (IWR-MAIN) System were used to project water demand from 1993 to 2015. Because of the mathematical limits of the time-series equations contained in IWR-MAIN, water demand from 2015 to 2050 was estimated using a unit-requirement model. In this model, gross per capita use values calculated from the results generated by the IWR-MAIN System for 2015 were applied to population projections to yield water demand. Population was projected using the log-linear form of the Box-Cox regression model.

Water demand for a scenario of steady growth would increase 57 percent (from 17.2 to 27.0 Mgal/d) from 1993 to 2015 and increase 119 percent (17.2 to 237.6 Mgal/d) from 1993 to 2050. In a scenario of higher growth for selected sectors, water demand would increase 64 percent (17.2 to 28.2 Mgal/d) from 1993 to 2015 and increase 148 percent (17.2 to 42.7 Mgal/d) from 1993 to 2050.

[1]U.S. Geological Survey, 7777 Walnut Grove Road, Suite LLB2, Memphis, Tennessee 37120; sshutson.er.usgs.gov; phone: (901) 766-2977

MAKING REGIONAL APPROACHES TO WATER RESOURCES MANAGEMENT WORK: A SUSTAINABILITY FRAMEWORK FOR THE SOUTHEAST

David L. Feldman, Ph.D.[1]

INTRODUCTION

The Southeast has begun to experience serious conflicts over water use and supply. Among the sources of these conflicts are contemplated interbasin water transfers, perceived inequities of water pricing mechanisms that penalize smaller communities undergoing economic revitalization, and threats to water quality that exacerbate interstate competition over freshwater (Mann, 1993; Sherk, 1994). These and other sources of conflict threaten sustainability, measured as the ability to supply enough clean water to maintain economic activities while protecting the natural environment. A regional approach to managing water resources is needed to resolve these conflicts that acknowledges interrelationships between physical, ecological, economic, and institutional constraints. Such an approach would offer a comprehensive, coordinated policy framework to encourage cooperation among jurisdictions, agencies, and stakeholders; recognize that water problems in one part of a region affect the welfare of other parts; and anticipate sources of conflict before they lead to political or legal impasse.

PREVIOUS FAILURES AND THEIR LESSONS

No single framework for making water resource management decisions is viewed by stakeholders as legitimate, credible, nor comprehensive. There are three major reasons for this. First, current management frameworks do not encompass all relevant choices, nor all relevant stakeholders who are wedded to particular choices. Encompassing this range of choices is necessary to ensure that water resource decisions are beneficial to the long-term public good--not just the economic development needs of the present (Cortner and Moote, 1994; Hartig, et. al., 1992; Landre and Knuth, 1993). Second, most regional frameworks lack an authoritative decision making body or instrument that is viewed as legitimate, and thus, able to bridge diverse, sometimes fragmented interests (Foster and Rogers, 1988; Feldman, 1995). Finally, these frameworks were originally designed to encompass only some needs of water users (e.g., flood control, power, navigation). They evolved as ad hoc responses to historically critical problems that arose at particular times and in particular places (Toward a New Era, 1995).

Because the water management problems, terrains, ecosystems, economies, and culture of the humid Southeast are diverse, this region serves as an excellent focal point for studying competing water uses, divergent management issues affecting these uses, and the risks water problems pose for present and future generations. This is particularly so because many of the causes of water resource conflicts found in other regions of the United States (e.g., diversion, pricing conflicts) have only recently begun to emerge in this region. Moreover, ways to resolve these conflicts in this region have not been evaluated by drawing upon the lessons of other regions' experiences.

Something like a regional approach to water management has been tried in many regions of the United States since the 1930s (e.g., river basin commissions, compacts). Historically, these regional instruments have failed to reconcile the interests of private users, been less than successful in overcoming

[1]Energy, Environment and Resources Center, The University of Tennessee, 600 Henley Street, Suite 311, Knoxville, TN 37996-4234; ph. 423/974-4251 email. feldman@utkvx.utk.edu

jurisdictional rivalries among agencies, states, and communities, been viewed as imposed from above rather than demanded from below, have had insufficient authority to engage in planning for long-term threats (e.g., climate change), and have often stressed water resources development over multi-purpose water management (Chang, et. al. 1992). These problems beg the question: why should a regional approach succeed where others have failed?

KEYS TO SUCCESS

The perceived need for regional approaches to resolving water problems has become more compelling in light of likely diminishing federal resources, or at least a leveling out of those resources (Long, 1993). In the past, stakeholders could look to Congress and multi-program agencies for public works projects and assistance to local and state governments in developing major supply and water quality initiatives. This no longer is true due to cost-sharing requirements, public demand for grassroots participation in policy making, and other changes in the political landscape that have challenged the viability of direct federal-to-state or local support (Stine, 1993; Reuss, 1991).

In addition, there is an emerging consensus among those who have long studied water problems--from natural-, engineering-, and social science perspectives alike--of the need for greater regional cooperation and planning and of the need to utilize principles of decision analysis to evaluate alternatives and optimally select choices. Consensus is coalescing around the principle that "paradigmatic shifts" in how we interpret causes of water problems must have greater impact on policy for reform to occur. Concerns over population pressures, endangered species, and conflicting stakeholder demands are among the issues driving this paradigm shift.

This can be seen in discussions surrounding attempts to resolve current Southeast water conflicts. Serious conflicts over supply, pricing, and threats to quality that exacerbate interstate competition over freshwater include contemplated interbasin water transfers (e.g., from the Roanoke basin to the Virginia Beach area), perceived inequities of water pricing mechanisms that allegedly penalize smaller communities undergoing economic revitalization, and serious threats to water quality that have, at their nexus, interstate conflicts over water use (e.g., management of the Savannah River by the states of Georgia and South Carolina). These sources of conflict threaten sustainability throughout the region--the ability to supply enough clean water to maintain economic activities while simultaneously protecting the natural environment. Moreover, some transboundary conflicts, like the proposed interbasin transfer of Roanoke River water to Virginia Beach, and multi-regional connections along the Ohio and Mississippi Rivers, are particularly contentious.

These water conflicts range in scale from multi-state issues of water quantity and quality in the Tennessee and Appalachacola-Chattahoochee-Flint basins to problems in individual municipalities. Similarly, some of these conflicts arise in response to infrequent events, such as the hundred year drought or flood, or may be prompted by chronic, long term problems in water quality and availability.

What is common to these problems, regardless of scale, are three things. First, they underscore the inadequacy of the traditional paradigm for water resources management based on an engineering-logistics approach that assumes the best use of water is for human consumption, and that the best policies are designed to provide an unlimited supply of water. Second, they underscore that the Southeast is not immune from water resource problems typically associated with the arid Western United States, such as equity issues in interstate and inter-basin water diversion, criticisms of wasteful or inefficient use of water, and charges of open or "hidden" economic subsidies that promote non-sustainable practices (National Research Council, 1992; National Implications, 1994; Matthews, 1994; McCormick, 1994). Third, they underscore the need for innovative approaches to management that encourage cross-disciplinary thinking about sustainability, recognize the importance of non-governmental stakeholders in resolving these problems, and encourage new institutional arrangements (Dudley and Stewart, 1994).

A SUSTAINABILITY FOCUS

Sustainability has three dimensions: economic development; maintenance of ecological values (e.g., sufficient instream flow for flora and fauna, preservation of aesthetic qualities); and equitable allocation (e.g., ability to balance allocation of water across multiple stakeholder needs, regardless of size or character of a community). A sustainable policy framework is one that preserves and restores, where possible, the integrity of natural systems in a given region, while recognizing their interdependency with social systems (President's Council, 1994). Such a framework does not currently exist in the Southeast because current mechanisms for managing water and resolving conflicts do not conform to best management practices associated with sustainability. These practices include efficient patterns of water consumption, accounting for the minimal quantitative and qualitative water requirements needed by domestic, industrial, agricultural, and other users for maintaining economic and social development, and incorporation of ecological values in the planning process (Gleick, 1994; Lele, 1994).

The advantages of a sustainability framework are two-fold: (1) pointing out possible effective decision making models for prioritizing multi-use values and making durable, yet sustainable decisions for water management in the Southeast (a need policy makers have begun to clamor for due to growing competition for existing supplies and declining resources) (Long, 1993); and (2) identifying conflicts that are likely to remain unresolved under existing decision-making mechanisms that fail to acknowledge the interrelationships between physical, ecological, economic, and institutional constraints, and that impede intergovernmental partnerships in planning (Stoerker, 1993).

Recent research has promoted the need for integrated basin and sub-basin water management schemes that acknowledge potential conflicts among users. While being promoted under various labels, including ecosystem management, community-based watershed management, or watershed restoration, these studies share in common the recognition that activities within these smaller units should integrate quantity and quality issues, and should be tied to the welfare of the larger region within which they take place (Dudley and Stewart, 1994; Shabman, 1993).

The National Governors Association (NGA, 1994) recently called for development of water management programs that acknowledge the interrelationships between ecological, societal, and hydrological factors, that permits comprehensive basin and watershed management, and encourage inter-jurisdictional cooperation and planning. NGA and others recognize the current opportunity for a regional sustainable framework for water management. Such a framework can provide an enduring dialogue between decision makers, water managers, and the research community on issues and conflicts.

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CRITICAL ISSUES IN SUSTAINING WATER RESOURCES IN THE 21st CENTURY

Michael J. Sale[1] and Barbara A. Miller[2]

Increasing attention is being focused on sustainable development within the United States and throughout the global community. If sustainability is to be achieved at global, regional, or local levels, new approaches must be developed to integrate economic and environmental policies for the protection of our natural resources. Water is also being recognized as a critical natural resource that continues to be at risk from development pressures and global change. Improved management of water resources is therefore central to sustainability. Globally, there is serious concern that available water supplies of suitable quality will be inadequate to meet growing demands spurred by urbanization, expanded agricultural production, and population growth. Within the United States, national efforts such as those by the President's Council on Sustainability and its Committee on Environmental and Natural Resources Research, have found that balancing competing demands for water is a critical factor in ensuring the availability, quality, and ecological health of water resources. At local and regional levels, however, water managers are finding that the current institutional and legal frameworks, policies, management practices, and analytical tools are often inadequate to resolve conflicts over competing uses for water. These problems appear particularly acute in the face of expanding economic development and heightened awareness of environmental needs. It has become apparent that a key challenge for the future is to develop the scientific information and technological base to facilitate the implementation of sustainable water resources policies and management practices -- to bridge the gap between science and implementation.

To identify specific research and development needs that are required to achieve sustainability of water resources in next century, Oak Ridge National Laboratory and the City of Chattanooga, Tennessee, will be conducting a workshop in May 1996. The workshop will involve national and international water experts from multiple disciplines and will center around four or more case studies the topics of flood management, water supply, and restoration/remediation of ecosystems. In this paper, we summarize the plans for this workshop and relate these issues to the situation in Tennessee.

[1]Research staff member and Group Leader for Ecological Risk, Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, MS-6036, Oak Ridge, TN 37831-6036 (phone: 423/574-7305, fax: 576-8543, e-mail: jon@ornl.gov); Oak Ridge National Laboratory is managed by Lockheed Martin Energy Research Corporation for the U.S. Department of Energy under contract number DE-AC05-96OR22464.

[2]President, Rankin International, Inc., 7801 Ember Crest Trail, Knoxville, TN 37938-3404 (phone: 423/925-1833, fax: 925-1834, e-mail: rankin@usit.com).

TRANSPORT OF ALDICARB, ALDICARB SULFOXIDE, AND ALDICARB SULFONE IN RUNOFF FROM AGRICULTURAL FIELDS IN THE BEAVER CREEK WATERSHED, WEST TENNESSEE

Shannon D. Williams[1]

The transport of aldicarb and its metabolites, aldicarb sulfoxide and aldicarb sulfone, was examined in storm runoff at a first order stream draining agricultural fields in the Beaver Creek watershed, West Tennessee. Aldicarb and its metabolites were detected in runoff during several rainfall events monitored from 1991 to 1995. The highest concentrations of aldicarb and its metabolites were detected during rain events occurring shortly after the application of aldicarb to the fields. The maximum concentrations detected were 410, 68, and 14 micrograms per liter for aldicarb, aldicarb sulfoxide, and aldicarb sulfone, respectively. Aldicarb concentrations detected in runoff samples were below analytical detection limits within a few weeks of aldicarb application. Aldicarb sulfoxide and aldicarb sulfone were more persistent, with concentrations of about 1 microgram per liter detected as late as 76 days after aldicarb application. The data indicated that significant transport of aldicarb and its metabolites is possible if severe rain events occur shortly after the application of aldicarb.

[1]Hydrologic Technician, U.S. Geological Survey, 7777 Walnut Grove Road, Suite LLB2, Memphis, Tennessee 37120; swilliam.er.usgs.gov; Phone: (901) 766-2977

EVALUATION OF A CONSTRUCTED WETLAND TO CONTROL AGRICULTURAL ROW CROP NONPOINT-SOURCE POLLUTION

John A. Smink[1]

Wetlands have the potential to reduce agricultural nonpoint-source pollution. Because of this intrinsic ability, constructed wetlands have been implemented as a low cost, low maintenance management practice to reduce some forms of agricultural nonpoint-source pollution. In the past, wetlands have been constructed to treat agricultural runoff from feed lots and animal barns or shelters. Constructed wetlands are also gaining popularity for controlling nonpoint-source pollution from urban areas, silviculture activities, construction activities, and mining activities.

The U.S. Geological Survey, in cooperation with the Shelby County Soil Conservation District, Tennessee Soybean Promotion Board, and the Natural Resources Conservation Service, constructed a wetland in November 1993 in the Beaver Creek watershed in West Tennessee. This project was designed to evaluate the effectiveness of a constructed wetland to improve water quality of runoff from row crops. The ability of the wetland to reduce pollutants in water as it flowed through the wetland was evaluated.

The constructed wetland was effective in reducing average concentrations and total loads of nonpoint-source pollution. Average concentrations of nitrogen, total phosphorous, suspended sediment, metolachlor, and acifluorfen were all lower at the downstream station than they were at the upstream station. These results indicate that constructed wetlands have the potential to become an integral part of best management practices to control, mitigate, or reduce nonpoint-source pollution.

[1]Student, Clemson University, Clemson, South Carolina

APPLICATION OF A GEOGRAPHIC INFORMATION SYSTEM TO PRIORITIZE STREAMS FOR NONPOINT-SOURCE MANAGEMENT

Tom D. Byl[1], H. Hankin[2], J.R. Mimms[3], and G. Hofstetter[4]

The North Fork - Fall Creek Hydrologic Unit Area (NFFC HUA) is a 75,000-acre watershed located in Bedford County, Middle Tennessee. The NFFC watershed is situated on a karst terrane with shallow soils, sinkholes, limestone caves, and conduit-type subsurface flow. The surface streams and ground-water system are well connected. The water quality in NFFC was classified as impaired due to nonpoint-source pollution in 1989. The primary water impairment was identified as fecal bacteria and nutrient enrichment. The NFFC watershed was added to the U.S. Department of Agriculture's list of Hydrologic Unit Areas, qualifying it for accelerated technical and financial resources to improve water quality. A geographic information system (GIS) was used to: (1) subdivide the NFFC watershed into seven manageable sub-basins, (2) identify potential sources of pollutants based on land-use activities and number of residences, and (3) prioritize the sub-basins for nonpoint-source management practices. Site visits and a variety of water-quality tests were used to evaluate the GIS results. The GIS model was used to prioritize several of the sub-basins for a variety of agriculture best management practices.

[1]U.S. Geological Survey, 810 Broadway, Suite 500, Nashville, Tennessee 37203; tdbyl.er.usgs.gov; Phone: (615) 736-5424

[2]Natural Resource Conservation Service, Cookeville, Tennessee

[3]Natural Resource Conservation Service, 801 Broadway, Nashville, Tennessee 37203

[4]Natural Resource Conservation Service, Shelbyville, Tennessee

DIOXIN LEVELS OF FISH COLLECTED IN THE TENNESSEE PORTION OF THE PIGEON RIVER

Gregory M. Denton[1]

BACKGROUND

The Pigeon River originates in the Blue Ridge region of North Carolina and flows in a northwesterly direction into Tennessee. During the 1980's, it was targeted for dioxin monitoring during the U.S. Environmental Protection Agency's (EPA) National Dioxin Survey because of the discharge of chlorine bleached pulp mill effluent near Canton, North Carolina. That and subsequent analyses documented elevated levels of dioxin in fish (Denton, 1993).

One of the responsibilities given to the Commissioner of the Tennessee Department of Environment and Conservation is to issue advisories when public health is threatened by pollution. In 1989, the Department issued a fish consumption advisory for the Tennessee portion of the river. The public was advised to avoid consumption of any type of Pigeon River fish because of the elevated dioxin levels. This advisory continues into the present.

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 is 2,3,7,8 tetrachlorodibenzo-p-dioxin or 2,3,7,8 TCDD. First noted as a byproduct of herbicide production, EPA testing on laboratory animals indicated that dioxin caused a wide variety of toxic and reproductive effects and was a potent carcinogen (EPA, 1987). These findings led to the ban of a specific category of herbicides, 2,4,5-T. Additional documented sources of dioxin include chlorine bleaching of pulp to produce paper, high temperature incineration, some municipal sewage plants, and types of wood preservation.

Since 1991, annual fish tissue monitoring has taken place in the Pigeon, primarily by the Champion Paper Company as a compliance monitoring requirement of their NPDES permit and by the Tennessee Wildlife Resources Agency (TWRA). Additional samples have been collected by Carolina Power and Light and the Department of Environment and Conservation. Long-term goals of this monitoring include providing data for the periodic reevaluation of the fishing advisory and allowing the identification of trends, if any, in dioxin concentrations in fish over time.

METHODS

Four stations were utilized for fish collections during the period 1991 - 1995 (see Figure 1).

- Mile 7.5 at Tannery Island near Newport. Collected by TWRA in 1992, 1993, 1994, and 1995; and by Water Pollution Control (WPC) in 1994 and 1995.

[1]Tennessee Department of Environment and Conservation, Division of Water Pollution Control, Planning and Standards Section, 7th Floor, L & C Annex, 401 Church Street, Nashville, TN 37243-1534

- Mile 16.5 near Denton. Collected by TWRA in 1991, 1992, 1993, 1994, and 1995; by Champion Paper in 1991; and by Carolina Power and Light (Carolina P & L) in 1991.

- Mile 19 near Bluffton. Collected by Champion Paper in 1992, 1993, 1994, and 1995.

- Mile 24.5 near the Waterville Bridge. Collected by WPC in 1995.

Fish collection and analysis followed EPA guidance and Champion's NPDES compliance monitoring requirements. At each sampling event, an attempt was made to collect samples consisting of game fish, catfish, and a bottom-dwelling species. Composite fillet, individual fillet, and wholebody samples have been collected at various times. Champion Paper, Carolina Power and Light, and Department samples were given a full screening of dioxin and furan congeners. The TWRA samples were analyzed for 2,3,7,8 TCDD and 2,3,7,8 TCDF only.

Fillet samples were analyzed skin-on for gamefish and carp and skin-off for catfish. Chain-of-custody, quality control, and quality assurance guidance was followed in the collection, handling, and analysis of samples. All results were translated into a total toxic equivalent (TEQ) using the factors suggested by EPA guidance (EPA, 1989). One-half of the concentration for compounds documented at below detection levels was included into the calculation of the TEQ, also as recommended by EPA (EPA, 1993).

DISCUSSION

Dioxin data collected during the period 1991 - 1995 are listed in Table 1. For each species of fish collected more than one time, a data summary appears below.

TYPE FISH	DATA RANGE	AVERAGE TEQ (ppt)	WEIGHTED * AVERAGE TEQ
Redbreast Sunfish	0.08 - 2.81	1.05	1.16
Common Carp	0.23 - 14.55	4.14	4.57
Channel Catfish	0.50 - 9.04	3.14	3.54
Smallmouth Buffalo	0.09 - 1.06	0.57	0.52
Smallmouth Bass	0.11 - 0.80	0.38	0.24
Spotted Bass	0.19 - 0.76	0.49	0.53

*Average weighted according to the number of fish in composite samples.

The data for each fish species are illustrated in Table 1. The only sampled species that have exceeded, on average, 1 part per trillion of dioxin during the 90's are carp, channel catfish, and redbreast sunfish. Smallmouth bass, smallmouth buffalo, and spotted bass averaged below 1 part per trillion. Only one sample of largemouth bass, northern hogsucker, and rockbass have been collected, each below 1 ppt.

Samples collected give the appearance that dioxin levels during the period 1991 - 1995 are lower than those documented in the 80's. However, factors such as species collected, fish sizes, and the lipid content of samples must be considered before true trends can be established.

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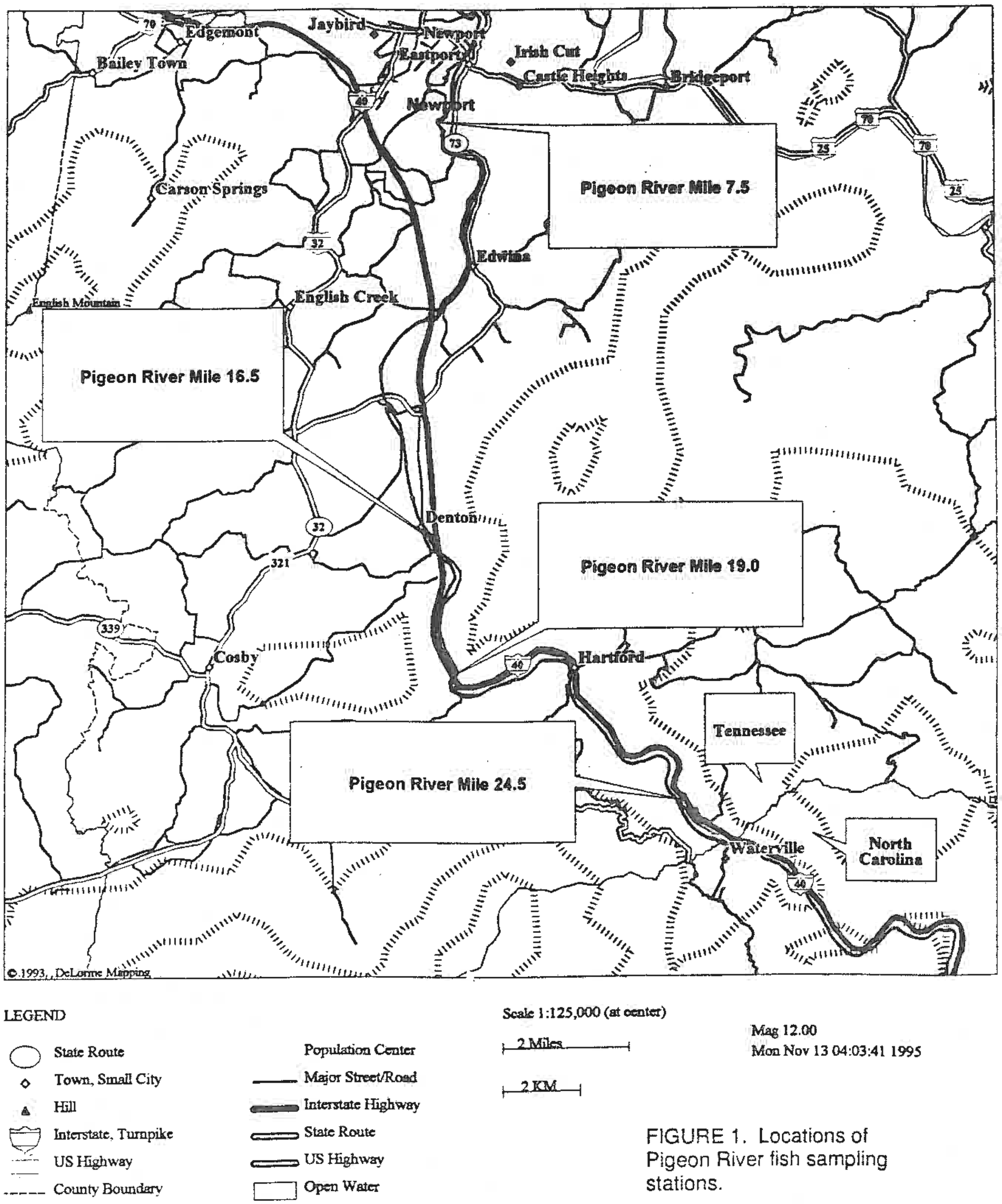

FIGURE 1. Locations of Pigeon River fish sampling stations.

TABLE 1

Pigeon River Fish Tissue Data
1991 - 1995 *[Sorted by Fish Type]*

Date Fish Collected	Collection Agency	Rivermile Location	Type of Fish	Type of Sample	# of Fish in Composite	Avg. Wt. of Indiv. in Composite	Lab Used	Full or Partial Congener Scan	Percent Lipid	Result as TEQ *
7/91	TWRA	16.5	Redbreast sunfish	Comp. Fillets	10	8.4 oz.	Wright State U.	Partial	1.2	2.45
7/91	Carolina P & L	16.5	Redbreast sunfish	Comp. Fillets	5	5.8 oz.	Triangle Labs	Full	1.8	0.98
8/91	Champion	16.5	Redbreast sunfish	Comp. Fillets	10	5.1 oz.	Enseco	Full	1.1	0.99
7/92	TWRA	7.5	Redbreast sunfish	Comp. Fillets	5	6.9 oz.	Wright State U.	Partial	2.52	2.81
7/92	TWRA	16.5	Redbreast sunfish	Comp. Fillets	10	9.4 oz.	Wright State U.	Partial	1.81	1.54
8/92	Champion	19.0	Redbreast sunfish	Comp. Fillets	10	7.0 oz.	Enseco	Full	0.65	0.54
7/93	TWRA	7.5	Redbreast sunfish	Comp. Fillets	10	6.5 oz.	Wright State U.	Partial	1.93	1.28
7/93	TWRA	16.5	Redbreast sunfish	Comp. Fillets	10	9.6 oz.	Wright State U.	Partial	1.2	1.24
8/93	Champion	19.0	Redbreast sunfish	Comp. Fillets	6	4.8 oz.	Enseco	Full	2	0.26
8/94	Champion	19.0	Redbreast sunfish	Comp. Fillets	6	4.3 oz.	Enseco	Full	5.9	0.08
7/94	TWRA	16.5	Redbreast sunfish	Comp. Fillets	10	7.6 oz.	Wright State U.	Partial	NA	NA
8/95	WPC	7.5	Redbreast sunfish	Comp. Fillets	5	6.4 oz.	Triangle Labs	Full	NA	0.13
8/95	WPC	24.5	Redbreast sunfish	Individual	-	5 oz.	Triangle Labs	Full	NA	0.24
7/91	TWRA	16.5	Carp	Comp. Fillets	5	5 lb. 5 oz.	Wright State U.	Partial	3.54	7.72
8/91	Champion	16.5	Carp	Comp. Fillets	2	4 lb. 14 oz	Enseco	Full	4.8	1.87
8/91	Champion	16.5	Carp	Comp.WB	2	4 lb. 6 oz.	Enseco	Full	8.8	14.55
7/92	TWRA	7.5	Carp	Comp. Fillets	5	5lb.	Wright State U.	Partial	5.06	3.36
7/92	TWRA	16.6	Carp	Comp. Fillets	5	3 lb. 14 oz.	Wright State U.	Partial	4.13	3.04
7/93	TWRA	7.5	Carp	Comp. Fillets	5	NA	Wright State U.	Partial	6.14	2.55
7/93	TWRA	16.5	Carp	Comp. Fillets	4	NA	Wright State U.	Partial	6.84	7.03
8/95	WPC	7.5	Carp	Individual	-	13 lb. 2 oz.	Wright State U.	Full	NA	0.23
8/95	WPC	7.5	Carp	Individual	-	8 lb. 2 oz.	Triangle Labs	Full	NA	0.51
8/95	WPC	7.5	Carp	Composite	2	5 lb. 9 oz.	Triangle Labs	Full	NA	0.56
7/91	Carolina P & L	16.5	Spotted bass	Comp. Fillets	3	11.2 oz.	Triangle Labs	Full	0.76	0.76
8/91	Champion	16.5	Spotted bass	Comp. Fillets	2	14.7 oz.	Enseco	Full	0.25	0.19
8/92	Champion	19.0	Spotted bass	Comp. Fillets	2	14.4 oz.	Enseco	Full	0.2	0.52

TABLE 1 (cont.)

Date Fish Collected	Collection Agency	Rivermile Location	Type of Fish	Type of Sample	# of Fish in Composite	Avg. Wt. of Indiv. in Composite	Lab Used	Full or Partial Congener Scan	Percent Lipid	Result as TEQ *
7/91	TWRA	16.6	Channel catfish	Comp. Fillets	3	2 lb. 2 oz.	Wright State U.	Partial	4.36	9.04
7/91	Carolina P & L	16.5	Channel catfish	Comp. Fillets	5	1 lb. 5 oz.	Triangle Labs	Full	4	6.11
6/92	TWRA	16.6	Channel catfish	Comp.	2	1 lb. 0.8 oz.	Wright State U.	Partial	5.21	4.12
7/92	TWRA	7.5	Channel catfish	Comp.	6	1 lb. 8 oz.	Wright State U.	Partial	5.84	3.85
7/93	TWRA	7.5	Channel catfish	Comp.	3	N/A	Wright State U.	Partial	6.18	0.50
7/93	TWRA	16.5	Channel catfish	Comp.	5	N/A	Wright State U.	Partial	1.2	1.38
11/94	WPC	7.5	Channel catfish	Individual	-	1 lb. 14 oz.	Wright State U.	Full	3.32	2.1
8/95	WPC	7.5	Channel catfish	Individual	-	3lb. 6 oz.	Wright State U.	Full	NA	0.85
8/95	WPC	7.5	Channel catfish	Individual	-	1 lb. 15 oz.	Wright State U.	Full	NA	2.16
8/95	WPC	7.5	Channel catfish	Comp.	3	2 lb. 8 oz.	Wright State U.	Full	NA	1.26
7/93	TWRA	7.5	Smallmouth bass	Comp.	5	N/A	Wright State U.	Partial	1.02	0.40
8/93	Champion	19.0	Smallmouth bass	Comp. Fillets	9	5.8 oz.	Enseco	Full	3.2	0.22
8/94	Champion	19.0	Smallmouth bass	Comp. Fillets	9	13.3 oz.	Enseco	Full	6.4	0.11
8/95	WPC	7.5	Smallmouth bass	Individual	-	1lb. 9 oz.	Wright State U.	Full	NA	0.80
7/91	Carolina P & L	16.5	Smallmouth buffalo	Comp. Fillets	5	2 lb. 12 oz.	Triangle Labs	Full	3.8	0.58
8/92	Champion	19.0	Smallmouth buffalo	Comp. Fillets	5	3 lb. 8 oz.	Enseco	Full	2.5	1.04
8/92	Champion	19.0	Smallmouth buffalo	Comp.WB	5	2 lb. 8 oz.	Enseco	Full	6.6	0.62
8/93	Champion	19.0	Smallmouth buffalo	Comp. Fillets	5	3 lb 5 oz.	Enseco	Full	5.7	0.40
8/93	Champion	19.0	Smallmouth buffalo	Comp.WB	5	4 lb.	Enseco	Full	12	1.06
8/94	Champion	19.0	Smallmouth buffalo	Comp. Fillets	9	3 lb. 2 oz.	Enseco	Full	8	0.09
8/94	Champion	19.0	Smallmouth buffalo	Comp.WB	5	4 lb. 8 oz.	Enseco	Full	10	0.23
8/95	WPC	7.5	Largemouth bass	Individual	-	1lb. 8 oz.	Triangle Labs	Full	NA	0.14
8/95	WPC	24.5	N. Hogsucker	Individual	-	11 oz.	Triangle Labs	Full	NA	0.2
8/95	WPC	24.5	Rockbass	Comp. Fillets	3	4.3 oz.	Triangle Labs	Full	NA	0.18

NA - Results not available at time of publication.
*Per EPA Guidance, one half of detection level added to all not detected congeners.

TENNESSEE MUNICIPAL WATER POLLUTION PREVENTION PROGRAM

Elizabeth Bunting[1]

With passage of the 1987 Amendments to the Federal Clean Water Act, funding options for municipal wastewater treatment plants (WWTPs) changed dramatically from grants to loans. As a result, new construction has become more expensive for communities, increasing the need for proper operation and maintenance of existing facilities. In 1992, Tennessee began development of a Municipal Water Pollution Prevention Program (MWPP). This is a voluntary program with a primary goal of assisting communities to extend the functional life of WWTPs and maintain NPDES permit compliance. Tennessee's program is based on similar programs in Georgia and Alabama and is partially supported by a development grant from the U.S. Environmental Protection Agency (EPA).

Major components of the MWPP include an Early Warning System, Reporting Process, and a Corrective Action Program. Early program efforts have centered on developing a self-inventory report, the Tennessee Municipal Assessment Report or TMAR, to be completed by the managers of individual wastewater treatment facilities. The TMAR covers permit compliance, operation, maintenance, and local funding for WWTPs. Analysis of TMAR results will guide development of a Corrective Action Plan by a committee of community-based and agency representatives. The Plan will identify resources of regional planning agencies, local governments, and state agencies that are non-regulatory in nature. Once the other program components are in place, The Early Warning System will use geographic informatin system technology to combine data bases and target WWTPs that have a high probability of environmental damage in ecologically sensitive locations.

[1]Tennessee Department of Environment and Conservation, Division of Construction Grants and Loans, 8th Floor L&C Tower, 401 Church Street, Nashville, Tennessee 37243-1583; phone: (615) 532-0435; Fax: (615) 532-0614

ZEBRA MUSSELS IN TENNESSEE WATERS: LEARNING FROM EXPERIENCES IN THE NORTHEAST

David Bruce Conn[1,2] and Denise Andriot Conn[2]

INTRODUCTION

Since invading the Great Lakes in the mid 1980's, the European zebra mussel, Dreissena polymorpha, and quagga mussel, Dreissena bugensis, have spread throughout most of the major freshwater systems of eastern North America. Zebra mussels were first encountered in the lower Tennessee River in 1991, and have since spread into the upper reaches of the Tennessee and Cumberland Rivers. We have conducted extensive research on these exotic mussels in the St. Lawrence River and Lake Ontario since 1990, focusing primarily on monitoring and control strategies, reproductive processes, parasites, and impacts of the mussels on native benthic and planktonic communities. We have also monitored temporal and spatial aspects of the spread of the mussels in the St. Lawrence River system. In 1993, we began preliminary studies on the Tennessee River, including monitoring for planktonic and benthic stages just downstream from Chattanooga. The Tennessee and Cumberland Rivers are similar to the St. Lawrence in being riverine systems with appreciable commercial and recreational traffic; however, they are much smaller than the St. Lawrence, and also differ in other important physical characteristics. The rivers are biotically similar in some respects, but different in others. (e.g., diversity of unionid clams; presence of the Asiatic clam, Corbicula fluminea). With the intention of being proactive, we are using our experiences in the heavily colonized Northeast to help us prepare for a more effective response to the more recent colonization of Tennessee waterways. In this report we have summarized four primary aspects of his work, and have cited our relevant publications.

THE SPREAD OF DREISSENID MUSSELS IN NORTH AMERICAN RIVERS

For this work, we have collaborated with teams from other universities, industries and governmental agencies in the United States and Canada. We have established monitoring sites along the St. Lawrence River from Lake Ontario to Quebec City, and on the Tennessee River from Chattanooga to South Pittsburg, Tennessee. In our monitoring work for adult mussels we have included a combination of hand sampling and benthic scraping from shore, deepwater dredging from a boat, SCUBA diving, deployment of artificial substrates, and examination of navigational buoys. For veliger monitoring we have used shore-operated portable pumps, towing behind boats, and tap valves in industrial water pipes to pass water through 68-micrometer mesh plankton nets. In the St. Lawrence River, adult zebra mussels first appeared in Fall, 1989 at an isolated focus approximately 160 km downstream from the river's outflow from Lake Ontario. By summer, 1990 veligers were spreading planktonically from this focus downstream, so that adults extensively colonized the river downstream from this initial focus to the estuarine region by 1991 (Conn et al., 1991). By contrast, dreissenid mussels colonized upper reaches of the river only in scattered foci by 1991, presumably via upstream transport of adults attached to the bottoms of watercraft (Conn et al., 1992c). Only in 1992 did the mussels become widely distributed in the upper 160 km of the river. Based on the

[1]Department of Biology, The University of the South, Sewanee, TN 37383; Internet: bconn@sewanee.edu; Phone: (615) 598-1715

[2]North American Scientific Enterprises (NASCENT), 944 Dogwood Dr., Monteagle, TN 37356; Phone: (615) 924-3329

mixture of zebra and quagga mussels in the upper river, as compared with only zebra mussels in the lower river, this later colonization upstream appeared to result primarily from planktonic dispersal of veligers downstream from well established populations in Lake Ontario (Conn et al., 1992a; Mills et al., 1993). By summer, 1994, virtually all living and non-living hard substrates in the St.Lawrence were extensively covered by dreissenids (unpublished data).

Colonization of the Tennessee River has proceeded slowly since the first report of mussels in the lower river in late 1991. Isolated foci were reported upstream to Nashville and Fort Loudoun by 1993. However, despite much monitoring of the plankton and benthos in the Tennessee River immediately downstream from Chattanooga since 1993, we have seen no evidence of the mussels becoming established breeders yet in this area. This slow initial buildup is consistent with what has been observed in other riverine systems. Based on our observations on the St. Lawrence River, as well as reports by others on the Ohio River, Mississippi River, and lower Tennessee River, we predict that zebra mussels will become widespread and well established as breeding populations throughout the navigable portions of the Tennessee and Cumberland Rivers by the end of summer, 1996 (Conn, 1994).

THE IMPACT OF DREISSENID MUSSELS ON NORTH AMERICAN AQUATIC BIOTA

As with the introduction of any successful exotic species into a new environment, the invasion of North American waters by dreissenids will have significant impact on our native biota. Many types of impact have been observed, and many more predicted (Conn, 1992). Competition for food and substrate are among the most important documented impacts of the mussels on native species. The most damaging impact has been the biofouling of hard-bodied animals such as crayfishes and clams. We have observed severe reduction or decimation of native populations of unionid clams as a result of zebra mussel colonization in the St. Lawrence River and Lake Ontario. We have also demonstrated that the quagga mussel is less likely to colonize the shells of living unionids than are zebra mussels. However, only zebra mussels are currently building up in the Tennessee and Cumberland Rivers, so this difference between the dreissenid species may be irrelevant to the current situation here. Based on observations from the Great Lakes area, we predict serious negative impacts to native unionid clams in Tennessee within the current decade. Negative impacts on other benthic and planktonic organisms require further study.

NATURAL NORTH AMERICAN ENEMIES OF DREISSENID MUSSELS

There is much interest in the possibility that natural enemies of dreissenid mussels might serve as agents of some degree of natural biological control. We have conducted studies in the St. Lawrence River/Lake Ontario region with the objective of identifying native competitors, predators, parasites, and other biotic associates that might play such a role. We have reported that dreissenid mussels often harbor populations of native nematodes and naidid oligochaete annelids (Conn et al., 1994). The latter includes Chaetogaster limnaei, which we have shown to be pathogenic to the mussels (Conn et al., 1996). Our attempts at experimental infection of mussels has revealed that cercariae of the native trematode, Echinoparyphium sp., are infective to the mussels (Conn and Conn, 1995). Unfortunately, these are unlikely to harm the mussels, and may actually cause a problem by using zebra mussels as a new vector for transmission to native waterfowl.

Our recent studies on the aquatic larvae of the caddisfly, Brachycentrus incanus, colonize the shells of living zebra mussels, possibly extracting some of the nutrients from their filter-feeding stream (unpublished data). We have reported that the native cnidarian, Hydra americana, preys on zebra mussel veligers, and that the large gelatinous colonies of the native ectoproct (bryozoan), Pectinatella magnifica, has overgrown and killed zebra mussels in the St. Lawrence River drainage (Conn and Conn, 1993). This species, common throughout eastern North America, grows on various hard substrates. From the limited observations reported here, P. magnifica clearly seems to be a native animal that outcompetes dreissenids for substrate, at least under some conditions. Unfortunately, P. magnifica itself can be a nuisance, damaging water-use facilities by clogging intake screens, particularly in southern reservoirs such as those of the Tennessee and Cumberland River systems. Other workers have reported extensive overgrowth of mussels by sponges in Lake Erie and the St. Lawrence River, with mussel mortality resulting. It remains to be seen whether sponges in Tennessee waters will grow profusely enough to cause similar mussel mortality.

DISCRIMINATION BETWEEN VELIGERS OF DREISSENA AND MYTILOPSIS

Estuarine areas of North America are the native home of one dreissenid species, Mytilopsis leucophaeata, which can be confused with its European confamilials (Baldwin et al., 1994). Waters of the Tennessee River are known to support a few adults of M. leucophaeata, primarily attached to the bottoms of vessels that have brought them through the Tennessee-Tombigbee Waterway from established populations in estuaries along the northern shores of the Gulf of Mexico. Fortunately, M. leucophaeata apparently is unable to breed in the Tennessee River. However, for areas where Dreissena spp. and M. leucophaeata might co-occur, we have developed an manual for discriminating their veligers in plankton samples (Conn et al., 1993). For monitoring programs in Tennessee waters it will be more important to discriminate between the veligers and postveligers of Dreissena spp. and Corbicula fluminea. We hope to develop a manual for this in the near future.

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ESTIMATED NUTRIENT LOADING FOR MAJOR TRIBUTARIES OF THE UPPER TENNESSEE RIVER BASIN

G. C. Johnson[1] and M. W. Treece, Jr.

The U.S. Geological Survey is conducting an assessment of water quality in the upper Tennessee River Basin as part of the National Water-Quality Assessment Program. The upper Tennessee River study area encompasses a total of about 21,400 square miles and includes the entire drainage of the Tennessee River and its tributaries upstream of Chickamauga Dam near Chattanooga, Tennessee. During the planning phase of this study, existing streamflow and water-quality data were compiled from local, State, and Federal sources. Nutrient loads for 23 monitoring sites in the basin were estimated for water years 1970 through 1993. Also, a general nutrient budget for the study area is being developed from point-source (effluent from industries and municipal sewage treatment plants) and nonpoint-source data (fertilizer application, animal waste, and atmospheric deposition).

Estimated nitrogen loads for the Tennessee River at Chattanooga, Tennessee, ranged from 99,600 kilograms per day (kg/d) in 1979 to 20,680 kg/d in 1988, with a mean load of 62,510 kg/d. Phosphorus loads at this site ranged from 11,270 to 1,620 kg/d in 1979 and 1988, respectively, and the mean load was 6,120 kg/d. The French Broad River near Knoxville, Tennessee, contributed the highest mean nitrogen load (21,830 kg/d), and the highest mean annual phosphorus load (1,560 kg/d).

The highest nutrient yields (load per unit area) were from the French Broad River watershed above Marshall, N.C., which averaged 2.18 kilograms per square kilometer per day ($kg/km^2/d$) for nitrogen, and 0.36 $kg/km^2/d$ for phosphorus. The land use in the upper French Broad River Basin was about 11 percent urban and 23 percent agricultural in 1976. In addition, there are numerous industries in the Asheville area. The lowest mean annual nutrient yields were in the Ocoee, Little Tennessee, and Emory River Basins for nitrogen (about 0.7 $kg/km^2/d$), and in the Ocoee, Little Tennessee, and the Clinch River Basins for phosphorus (0.03, 0.03, and 0.02 $kg/km^2/d$, respectively).

[1]U.S. Geological Survey, 1013 N. Broadway, Knoxville, Tennessee 37917; phone: (615) 32-8748; FAX: (615) 632-8753

TVA POLLUTION PREVENTION MODEL DEMONSTRATION PROGRAM

Michael F. Broder[1]

In the late 1980's TVA's National Fertilizer and Environmental Research Center (now known as Environmental Research Center) began a program to showcase pollution prevention technologies at retail agricultural dealerships across the United States. The decision to conduct the program coincided with the Center's shift from fertilizer research and development to environmental research and development. The retail fertilizer industry, who was then the beneficiary of much of the Center's work, also suggested that the Center develop some model sites to demonstrate state-of-the art technologies for preventing pollution. When developing model sites, Center engineers and scientists conduct an environmental assessment of the site then provide recommendations and designs for a comprehensive pollution prevention program. The dealer then pays for any modifications or new construction and agrees to allow the facility to be used in educational forums ranging from open houses to publications describing the details of the design. The emphasis of the program is to transfer technology and to develop and introduce new technologies.

In addition to the commitments by the dealer and TVA, agencies in the state involved with environmental regulation of the site, the Cooperative Extension Service, State Department of Agriculture, universities, and the state fertilizer and agrichemical associations are involved in the selection of the sites and in sponsoring and promoting the educational activities. The selection of sites is based on several criteria. The main ones are the perceived environmental attitude of the facility personnel, the facility's location, the number and types of products handled, and the applicability of the pollution prevention strategies to other sites.

Eighteen agricultural retail sites have been either modified or newly constructed to become TVA pollution prevention model sites (see table 1). Since the sites are described in detail in a TVA circular (1), this abstract summarizes other aspects of the program such as knowledge gained, new technologies developed, estimated costs ad benefits to the participants, findings of research stemming from the program, and educational materials developed. Model sites recently developed in Tennessee with non-agricultural businesses, namely, structural pest controllers and lawn care companies, are also discussed.

KNOWLEDGE GAINED

Environmental site assessments are essential for developing a comprehensive pollution prevention program. Site assessments conducted in this program revealed a number of poor management practices and environmental liabilities that were common at a number of sites. Wells were often located near the site of mixing and loading of fertilizers and pesticides. Well casings were not elevated. Some were at the bottom of concrete pits which were not water tight. Some sites had a single check valve for preventing product from back-siphoning into the well or public water supply.

Many sites had large accumulations of solid waste ranging from wood and metal to used tires and batteries. Some burning of solid waste was noticed as was improper storage of solvents and paints. Most sites lacked secondary containment for fuel and oil tanks. The soil around loading areas was typically stained with petroleum.

[1]Tennessee Valley Authority, P.O. Box 1010, Muscle Shoals, AL 35662-1010; Telephone 205-386-2475

Poor handling of dry fertilizer is perhaps the most serious cause of stormwater contamination from agricultural retail sites. Spills at rail car and truck unloading stations are not expeditiously recovered. Fertilizer dust evolved during transfer operations normally is not collected. Some companies leave a considerable amount of scrap fertilizer from equipment cleaning outside and uncovered. More than one dealer piled scrap materials impregnated with herbicide outside with no cover.

Liquid products are stored without secondary containment. Valves, and pump seals leak. Incompatible metal fittings are used, sight gauges are not protected from damage or vandalism, and threaded fittings are used where welded ones should be. Product transfers are made over gravel with no loading pad to intercept spills. At two sites where soil was sampled, herbicide contamination was detected where product was loaded and where equipment was washed. Our findings agree with those of EPA (2) that, aside for tank failures, spills during product transfer are the most common spills at bulk pesticide handling operations. Two dealers, not associated with the model site program, claimed that soil beneath their nitrogen solution loading stations had to be excavated to a depth of 15 to remove the contamination.

Field experiences revealed that concrete, while structurally well suited for secondary containment structures, is chemically incompatible with some fertilizers and too porous to provide an adequate barrier to pesticide penetration. Laboratory research to find a better concrete will be discussed later.

Field experience also revealed that the designs of concrete structures must be based on accurate data regarding the structural properties of the soil beneath the structure. Expansion joints must be properly installed and located to minimize the formation of cracks in concrete structures. The Midwest Plan Service (3) has an excellent handbook which gives specifications for the design of concrete secondary containment structures.

Stormwater management is a critical part of pollution prevention strategies. To reduce the capital cost of secondary containment structures, many dealers opted not to place a roof over them. Problems associated with handling and recycling contaminated precipitation have persuaded most dealers to invest in roofs. Otherwise, spills and rinsate are recovered expeditiously and surfaces coming in contact with precipitation are cleaned daily.

Large tanks, those with volumes of at least 100,000 U.S. gallons, present special challenges. Most of these tanks had no secondary containment in 1990. Many sites lacked the space to construct earthen secondary containment structures. The biggest challenge is the installation of a barrier beneath existing tanks. Many dealers have successfully moved and placed tanks onto an impervious liner using the same method house movers use. Steel, concrete, natural clay, synthetic liners, and soil amended with swelling clay have all been used to construct the containment. Large tank secondary containment is discussed in more detail in a TVA bulletin (4).

A final lesson learned from the model site program is that the success of pollution prevention programs rests heavily on the employees of the site. Everyone from management to the laborers must understand the importance of pollution prevention and must know the correct operating procedures and management practices. Otherwise, poor practices may continue. A case in point involved an employee who was rinsing fertilizer and pesticide residues from a vehicle onto the ground adjacent to a newly-constructed loading pad. The employee explained to an observer, who happened to be a state regulator, that if he washed the equipment on the pad he would have to retrieve it and clean the pad.

COST AND BENEFITS TO PARTICIPANTS

The average investment in pollution prevention structures was $182,000 per location (5). The median investment was $100,000. In many cases the environmental improvements included improvements in mixing equipment, increases in storage capacity, and improvements in traffic flow and efficiency of the operation. On average, these investments, plus the cost of other items related to environmental regulations, cost the dealers $4.83 per ton of product sold. Because of the competitive nature of their businesses, these dealers did not increase their prices nor did they have to increase their volume of sales to offset these environmental investments.

Dealers, however, benefited from larger market shares for two reasons, 1) because of their image as environmental leaders, and 2) because of their increased efficiency. Other tangible benefits were that they decreased their annual loss of fertilizer by an average of $3,412, they reduced their insurance costs, and received higher rebates from chemical companies for their environmental improvements. Among the intangible benefits were a boost in employee morale and peace-of-mind for the owners.

RESEARCH FINDINGS

Much of the research supporting the pollution prevention program involved materials of construction. Concrete, the material of choice for secondary containment structures, is particularly susceptible to corrosion by urea ammonium nitrate (UAN) solution. Tests conducted with a variety of concrete mixtures revealed that, despite the use of several strengthening agents and additives, Portland cement-based concretes were all susceptible to corrosion by UAN. Micro-fine silica reduced the porosity of concrete specimens and their rate of degradation from UAN. Plastic fiber additives provided a conduit for UAN to enter the concrete and increased the rate of corrosion. The reaction of UAN to concrete is similar to that from a strong acid. In drip tests the samples were completely destroyed in a few weeks (6).

Tests with pesticides revealed that solvent-based products easily penetrated concrete samples after 5 simulated spills despite being rinsed shortly after each spill. Penetration was so rapid that, 15 minutes after a spill, water was ineffective in removing pesticide from inside the concrete. High levels of pesticide were detected in the samples after four months without further exposure. After being immersed in concrete for 90 days the compressive strength was reduced by 50 percent even though there was no visible deterioration.

To assist the U.S. Environmental Protection Agency in developing their proposed rules for bulk pesticide secondary containment, studies were conducted to determine concrete coatings that would be suitable for pesticide secondary containment structures. Solvent-based pesticides were destructive to the elastomeric coatings; elastomeric urethane, polysulfide, and poly-urea urethane. The epoxy based products and vinyl ester were found to be adequate for pesticide service. Fertilizer solutions and water-based herbicides had little effect on the coatings. The results of the study are summarized in the Journal of Protective Linings and Coatings (7).

Compatibility tests were also conducted with synthetic liners and pesticides. Of the 11 liners tested, only high density polyethylene and polybutylene terepthalate were found suitable for lining secondary containment structures exposed to solvent-based pesticides. The results of these tests are summarized in the TVA bulletin (4).

EDUCATIONAL MATERIALS

Much of the knowledge gained from the Pollution Prevention Model Site Program is summarized in the Environmental Handbook for Fertilizer and Agrichemical Dealers (4). In addition to guidelines for designing and building secondary containment structures, this handbook discusses all aspects of environmental stewardship for the agricultural retailer, as well as state and federal regulations effecting them.

A separate bulletin describing how to coat concrete secondary containment structures exposed to agrichemicals was developed (8). A copy of the coating bulletin is included in the environmental handbook. Other chapters in the environmental handbook are available as separate documents; the chapter on large tank secondary containment, the chapter on secondary containment, and the summary of the pollution prevention model sites, and the summary of the economic cost and benefits associated with pollution prevention structures (5).

A number of video tapes dealing with secondary containment were developed in cooperation with universities across the U.S. All of these educational materials are available from the TVA Bookstore, Environmental Research Center, P.O. Box 1010, Muscle Shoals, Alabama 35662-1010.

POLLUTION PREVENTION MODEL SITES IN TENNESSEE

The most recent agricultural retail pollution prevention sites were established in Tennessee (Table 1). The site in Athens, Tennessee, is still under construction. At both sites contaminated soil was found. At one site the soil was excavated and the concentration of trifluralin herbicide was used as a basis to field apply the soil. Nine months after the application, no trifluralin was detected in the field. At the other site, in situ bioremediation will be used to remove the contamination. Preliminary results indicate that the containment, atrazine, will break down fairly rapidly with the proper biological amendments.

In the initial assessment of the Jackson site, pesticide was detected in the ditch which drained stormwater from the property. Since then all fertilizer and pesticide handling has been done under roof and pesticides are no longer detectable in stormwater leaving this site. Stormwater samples at the Athens site had detectable levels of pesticide in the spring of 1995. This was largely attributable to herbicide residues in equipment parked outside. This problem should be eliminated in the future when the large equipment shed, constructed in the fall of 1995, is used.

The non-agricultural model sites include two structural pest control companies and two lawn care companies. The Tennessee Department of Agriculture's Division of Plant Industries is the lead agency in these projects with some support coming from EPA. Much of the technology is derived from the agricultural retail sites, however, their smaller scale and urban setting dictates some unique designs. For example, portable loading pads made of steel are well suited for these companies because they have smaller vehicles and operate inside a rented building. The different designs developed for these model sites will serve as a guide for developing rules in Tennessee for these commercial pesticide users.

The Tennessee Department of Agriculture plans to develop model sites for all large users of pesticide, a horticultural nursery, a golf course pesticide and fertilizer handling facility, and a large row-crop farm. The aim of this program is to minimize the adverse impact of pesticide use on Tennessee's environment. Educational materials specific to these industries will be developed as part of the program.

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Table 1.

Agricultural Retail Pollution Prevention Model Sites

John Pryor Company	Salinas, California
Agriform Farm Supply	Woodland, California
Ranch Fertilizer	Okeechobee, Florida
Shields Soil Service	Dewey, Illinois
Farmer's Fertilizer Company	Smith's Grove, Kentucky
Ouachita Fertilizer Company	Monroe, Louisiana
Willard Agri-Service, Inc.	Frederick, Maryland
B&W Co-op, Inc.	Breckenridge, Michigan
South Central Co-op	Fairfax, Minnesota
Glasgow Cooperative Association	Fayette, Missouri
TriCo Farm Service	Oxford, Nebraska
CaroVail, Inc.	Niverville, New York
Convoy Equity Exchange Company	Convoy, Ohio
Wilbur-Ellis Company	Umatilla, Oregon
Cone Ag Service	Pierre, South Dakota
Hutson Ag Service	Jackson, Tennessee
McMinn Loudon Farmers' Co-op	Athens, Tennessee
Alliance Agronomics, Inc.	Mechanicsville, Virginia

AN OVERVIEW OF NITROGEN SATURATION STATUS IN THE GREAT SMOKY MOUNTAINS

Terry Flum[1], Stephen C. Nodvin[2], John Shubzda[3], Anita K. Rose[3], and Heather L. H. Rhodes[3]

Acidification of soils and surface waters by atmospheric sulfur and nitrogen pollutants is a particularly insidious problem because it impacts on otherwise pristine areas such as the Great Smoky Mountains National Park. Each year over 2,100 Eq ha^{-1} of sulfur and 1900 Eq ha^{-1} of nitrogen are deposited at high elevations in the Park - some of the highest rates measured in North America. Water quality monitoring involving cooperation of the national Park Service, National Biological Service, and The University of Tennessee, indicates that this deposition results in low stream pH (<5.5) and Acid Neutralizing Capacity (<50 μeqL^{-1}). Unlike most areas impacted by acid precipitation however, the predominant strong acid anion is nitrate, not sulfate. Sulfate adsorption, which is enhanced by high nitrate levels, is probably responsible for reducing sulfate mobility. The high levels of nitrate leaching to stream waters indicates that the forests are saturated with nitrogen. Nitrogen saturation progresses in a series of four stages (0-3) distinguished by seasonal variation in nitrate concentrations. Current seasonal patterns suggest that streams at high elevations are now at an advanced stage of saturation (stage 2). At lower elevations nitrate levels decline but at a much slower rate in catchments with old growth forests. This pattern suggests that continued high levels of atmospheric deposition may lead to progressing nitrogen saturation downslope and into areas where relatively young forests are now maturing. The effect of increased nitrogen levels on surface water acidification is uncertain due to the interaction between nitrogen and sulfur in the soils.

[1]Department of Ecology and Evolutionary Biology, 569 Dabney Hall, University of Tennessee, Knoxville, Tennessee 37901-1601

[2]National Biological Service and Graduate Faculty for the Department of Ecology and Evolutionary Biology, 569 Dabney Hall, University of Tennessee, Knoxville, Tennessee 37901-1601

[3]Department of Forestry, 274 Ellington Plant Sciences, University of Tennessee, Knoxville, Tennessee 37901-1071

MONITORING THE IMPACT OF CUMBERLAND GAP TUNNEL CONSTRUCTION ON NEWLY CREATED AND PREVIOUSLY EXISTING STREAMS

Stephen C. Nodvin[1], Heather L. H. Rhodes[2], John Shubzda[2], and Terry Flum[3]

The Cumberland Gap Tunnel was built to reroute US Highway 25E from its present location and allow restoration of the original Cumberland Gap Trail. Tunnel construction altered the pattern of surface flow and created a new permanent stream that drains into Little Yellow Creek. The monitoring plan developed to prevent excessive negative impacts to water quality and biota focuses on three primary monitoring stations, one in the new stream and two others just upstream and downstream of the confluence with Little Yellow Creek. Water chemistry samples were collected biweekly, and benthic invertebrates were surveyed quarterly. A hydrolab unit was stationed in the new stream to continuously monitor pH, Eh, conductivity, dissolved oxygen and temperature. Regulations required that the contractor "adjust" the new stream if pH dropped below 6 or went above 9. Sulfuric acid and sodium hydroxide were used for this purpose. The use of strong acids and bases resulted in disastrous changes in pH, however, often dropping below 4 to above 10 and back to 4 in a matter of hours. The result was a drastic decline in water quality and biotic diversity in Little Yellow Creek. Although appropriate channels were used to notify the Federal Highway Administration and the contractor, work was only stopped once and methodologies for taking corrective actions were never changed. Since completion of the drilling phase of tunnel construction, water quality has stabilized and biotic diversity has improved. Colonization of the new Tunnel Creek is treated as a case study in ecological assembly.

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[1]National Biological Service and Graduate Faculty for the Department of Ecology and Evolutionary Biology, 569 Dabney Hall, University of Tennessee, Knoxville, Tennessee 37901-1601

[2]Department of Forestry, 274 Ellington Plant Sciences, University of Tennessee, Knoxville, Tennessee 37901-1071

[3]Department of Ecology and Evolutionary Biology, 569 Dabney Hall, University of Tennessee, Knoxville, Tennessee 37901-1601

BIOMONITORING USED AS A WATER QUALITY ASSESSMENT TOOL IN URBAN STREAMS

Wayne Schacher[1]

In May of 1990, a Master Plan adopted by the city of Knoxville, Tennessee set goals and objectives intended to facilitate improvement and development of the city's waterfront property along Fort Loudoun Reservoir. Plan goals included the identification of water quality issues and problems along the city's reservoir waterfront and within the watersheds of city tributary streams. A Water Quality Forum was created to team federal and state resource regulatory agencies with municipal governmental departments, the University of Tennessee, and other entities to investigate water quality problems within the watersheds of tributary streams.

Biomonitoring tools chosen by the WQF to establish benchmark assessments of the status of the fisheries and benthic macroinvertebrate communities within the seven major tributary streams were the Index of Biotic Integrity (Karr, et a. 1981) and qualitative and quantitative collections of benthic macroinvertebrates. An IBI survey completed in lower Third Creek in 1991 yielded a score of 28 (Poor). In May of 1992, IBI surveys completed on all seven City of Knoxville tributaries yielded IBI results as follows: First Creek - 44 (Fair); Second Creek, lower site - 40 (Fair), intermediate site - 32 (Poor), upper site - 36 (Fair/Poor); Third and Fourth Creeks - 32 (Poor), Baker Creek - 36 (Poor/Fair), Goose Creek - 32 (Poor) and Williams Creek - 40 (Fair). Simultaneous benthic macroinvertebrate assessments on each stream resulted in greatly reduced total taxa, severely depauperate EPT taxa and domination by tolerant organisms.

An IBI survey conducted on the lower site of Second Creek during 1994 produced a score of ___ ( ). April and May, 1995 results from IBI surveys on City of Knoxville streams resulted in scores of 24 (Very Poor/Poor) on East Fork of Third Creek; 36 (Poor/Fair) on the lower site of Third Creek, 38 (Poor/Fair) on the upper site of Third Creek; and 32 (Poor) on the lower, intermediate and upper sites of Second Creek. Benthic macroinvertebrate data are not available at t his time.

Evaluation of the fisheries and benthic macroinvertebrate communities within the City of Knoxville streams sampled indicated a significant degree of impairment in water quality and/or physical habitats.

[1] JAYCOR, 601-D Scarboro Road, Oak Ridge, Tennessee 37831; Phone: (423) 481-8487; FAX: (423) 481-8488

THE INFLUENCE OF RIPARIAN VEGETATION ON THE STRUCTURE AND FUNCTION OF A CHANNELIZED STREAM IN WEST TENNESSEE

Susan S. Hutson[1], Yun Jiao[2], Thomas D. Byl[3]

The influence of riparian vegetation on the biological structure and processing functions of a first order stream was investigated. The study stream was located in an agricultural basin planted in row crops; the stream has been channelized for drainage. Herbaceous plants line the upper reach of the stream. Mature woody vegetation line the lower reaches. Biological and chemical monitoring was done during the 1995 growing season. Rate of leaf decomposition was measured using leaf packs. Also, qualitative visual observations were made concerning habitat stability. Herbaceous and woody reaches were compared. The herbaceous reach had a greater diversity and abundance of organisms during spring and early summer. However, the abundance decreased approximately 85 percent during late summer. The woody reach was more stable than the herbaceous reach with regard to pH, temperature, dissolved oxygen, and specific conductance. The biological abundance and diversity were also more constant during the study period in the woody reach than the herbaceous reach. The rate of leaf decomposition was approximately 45 percent greater in the herbaceous reach compared to the woody reach. These biological results are considered in the framework of the chemistry and habitat stability of the two reaches.

[1]U.S. Geological Survey, 7777 Walnut Grove Road, Suite LLB2, Memphis, Tennessee 37120; sshutson.er.usgs.gov; Phone: (901) 766-2977

[2]Student, Department of Geography, The University of Memphis, Memphis, Tennessee

[3]U.S. Geological Survey, 810 Broadway, Suite 500, Nashville, Tennessee 37203

IMPACT OF THE CLAY CONTENT OF AN AQUIFER ON THE MOVEMENT OF TNT

David M. Smith, M.S.[1] and John W. Smith, Ph. D., P.E., DEE

ABSTRACT

Ground water contamination is a nationwide problem. Munitions manufacture and storage facilities are one of the myriad of possible ground water contamination sources. One chemical commonly detected during munitions facilities investigations is 2,4,6-trinitrotoluene (TNT). The purpose of this study was to assess the impact of the clay content of an aquifer on the movement of TNT. The impact was assessed through the construction and monitoring of model aquifers containing various soil media, (a fine grained sand, a 1% bentonite clay and sand mixture, and a 2% bentonite clay and sand mixture). The model aquifers were used to investigate TNT adsorbance onto the soil media. At the conclusion of the sand aquifer adsorption test, a desorption test was performed to qualify the presence of hysteresis. The adsorption of TNT onto aquifer solids was quantified by the partitioning coefficient, K_d. The distribution coefficient of sand was found to be 0.2 ml/gram, and for clay the distribution coefficient was found to range from 11.31 to 24.02 ml/gram. The range of values is attributed to channeling effects noted during the test. Based on the lack of hysteresis noted in the sand desorption test, soil flushing may be a possible remediation option for TNT in sand aquifers.

BACKGROUND

Trinitrotoluene has been one of the most commonly used high explosive among those derived from aromatic hydrocarbons. In a recent investigation of federal facilities contaminated with explosive or radioactive wastes reported by the Environmental Protection Agency, TNT was found at 85% of investigated sites in one study, and at 76% of investigated sites in another study (1). TNT has been popular due to its relatively safe and simple manufacturing process, its high explosive power, and its high chemical stability/low sensitivity to impact and friction (6). While TNT is relatively insensitive to a variety of influences, it has been reported that TNT is extremely sensitive to the effects of photolysis.

The first large scale manufacture and use of TNT was during World War I. Numerous deaths and illnesses were reported from the TNT manufacture and production facilities. Common conclusions from extensive studies following the First World War were that TNT did accumulate in the liver and kidneys and could lead to death caused by either aplastic anemia, methaemoglobinaemia, or jaundice (6). Various investigators (1,5,6) have reported that wastewater with TNT concentrations as low as 25 mg/L reduced the oxygen consumption by bacteria 5-30%, possibly impairing bacteria activity. In fish studies performed in 1949, it was found that concentrations of 1.0 mg/L of TNT were toxic to fish. A separate toxicity study documented a lethal concentration of 0.15 mg/L of TNT as being toxic to plankton, the primary food source of fish.

Trinitrotoluene has been found in the ground water at several Army Ammunition Plants (AAP). Spalding and Fulton in 1988 (5) summarized the soil test findings and plume delineation of munitions residues at the Cornhusker Army Ammunition Plant, where RDX and TNT were presented as well as

[1]Ground Water Institute, The University of Memphis, Memphis, TN 38152; *david@ce5.gwi.memphis.edu*

concentrations for degradation products. The potential pathways into the environment were identified as cesspools, burning areas, and leaching pits.

The Milan Army Ammunition Plant was constructed in 1941 to produce and store fuses, boosters, and small and large scale ammunition. One process line, the "O line", has been used to remove explosives from munitions by injection of high pressure hot water and steam. Originally, the wastewaters generated by this process were processed by passing though a series of baffled, concrete sumps before discharge into an open ditch. After initial operation, a series of 11 surface impoundments were constructed at the downstream end of the O line discharge. In 1991, a Remedial Investigation was performed on the ground water contamination of the site, which identified a contaminant plume of 2,500 feet long, 1,500 feet wide, and extending up to 170 feet below ground surface. The approximate volume of contaminated ground water was estimated to be 100,000,000 gallons, with TNT concentrations ranging from detectable levels to 26 mg/L.

PROCEDURES

The purpose of the study was to determine the impact of the clay content of an aquifer on the movement of TNT under simulated flow conditions. The impact of the clay content was quantified through two aquifer tests. The first test was an aquifer simulation to establish base flow conditions through a fine silica sand media. The second test was the flow test through two sand/clay mixtures. The first mixture was 1% bentonite clay and sand, and the second mixture was 2% bentonite clay and sand.

The sand aquifer was constructed to provide a 4.4 inch head of water to two parallel confined three foot long, six inch wide, one foot deep test cells of sand, while providing monitoring ports at one foot intervals over the entire depth. The aquifer had a common feed inlet and separated outlets for sample collection. The sand/clay mixtures aquifer was constructed to provide a 4.4 inch head of water to four parallel confined one foot long, six inch wide, one foot deep test cells, while providing monitoring ports at four inch intervals. Once the aquifers were constructed and filled, aquifer flow tests were performed to stabilize the aquifer and to determine the permeabilities of the test cells. The permeabilities were calculated from head loss and flow rate measurements to determine sampling intervals and anticipated breakthrough times of the contaminant front.

Once the sampling times and flow test lengths were established, the flow test with TNT in a darkened controlled temperature environmental chamber was initiated. An aqueous solution of approximately 100 mg/L was used as the influent solution and was pumped into the constant head reservoir with a peristaltic pump. Samples were taken from the mid-height of the aquifer test cells and analyzed with a gas chromatograph. Upon completion of the sand aquifer study, a desorption test was run on the sand aquifer with tap water as the influent for the same time period as the adsorption test. Samples were taken at the mid-height of the aquifer at the same sampling interval as the adsorption test.

RESULTS

Knowledge of the hydraulic conductivities of the aquifer systems enabled the development of the sampling plans for the continuous flow studies based on the time necessary for equivalent bed volumes of influent to pass through the systems. The permeabilities of the sand aquifer and sand/ clay aquifer were measured, as shown in Table 1. A decrease in the hydraulic conductivity of the aquifer material of nearly three orders of magnitude occurred with the addition of only 1% clay.

Table 1. Hydraulic Conductivities of Aquifer Cells

Aquifer and Test Cell	Hydraulic Conductivity (cm/sec)
Sand Aquifer, Left Side	1.2×10^{-2}
Sand Aquifer, Right Side	2.0×10^{-2}
Sand and Clay Aquifer, 1% Clay	4.59×10^{-5}
Sand and Clay Aquifer, 1% Clay	4.09×10^{-5}
Sand and Clay Aquifer, 2% Clay	1.27×10^{-5}
Sand and Clay Aquifer, 2% Clay	2.25×10^{-5}

The amount of TNT retained on the aquifer solids was determined by plotting the ratio of the concentration of TNT at a sampling port to the original concentration of TNT (C/Co) versus time, expressed in the number of bed volumes which passed a particular port. The concentration values, C and Co, were calculated from peak area measurements from the gas chromatograph. The appropriate value for Co was based on hydraulic conductivity values as the influent material that would have passed through the particular test cell at the sampling time. The C/Co ratio was then plotted versus time. The calculated breakthrough of Co at the sampling port was delayed at all ports, as shown in Figure 1. The area above the C/Co curve over the length of the retardation was taken as the quantity of TNT adsorbed onto the aquifer solids.

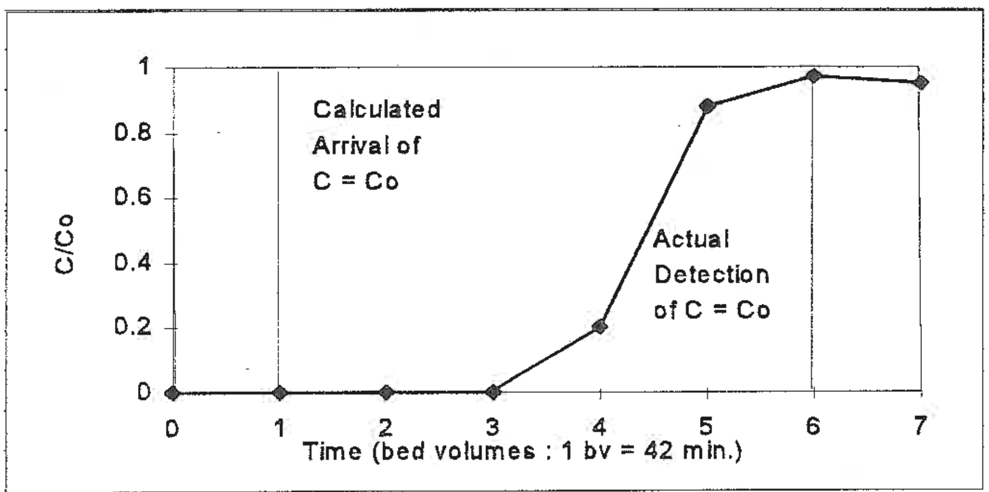

Figure 1. Retardation Determination of Sand Aquifer

Due to channeling effects, the hydraulic conductivies of several of the test cells dramatically increased over the testing period. These data were not analyzed since the data was not representative of flow through a soil media, since the flow channeled along the top of the soil media.

The concentration versus time curves were analyzed for both aquifers and the mass of TNT adsorbed was calculated by the previously described method. For the sand aquifer, the mass of TNT retained by the aquifer solids in the given sample cell was then divided by the mass of the sand in that cell. For the sand/clay aquifer, the mass of TNT retarded on the sand was calculated, and then subtracted from the total mass of TNT retarded and divided by the mass of clay in the test cell. The result are summarized below in Table 2.

Table 2. Mass of TNT Retained in the Aquifer Flow Studies

Sample Point	Retardation Time per Sample Cell	Mass of TNT Retained (mg)	Mass of TNT Retained (mg) per gram of Sand or Clay
Sand, First Foot	126 min.	756	0.02016 / Sand
Sand, Second Foot	84 min.	504	0.01344 / Sand
Sand, Third Foot	126 min.	756	0.02016 / Sand
1% Clay, Four Inches	181 hr.	414	1.1312 / Clay
1% Clay, Eight Inches	221 hr.	422	1.3827 / Clay
2% Clay, Four Inches	262 hr.	656	1.6358 / Clay
2% Clay, Eight Inches	144 hr.	688	1.7630 / Clay
2% Clay, One Foot	196 hr.	848	2.4023 / Clay

Upon completion of the study of the retention of TNT on the sand aquifer solids, the aquifer was flushed with tap water to examine the continued movement of TNT. The analysis of the data indicated that no detectable TNT concentration was observed in any of the sampling ports after 630 minutes.

The data collected from the sand aquifer indicated that the breakthrough of TNT was retarded. The concentration of TNT in the sampling port reached that of the influent concentration within three bed volumes. The retardation reflected the reversible adsorption of the TNT onto the sand grains (2), which is consistent with the conclusions of Spalding and Fulton in mapping the TNT plume at the Cornhusker Army Ammunition Plant (5). Mackay and others (3) concluded that sorption of hydrophobic organic solutes in dilute concentration can be approximated as reversible and described by a linear equilibrium isotherm.

A common method for quantifying the impact of aquifer solids on the movement of contaminants is the calculation of the partitioning coefficient, K_d. The distribution coefficient is the ratio of the mass of the solute on the solid phase per unit mass of solid phase to the concentration of solute in solution. The distribution coefficient found for TNT in sand was 0.2, and for TNT in bentonite clay was 11.31. These values are in agreement with published literature (4).

CONCLUSIONS

The impact of the clay content of the aquifer on the movement of TNT was not limited to concentration reduction by sorption onto aquifer solids. The simulated aquifer with 1% clay had a hydraulic conductivity nearly three orders of magnitude lower than the sand aquifer. The increase of the clay content to 2% further decreased the hydraulic conductivity by a factor of 2.5.

Based on the results of this study, it was concluded that the presence of small amounts of clay (1-2%) significantly reduces the hydraulic conductivity of a sand aquifer. The movement of TNT though an aquifer with small amounts of clay is significantly retarded due to the lower hydraulic conductivity and the greater adsorption of TNT onto clay particles in comparison with sand. Desorption of TNT from a sand aquifer through soil flushing is a possible remediation technique as shown by the lack of hysteresis in the sand aquifer desorption study.

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VAPOR-PHASE TRANSPORT OF CARBON TETRACHLORIDE

Randall W. Gentry[1]

Carbon tetrachloride is a common ground water pollutant at Superfund sites in Memphis and Hardeman County, Tennessee. Because it is a highly volatile compound, the understanding of the vapor phase migration is important in the design of remediation systems for sites contaminated with carbon tetrachloride.

The objective of this study was to simulate the vapor phase migration of carbon tetrachloride using both a numerical model, TOUGH-2, and a laboratory-scale and aquifer. The model aquifer was fitted with several sampling ports so that gas samples could be collected by syringe and injected directly into a gas chromatograph for analysis. The results of the laboratory study were used in the calibration of the numerical model. The calibrated model may be used in predictive simulations to examine different remediation options, i.e., capping, soil vapor extraction, etc. The laboratory model may be used to examine the effects of various soil mixtures on the vapor phase transport of carbon tetrachloride.

[1]Research Assistant, Master's Student, Ground Water Institute, The University of Memphis, Engineering Administration Room 300, Memphis, Tennessee 38152; Phone: (901) 678-4315; Fax: (901) 678-3078

QUANTIFYING DIFFUSIVE MASS TRANSFER WITH NON-REACTIVE TRACERS AT THE LABORATORY AND FIELD SCALES

O. C. Reedy, P. M. Jardine, W. E. Sanford, and J. P. Gwo[1]
G. V. Wilson[2]
H. M. Selim[3]

Subsurface transport processes of low-level radioactive contaminants at hazardous waste sites are highly complex due to a vast continuum of pore regions in heterogeneous media. Contaminant transport is typified by a multitude of interacting concentration profiles that exist due to the complex subsurface hydrogeology in Eastern Tennessee. Two concentration profiles are typically assumed to describe the transport of solutes in heterogeneous subsurface media. These profiles provide a means for subsurface contaminants to move rapidly through preferential flow paths associated with larger pores, or they may move slowly and continuously through smaller pore regions (Wilson et al., 1993). During transport, however, contaminant mass is continuously transferred between the various sized pore regions via hydraulic and concentration gradients.

Traditionally, solute flow through structured soils has been viewed as rapid transport occurring through preferential paths coupled with diffusive mass transfer of solutes between the rapid flow region and the stagnant region, i.e. the mobile-immobile concept (van Genuchten, 1981; Seyfried and Rao, 1987; Nkedi-Kizza et at., 1982; Pandy and Gupta, 1984). A recent review by Jury and Fluhler (1992) on the theoretical and experimental approaches for solute transport in unsaturated soil concluded that substantial water flow may occur in the soil matrix in addition to the rapid movement in the macropores and preferential flow regions. The mobile-immobile concept neglects solute movement within the soil matrix and implicitly assumes that physical equilibrium exists within the soil. However, under variably saturated and unsaturated soil conditions, preferential flow causes physical nonequilibrium, thus causing hydraulic gradients between the stagnant region and the preferential flow zones. During such conditions, diffusion and convection will drive solute mass transfer between the two regions (Jardine et al., 1990), thus initially causing a condition of nonequilibrium. This state of nonequilibrium will progress to a condition of near-equilibrium as the solute continues to flow through the media. The occurrence of sorption nonequilibrium results in the breakthrough of a contaminant plume at a point of interest earlier than otherwise predicted.

Due to the importance of sorption/physical nonequilibrium, there is a need to investigate the occurrence of, and the processes responsible for, these phenomena. Unfortunately, current techniques are not always capable of identifying the causative mechanisms. Under certain conditions, sorption nonequilibrium cannot be readily perceived when analyzing data obtained with the typical continuous flow column experiment (Brusseau et al., 1989). Thus, a more sensitive technique must be implemented for the detection and quantification of such a process. One technique known as "flow interruption", where the steady-state flow process is stopped for a designated period of time and a new chemical equilibrium state is approached, is used in the quantification of the diffusive process.

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[1]Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN 37831-6038

[2]Dept. of Plant and Soil Science, University of Tennessee, Knoxville, TN 37996

[3]Dept. of Agronomy, Louisiana State University, Baton Rouge, LA 70803

In this series of investigations, lab-scale experimentation involved the use of large, undisturbed subsurface soil columns (16.6 x 42 cm) of highly weathered fractured shale acquired from a proposed waste site on the Oak Ridge Reservation in Eastern Tennessee. The flow interruption technique was used in nonreactive tracer experiments involving the transport of Br^- (a tritium surrogate) under saturated conditions. The technique involved the displacement of the nonreactive tracer into the column, inhibiting tracer infiltration for a designated time period (interruption), and then reinitiating the tracer flow. Experiments considered tracer infusion and flushing, variations in the duration of flow interrupt, and variations in mean pore water velocity.

Displacement of Br^- through the undisturbed media was characterized by asymmetric breakthrough curves (BTC) that are indicative of heterogeneous flow phenomena (Figs. 1 and 2). The rapid initial breakthrough and exaggerated "tailing" in the BTCs are indicative of rapid solute transport through preferential flow zones coupled with slower transport into the soil matrix. When flow interruption was initiated during the infusion of Br^-, a concentration (C/C_0) decline was encountered upon flow reinitiation indicative of diffusion between the preferential flow zones and the soil matrix during the interrupt period. Likewise during tracer leaching from the column, flow interruption resulted in a concentration rise due to Br^- diffusing from the soil matrix into the preferred flow channels (Figs. 1 and 2). Variations in flux and interrupt duration had profound affects on the magnitude of concentration perturbation encountered after flow interruption. Larger concentration perturbations were observed at higher fluxes because the heterogeneous media was initially further removed from equilibrium. In a similar manner, longer interrupt durations resulted in larger concentration perturbations since the concentration gradient between pore regions was allowed to more closely approach equilibrium. Observed effluent concentrations were adequately modeled with a two-region flow interruption code using independent model parameters and adjusting the mass transfer coefficient to match the experimental breakthrough curve. Model estimated mass transfer rates were found to increase with increasing flux, and remain nearly constant for variations of interrupt duration.

Field-scale investigations involved the long term natural gradient injection of Br, He, and Ne into a fast-flowing fractured regime at a contaminated waste site. Tracer mobility was monitored spatially and temporally within the fracture and matrix regimes using multi-level sampling wells and drive point wells. A portion of the tracer plume moved preferentially along fast flowing fractures that follow geologic strike, while another portion of the plume slowly migrated into the surrounding bedrock matrix. The use of multiple tracers having different diffusion coefficients confirmed that molecular diffusion was a significant process controlling solute mobility. The time-scale of the mass transfer rate for solute movement to and from the matrix regime is on the order of days to years. With regards to contaminants, the diffusion process creates a secondary contaminant source within the rock matrix that can persist for long periods of time.

Coupling these two experimental approaches will provide an improved understanding and predictive capability of contaminant solute transport. In heterogeneous subsurface systems where traditional pump and treat methods have failed because of slow contaminant diffusion, modification of contaminant removal processes may enhance the effectiveness and efficiency of subsurface contaminant removal.

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INVESTIGATION OF SINKHOLE FLOODING PROBLEMS IN KNOXVILLE, TENNESSEE

Albert E. Ogden[1]

INTRODUCTION

By the first three months of 1994, the City of Knoxville and many surrounding communities had already received rainfalls in excess of the average annual precipitation. As a result, many sinkholes flooded, roads were closed, homes had to be abandoned, and businesses were inundated. Since the rains were a result of continued downpours over several months and not a single large storm, the problems persisted, requiring actions to be taken. At two locations, large pumps were installed and run nearly continuously for two months to keep the rising waters at bay. Even the Knoxville Zoo had to be temporarily closed as its parking lot filled with feet of water. The basic question to be answered was whether the sinkholes had been clogged over the years or had the water table simply risen above the bottom of the sinkholes. If the sinkholes were clogged there is a chance that excavation and/or the drilling of storm drain wells could help alleviate the problem.

Approximately 15% of the City of Knoxville is built around or in sinkholes. The City does not have a specific "sinkhole ordinance" so development historically went unchecked with no regards to the dangers of sinkhole flooding. In more recent years, City engineers have gained an appreciation of this potential problem and have provided advice, warnings, and constraints on developers. Unfortunately, people did not know what the winter of 1994 had in store for them.

GEOLOGY

All of Knox County lies within the Valley and Ridge Province of the Appalachian Mountains. Differential erosion and weathering of the folded and faulted rocks has created a group of subparallel ridge and valleys oriented at approximately N55° E (Clark, 1973). Figure 1 shows the location of Chilhowee Park (the zoo), the Emily sinkhole, Prosser Road, and a warehouse that all had been flooded. This figure also shows the location of springs that were found by subsequent dye tracing to drain the area. Rocks dip from 55°-65° to the southeast and strike from N78°-85° E. The Knoxville Thrust Fault crosses Prosser Road near the entrance to the Zoo, and at that location the Ordovician-aged Holston Formation is on both sides of the fault. The sinkholes at Chilhowee Park and Emily Avenue are in this formation. The sinkhole around the warehouse is underlain primarily by the Lenoir Limestone and to a lesser degree, the Holston Formation. Northeast of the Zoo, the Knoxville Fault has thrusted beds of the Ordovician-aged Chapman Ridge Sandstone between beds of the Holston Formation. The Chapman Ridge Sandstone is composed of calcareous sandstones and shales, and thus is non-karstic. The Ottossee Shale overlies the Chapman Ridge Sandstone and is composed largely of brown and gray shales with some beds of limestone.

GROUND WATER FLOW-DYE TRACE RESULTS

In the Chilhowee Park area, the Chapman Ridge Sandstone and Ottossee Shale form an impermeable barrier to ground water flow between the Holston/Lenoir carbonate aquifer and the older Cambrian-aged Copper Ridge Dolomite aquifer. Likewise, the Chapman Ridge Sandstone exposed along the Knoxville

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[1]Department of Geography and Geology, Middle Tennessee State University, Murfreesboro, Tennessee 37026, phone: (615) 898-4877

Thrust Fault prohibits or at least impedes the flow of ground water in the Holston Formation north of the fault to the Holston Formation south of the fault. Therefore, based on the geologic inferences, the recharge area for Holston High Spring is confined to a narrow outcrop zone of Holston Limestone situated between the two belts of Chapman Ridge Sandstone. Southwest of Chilhowee Park where the Holston Formation occurs on both sides of the fault, ground water appears to be able to cross the fault. This is based on a report that waste water accidentally released from a blue jeans factory on Cherry Street entered a sinkhole north of the fault and came out at Holston High Spring. The ground water basin for Love Creek Spring, located south and near the intersection of Rutledge Pike and Love Creek Road, includes recharge to sinkholes north of the fault. A filled cave shown on Figure 1, is reported to contain a stream. This is likely the same water emerging from the spring. Sinkholes on the Mascot Dolomite and Lenoir Limestone may contribute recharge to this spring in addition to those on the Holston Formation.

Three ground water traces were performed during this investigation. The first trace was conducted from the Prosser Road Sinkhole for the purpose of determining which spring was being affected by petroleum product contamination. Approximately three ounces of rhodamine WT red dye were used. What appeared to be gasoline or diesel fuel was observed to be emerging from an embankment on Prosser Road where it traveled on the surface for about 100 feet before sinking into the ground. Rhodamine dye injected at the sink point was detected at the spring in the back yard of a home in the bottom of Emily Avenue and Timothy Street sinkholes, and at the Holston School Spring (see Figure 1). Therefore, former pumping of the Zoo's flooded sinkhole into the Prosser Road Sinkhole only contributed to the flooding problem at the Emily Avenue Sinkhole.

For the second trace, approximately three ounces of fluorescein green dye were injected into the sinkhole next to the Interstate in which water from the Emily Avenue Sinkhole was being pumped. Passive charcoal dye absorption packets were placed prior to dye injection into Holston School Spring on Love Creek, Emily Avenue Sinkhole, and two springs emerging from yards immediately next to the Emily Avenue Sinkhole. At the time of the dye trace, the Interstate Sinkhole was spilling over onto the Cummins Industries' property and running off into another sinkhole. As a result, fluorescein dye may have also traveled to Peterbilt Spring upstream of Holston School. This cannot be stated with certainty since the dye concentrations found at the spring may represent background contamination. Levels of fluorescein dye nearly 2.5 times background were observed in Holston High Spring and in a spring entering Emily Avenue Sinkhole.

These results suggest that some of the pumped water returns to the Emily Avenue Sinkhole, but most of the water moves to the Holston School Spring. Pumping of the water likely creates a ground water mound beneath the Interstate Sinkhole, thus allowing some of the water to move south/southwest in a direction that is believed to be upgradient under normal water table conditions.

The third dye trace was conducted from one of the drilled storm drain wells on the warehouse property. Approximately ¾ pound of rhodamine WT dye was injected into the well and flushed with 3000 gallons of water. The dye was detected strongly at Peterbilt Spring and also possibly at Holston School Spring.

DEPTH TO WATER TABLE CONSIDERATIONS

A generalized topographic cross-section was drawn from the Warehouse Sinkhole to the Holston High Spring on Love Creek for the purpose of comparing sinkhole depths to the depth of an inferred water table. The Holston High Spring and the stream flowing across the floor of a quarry along the south side of the Interstate was inferred to represent the water table for the ground water drainage basin. Projecting a line through these two points on the provided a means of roughly estimating the depth to ground water beneath the sinkholes. Without depth to water measurements from drilled piezometers, the actual position of the water table could not be determined. This inferred water table showed that the bottom of the Emily Avenue Sinkhole is about 15 feet above the water table. The Chilhowee Park Sinkhole appears to be about 20 feet above the water table. The bottom of the Warehouse Sinkhole actually appears to be below but close to the water table. Recent visits to the Warehouse (Fall, 1994) have led to the discovery of newly opened and dry sinkholes between the Warehouse, Prosser Road, and railroad tracks that are at least 5 feet below the level of the lake. The inferred shallow depth to the water table throughout the study area suggests that the excavation of sinkholes or the drilling of storm drain wells will only help alleviate flooding during low to moderate storm periods, but may not prevent flooding from longer term catastrophic storm events. Piezometer wells are needed throughout the two spring basins to verify this hypothesis.

REMEDIAL ACTIVITIES

The long lasting, heavy rains of the winter of 1994 caused the water table to rise above the bottoms of some sinkholes likely due to clogging of the karst drainage network. For economic purposes, the owners of the warehouse needed to attempt to better drain the sinkhole before the rains of 1995 in hopes of preventing such a rapid buildup of the water table. Since the potential existed to intercept some of the surface runoff and injecting it to the subsurface before reaching the warehouse, storm water injection wells were drilled. In addition, wells were drilled in the sinkhole bottom to divert rain water hitting the large parking area and storm water running onto the property from another sub-basin. Thirteen exploration holes were drilled, and five of these intersected cavities or solution-enlarged fractures and bedding planes. These five were then reamed out to eight inch diameter cased and grouted to bedrock. The other holes were sealed with grout. The injection wells were covered with a steel grate and surrounded with a perforated concrete box to act as a settlement and debris trap. Unfortunately, the injected water captured before entering the sinkhole bottom during storms creates a ground water mound, and some of the water flows back towards the sinkhole. Additional remedial activities are therefore planned.

CONCLUSIONS AND RECOMMENDATIONS

Natural siltation of sinkhole bottoms, enhanced siltation from man's activities, and greater runoff volumes from more paved area through time, all have worsened the flooding problems. Unclogging of the sinkhole bottoms and drilling of storm drain wells may not prevent flooding from catastrophic storm events, but it may prevent the rapid rise of water perched in sinkholes and may more rapidly drain runoff, and thus slow the overall rise in the water table. This was discussed with city officials and the owners of the warehouse prior to drilling. The alternative of continued pumping is an expensive and unrealistic long-term solution to the problem. The immediate needs of the warehouse necessitated that an attempt to better drain their sinkhole be made. Both the warehouse personnel and the city are waiting to see if the drilled storm drain wells and sinkhole modification will help. In the mean time, city engineers are looking much more closely at construction in and around sinkholes and considering stringent regulation of development in its karst areas.

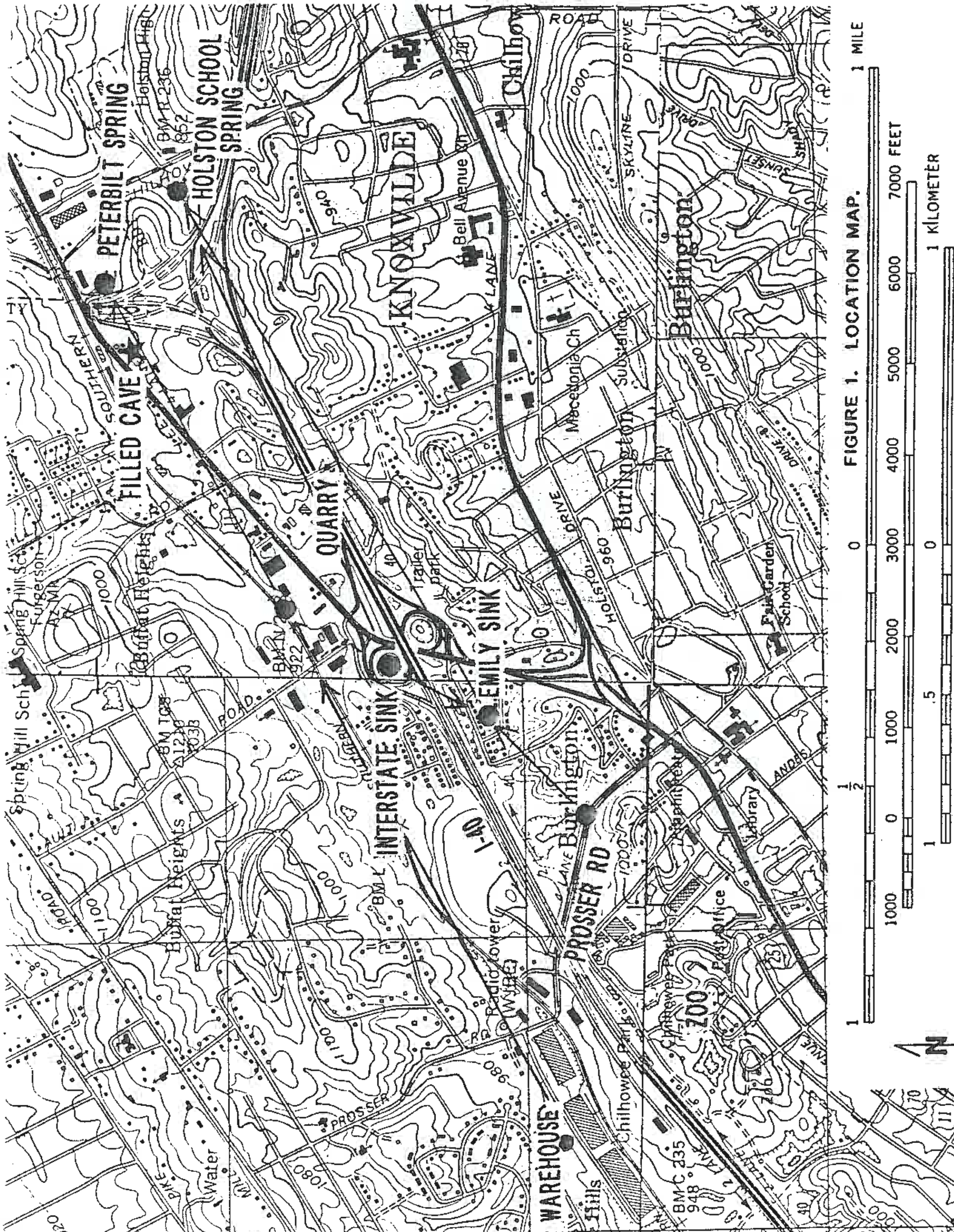

FIGURE 1. LOCATION MAP.

CONTOUR INTERVAL 20 FEET

REGIONAL MAPPING OF GROUNDWATER DYNAMICS THROUGH WELL HYDROGRAPH ANALYSIS

Gerilynn R. Moline[1], William E. Doll[2], Darlene E. Allred[3], Alex Woronow[4], John J. Beauchamp[5]

Knowledge of groundwater dynamics at a regional scale is critical to addressing many specific questions or needs. For example, the distribution of input parameters for groundwater models often involves arbitrary decisions based on assumed geologic or other controls on groundwater dynamics without concrete evidence to support those assumptions. Given a dynamic framework within which those assumptions could be explored, more realistic decisions about parameter allocations could be made. In addition, the ability to predict how groundwater dyamics may vary under certain precipitation conditions is essential to some applications such as predicting the effectiveness of mechanisms for hydrologic isolation of hazardous wastes. Direct measurements of the hydrologic parameters controlling flow dynamics such as hydraulic conductivity, effective porosity, fracture geometry, recharge, and evapotranspiration are difficult and costly to obtain, particularly in a heterogeneous system where sparse information provides a poor picture of the overall dynamics of a region. However, if related data can be used to construct a three-dimensional picture of the dynamics, then the distribution and relative magnitude of these parameters can be estimated, and links to specific controlling mechanisms can be made.

This project focuses on the use of well hydrographs as indicators of local hydrologic properties, and includes an analysis of over 500 wells and piezometers within Melton Valley on the Oak Ridge Reservation. Melton Valley is underlain by fractured shales and limestones of the Cambrian Conasauga Group that have been subject to extensive post-depositional deformation, resulting in a complex, heterogeneous flow system that has been difficult to characterize on a regional scale. The nature of stratigraphic and structural controls on groundwater flow characteristics has not been well established, in part due to the limited distribution of hydrologic data relative to the degree of heterogeneity. A method is under development that will allow the variability in hydraulic parameters, as reflected in the dynamic response of the well, to be mapped in a manner that facilitates the identification of spatial trends and controlling factors which can be used for interpolation between well locations.

A three-phase approach is being used which involves classification of hydrographs into groups based on their dynamic characteristics, determination of mathematical filters that translate precipitation input into hydrograph output, and probabilistic assignment of additional hydrographs to the previously determined dynamic groups. In the first phase a subset of 39 wells having daily water level measurements during the same three-year window was selected and a filter was applied to separate the seasonal and storm components (figure 1). From these separate components, six classification parameters were developed (figure 2), three for

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[1]Environmental Sciences Division, Bldg. 1509, MS-6400, P.O. Box 2008, Oak Ridge, Tennessee 37831-6400; phone: (423) 576-5134.

[2]Environmental Sciences Division, Bldg. 1509, MS-6400, P.O. Box 2008, Oak Ridge, Tennessee 37831-6400; phone: (423) 576-9930.

[3]University of Tennessee, Knoxville, Tennessee

[4]Department of Geosciences, University of Houston, Houston, Texas

[5]Computer Science and Mathematics Division, Bldg. 1505, MS-6036, P.O. Box 2008, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6036; phone: (423) 574-6367

the storm response and three for the seasonal response. Parameter values were then determined for each of the wells in the subset and cluster analysis was applied, resulting in the identification of seven dynamic groups.

Phase 2 requires the determination of mathematical functions that can predict water level variations using rainfall data. The conceptual model underlying this work is a "black box" in which the input function is a precipitation record (and possibly a seasonal parameter such as julian data) and the output function is a well hydrograph representing the response of the formation (figure 3). The relationship between input functions, formation and well characteristics, and output functions can be summarized as follows:

$$\Sigma F_i * T_{ij} = R_j$$

where F_i are the forcing functions, R_k is the response in the j^{th} well, T_{ij} is the transfer function for the i^{th} forcing function at the j^{th} well location, and * is the convolutional operator. The black box represents all of those factors that control the response of the formation to precipitation input. While the exact relationships between these controlling factors and water level response to precipitation variations may not be known explicitly, the sum total of their effects can be represented by a system of equations, also known as earth filters.

Currently, both deconvolution and neural net methods are being evaluated using a test hydrograph that contains all of the complexities observed within the test set of wells (large seasonal component, large storm response, seasonal differences related to EVT). Preliminary results demonstrate the seasonality of the storm response as reflected by nonstationary filter coefficients in the linear system of equations. This

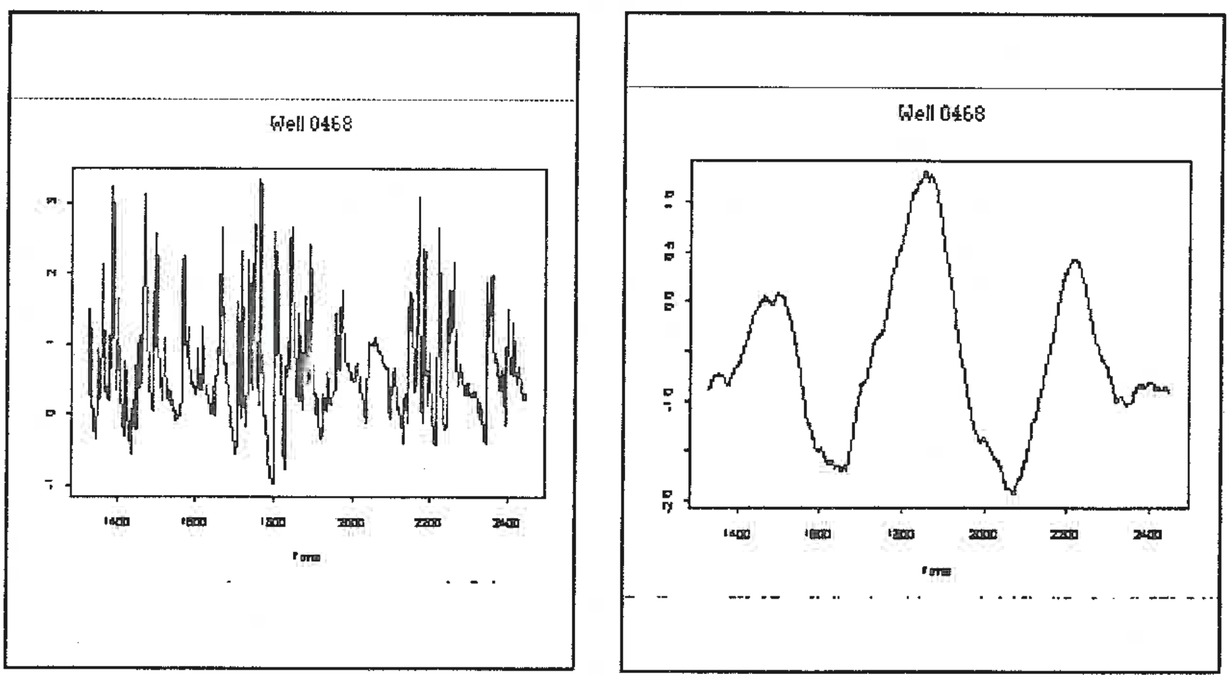

Figure 1. a) High frequency (storm) response. b) Low frequency (seasonal) response.

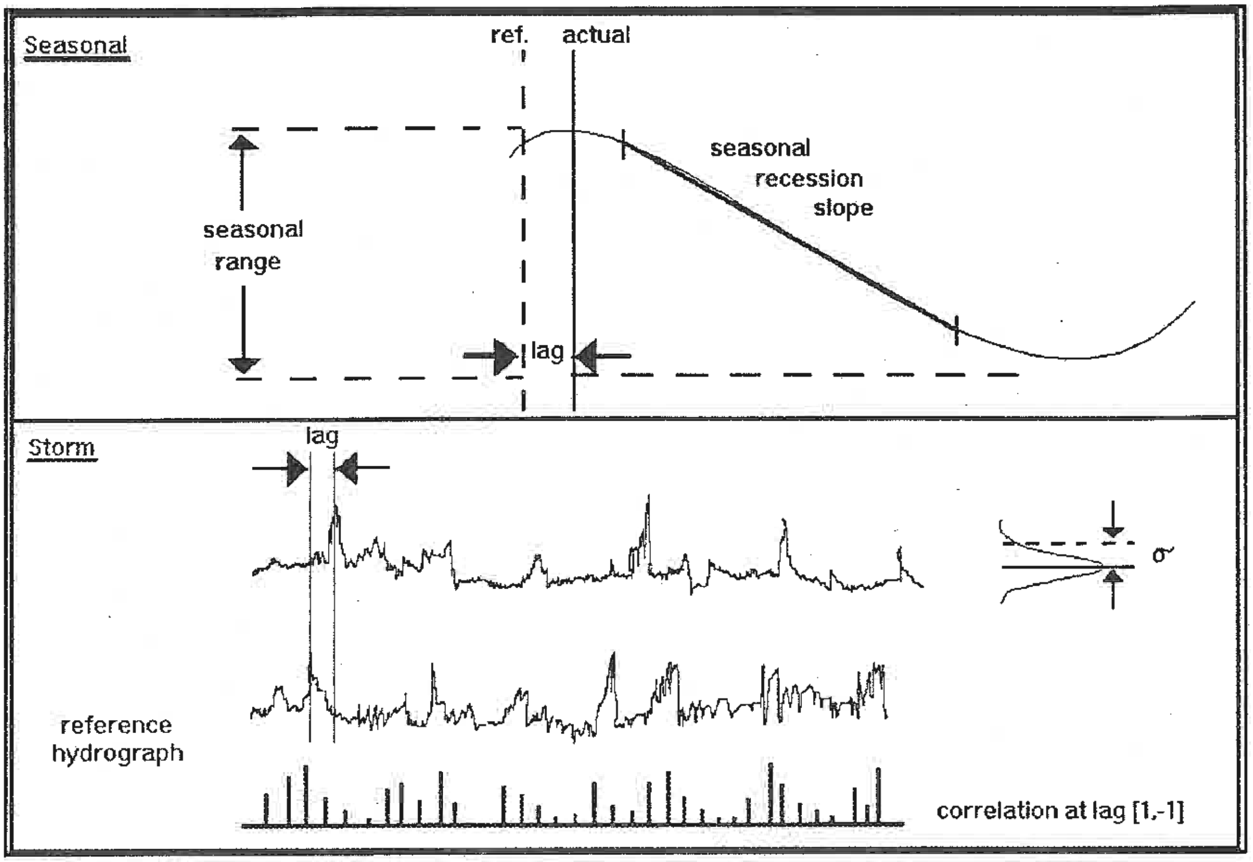

Figure 2. Six parameters define the seasonal and storm related responses.

nonstationarity appears to be handled reasonably well in the neural net method by including a transform of the julian date as part of the input data. Preliminary work has also been started to develop the theoretical

basis for a statistical measure of fit and the transformation of that measure to a probability using Bayesian methods. Following classification of the entire set of wells, 3D graphical visualization packages will be used to construct the hydrodynamic framework and to examine the links between groundwater dynamics and controlling factors.

* Managed by Lockheed Martin Energy Research Corp., under contract DE-AC05-96OR22464 with the U.S. Department of Energy.

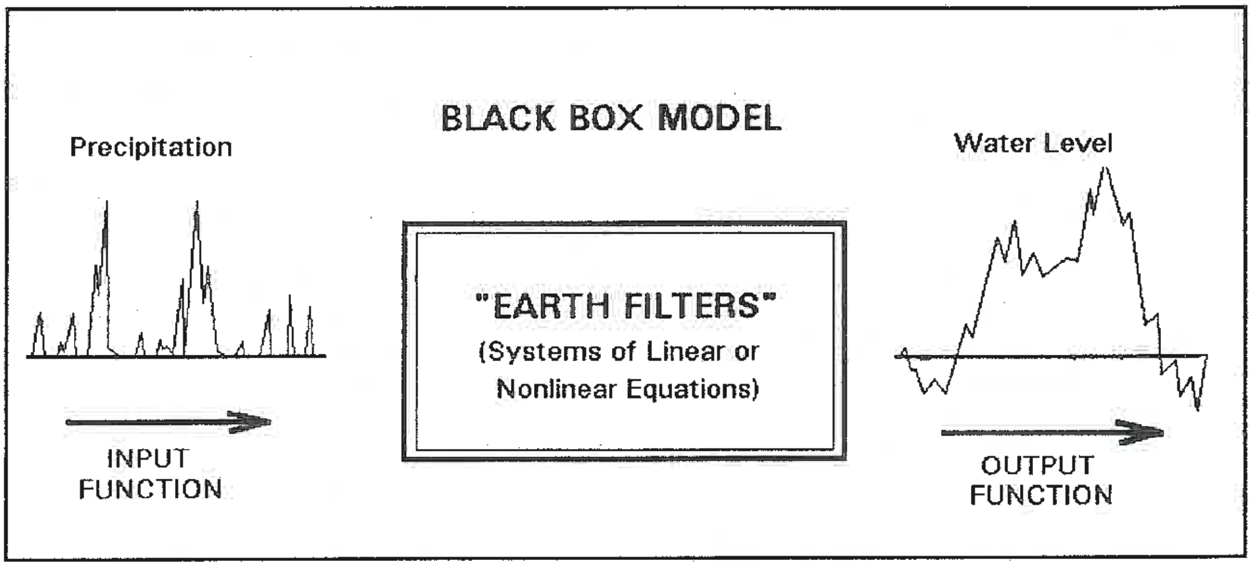

Figure 3. "Black box" conceptual model.

EVALUATION OF PUMP-AND-TREAT REMEDIATION IN A FRACTURED BEDROCK

D. H. Barton[1], S. C. Young, N. J. Williams, B. T. Hurst, and C. Wallen

INTRODUCTION

Environmental Consulting Engineers (ECE) integrated geological, hydrological, chemical, and meteorological data into a conceptual model of groundwater flow and transport in the area adjacent to the Entomology Shop at Loring Air Force Base (LAFB), Maine. In order to address the effectiveness of pump-and-treat remediation, ECE developed two groundwater flow models. One model assumed a porous media groundwater flow system while the other included fractures in the bedrock(in the area of the TCE plume). The porous media model properly predicts bulk groundwater flow but is lacking in that it cannot accurately represent contaminant transport through fractured bedrock. The fracture flow model was developed to more accurately reflect the site conceptual model. A concern relative to the fracture flow model is that there is limited information on which to define the fracture system in the area of the Entomology Shop.

SITE HYDROGEOLOGY

The overburden thickness at LAFB varies approximately 15 to 25 feet in the vicinity of the Entomology Shop. Most of the overburden consists of glacial-fluvial tills. In some regions, the till has been reworked by man and has been redeposited as fill. Although the fill may not retain its original structure, there is insufficient data with which to delineate the fill pattern or to quantify the hydraulic differences between the fill and the original till. As a result, the overburden is considered a homogeneous unit in the groundwater flow model.

Beneath the till is a bedrock of predominantly metamorphosed, pelitic limestone associated with the Carys Mills Formation. The bedrock map reveals an undulating surface with a southwesterly dip in the vicinity of the Entomology Shop. Fractures and remnant bedding planes dip at angles from 30 degrees to almost 90 degrees. Fracture orientation varies considerably across LAFB. At borehole JWM-3284 (near the Entomology Shop) the major fracture axis is 5 degrees south of east and the minor axis is 5 degrees east of north. A prominent geologic feature is a near vertical fault aligned with the Flightline Drainage Ditch (FLDD) (see Figure 1). The fault is assumed to represent a no-flow boundary at depth. Near the upper bedrock and within the overburden, the FLDD is a major surface water feature. The average discharge rate in the ditch is 0.7 cfs.

DEVELOPMENT OF GROUNDWATER FLOW MODEL

Model Boundaries and Grid Network

Shown in Fig. 1 is the finite difference grid used for the two groundwater flow models. The model has a constant thickness of 200 feet, which is divided into 11 elemental layers. The grid spacings in the x and y directions is 40 feet except in the vicinity of the Entomology Shop where the spacing is reduced to 20 feet.

[1]Environmental Consulting Engineers, Knoxville, TN. USA Phone: 615-691-3668; Fax: 423-691-0661

The top 8 layers of the model are 10-feet thick . Beneath 80 feet, the layer thickness gradually increases to a maximum thickness of 40 feet. The total number of elements in the model is 36861.

Table 1 lists the boundary conditions assigned to the sides of the model domain. The lower boundary at 200 feet was assigned as a no-flow boundary. Recharge across the model domain was set to 8.75 inches/year except beneath buildings and parking lots, where the recharge was set to 0.01 inches/year.

Table 1
Boundary Conditions for the
Groundwater Flow Model

Node Layer	North Boundary	Southeast Boundary	Southwest Boundary	West Boundary	East Boundary
9 to 12	no flow	no flow	constant head	constant head	constant head
5 to 8	no flow	no flow	constant head	no flow	constant head
1 to 4	no flow	no flow	constant head	no flow	no flow

Input Parameters

The overburden and the bedrock was assumed to be isotropic so that $K_x = K_y = K_y$ .The overburden was assigned a uniform K of 0.5 ft/day. The bedrock K values were determined from an analysis of slug test and packer test data. The bedrock was assigned K values between 0.5 ft/day and 30 ft/day. Bedrock below 80 feet of the bedrock surface was assigned a K of 0.5 ft/day. In the vicinity of the FLDD and west of the 675 ft bedrock contour (location where the water table lies in the upper bedrock near the FLDD), the uppermost 30 feet of bedrock was assigned a K of 30 ft/day. In the vicinity of the Entomology Shop and east of the 675 ft bedrock contour, the uppermost 30 feet of bedrock was assigned a K of 1.0 ft/day. The bedrock K for the depths between 30 and 50 feet below the top of bedrock was assigned a K value of half that for the overlying weathered bedrock. The porosity values assigned to each of the K units was based on ranges provided for till and limestone bedrock in Freeze and Cherry (1979) and Domenico and Schwartz (1990).

The groundwater flow model that included fractures represents a modification of the porous media model. Fractures were added along the X and Y coordinates at depths of 0 to 60 feet below bedrock surface in a 903,000 ft^2 area that included the Entomology Shop. A total of 10764 fractures were added to the model. Within the affected area, fractures were added along the x and y axis and in a matter that would not change the bulk transmissivity of the bedrock. The K the fractures were selected so that the fractures would have a K approximately 1,000 times greater than the K of the bedrock matrix.

Model Calibration

The groundwater model was calibrated to April 1995 water table measurements. Across the site, the water table elevations ranged approximately 50 feet. The groundwater code used to simulate the porous media and fracture media flow models was FRAC3DVS (Therrein et al., 1995). The two models produce nearly identical results. For both models the root-mean square (RMS) for 27 wells was 2.71 feet.

EVALUATION OF REMEDIATION ALTERNATIVES

Groundwater Solute Transport Model

The objective of the transport model is to illustrate the impact of alternative remediation options as well as fractured flow on the migration of TCE. To meet this objective, the solute model PTRAX (ECE, 1995) was selected. PTRAX is a fast, three-dimensional particle tracking code capable of three-dimensional simulations for grids based on an assortment of element types. PTRAX can handle both retardation, biodegradation, dispersion, and molecular diffusion.

To simulate dispersion, dispersivities values of 6 ft, 6 ft, and 0.03 ft were used for flow along the x, y, and z axes. To simulate diffusion, a diffusion coefficient of 0.00046 ft^2/day was used. Retardation values of 1.2 and 1.8 were used for the bedrock and overburden, respectively. These values are representative of many granular aquifers and are likely too high if the organic carbon content in the bedrock is below 0.01%. For the groundwater transport simulations, a half-life for TCE was set to 1E+30, which prevents any naturally degradation from occurring.

Pump-and-Treat Remediation

For the porous media and the fracture groundwater models, TCE removal was simulated by pumping approximately 7 gpm from an extraction well located at the downgradient edge of the plume at coordinates x=110553 ft and y=1335.2 ft As shown in Figure 2, the removal of TCE mass from the bedrock is significantly less for the model with fractures. Whereas, the porous media model predicts 95% removal of the TCE within about 2.5 years. The estimate time for reach 95% removal of the TCE with the fracture flow model is 110 years

In the porous media model, the removal of the TCE plume by pumping is analogous to the deflation of a balloon -- both rates of change are directly controlled by the rate of fluid removal. With the fracture model, removal of TCE is not so much controlled by the pumpage rate as by the rate at which the TCE leaves the bedrock matrix and joins the fracture flow toward the well.

SUMMARY

Two groundwater flow models were developed to evaluate remedial alternatives for a TCE plume near the Entomology Shop at LAFB. One of the flow models is based on the concept of equivalent porous media and the other includes 10764 fractures in the vicinity of the Entomology Shop. The groundwater flow models include 11 elemental layers and extend to approximately 180 feet below the top of bedrock. The K values for the models were obtained from slug and packer test data. Both groundwater flow models were calibrated to 25 water table measurements with in April 1995.

With respect to bulk groundwater movement, the porous media and the fracture flow model produce nearly identical results for ambient flow and pumping conditions. However, the two models different significantly with respect to solute movement. For instance, with respect to pump-and-treat remediation, the time predicted for remove 95% of the TCE mass is 2.5 years and 110 years for the porous media and fracture flow models, respectively. Based on the field data, the fracture flow model appears to more closely represent site conditions than does the porous media model.

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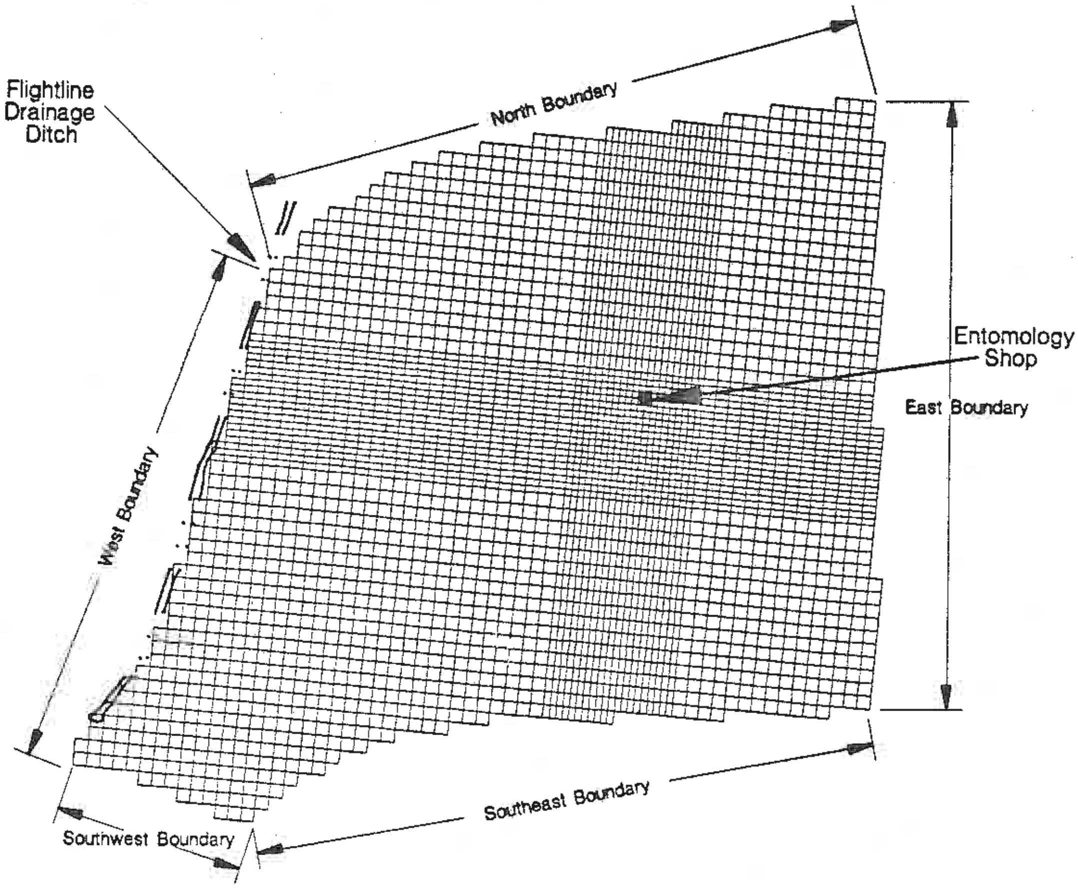
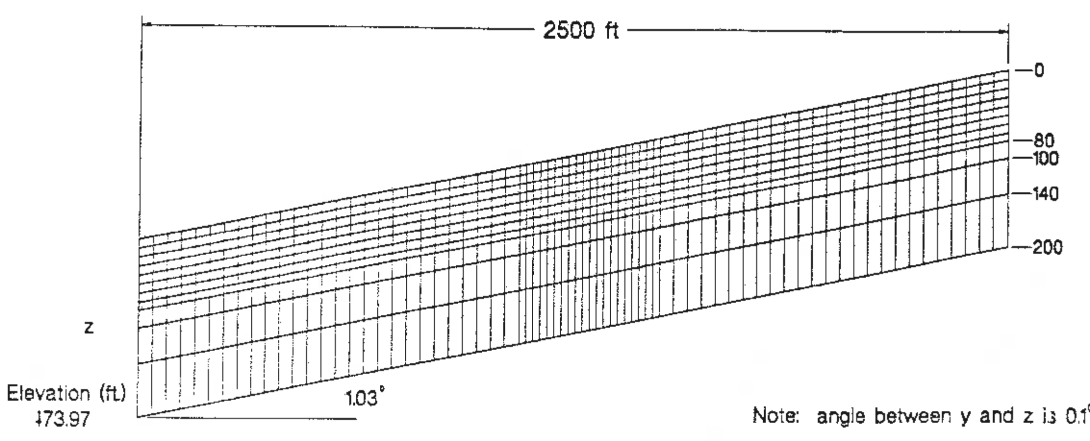
Figure 1. Grid Mesh for Groundwater Flow Model

Horizontal Cross-Section



Vertical Cross-Section



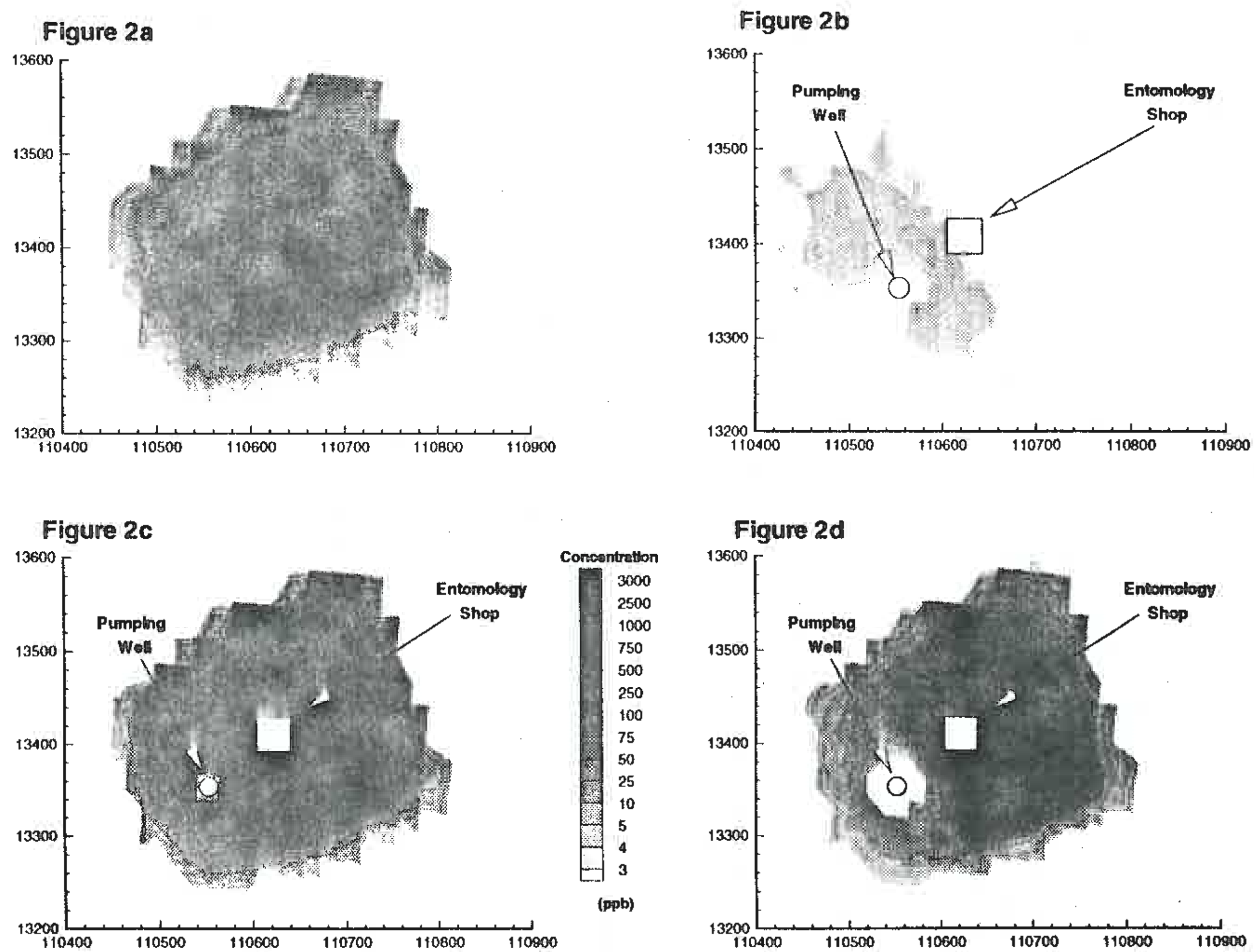


Figure 2. TCE concentrations at layer 9 during pumping conditions for: a) initial conditions; b) 2.5 years of pumping in a porous matrix without fractures; c) 2.5 years of pumping in a porous matrix with fractures; and, d) 30 years of pumping in a porous matrix with fractures.

USE OF A GAUSSIAN PLUME MODEL FOR GROUNDWATER CONTAMINANT TRANSPORT

Larry S. Blackwelder[1] and James L. Smoot, Ph.D., P.E.[2]

INTRODUCTION

The techniques and methods currently employed in groundwater contaminant transport modeling have been developed as an extension of the traditional methods used for groundwater supply modeling. In general, this involves the solution of the partial differential equation representing the processes and conditions germane to the problem being considered. For simple scenarios, the equation can be solved analytically. For more complex problems, a numerical solution is required, using either finite element or finite difference techniques.

The development of groundwater contaminant transport models has occurred during the same period as the emergence of air quality modeling. However, most accepted air quality models do not rely on a mathematical solution to the transport equation even though the physical processes of air dispersion modeling are similar to those of groundwater contaminant transport. Instead, most air quality models are based on the observations that (1) the contaminant concentration profile in a simple medium can be estimated by a Gaussian distribution and (2) more complex environments can be modeled by manipulation of the Gaussian model in lieu of a rigorous solution.

To date, the application of the Gaussian plume model to groundwater contaminant transport has received little attention. If these techniques were successfully applied to groundwater, the results would provide an alternative method for predicting contaminant fate and could yield a better understanding of contaminant transport as it is observed in the field. The methods presented by this paper provide the initial investigation needed to open this promising area to the groundwater community.

THE GAUSSIAN PLUME EQUATION

The Gaussian plume model is based on the assumption that the contaminant concentration profile from an instantaneous, point source in an infinite, homogeneous medium can be represented by a Gaussian distribution. For a release of mass M, the three-dimensional Gaussian equation takes the following form:

$$C = \frac{M}{n(2\pi/R)^{3/2}\sigma_x\sigma_y\sigma_z} \exp(-\lambda t) \exp\left(- \frac{(x - vt/R)^2}{(2\sigma_x^2)/R} - \frac{y^2}{(2\sigma_y^2)/R} - \frac{z^2}{(2\sigma_z^2)} \right) \quad (1)$$

[1]Ph.D. candidate, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, Tennessee 37996; phone: (423) 482-7898, Fax: (423) 463-1869.

[2]Associate Professor, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, Tennessee 37996; phone: (423) 482-9024, Fax: (423) 483-9206

where C = the contaminant concentration
M = the mass of contaminant released
x, y, z = coordinates relative to plume center of mass
$\sigma_x, \sigma_y, \sigma_z$ = standard deviation for the i^{th} axis

The basic Gaussian equation must be modified to better reflect the transport problem as commonly encountered in groundwater contaminant transport. First, the term x^2 is replaced by $(x - vt)^2$, where v is the groundwater velocity along the x axis and t is the elapsed time since release. This modification references the coordinate system to the medium rather than the plume center of mass. Second, the first term is divided by the porosity, n, which changes the concentration value from "mass per unit volume of aquifer" to "mass per unit volume of water." The result is the basic Gaussian plume equation for an instantaneous, point release in an infinite, homogeneous media:

$$C = \frac{M}{n(2\pi/R)^{3/2}\sigma_x\sigma_y\sigma_z} \exp(-\lambda t) \exp\left(- \frac{(x - vt/R)^2}{(2\sigma_x^2)/R} - \frac{y^2}{(2\sigma_y^2)/R} - \frac{z^2}{(2\sigma_z^2)/R} \right) \quad (2)$$

The basic Gaussian plume equation can be compared with traditional analytical solutions by substituting the value $2D_it$ for σ_i^2 in Equation (2), where D_i is the dispersion coefficient in the i^{th} direction. The resulting equation, derived with no reference to the mathematical form of the contaminant transport processes, is identical to the analytical solution to the three-dimensional advection-dispersion equation for an instantaneous, point source as derived by Hunt (1983) and others:

$$C = \frac{M}{n(2\pi/R)^{3/2}\sigma_x\sigma_y\sigma_z} \exp(-\lambda t) \exp\left(- \frac{(x - vt/R)^2}{(2\sigma_x^2)/R} - \frac{y^2}{(2\sigma_y^2)/R} - \frac{z^2}{(2\sigma_z^2)/R} \right) \quad (3)$$

Equation (3) can be further modified to reflect changes in the Gaussian distribution caused by contaminant retardation and first-order decay or transformation. By observing the changes to the Gaussian form caused by the additional processes and by adding factors to match those observations, the following equation is obtained:

$$C = \frac{M}{n(2\pi/R)^{3/2}\sigma_x\sigma_y\sigma_z} \exp(-\lambda t) \exp\left(- \frac{(x - vt/R)^2}{(2\sigma_x^2)/R} - \frac{y^2}{(2\sigma_y^2)/R} - \frac{z^2}{(2\sigma_z^2)/R} \right) \quad (4)$$

where R = the retardation factor
λ = the first-order reaction coefficient

SPATIAL AND TEMPORAL VARIANTS

Since the form of the Gaussian plume model for an instantaneous, point source is identical to the analytical solution, there is little reason to prefer one over the other. The major advantages of the Gaussian plume model are demonstrated when modeling sources that are not point sources (line, area, or volume sources) or are not instantaneous (steady state or continuous). Although mathematically accurate, analytical solutions fail to provide the user with an intuitive feel for the transport process. In addition, the analytical solutions seldom allow the same equation to be used for different source configurations (for example, the analytical solution for an area source may not be defined if one dimension is set to zero to model a line source).

For the various spatial source configurations, the Gaussian plume model takes advantage of the observation that the plume from a non-point source cannot easily be distinguished from the plume from a point source located at a further distance from the observation point. This point source is the "virtual image" of the true source and the distance between the two sources is the "virtual image correction distance." Since the sigma values determine both the maximum value and the spread of the Gaussian distribution in Equation (2), the only calculation needed is to determine the new sigma values for the Gaussian plume equation.

To simulate a plane source with a point source, it is only necessary to determine how far the point source must be located from the true source to result in a match between the two plumes. Using a 100-point grid of point sources to represent an area source, it was determined that the new sigma values (σ_i) could be determined by a three step procedure:

(1) Divide the dimension of the source parallel to the axis of concern by 3.25 to provide the sigma (standard deviation) of the plume at the virtual source correction distance.
(2) Using a relationship defining plume spread such as $\sigma^2 = 2Dx/v$, calculate the virtual source correction distance, x_o.
(3) Determine the new sigma value to be used in Equation (2) by $\sigma^2 = 2D(x + x_o)/v$. Note that this distance need not be equal for each axis.

Even though the example used the relationship $\sigma^2 = 2Dx/v$ to determine the spread of the plume, any function or set of field measurements could have been used (an option not available with analytical solutions). The Gaussian plume model also provides an intuitive feel for the effects of changes in source geometry (a factor also not available with analytical solutions) and the various spatial configurations converge (a volume source with a zero dimension results in an area source with no changes to the basic equation).

Changes in the basic Gaussian plume model for non-instantaneous sources are made similar to those for non-point sources. For a continuous plume, the plume is divided into the "steady-state region" and the "leading edge." The "steady-state region" is that portion of the plume that has reached steady state (typically from the source location to approximately half of the distance to the advective front) and is modeled without Gaussian spreading along the x-axis. The first term in Equation (2) is adjusted to reflect a continuous release of contaminant. The "leading edge region" (from the "steady-state region" to the leading edge of the plume) is modeled as the sum of a series of instantaneous, point source releases. A minimum of five segments or "puffs" comprising the "leading edge region" is recommended for best results.

PHYSICAL BOUNDARIES

Due to the relatively small vertical dimension of most aquifers, the effect of horizontal boundaries on the contaminant plume must be included in any useful model. Lower boundaries are usually aquitards while upper boundaries may be either aquitards or water tables. At both types of boundaries, contaminant may be loss across the interface. The Gaussian plume model assumes that the interaction with physical boundaries can be accurately modeled as reflections at the interface.

To model the reflection of the plume, the reflected portion plume is represented by a virtual or mirror image located at the same distance from the observer with respect to the flow direction but at a point mirrored by the boundary. For a loss at the interface, the amount of contaminant released at the virtual image is reduced to remove the amount of contaminant from the plume corresponding to the loss. This method of mirror images is also often used for analytical solutions.

SUMMARY

At a minimum, the Gaussian plume model provides the same problem-solving capability provided by analytical solution but with less mathematical complexity and computational requirements. In addition, the Gaussian plume model offers solutions not readily available through analytical solutions, such as spatially-dependent diffusivities, effectively extending the useful range of applications beyond current analytical solutions. All of this is obtained with little or no loss of accuracy when compared to analytical solutions.

FAST 3D PARTICLE TRACKING VIA SPATIAL INTEGRATION

Dudley J. Benton[1]

INTRODUCTION

Particle tracking has been successfully used to model diverse phenomena. This method is particularly useful for modeling contaminant transport within a groundwater system. Not only can this method provide concentration maps, reversing the flow field and *back-tracking* can be used to identify the probabilities associated with multiple sources. An innovative approach which incorporates dispersion modeling as a *random walk* and achieves significantly greater computational efficiency than convention methods is presented.

SPATIAL VS. TEMPORAL INTEGRATION

The conventional method for particle tracking is temporal integration, or a *Lagrangian* approach. Many small time-steps are required with this approach, resulting in intense computations. Various methods for adaptive time-stepping can provide significant improvements; however, this introduces a problem with dispersion modeling, which will be detailed subsequently. The present method is based on velocity and spatial, rather than temporal, steps; thus, it might be thought of as a *Hamiltonian* approach. In the Lagrangian approach, velocity is integrated over time to determine position. In the present Hamiltonian approach, velocity is integrated over position to determine time. In a region of low velocity, the time-steps will be large. In regions of high velocity, the time-steps will be small. The present approach inherently achieves optimal time-steps. The steady-state flow field is generated using an *Eulerian* approach, which is spatially-based and has no temporal component. Coupling the present Hamiltonian particle tracker with the Eulerian velocity field is a better match than coupling it with a Lagrangian particle tracker.

DISPERSION VIA. RANDOM WALK WITH *LURCHING*

Dispersion is an important factor in groundwater modeling. Dispersion is often modeled as a *random walk* of the particles. In order to achieve correct statistical properties, it is necessary to base the random factors on a constant time-step; because the mean random displacement and velocity must be zero. The effective random velocity is equal to the random spatial-step divided by the time step. The time-step must be a constant if both averages are to be zero, as illustrated in the following equation.

$$\sum_{I=1}^{N} \Delta\tilde{S}_I = \sum_{I=1}^{N} \frac{\Delta\tilde{S}_I}{\Delta\tilde{T}_I} = 0 \Rightarrow \Delta\tilde{T}_I = constant \qquad (1)$$

Where ΔS is the spatial-step, ΔT is the time-step, and N is the number of steps along a particle track. This requirement of constant time-steps conflicts with the adaptive time-step Lagrangian and simple Hamiltonian

[1]Environmental Consulting Engineers, 10938 Hardin Valley Road, Knoxville, Tennessee 37923; phone: (423) 691-3668; FAX: (423) 691-3668

approaches. If adaptive time-stepping is not used with the Lagrangian approach, the computations may be prohibitive.

The present method uses an innovative approach which might be described as particle *lurching*. The Hamiltonian spatial integration of velocity is allowed to determine the optimal varying time-steps; however, these time-steps are periodically synchronized with a constant interval. Rather than selecting the time-step based on the smallest ratio of cell size to velocity, as is typical with the Lagrangian approach, the synchronous time-step is selected such that the average particle track is a statistically significant sample. If the statistical requirements are met for each particle track, then they will also be satisfied for the ensemble. The random walk is based on the following equation.

$$\Delta S = R\sqrt{2\alpha\,|V_m|\,\Delta T} \qquad \mathbf{(2)}$$

Where $\boldsymbol{R}$ is a normalized random number (i.e., having a mean of 0 and a standard deviation of 1), $\boldsymbol{\alpha}$ is the dispersion length, $|\mathbf{V}_m|$ is the mean velocity, ΔT is the time-step, and ΔS is the spatial-step associated with a particular $\boldsymbol{\alpha}$. Multiple dispersion lengths and associated steps may be specified for the three dimensions, either locally for each particle or globally. The dispersion lengths may be uniform or specified for each cell.

THE PTRAX CODE

This approach has been implemented as a computer code named, PTRAX. The code was written in C and utilizes dynamic memory allocation. The domain may be two- or three-dimensional and may be composed of triangles, quadrilaterals, tetrahedra, pentahedra (prisms), or hexahedra (bricks). More complex elements are split into triangles or tetrahedra. Finite-element methods and linear basis functions are used for all calculations. Many checks are performed as the system is built and before tracking any particles, such as: redundant nodes, degenerate elements, and overlapping or disjointed sub-domains. The initial order and orientation of elements is immaterial, as each element is re-oriented and split according to an internal convention. A complete finite-element matrix set is created and can be listed as an additional check.

The program builds a linked-list of cells and cell faces, which becomes the *road map* for tracking particles. This list contains the cell or boundary adjacent to each cell at each face. Particles are tracked using the Hamiltonian integration approach with lurching, from their initial position through intervening cells until they terminate at a boundary, are captured by a well, are completely decayed, or are stagnated.

Unlike conventional approaches where all particles are tracked simultaneously, in the present approach, each particle is tracked over its entire lifetime before tracking the next particle. The particles in the ensemble are tracked sequentially. The ensemble is accumulated at specified time intervals called *snapshots*. All of the snapshots are kept in memory and are updated at the end of each particle track.

At the end of the simulation, the snapshots are stored in files. The particle tracks may also be stored in files. Track files are practical if only a few thousand particles are involved, as these files quickly reach hundreds of megabytes in size. Snapshot files are only a few megabytes, regardless of the number of particles. Well capture logs may also be filed. These include a list of each particle captured by each well, at what time it was captured, and from what cell it originated. The cumulative mass captured by each well during each time interval is also stored in the snapshot files. Automatic reverse tracking is also provided as an option.

RESULTS AND PERFORMANCE

The figure shows the random walk of 1000 particles arising from dispersion within a uniform flow field. The table compares the results of numerical simulations with the analytical dispersion model, AT123D, which was developed in 1981 by G. T. Yeh at the Oak Ridge National Laboratory. Typical runtimes of 2 minutes are achieved on a Pentium 90 for 10,000 particles tracked over 30 years. Simulations have been performed for over 1,000,000 particles and durations of over 10,000 years. A 30-year track of 800,000 particles on a Pentium 90 requires 4 hours.

Table 1. Comparison of Numerical Model and Analytical Solution

Test Case	Dispersivity			Model	15 Years						30 Years					
	α_X	α_Y	α_Z		$\overline{X}$	$\overline{Y}$	$\overline{Z}$	σ_X	σ_Y	σ_Z	$\overline{X}$	$\overline{Y}$	$\overline{Z}$	σ_X	σ_Y	σ_Z
1	3	3	0.3	Numerical	109.4	0.4	0	25.6	25.8	8.0	218.7	0.8	0	37.1	36.9	11.3
				Analytical	109.5	0	0	25.6	25.6	8.1	219.0	0	0	36.2	36.2	11.4
2	3	0.3	0.3	Numerical	109.3	0.1	0	25.9	8.7	8.1	218.7	0.3	0.1	37.1	12.0	11.4
				Analytical	109.5	0	0	25.6	8.1	8.1	219.0	0	0	36.2	11.4	11.4
3	12	12	0.3	Numerical	109.1	0.5	0	51.1	51.1	8.1	217.7	1.4	0.1	73.5	72.8	11.4
				Analytical	109.5	0	0	51.3	51.3	8.1	219.0	0	0	72.4	72.4	11.4
4	12	1.2	0.3	Numerical	109.5	0.3	0.2	50.6	16.4	8.2	218.2	0.5	0.1	72.7	23.3	11.4
				Analytical	109.5	0	0	51.3	16.2	8.1	219.0	0	0	72.4	22.9	11.4

Notes: Numerical indicates the results of PTRAX
Analytical indicates the results of the AT123D analytical model
$\overline{X}$ is the mean distance traveled by the plume in the X direction (first moment of the mass about X)
$\overline{Y}$ is the mean distance traveled by the plume in the Y direction (moment of the mass about Y)
$\overline{Z}$ is the mean distance traveled by the plume in the Z direction (moment of the mass about Z)
σ_X is the X dispersion (second moment with respect to X of the mass about $\overline{X}$)
σ_Y is the Y dispersion (second moment with respect to Y of the mass about $\overline{Y}$)
σ_Z is the Z dispersion (second moment with respect to Z of the mass about $\overline{Z}$)

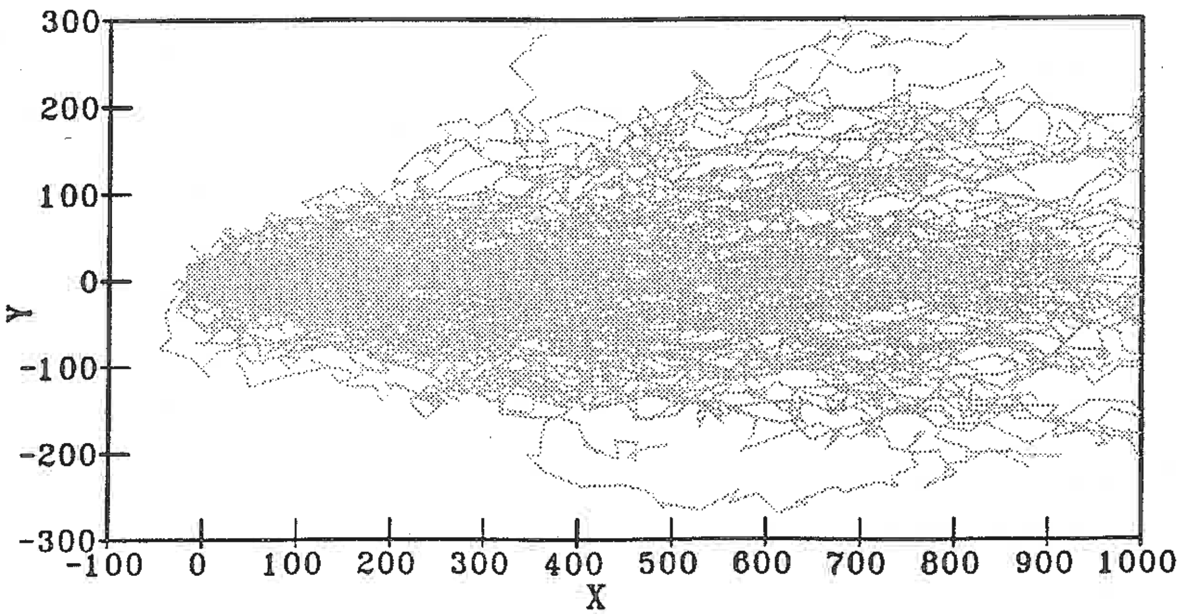


Figure 1. Track of 1000 Particles with Dispersion

LAYER PERPENDICULAR FLOW IN FRACTURED SEDIMENTARY ROCKS

David M. Doolin[1] and Matthew Mauldon

ABSTRACT: Continuum models using permeability tensors to quantify anisotropy in fractured rock masses assume that fractures are connected to conduct flow. In layered sedimentary rocks, the nature of fracture connections may profoundly affect the value of permeability normal to layering. A new expression is presented incorporating previous results on permeability of granular porous media and fractured rock masses, with a correction term to quantify the effect of head loss incurred by flow along the layer interface. The results show bed-normal permeability is highly influenced by the aperture of layer interfaces, and that the permeability may be reduced by several orders of magnitude.

INTRODUCTION

Stratified, highly fractured (up to 50 fractures per meter) shales and siltstones commonly occur in east Tennessee at hazardous waste disposal sites such as are found on the Oak Ridge Reservation. Groundwater contaminant plume migration and containment at these sites is greatly influenced by fracture geometry. Flow in fractured rock may be modeled as flow through a network of discrete fractures or, in highly fractured rock, as flow through an equivalent porous medium (EPM). Discrete fracture models suffer from several limitations. Collecting accurate, three dimensional fracture data from opaque rock masses is difficult; usually data must be inferred from two dimensional fracture traces visible on outcrops. Also, matrix assembly and node numbering schemes are difficult to implement for numerical solution. EPM, or continuum models define bulk properties of the rock mass, such as permeability, in terms of scalar, vectorial, tensorial or functional coefficients used in constitutive equations. An EPM is constructed by choosing a representative elemental volume of the rock mass that has a permeability statistically similar to the region under study. Permeability is a material property measuring a medium's capability to conduct flow. In rock masses, permeability can be quantified from laboratory and field measurements of fracture parameters such as fracture area, aperture, orientation, spacing (or frequency) and connectivity. Fracture connectivity is a crucial link for establishing flow through fractures in a rock mass: if the fractures are not connected, there is no flow. In discrete fracture models, fracture connectivity is implicit in the model. Fracture parameters are known from the outset, and connectivity can be measured from the model. In a continuum model, the fractures must be assumed to connect, or the connectivity must be modeled explicitly. In this paper, an explicit scheme quantifying the effect of fracture connectivity on permeability in layered, fractured sedimentary rocks is presented and illustrated with a simple example.

EXISTING APPROACHES

In continuum models of fractured rock masses, fracture data are collected and statistically reduced to construct a permeability tensor. The permeability tensor is a linear vector operator that converts a gradient vector into a flow vector. Two notable approaches for deriving a permeability tensor for fractured rock masses have been investigated by D. Snow (1969) and M. Oda (1985). Snow (1969) developed a

[1]Institute for Geotechnology, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, TN, 37996-2012; phone: 423-974-7713

permeability tensor for fracture systems that allowed variable orientation, aperture and spacing, but assumed that fractures were infinitely extensive through the rock mass. In sedimentary rocks, bedding planes can be assumed to be unbounded fractures through the domain of interest, but other discontinuities, such as bed-normal fractures, commonly terminate on bedding planes. Oda (1985) developed a similar tensor from probability density functions of fracture spacing, aperture, orientation and size or extent, but did not explicitly incorporate fracture connectivity effects, crucial for establishing a flow network in fractured rocks. Although both Snow's and Oda's permeability tensors implicitly assume fracture network connectivity, fracture permeability is assumed to be independent of connectivity relations between different fracture sets. In layered sedimentary rocks, fractures are commonly discontinuous, but connected along an interface between the layers, such as a bedding plane, causing flow to be directly dependent on fracture connectivity relations.

Characteristic features of sedimentary rocks are beds bounded by bedding planes. The bulk permeability of bedded, or layered media can be derived from continuity. The bed-normal component of permeability k (Equation 1) has been proven to be most influenced by the least permeable bed (Freeze and Cherry, 1979). In layered granular porous media (Figure 1), fluid flow is assumed to occur under conditions of saturated, low Reynolds number laminar flow in homogeneous layers, with no storage. The permeability of a layer is a function of its grain size distribution and layer thickness, and there is no head loss at the layer interface.

$$k = \frac{d}{\sum_{i=1}^{n} \frac{d_i}{k_i}} \tag{1}$$

In a fracture permeability model, bedding planes are equivalent to infinitely extensive, unbounded fractures. Fracturing (jointing) within each bed is commonly orthogonal to the bedding planes and confined within the beds. The permeability k_i of the ith rock layer is a function of the mean cubed aperture e_i of the fractures in the ith layer divided by the fracture spacing S_i in the ith layer (Equation 2, Snow 1969). This is in contrast to standard porous media models where permeability is a function of grain size.

$$k_i = \frac{e_i^3}{S_i} \tag{2}$$

NEW APPROACH

For fracture permeability, assume that the rock mass permeability is zero, that flow is saturated and laminar, with low Reynolds number, and that there is no storage in the flow regime. In a fractured layered system, unlike granular porous media, there is head loss from flow along the layer interface (Figure 2). Using a granular porous media model as an analogue, the layered rock mass can be transformed to an equivalent porous media system through the device of an "interlayer" whose "thickness" is the mean length of all flow paths along the bedding plane, and having a "fracture spacing" equivalent to the fracture spacing S_i in the source layer (Figure 3). The mean length of flow paths along the interlayer is determined by the expected value of the probability density function of fracture spacing, assuming that the flow will follow a path of least resistance, that is, that the flow will exit a bedding plane via the closest available fracture in the sink layer. Fracture spacings following constant and negative exponential distributions were analyzed to determine mean flow path length (Doolin and Mauldon, 1995a). If fractures in any bed are assumed to occur independently of fractures in any other bed, the mean flow path length for constant spacing fractures can be shown to be one quarter of the spacing of the next bed ($S_j/4$). For negative exponential fracture spacings, the mean flow path length is one half the spacing of the next bed ($S_j/2$). Direct substitution of Equation 1 into Equation 2 must be accompanied by a correction term to account for head losses along the layer interface. The complete expression (Equation 3), in which $j = I+1$, and e_{ij} is the aperture of the interface between two beds, gives the bed-normal permeability k as the weighted harmonic mean of the sum of n layers and n-1 interlayers. In short, the interlayer model extends the bed-normal permeability equation (Equation 1) using Snow's equation (Equation 2) and a correction term to quantify the effects of fracture connectivity on the bulk permeability of a layered rock mass.

$$k = \frac{1}{12} \frac{\sum_{i=1}^{n} T_i}{\sum_{i=1}^{n} \frac{T_i S_i}{e_i^3} + \sum_{i=1}^{n-1} \frac{S_i S_j}{c e_{ij}^3}}, \qquad c = 2,\ 4. \tag{3}$$

DISCUSSION

Equation 3 shows that fracture permeability normal to stratification is a function of: (1) the fracture spacing S_i; (2) the layer thickness T_i; (3) fracture apertures e_i in each layer; (4) the aperture of the layer interface e_{ij}; and (5) the product of fracture spacings of adjacent beds $S_i S_j$. Two surface plots (Figures 4 & 5) illustrating the response of permeability to changes in fracture spacing in the layers (beds) and aperture of the bedding planes are shown. Both plots represent a two layer system where each layer I and j are unit thickness. The fracture apertures in each layer are equal and constant. Fig. 4 shows the permeability k as a function of fracture spacing ratio S_i/S_j and the interface aperture e_{ij}. Figure 5 shows the permeability k as a function of the product $S_i S_j$ of fracture spacing and the interface aperture e_{ij}. Both plots show that as the interface aperture decreases, and the fracture spacing increases, the permeability decreases dramatically. The combined effect can result in permeability anisotropy of several orders of magnitude.

An illustrative example using the correction term can be found by constructing a 2-dimensional permeability tensor for bed-normal permeability in the Maryville Limestone formation of East Tennessee. The Maryville Limestone is a thin to medium bedded sequence of limestones, shales and siltstones. Many of the limestone beds have solutionally enlarged bed-normal jointing extending between confining beds of impure limestone, shale or siltstone (Figure 6). The fracture apertures of the bed normal joints are clearly larger than the aperture of the bedding planes. Table 1 shows typical fracture orientations and spacings in Maryville limestone measured along a road cut in Anderson County, Tennessee. The aperture values should be regarded as order of magnitude estimates due to the difficulty in accurately measuring fracture apertures.

Table 1: Fracture parameters for Maryville limestone.

Fracture Set	Azimuth of fracture pole	Spacing S, (m)	Aperture e, (m)
1	90	0.5	0.01
2	0	0.2	0.001

Disregarding the connectivity effect, the permeability tensor (in m^2) for this system is (Doolin and Mauldon, 1995b)

$$k = \frac{1}{12}\begin{bmatrix} e_2^3/S_2 & 0 \\ 0 & e_1^3/S_1 \end{bmatrix} = \begin{bmatrix} 1.167\times10^{-10} & 0 \\ 0 & 1.667\times10^{-7} \end{bmatrix}. \tag{4}$$

The tensor of Equation 4 quantifies bed-normal permeability without considering that bed-normal flow may have a bed-parallel component. The corrected bed-normal permeability, using the interlayer equation (Equation 3) is 2.662 x 10^{-9} m^2, a two order of magnitude difference. The corrected tensor (in m^2) should be

$$k = \begin{bmatrix} 1.167\times10^{-10} & 0 \\ 0 & 2.662\times10^{-9} \end{bmatrix}. \tag{5}$$

CONCLUSIONS

Continuum models of groundwater flow through fractured rock masses must consider the effect of fracture connectivity on the permeability of the rock mass. A practical, analytic solution (Equation 3) is now available for quantifying permeability normal to layers in sedimentary rocks. The bed-normal permeability is highly influenced by the aperture of the layer interface and the product of fracture spacings in adjacent layers. The solution is valid for beds containing fractures occurring with random and constant spacings, and is useful for correcting previous constructions of a permeability tensor. Uncorrected, the permeability tensor may grossly overestimate the permeability of a fractured layered rock mass. It may also be noted that the spacing product term ($S_i S_j$ in Equation 3) implies that permeability normal to layers in a fractured layered rock mass depends on the order in which the layers are arranged.

ACKNOWLEDGMENTS

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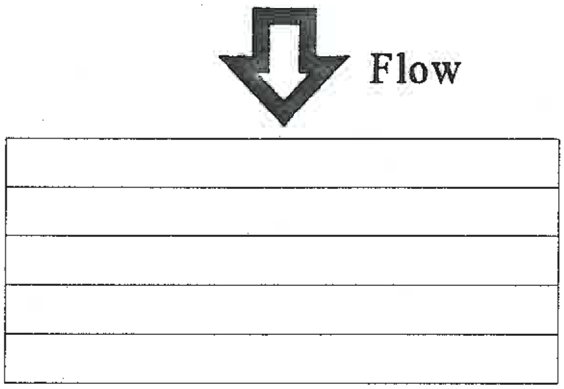

Fig. 1: Bed-normal permeability in layered, granular porous media is most influenced by the least permeable layer.

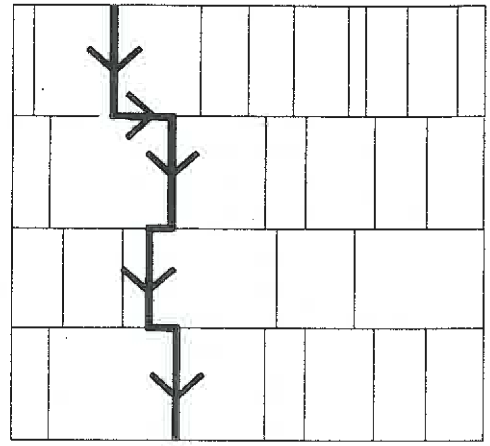

Fig. 2: Head loss occurs along the bedding plane as well as within fractures confined to rock layers.

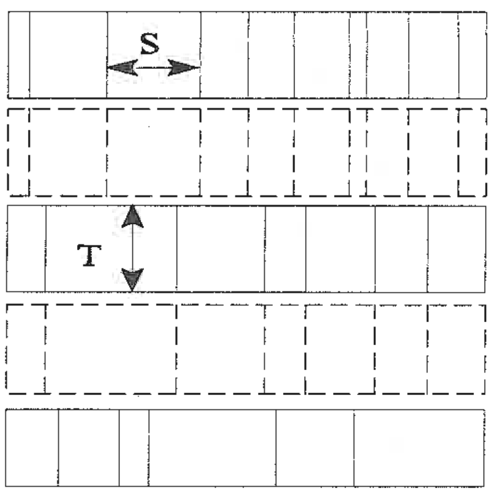

Fig. 3: The original rock layers are shown in solid lines; the interlayers in dashed lines.

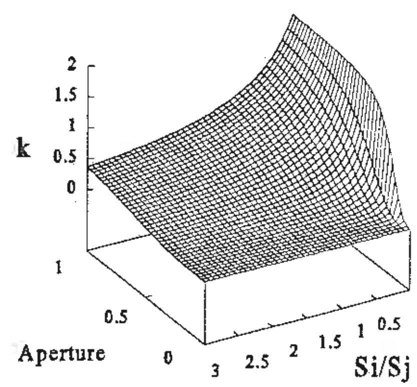

Fig. 4: Surface plot showing how k changes with the fracture spacing of one layer increasing against a fixed fracture spacing in an adjacent layer in a two layer system.

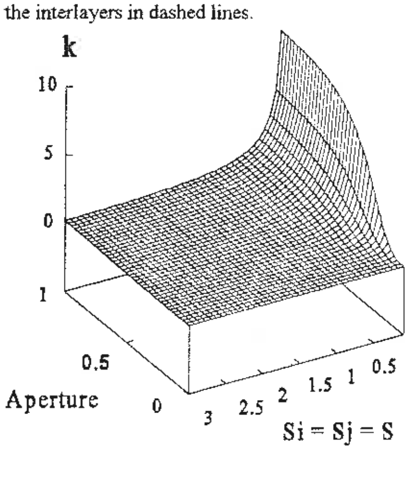

Fig. 5: Surface plot showing how k changes with constant, increasing fracture spacing in both layers of a two layer rock mass.

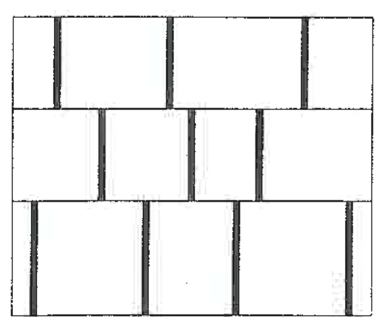

Fig. 6: Idealized model of fractures in the Maryville Limestone, Anderson Co. Tennessee. The aperture of bed-normal fractures is roughly an order of magnitude larger than the bedding plane apertures.

PESTICIDE AND NITRATE RESULTS FOR PRIVATE WATER WELLS IN TENNESSEE

Ken Nafe[1]

Pesticide use in Tennessee and its effect on ground water has become an issue in recent years to rural land owners and other concerned citizens. This concern has been transferred to a national level where the five chemicals are under special review by U.S. EPA. The special review will determine if these pesticides will continue to be registered for use in the US. EPA has transferred some of the decision-making to the states. EPA is working with Tennessee in an effort to manage the chemical instead of canceling the use. Managing a chemical correctly will allow the chemical to be used effectively and will prevent the chemical from contaminating ground water.

Tennessee Department of Agriculture (TDA) has taken the first step to evaluate how much pesticide is contaminating ground water. In 1994, TDA, the Tennessee Department of Environment and Conservation (TDEC) and rural well owners started a state-wide monitoring for pesticides in ground water. Most of the wells were located on working farms. A total of 100 private drinking water wells was sampled 1994 and 1995. Ground water was analyzed for 10 pesticides and Nitrates. These wells were located in 21 counties where pesticide use was the heaviest.

The lab results are not complete as of the writing of this abstract, but they should be complete by the time of the meeting in January.

[1]Tennessee Department of Agriculture, Division of Plant Industries, Pesticide Section, P.O. Box 40627, Nashville, Tennessee 37204; Phone: (615) 360-0798

PIN-POINTING SOURCES IN A NON-POINT SOURCE AREA

D.D. Huff[1]

At Oak Ridge National Laboratory, an effort is underway to pin-point waste sources within larger non-point source areas, to provide cost-effective methods for controlling releases. An example has recently been completed at Solid Waste Storage Area (SWSA) 4, where a site investigation located the sources of ^{90}Sr release, determined the relative ranking of their importance, and provided sufficient information to evaluate alternatives for an interim control measure. The strategy involved "back-tracking" along the discharge pathway to the most important contributing sub-areas, then conducting surveys to locate discrete discharge points, and examining suspect trenches up slope of the seeps through use of drive point wells to quantify ^{90}Sr concentrations and pinpoint locations of "hot spots." Throughout the study, data were synthesized using a geographic information system, which was vital to tracking progress and making field decisions as the study progressed.

It was possible to isolate four apparent major sources in trenches directly up slope from the two most important contributing seeps. In each case, the ^{90}Sr concentration at the seep was approximately from 35% to 50% of the highest value observed in the up slope trench most likely to be the source. It is believed that control of these few sources is the key to a cost-effective interim action.

[1]Environmental Sciences Division, Oak Ridge National Laboratory, Bldg. 1509, MS-6400, P.O. Box 2008, Oak Ridge, Tennessee 37831-6400; phone: (423) 574-7859

ZEOLITE TREATMENT OF TWO RADIOACTIVE GROUNDWATER SEEPS AT OAK RIDGE NATIONAL LABORATORY

Al Hardesty and Jim Defenderfer[1]

In 1994 a removal action under CERCLA was initiated to collect and treat radioactive groundwater at the Oak Ridge National Laboratory (ORNL), in East Tennessee. Passive flow, in-situ treatment technology was implemented in an effort to reduce the costs associated with waste water treatment. The groundwater is intercepted and treated in a simple under ground facility that requires no energy, will operate on its's own without human assistance for up to 6 months, and removes 99.9% of the contaminant it was designed for.

From 1955 to 1963 ORNL was designated as the southern regional burial ground by the Atomic Energy Commission. During this period wastes produced at various nuclear facilities were disposed of in unlined trenches and auger holes. A hydrofracture facility was also used to inject liquid low level waste grout mixtures into underground shale formations.

Waste Area Grouping 5 (WAG 5) is one of several areas used for such purposes. WAG 5 is located south of the main ORNL plant area and is bounded on the west by White Oak Creek and on the south by Melton Branch. The topography of WAG 5 consists of low, gently rolling hills.

Waste burial trenches were excavated into residual soils of the Maryville and Nolichucky Formations, which are predominantly shales with interbedded limestone lenses. Portions of many trenches are perennially inundated by groundwater, others only seasonally. Geologic and hydrologic conditions allow the migration of contaminants leached from buried waste through the shallow groundwater system to seeps located at the toe slope, adjacent to the streams.

Sampling results from the WAG 2 and Wag 5 Remedial Investigations identified two seeps entering Melton Branch along the southern boundary of WAG 5. These two seeps, designated Seep C and D, were estimated to contribute roughly 35% of the Sr-90 leaving ORNL at White Oak Dam.

Seep C is a discrete discharge at the base of a natural drainage swale, flowing 20' along the surface before entering Melton Branch. The source of Sr-90 contamination at Seep C is located in the waste storage trenches 75' up gradient from the seep. The concentration of Sr-90 at Seep C ranges from 276-573 nCi/L depending on the season and the flow rate. The flow rates ranged from 0 gpm in late summer/early fall to over 5 gpm during winter storm events.

Seep D is located 1/4 mile downstream from Seep C and is a discrete, upward flowing discharge into the bed of Melton Branch through bedrock fractures. The source of Sr-90 contamination is thought to be associated with the hydrofracture facility or the nearby trenches in WAG 5 which are roughly 600-800' away. Sr-90 concentrations were relatively consistent at 150 nCi/L. The estimated flow rates ranged from 0.25-0.55 gpm.

Because of the risk to the public, an early action was taken to remove the flux of Sr-90. The approach that was ultimately selected for removing this contamination involved intercepting the groundwater and diverting it through a treatment facility located at the site.

The Seep C treatment facility was designed as a passive system, whereby contaminated groundwater flows through the treatment unit by gravity alone. The groundwater is collected in a french drain up gradient of the treatment unit. The drain is 65' long consisting of river gravel wrapped in a filter fabric, and covered

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[1]Environmental Consulting Engineers

with 2' of clay. The water preferentially flows to a low spot in the french drain where a connector pipe leads to the treatment unit.

The Seep C treatment unit is housed 12' below ground in a concrete vault. Inside the vault are 8 drums (55 gallon) filled with zeolite, which absorbs the Sr-90 out of the collected water. The filtered water is then discharged to Melton Branch.

The Seep D treatment facility required pumping since the collection system is located beneath the bed of Melton Branch. A sump was constructed where the contaminated groundwater was known to be entering the stream. It was designed with no floor to allow the seep water to enter from below, and with a lid to prevent Melton Branch from entering above. The collected water is then pumped to the treatment unit located on the west bank above the 100 year floodplain.

The treatment system at Seep D consists of (2) 140 gallon columns filled with zeolite. The filtered water is then discharged back into Melton Branch.

The collection and treatment systems began operating in November 1994 and have been effectively reducing the flux of Sr-90 entering Melton Branch. The in-situ treatment units are removing 99.9% of the Sr-90 from the water that is being collected. Results also indicate that the collection systems are intercepting most of the contaminated groundwater.

USING SITE- AND SPECIES-SPECIFIC DIFFERENCES IN PCB CONGENER PATTERNS TO ASSESS THE DISTRIBUTION OF PCBs IN A LARGE RESERVOIR SYSTEM

Mark Bevelhimer[1] and Robert LeHew

The presence of polychlorinated biphenyls (PCBs) in fish tissue is one of the primary causes of fish consumption advisories in Tennessee and throughout North America. Fish tissue samples in Watts Bar Reservoir, Tennessee, were analyzed for 44 individual PCB congeners (in addition to the more common measurement of Aroclor mixtures) for reasons of greater analytical accuracy and toxicological relevance, and to evaluate source-related site-specific differences in congener makeup. We collected and analyzed over 600 fish samples representing six species (catfish, largemouth bass, striped bass, gizzard shad, carp, and bluegill) from 12 sites in Watts Bar from 1992 to 1994 and from three sites near suspected PCBs sources to Watts Bar. We used canonical discriminant analysis (CDA) and other statistical techniques to evaluate among-site and among-species differences in congener patterns to evaluate which of the possible upstream sources is most likely responsible for the PCBs presently found in the lower part of Watts Bar. The likely responsible for the PCBs presently found in the lower part of Watts Bar. The CDA analysis identified significant among-site differences, but provided no indication that any one upstream source was primarily responsible for the PCBs presently found in fish in lower Watts Bar. However, significant temporal and among-species differences were found.

[1]Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee 37831-6038; phone: (423) 576-0266

EFFECTS OF LIGHT AND AIR TEMPERATURE ON NITROGEN, PHOSPHOROUS AND BOD_5 REMOVAL IN TWO TYPES OF CONSTRUCTED WETLANDS

Matthew W. Bowling[1] and D. Raj Raman

Constructed wetlands are an attractive option for wastewater treatment. However, the design of such systems is still in infancy. To better understand how these treatment systems work, the treatment performance of four constructed wetlands (two overland flow and two subsurface flow) has been evaluated since December 1994. The wetlands provide tertiary treatment of a Southeast Tennessee food processing plant's wastewater. All four wetlands are established with a variety of wetland plants. Wetland influent and effluent are sampled weekly. Samples are tested for BOD_5, TKN, NH_4^+, NO_3^-, and PO_4^- among others. Multiple samples are collected to maintain quality control. Air and water temperatures, P.A.R., and precipitation have been monitored since the beginning of the study.

Bench-scale test cells have been established on-site. Each full-scale wetland has a bench-scale cell (5 ft by 1.7 ft) set up with similar plant populations, plant types and effluent velocities. The bench-scale cells are sampled in a similar manner to the full-scale wetlands. We will report on the following: (1) correlation between treatment performance and air temperature; (2) correlation between treatment performance and light intensity; (3) correlation between treatment performance and water temperature; and (4) how well the small scale cells predict the performance of the full-scale cells. This information will be useful in future designs of constructed wetland systems for wastewater treatment.

[1]Agricultural Engineering Department, P.O. Box 1071, Knoxville, Tennessee 37901-1071

DEVELOPMENT OF A CHEMICAL RINSATE DISPOSAL DESIGN

Brian K. Corwin[1] and Daniel C. Yoder

One of the consequences of agriculture's reliance on chemicals is the production of pesticide-contaminated wastes. Much of this waste is made up of equipment rinsewater and spray tank rinsates, inappropriate disposal of which threatens the quality of the nation's water resources. One promising disposal technique employs an evaporation/degradation system, which consists of a lined bed or pit filled with soil and into which the wastewater is placed. The water evaporates, and the pesticide residues are absorbed onto the soil and are eventually degraded by soil micro-organisms. Researchers have investigated variations of this system and obtained promising results. However, none of the previous reports indicate that much background analysis went into the designs. The goal of this research is thus to seek the combination of factors resulting in the optimum combination of evaporation and degradation. The variables that influence both of these processes and are being studied are: (1) temperature, (2) soil texture, (3) evaporation rate, (4) mode of application of the pesticide solution to the soil, and (5) time. A test apparatus was constructed employing individual soil columns to simulate different conditions in a soil bed. A contaminant mixture made up of water and the herbicides atrazine and fluometuron at low concentrations was supplied to the columns. Continuous records were kept of the amount of contaminant solution supplied to each soil column to meet its evaporation requirements. Additionally, at prescribed time intervals, the soil in the columns was tested for pesticide concentration levels as an indication of the rate of microbial degradation. Since we were interested in the interactions of all of these variables, a complete factorial design with four replications was utilized. Preliminary data are presented describing the evaporation and degradation rates and the interactions of the various variables.

[1]University of Tennessee, Agricultural Engineering Department, P.O. Box 1071, Knoxville, Tennessee 37901-1071

WATER QUALITY IN POPLAR CREEK: IT IS IMPACTED BY FEDERAL FACILITIES ON THE OAK RIDGE RESERVATION?

C. Ford[1], C. Rash[1], K. Campbell[2], and R. Harris[3]

INTRODUCTION

The operation of U. S. Department of Energy (DOE) facilities in Oak Ridge has released contaminants to off-site surface waters, including Poplar Creek and The Clinch River, throughout the 50 year history of Oak Ridge. However, current release levels are much reduced from those of only a few years ago. Surface water in Poplar Creek, which receives discharges from two of the three DOE facilities on the Oak Ridge Reservation (ORR), was recently investigated as part of the Clinch River / Poplar Creek Remedial Investigation. This study was designed to provide a statistically sound assessment of contaminants and water quality in Poplar Creek. Four study sites were selected within the 5.5 miles of Poplar Creek between the confluence with East Fork Poplar Creek (EFPC) and the confluence with the Clinch River. Each site was selected based on documented contaminant releases to Poplar Creek surface waters from contaminated streams or outfalls (Table 1). Four reference sites were chosen in Poplar Creek upstream from the influence of the ORR. Water samples were collected from a depth of 1-m in Poplar Creek four times per season (winter, spring, and summer) from each of the eight sites from November 1993 through September 1994.

RESULTS

Poplar Creek dissolved copper concentrations in summer were significantly higher than concentrations in winter or spring ; however, total copper concentrations were similar for all seasons. Dissolved copper concentrations were similar throughout Poplar Creek during any given season. Mean dissolved and total manganese concentrations from the reference reach were higher than concentrations in all study reaches, particularly during summer. Manganese is not considered to be a contaminant associated with the ORR, as it is a natural component of the Poplar Creek watershed.

Dissolved and total nickel concentrations were similar for all Poplar Creek reaches, but dissolved concentrations were as high or higher than total concentrations in all reaches. Nickel is usually considered to be particle-associated and total concentrations are usually much higher than dissolved; however, these results were similar to those found by Perhac (1972), where 93.1% of the nickel occurred in the dissolved form in two streams in northeast Tennessee. Dissolved and total concentrations were similar across Poplar Creek during any given season.

Nitrate/nitrite concentrations from were significantly higher below Mitchell Branch than elsewhere in Poplar Creek, indicating that Mitchell Branch may be a source of nitrate/nitrite to Poplar Creek. Summer concentrations were highest in Poplar Creek; however, nitrate/nitrite values for all seasons were similar.

[1]Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

[2]Environment and Energy Resource Center, University of Tennessee, Knoxville, TN

[3]Automated Sciences Group, Oak Ridge, TN

Table 1 Study sites used in Poplar Creek Contaminant Study (PCM = Poplar Creek Mile).

Water Sampling Site(s)	Description
PCM 6.0 PCM 6.5 PCM 7.0 PCM 7.5	Reference reach, Poplar Creek above the confluence with EFPC (influence of the ORR)
PCM 5.1	Poplar Creek below EFPC
PCM 4.3	Poplar Creek below Mitchell Branch
PCM 2.9	Poplar Creek below the K-25 Central Neutralization Facility
PCM 1.0	Poplar Creek below the K-770 ash disposal site

Because chromium was used historically at K-25, significant concentrations in the Poplar Creek study reaches were expected. Chromium was detected in Poplar Creek surface water; however, concentrations were low and chromium was not found to be a contaminant of potential concern. High arsenic concentrations were also expected below the ash disposal site (PCM 1). However, arsenic was not found to be a contaminant of potential concern in Poplar Creek; arsenic was not detected in Poplar Creek the majority of the time.

Several metals were highest in the reference reach or as high in the reference reach as in the study reaches: dissolved antimony, dissolved and total copper, dissolved and total manganese, dissolved and total nickel, dissolved and total zinc. With the exception of manganese, high concentrations of these analytes could be a result of either an upstream source or possible groundwater seepage from DOE facilities. Many of the inorganic concentrations were highest in summer which is typically a season of lower rainfall, surface water flow, and groundwater flow.

Dissolved methyl mercury concentrations in Poplar Creek were similar for all sites and seasons. However, total methyl mercury concentrations throughout Poplar Creek were significantly higher than those in the reference sites.

Total inorganic mercury concentrations were highest at PCM 1, decreasing with distance upstream. Both total and dissolved inorganic mercury concentrations at PCM 2.9 and PCM 1 were significantly higher than reference sites. Though they were expected to be related, no significant correlation was observed between total inorganic mercury and a total suspended particles. In an analysis of variance, site explained 48% of the variation in the total inorganic mercury concentration in Poplar Creek; however, using total suspended particles and site as dependent variables explained 25% of the variation in total mercury concentrations.

Most organic analytes were not detected in Poplar Creek. Phthalates, organic constituents of plastics, were most commonly observed. Di-n-butylphthalate and bis(2-ethylhexyl)phthalate were detected most frequently, at most sites, and in all seasons. Di-n-butylphthalate concentrations were higher downstream in Poplar Creek, from the reference site or immediately below EFPC. Bis(2-ethylhexyl)phthalate concentrations were highest at the reference sites, suggesting that the source of this compound is upstream of the ORR.

Both gross alpha and gross beta-emitting radionuclides were detected in Poplar Creek, though none were at levels contributing to human health or ecological risk and may be attributable as much to background as to ORR contamination.

CONCLUSIONS

Results indicate that average contaminant values were below levels of concern for human health and ecological risk. However, contaminant distributions sugges that episodic events contribute sufficiently to system contaminant levels to be of concern. Additionally, water-column contaminant levels were significantly higher in particle-deposition areas than near known sources of contamination. Levels of organic compounds in reference areas exceeded those in the Popıar Creek study area. In Poplar Creek, statistical differences in heavy metals from known contaminated areas were found. This outcome confirmed previous results and permitted an independent means to distinguish between sites.

SUBSURFACE MAPPING OF HYDROGEOLOGICAL FEATURES IN WEST TENNESSEE USING GROUND PENETRATING RADAR

Robert S. Freeland[1]

Ground penetrating radar (GPR) technology was evaluated for nondestructive soil moisture reconnaissance within loess soils. The studies were conducted on a water quality research site in West Tennessee, which is approximately 50 miles southwest of Jackson, Tennessee near the community of Grand Junction.

Methods of calibration, small and large area survey methods, data interpretation, and the identifiable subsurface features are presented. Three-dimensional visualization mapping is also presented that illustrates the subsurface moisture detected nonintrusively at the site, along with its seasonal movement.

Soil physical properties were obtained for calibration and comparison. Samples were obtained using a truck mounted core drill that reached to a depth of 14 feet. Samples were classified (percent sand, silt, clay, and moisture) by laboratory analysis at 6 in. Increments. The soil's physical properties allowed interpretation of the radar surveys scanned at the site.

Using a 300-MHZ antenna, penetration depths of 25 feet were obtained with a range of 160 ns and a dielectric of 8.72, a value determined by physical measurement. The dielectric constant of the soil was measured by imaging metal pipes inserted at known depths within the profile. Interfaces of minimum and maximum moisture and clay content were located within the radar images using the corresponding physical data. The technology also shows promise in mapping the depth to the loess/paleosol interface, an interface of high silt to high sand.

[1]Associate Professor, Department of Agricultural Engineering, The University of Tennessee, P.O. Box 1071, Knoxville, Tennessee 37901-1071

WATER-QUALITY, DISCHARGE, AND BIOLOGIC DATA FOR STREAMS AND SPRINGS NEAR A LANDFILL, BEDFORD COUNTY, TENNESSEE

E.F. Hollyday[1] and Thomas D. Byl

From November 1994 through April 1995, streams and springs in 9 drainage basins, each having a drainage area of about 2 square miles, were observed and sampled during base flow at 176 sites to obtain information on environmental quality near the Quail Hollow landfill, Bedford County, Tennessee. Reconnaissance data were collected to establish a regional pattern; water samples from 26 seepage sites were analyzed to specify water-quality conditions. During reconnaissance, conductivity ranged regionally from 17 to 617 microsiemens per centimeter (μS/cm). Conductivity was less than 50 μS/cm at and upstream of the outcrop of the Chattanooga Shale but increased downstream to between 150 and 300 μS/cm. The biologic diversity of most streams had a unimodal distribution of number of orders per site. Of the constituents and properties analyzed, only pH and four metals at six sites had values that were not within the limits set by the State of Tennessee for drinking water. Conductivity, chloride, and dissolved manganese were highest for a spring and a seep adjacent to the landfill. Scans indicated the presence of about 37 unidentified organic compounds at these same two sites.

[1]U.S. Geological Survey, 810 Broadway, Suite 500, Nashville, Tennessee 37203; efhollyd.er.usgs.gov; phone: (615) 736-5424

RELATING A MANAGEMENT PRACTICE INDEX TO A WATER QUALITY INDEX

Gary S. Honea[1] and Ronald E. Yoder

Much effort is spent in trying to relate water quality to management practices that influence water quality. Successes have been achieved but it has often been difficult to tie a change in water quality to a management practice, or to conclusively document actual water quality improvement. This research utilizes a systems approach to look at the water quality that can be expected when a whole system of management practices are implemented on an operational unit such as a dairy farm. This research is being conducted on a relatively well run dairy farm in northeast Tennessee. Two indices are being computed for the overall farm, one for management practices and one for water quality. Both are based on four contaminants of interest: sediment, nitrogen, phosphorus, and coliform bacteria. The water quality is being sampled and analyzed for these four parameters at four different sampling points. A single board computer has been configured and programmed to trigger an automatic sampler on a flow proportional basis at each site. The loads of these four contaminants will be compared to water quality standards and to the total amount of these contaminants that could be introduced into the receiving streams for a worst case scenario. The resulting water quality index will reflect the quality of water leaving the farm and be related back to the management practice index that was computed. Initial evaluation has resulted in a management practice index of over 0.9 of a possible 1.0. Sampling and analysis are continuing at the four locations. More complete data and conclusions will be presented when research is complete at the end of the year.

[1]University of Tennessee, Agricultural Engineering Department, P.O. Box 1071, Knoxville, Tennessee 37901-1071

THE TENNESSEE DIVISION OF WATER POLLUTION CONTROL'S USE OF GEOGRAPHIC INFORMATION SYSTEMS TO ASSESS WATER QUALITY PROBLEMS

Katherine A. Larrieu[1]

The ability to link geographic information with water quality data de-mystifies many of the Division of Water Pollution Control's duties, such as stream assessments, NPDES permit writing, modeling, and Total Maximum Daily Loads. A Geographic Information System (GIS) makes it possible to couple WPC's ecoregion project with watershed planning. Although GIS is still relatively new to WPC, we have made great strides in using the technology for many aspects of our daily work.

WPC has succeeded in linking data in EPA's STORET database to spatial information. This linkage makes background water quality data easily accessible to permit writers for use in calculating permit limits. Digital stream arcs merged with stream assessment tables allow the pinpointing of areas of poor water quality and monitoring gaps. This information can be used to prioritize monitoring and corrective efforts. Overlaying ecoregion maps over watershed maps enables us to plan for monitoring and other objectives of both projects. GIS produced maps are invaluable in clearly and accurately communicating WPC plans and objectives.

[1]Tennessee Department of Environment and Conservation, Division of Water Pollution Control, 7th Floor, L&C Annex, 401 Church Street, Nashville, Tennessee 37241-1534

GEOACOUSTICAL SEDIMENT CHARACTERIZATION OF THE CLINCH RIVER AND POPLAR CREEK, TENNESSEE

D. A. Levine[1] and W. W. Hargrove[2]

The Clinch River arm of Watts Bar Reservoir has been accumulating sediment-bound contaminants from three Department of Energy (DOE) facilities on the Oak Ridge Reservation, Tennessee. The first step in characterizing Clinch River sediments was to determine the locations of deposition zones and sediment type distribution within deposition zones. A dual-frequency hydro-acoustic survey was performed to determine: (1) depth to the sediment water interface, (2) depth of the sediment layer, and (3) sediment characteristics (density) with depth (approximately 0.5-foot intervals). An array of geophysical instruments was used to meet the objectives of this investigation. The basic suite of systems included: a 3.5 kHz high resolution "pinger" system, a high definition broad spectrum acoustic profiling "chirp" system, and a dual-frequency side-scan sonar system. A real-time-differential Global Positioning System was used to navigate along pre-determined survey lines and to obtain precise locations of data points. Approximately 80 linear miles of survey lines were navigated to cover a 22 mile length of river. Sediment density with depth data were created for approximately 4000 points from the hydro-acoustic survey. These data were used as input to a Geographic Information System (GIS) program that performed a 3-D regularized spline with tension interpolation technique to generate bathymetry and sediment density volumes. The resulting model were used to evaluate dredging scenarios near Brashear Island where the navigation channel has become shallow. Volumes and sediment types required to be removed to re-establish the navigation channel were estimated. Data visualization techniques will be presented to portray this information.

[1]Automated Sciences Group, Inc., Oak Ridge Tennessee

[2]University of Tennessee, Knoxville, Tennessee

CONTAMINANT CHARACTERIZATION OF SEDIMENT AND PORE-WATER IN THE CLINCH RIVER AND POPLAR CREEK

D. A. Levine[1], R. A. Harris[1], W. W. Hargrove[2], K. R. Campbell[2], and C. D. Rash[3]

Sediment and pore-water samples were collected from 80 locations in the Clinch River and Poplar Creek system to characterize concentrations and spatial distribution of contaminants for use in ecological risk assessment. Sediment cores were collected at each site and the top 15 cm was analyzed to represent the biologically active zone. Sediment for pore-water extraction was collected in large volumes using a Ponar grab sampler. Pore-water was extracted from this sediment using centrifugation. All samples were analyzed for metals (including methyl mercury), organics, and radiological constituents. Additionally, sediment was analyzed for physical properties: particle size distribution, density, and porosity. Sediment and pore-water were also analyzed for total organic carbon and nitrogen and ammonia levels. Sediment and pore-water results indicate that there are several areas where concentrations of a variety of contaminants are high enough to cause ecological effects. These locations in the river are immediately downstream from known sources of contamination from on-site DOE facilities. East Fork Poplar Creek is a source of several metals, including mercury, cadmium, chromium, and copper. Mitchell Branch is a source of number of metals, uranium isotopes, technicium-99, and several PAHs. There are two clear sources of arsenic and selenium to the system, one in Poplar Creek and one in Melton Hill Reservoir, both related to past disposal of coal-ash. High concentrations in sediments did not always coincide with high concentrations in pore-water for the same sites and contaminants. This appears to be related to particle size of the sediment and total organic carbon.

[1]Automated Sciences Group, Inc., Oak Ridge Tennessee

[2]University of Tennessee, Knoxville, Tennessee

[3]Oak Ridge National Laboratory, Oak Ridge, Tennessee

USING LONG TERM BIOLOGICAL MONITORING DATA TO EVALUATE THE RECOVERY OF DISTURBED SYSTEMS

J. M. Loar[1]

Biological monitoring has been conducted in industrially impacted streams near U.S. Department of Energy facilities in Tennessee and Kentucky for almost ten years. A comprehensive Biological Monitoring and Abatement Program, which was developed to meet National Pollutant Discharge Elimination System permit requirements, includes tasks on (1) toxicity testing; (2) bioaccumulation in aquatic and terrestrial biota; (3) bioindicators of fish health; and (4) fish, macroinvertebrate, and periphyton community surveys. These studies have been used successfully to characterize spatial trends and demonstrate temporal recovery resulting from remedial actions and pollution abatement activities, identify contaminant sources, and provide data for conducting ecological risk assessments. The program uses multiple lines of evidence to evaluate stream recovery and illustrates the importance of using an integrated approach when determining stream health. An overview of data collected from studies on East Fork Poplar Creek since 1985 are presented to illustrate the ability of the program to document recovery at several levels of biological organization, including individuals, populations, and communities. Unique attributes of each task are highlighted to demonstrate the flexibility of both the Program and its components. The development of an integrated database and GIS technology to more comprehensively evaluate the data is presented.

[1]Oak Ridge National Laboratory, Oak Ridge, Tennessee

RESULTS OF THE SPRING AND SEEP INVENTORY CONDUCTED ON THE DEPARTMENT OF ENERGY RESERVATION AT OAK RIDGE, TENNESSEE

Son Nguyen[1], Brian Benham, G. C. Johnson, and J. A. Robinson

In order to develop a better understanding of bround-water and surface-water interactions and ground-water flow patterns on the Oak Ridge Reservation, Oak Ridge, TN, the U.S. Geological Survey (USGS) conducted a reconnaissance and inventory of stream flow, springs, and seeps. This activity is part of the ground-water/surface-water observation program established by the Department of Energy to monitor water quality and possible contaminant transport. The inventory included 824 sites over a 6.8 mi^2 area in Bethel Valley and Melton Valley near the Oak Ridge National Laboratory, 701 sites over a 7.2 mi^2 area in the Bear Creek Valley from Y-12 to the Clinch River, and 384 sites over an 8 mi^2 area surrounding K-25. Inventoried sites were georeferenced using a Global Positioning System and classified with respect to their source and flow characteristics. Seeps along the banks of Poplar Creek and the Clinch River, adjacent to K-25, were also inventoried. Sites were visited at high-base and low-base flow conditions in an effort to characterize temporal discharge and water-quality variations. Data collected included: discharge, pH, specific conductance, temperature, and dissolved oxygen. Presentation graphics will include Geographic Information System generated coverages relating water-quality and discharge data to the topography and geology at each of the specific facilities. The extended abstract presents summary statistics broken down by site classification and high-base and low-base flow inventories. Sites with perennial discharge are referenced to significant geologic formations.

[1]USGS, 1013 N. Broadway, Knoxville, Tennessee 37917; phone: *615) 545-4140; Fax: (615) 545-4227

AUTOMATIC SAMPLING TO MONITOR GROUND WATER MOVEMENT IN THE VADOSE ZONE

N. Randy Rainwater[1], Ronald E. Yoder

INTRODUCTION

Increasing concern about ground water movement and solute transport in the vadose zone requires further development of monitoring systems to characterize subsurface hydrology. An interdisciplinary team of researchers at The University of Tennessee has developed a research facility on a 994-ha agricultural watershed in west Tennessee. Since the fall of 1990 a 10-ha test site of the watershed has been in conservation tillage. A square 0.4-ha test plot has been established within the 10-ha site. A monitoring system is installed in, and surrounding, the field-test plot to characterize surface and subsurface hydrology. Shallow wells are installed with a screen at the loess-paleosol interface to collect perched water caused by differences in the physical characteristics of the soil layers. Shallow wells were installed, in 1992, at 23 locations (figure 1), on concentric circles with radii of 45, 60, 90, 150 m from the center of the 0.4-ha test plots (Yoder et al., 1994).

On March 9, 1993, a bromide tracer was surface applied to the plots at the rate of 300 kg/ha. Monitoring of the bromide movement began immediately after the application and is continuing. Based on the spatial distribution of the shallow wells that have yielded bromide (figure 1), 17 additional shallow wells were installed in April 1995 to more accurately characterize subsurface hydrology. These additional shallow wells are installed on the west side of the 0.4-ha test plot. An automatic sampling system was designed and installed to collect samples from 21 shallow wells, including the 17 additional shallow wells. The automatic sampling system will improve data collection by giving time resolution.

RESEARCH IN MONITORING SUBSURFACE WATER MOVEMENT

Most previous research has been primarily concerned with the vertical movement of water and contaminants toward the underlying aquifer and the resulting concentrations of contaminants in the aquifer (e.g., Staver and Brinsfield, 1991; Dorrance et al., 1991). Little attention has been given to monitoring the lateral movement of ground water and agricultural chemicals in the unsaturated or vadose zone above the aquifer:

> At present, the primary concern with regard to the leaching of nitrate, as well as other potential groundwater pollutants used in agricultural systems, is not the rate of leaching but the resulting concentration of that pollutant in groundwater.
> As a result, groundwater concentration studies generally rely heavily on groundwater concentration data, with little consideration given to vadose zone parameters (Staver and Brinsfield, 1991).

The significance of monitoring ground water and agricultural chemical movement in the vadose zone is beginning to be recognized by researchers and engineers. However, there is no apparent consensus on the criteria by which such a monitoring system should be designed. Dorrance et al. (1991) give a detailed

[1]Department of Agricultural Engineering, The University of Tennessee, P.O. Box 1071, Knoxville, Tennessee 37901

summary of pore-liquid samplers for the vadose zone. These researchers state specifically the value of monitoring perched ground water:

> Perched water occurs where varying permeability layers in the vadose zone retard downward movement of liquid. Over time, liquid collects above lower permeability layers and moisture content may increase to saturation... Once soil becomes saturated, wells and other devices normally installed below the water table can be used to collect samples.
>
> Sampling perched liquid is attractive because the perching layer collects liquid over a large area. Such integrated samples are more representative of areal conditions than suction samples... This also allows the sampler to potentially detect contaminants which may not be moving downward immediately adjacent to the sampler. In addition, larger sample volumes can be collected than those which can be obtained by suction samplers (Dorrance et al., 1991).

Much progress has been made in monitoring and analyzing water and solute transport. Challenges that remain include (a) how to best deal with preferential flow and transport, (b) how to best model the effects of local and regional spatial and temporal variabilities of soil hydraulic properties on solute transport, and © how to improve field methods for measuring vadose zone transport parameters (Nielsen, et al., 1987).

OBJECTIVES

Any monitoring system must be based on the questions to be answered. Prior to the implementation of this automatic sampling system, several questions were raised by the researchers conducting the project referred to as "The Ames Plantation Water Quality Project." What are the flow paths of the tracer within the perched water table from the 0.4-ha test plot? What is the time relationship between the perched water table depth and infiltration? What is the best method of monitoring subsurface water movement at the loess-paleosol interface? With these questions in mind, an automatic shallow well sampling system was designed and implemented with the following objectives: (1) automatically sample water from 21 shallow wells as it is collected in the well casing, (2) provide capability to record the time the sample was taken, and (3) provide in situ collection devices protected from the weather.

MATERIALS AND METHODS

The automatic sampling system had to meet several criteria that guided the selection of materials. Due to the location, the system had to have minimal power requirements, have minimal maintenance requirements, and be weather resistant. The design should not be cost prohibitive and needed to be implemented within 12 months. The system was designed as a team effort among the researchers in the Agricultural Engineering Department at The University of Tennessee. The system is divided into three separate sampling systems, each monitoring seven shallow wells. Each of the systems is capable of handling one additional shallow well.

The primary components of each sampling system include a microcontroller card with 32K of memory and 24 input/output lines, liquid level switches, flow sensors, isonic valves, two vacuum tanks, 12-V battery, and a solar panel. The microcontroller card is programmable with Cambasic programming language. The program allows a maximum of one sample every 4 hours to minimize drawdown of the perched water table. The program also collects a sample after one week from the last sample in case less than the amount required to trip the liquid level switch has collected in the well casing. This maximum and minimum sampling frequency can be adjusted if necessary. A 286 laptop computer is used to communicate with the microcontroller and to download data.

Approximately 100 ml of water in the well casing will trip the liquid level switch. When the liquid level switch trips, the microcontroller card opens the isonic valve controlling the vacuum to that well. The water is pulled from the well casing into a sample jug. A slow sensor is located in the vacuum line between the well and the sample jug. The flow sensor signals the microcontroller card to close the isonic valve when flow ceases.

The flow sensors were designed and assembled within the Agricultural Engineering Department. The final design consisted of an infrared emitting diode and a NPN photo transistor (detector) mounted in a 9-cm length of thick wall neoprene tubing. Resistors were added to the diode and transistor to adjust the strength of the signal and the sensitivity of the photo detector such that water flowing between the emitter and detector would interrupt the signal. This component of the system could be improved by using a more rigid tubing with the mounting holes for the diode and photo transistor precision machined into the tubing. This will assure better alignment of the light emitting diode with the photo transistor. The flow sensor is powered by 5 V from the microcontroller.

The isonic valves are essentially miniature solenoid valves that are very compact and are ideal for the application. They are powered by 5 V and controlled by the microcontroller. The valves control the vacuum supplied to the sample jug. Vacuum is supplied to the valve manifold by two, 11-gallon (42.6-L) vacuum tanks with 4-mm tubing.

A 5-gallon (19-L) water cooler was buried approximately 40 cm from each well in the sampling system. The cooler was buried up to approximately 10 cm from the top. The sample jug and flow sensor were placed in the coolers. The coolers were connected to the well casing with PVC conduit. One-quarter inch (6.35-mm) vacuum tubing and 22-ga, 2 wire cable were run through the conduit down into the well casing to the liquid level sensor and to the well casing bottom.

The microcontroller card, isonic valves, and other electronics were mounted in a nema-IV enclosure. The enclosure, vacuum tanks, and 12-V battery are located in a small structure referred to as the control center. Twenty two gage, 4 wire cable was run through conduit to each of the seven wells on a system. Four-mm vacuum tubing from the isonic valves was also run through the conduit to the sample jugs located in the buried coolers. The conduit was buried approximately 25 cm below the surface of the ground. The control centers were erected approximately 10 m from the closest well in the system and approximately 45 m from the farthest well in the system. Several tests were conducted in the laboratory to determine the vacuum drop and time required to sample with various lengths of 4-mm tubing and at different levels of vacuum. Empirical data indicated that as long as 38 cm of Hg vacuum were maintained in the vacuum tanks, using 4-mm tubing would not create a problem due to flow resistance in the tubing.

RESULTS

The automatic sampling system was installed during the summer of 1995. It has operated since the end of August. Due to minimal precipitation, only two samples have been collected to date. Some field adjustments were necessary. A protection against flow sensor failure was included in the program. The protection closes the isonic valve after a specified amount of time has passed. Separate loops in the program were required for wells closest to the control center and for those farthest away from the control center due to the difference in time required to pull the complete sample. Initially, the vacuum tanks required recharging two or three times a week with a significant loss of vacuum in the vacuum tanks. To date, the new panels have provided adequate charge to the 12-V batteries.

Despite some minor problems, the automatic sampling system appears to be functioning well. Data collection will continue and the effectiveness of the sampling system will be evaluated.

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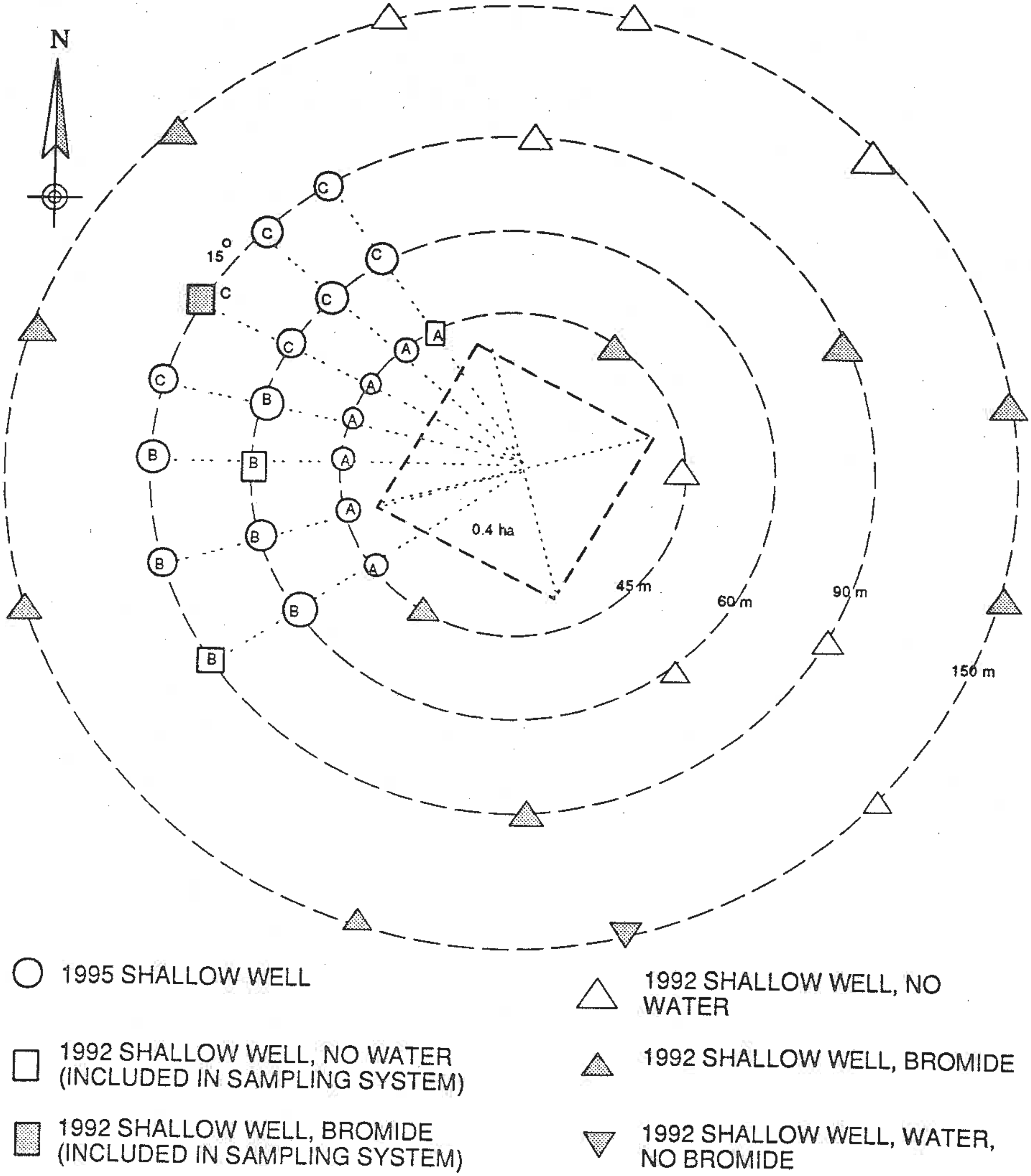

Figure 1

Letters indicate which of the three sampling systems the well is on.

ECOLOGICAL RISK ASSESSMENT OF PISCIVOROUS WILDLIFE OF THE CLINCH RIVER

B. E. Sample[1]

A weight-of-evidence approach was employed to assess risk to osprey, great blue heron, and mink along the Clinch River, downstream of the Oak Ridge Reservation (ORR). Available data consisted of comparisons of exposure estimates to literature-derived NOAELs and LOAELs (all three species), field surveys (osprey and heron only), and toxicity tests (mink only). Contaminants of potential concern (COPCs) were identified by comparing exposure estimates generated using point estimates of parameter values to NOAELs. COPCs included mercury, PCBs and selenium. Exposure to COPCs was re-estimated using Monte Carlo simulations then compared to LOAELs. Exposure of osprey to mercury was identified as a significant risk at only one location. This location did not present a risk when the foraging area of osprey was included in the exposure model. Estimated exposure for heron or mink was not sufficient to present a risk for any COPC or location. Field surveys of four heron rookeries indicated that while contaminant levels are elevated in eggs and chicks near the reservation, reproduction is not affected. Fledging success at three osprey nests near the ORR exceeded the mean for U.S. osprey. Mink fed fish from the Clinch River displayed impaired reproduction only in the most contaminated of five toxicity test diets. Mercury in all diets was less than the literature-based LOAEL. PCBs in the highest diet that produced no adverse effects were 16 times greater than the literature-based LOAEL. The maximum exposure estimated for mink along the Clinch River was significantly lower than the toxicity test exposure that produced adverse effects. The weight-of-evidence indicates that contaminants from the ORR do not present a risk to piscivorous wildlife along the Clinch River.

[1]Environmental Sciences Division, P.O. Box 2008, MS-6038, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6038; phone: (423) 241-3933; Fax: (423) 576-8646); email: pz7@ornl.gov

RURAL, URBAN, MIXED, AND WOODLAND LAND USE IMPACTS ON WATER QUALITY

Bryan F. Staley[1]

Little research has been done comparing how various land uses impact water quality. Determining which land uses contribute most to water quality degradation is important in effectively targeting specific problems. In addition, an established set of water quality data from each land use will help to reduce speculation that most water quality problems are due to a single land use. Impacts on water quality by rural, urban, woodland, and mixed land uses are currently being studied in a 24 square mile watershed in eastern Tennessee. The land uses are striated rather well into separate sub-watersheds that are situated sequentially along a stream. This sequential approach allows for easier comparisons to be made since samples are taken at different locations from the same stream. To date, 12 different water quality constituents are being tested for in an effort to detect as many differences as possible without bias for any particular land use. The sampling regime used is flow proportional. A small single-board computer controls automatic samplers at the four sampling locations by calculating streamflow based on stream depth and the stage-discharge curve at that location. The computer allows for sampling versatility during storm events and cyclical differences in flow. The programming enables more intensive sampling to be done during the rising limb of a storm hydrograph so the first flush of runoff can be accurately characterized. Preliminary conclusions have been made from the one year of data already collected.

[1]Agricultural Engineering Department, The University of Tennessee, P.O. Box 1071, Knoxville, Tennessee 37901-1071

CONCEPTS OF GROUND-WATER FLOW BENEATH A LANDFILL IN KARST TERRAIN

Ank Webbers[1] and E.F. Hollyday

The monitoring of ground-water quality at landfills in Tennessee requires a minimum of three wells--one upgradient and two downgradient--that yield water samples from the uppermost aquifer. Traditionally, for a landfill in karst terrain, the regolith (clay, sand, weathered rock) generally is regarded as the uppermost aquifer. For these landfills, monitoring concepts assume that (a) the regolith has a sufficient saturated thickness to form a continuous water-table aquifer with a major component of horizontal ground-water flow, (b) limited, vertically downward drainage occurs from the saturated regolith into localized fractures and solution openings in the underlying bedrock, and (c) a second, minor aquifer is present in the bedrock. At some landfills in karst, however, the regolith may not yield sufficient water to monitoring wells to validate the assumption of an upper most aquifer in the regolith.

A hydrologic investigation of a landfill in the karst terrain of Middle Tennessee by the U.S. Geological Survey included installing six monitoring wells in regolith. The water level in one well recovered rapidly following pumping; the water level in another well recovered slowly; and four wells had insufficient water to pump. Based on these data, an alternative, site-specific monitoring concept suggests that (a) no laterally continuous, water-table aquifer exists in the regolith, (b) downward vertical drainage occurs through the regolith and upper part of the bedrock into localized fractures and solution openings in the bedrock, and (c) the only laterally continuous zone of saturation is in the bedrock.

Based on this investigation, the regolith may not contain the uppermost aquifer at landfills in karst terrain. Thus, an effective ground-water monitoring method must include wells that penetrate (and can be used to collect water samples from) that uppermost zone of saturation where the ground-water flow has a major horizontal component.

[1]U.S. Geological Survey, 810 Broadway, Suite 500, Nashville, Tennessee 37203; awebbers.er.usgs.gov; phone: (615) 736-5424