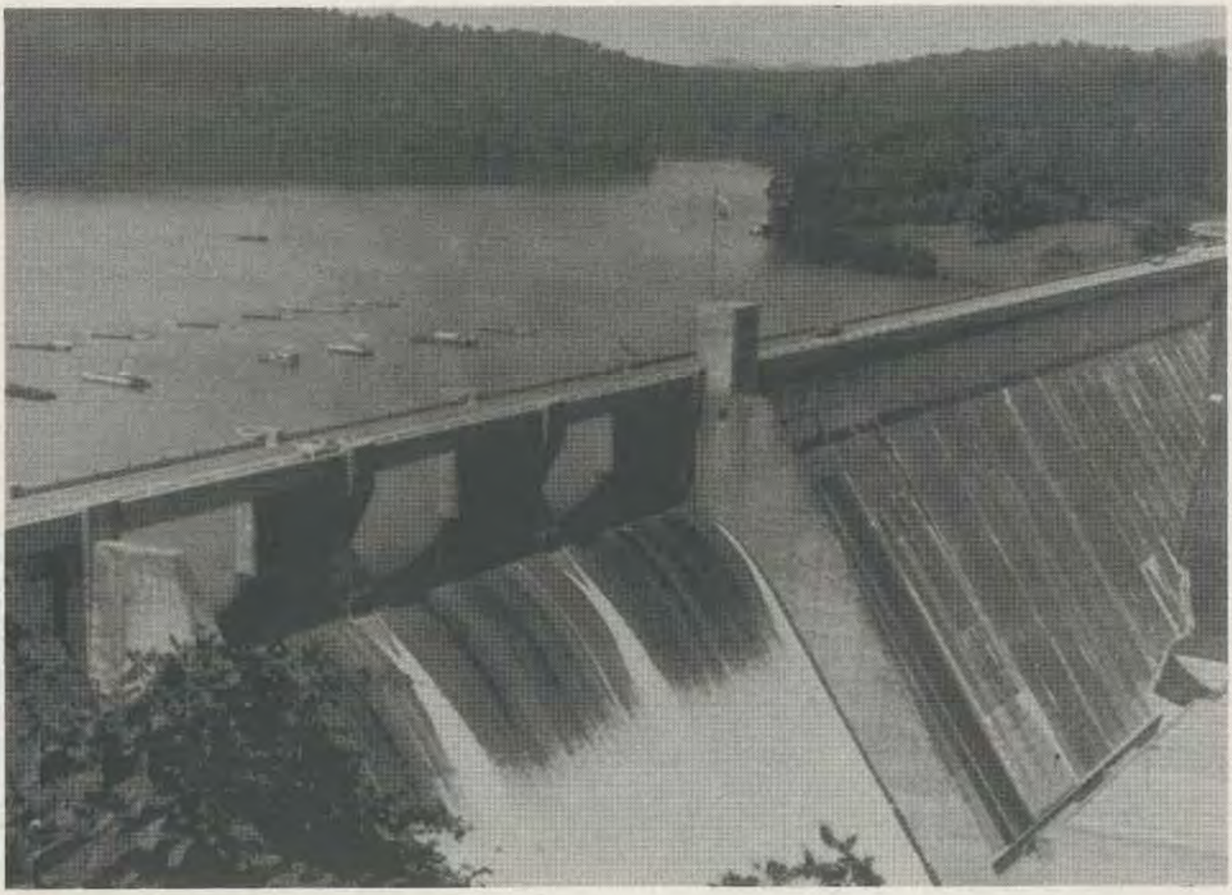
CONF-910923--Absts.

EXTENDED ABSTRACTS FROM

FOURTH TENNESSEE WATER RESOURCES SYMPOSIUM

Knoxville, Tennessee
September 24-26, 1991



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Environmental Consulting Engineers, Inc.
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The University of Tennessee, Knoxville
U.S. Army Corps of Engineers, Nashville District
U.S. Geological Survey, Water Resources Division

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September 24-26, 1991

Compiled by:

Michael J. Sale
and
Patricia M. Presley

Environmental Sciences Division
OAK RIDGE NATIONAL LABORATORY

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Cover Photo: *Norris Dam and Reservoir in Anderson and Campbell counties, Tennessee (photograph provided by staff of the TVA Engineering Laboratory).*

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PREFACE

The annual Tennessee Water Resources Symposium was initiated in 1988 as a means to bring together people with common interests in the state's important water-related resources at a technical, professional level. Initially the symposium was sponsored by the American Institute of Hydrology and called the Hydrology Symposium, but the Tennessee Section of the American Water Resources Association (AWRA) has taken on the primary coordination role for the symposium over the last two years and the symposium name was changed in 1990 to water resources to emphasize a more inter-disciplinary theme. This year's symposium carries on the successful tradition of the last three years. Our goal is to promote communication and cooperation among Tennessee's water resources professionals: scientists, engineers, and researchers from federal, state, academic, and private institutions and organizations who have interests and responsibilities for the state's water resources.

The Fourth Tennessee Water Resources Symposium combines something old with something new. While the strategy of bringing water resource professionals together at the state level remains the same, the location of the meeting has been moved temporarily to Knoxville as an experiment to diversify participation. We plan to return the symposium to Nashville in 1992, and in alternating years thereafter. Proposals for alternative sites will be considered in odd-numbered years, hopefully to encourage more involvement from people throughout the state.

This publication of extended abstracts is intended to provide a means of identifying who is doing what around the state. Phone numbers and mailing addresses of senior authors or speakers have been included on the first page of each abstract to facilitate further contacts.

We hope you find this year's symposium an interesting and useful forum for developing contacts and communication in your profession. We encourage everyone to join the Tennessee Section of the AWRA as part of your participation, so that we can continue this event in the future. If you have comments on this year's symposium, or would like to help in future symposia, you should contact our next Tennessee AWRA Section President, Harold Sansing, at 615/736-5675 or write him at USACED, Nashville, P.O. Box 1070, Nashville, TN 37202.

Michael J. Sale and
Harold T. Sansing
1991 Symposium Co-Chairmen

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ACKNOWLEDGEMENTS

A large number of people and organizations from throughout the state of Tennessee have contributed to this year's Water Resources Symposium, as is reflected in the membership of our Organizing Committee. Funding for publication of these Extended Abstracts was provided by the Environmental Restoration Program, Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee. Funding to assist student participation in the symposium was provided, in part, through the Center for Global Environmental Studies, Oak Ridge National Laboratory, which is managed by Martin Marietta Energy Systems under contract DE-AC05-84OR214000 with the U.S. Department of Energy. Additional financial support for the opening reception was provided by the following corporate sponsors:

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A CASE FOR WATER RESOURCE REALLOCATION

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Introduction

One may assume that the wisdom of the day, combined with political expediency was used in deciding how to allocate and manage water resources of a region, when the Federal government began indulging in multipurpose water resources developments earlier in this century. The structural and operational measures that were decided on to implement these projects have now established a status quo. As nobody can claim to have the perfect crystal ball, some consequences of adopted measures were not foreseen at the time and the importance of certain uses was over- or underestimated. Therefore, a reconsideration of existing allocations from time to time seems a reasonable thing to do.

One will generally find that the status quo is strongly defended by those who have been favored by it and challenged by those whose expectations have not been met. Can the institution in charge cope with the resulting conflicts between old and new interests? A reallocation must deal with the status quo and its defenders, the contemplated changes, old and possibly new externalities and inequities, the cost and the legality of change. A real world example will be used in which an institution ventures out to change the status quo, gets promptly censored by its defenders, causes disappointment to the challengers and concludes that it has made the biggest step in fifty years.

Water Management Conflict

A growing number of people in the headwater areas of the Tennessee River basin demand more consideration in reservoir management during the recreation season. In some of the economically most depressed counties, which happen to harbor major TVA tributary reservoirs, the TVA has been collecting and turbining water and distribution the power to beneficiaries hundreds of miles away for 50 years. For as many years people have perceived the lakes as keys to improved income, not through power production but through tourist industry. The economic depression in these areas cannot be exclusively blamed on what is perceived as inadequate lake levels. A poor transportation infrastructure and land ownership are also unfavorable for water-related recreation industry development. But if vacationers come to the area, high water levels might hold them there for a while.

But for the TVA power program and its watchdogs (power advocates) no time is a good time when it comes to giving up hydropower. Hydro power more is the cheapest possible source to cover the expensive power peaks during the summer season. Thus, the stage was set for a conflict between incompatible, competing water uses.

Lake Level and Power Alternatives

A draft environmental impact statement (TVA, 1990a) recommended alternative 1 which suggests a high reservoir fill by June 1, followed by restricted drawdown until August 1, followed in turn by 'unrestricted drawdown' through the rest of the year. Fig. 1 shows alternative 1 (August 1), and another alternative (Labor Day) as compared to 'No Action' which stands for

[1] Water-Wunderlich Consulting, 3221 Essary Drive, Knoxville, Tennessee 37918 (615/687-6591).

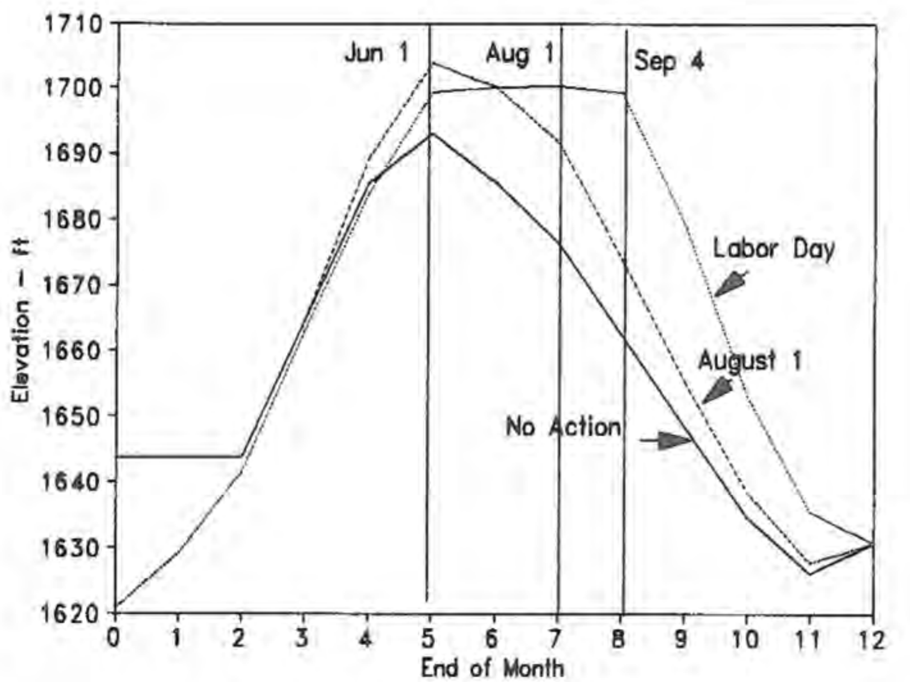

Fig. 1. Comparison of lake level alternatives for Fontana for lower minimum flows. Lake levels are higher than those shown in 50% of years. Above El 1710 is the vegetated zone {after TVA Final Environmental Impact Statement (TVAb)}: No Action: present operation; August 1: alternative 1 (recommended by TVA); Labor Day: an alternative rejected by TVA.

present operation. August 1 is also called 'mid summer' in the report. One could also call it 'mid tourist season.' It does not seem reasonable to propose an unrestricted drawdown at such a point in time in response to local demands for recreation development needs. Most comments expressed hope that the levels be held up beyond August 1 (TVA 1990b). There would be increased power costs with higher lake levels. But what was expected here was improved multipurpose water management. A minor drawdown throughout the recreation season from June 1 through September 4 could probably be sustained by recreation use. Four more alternatives were analyzed in response to comments but all were rejected (TVA, 1990b). The analysis procedure used was also not designed to find a multipurpose optimal policy among a myriad of possible alternatives. The one that pulls the plug on August 1 was a sort of minimum power impact solution.

Any results on the subject produced by the TVA can only be the product of an inhouse conflict of interest, as the agency is steward of multipurpose operation and power company at the same time. TVA's power program had made a prior commitment to its clientele to keep the lid on power rates for the next few years in the face of continuing troubles with its nuclear program. It should not be surprising then if a ($5-billion budget) power tail wags a ($135-million budget) water resources dog while trying to appease fierce outside power interests.

Years ago when it became clear that nuclear reactors would be so inflexible to allow only the production of steady base load, this was also bad news for the water system, as hydropower would remain for any foreseeable future the almost indispensable source of cheap peaking power. But since it was so cheap it was also there to be depleted, by running it 12 hours and more a day, even in lieu of available thermal power and pumped storage, let alone even more expensive gas- and oil-fired combustion turbines, just to make sure all the water got through the turbines in time. The 'No Action' water levels in Fig. 1 reflect this approach. Interestingly, a 'refined analysis' (TVA 1990b) did not require additional capacity for alternative 1, as it could be generated elsewhere. Still, TVA did hardly dare to submit the final report to public scrutiny. A local power watchdog group promptly took offense of even this minimum plan (Knoxville News Sentinel, Dec. 25, 1990).

Funding of Operation Changes

The TVA study (1990a and b) comes to the conclusion that the people who want more recreation must pay for the power foregone. And if this should be impractical, the taxpayers at large (in the form of federal appropriations) should pay. The taxpayer already pays for flood control and navigation, whether he gets it or not, he may as well pay for recreation. But here comes the additional twist: he is supposed to pay for power forgone. After power has increasingly encroached on the water system it now wants to be paid off.

In principle, all beneficiaries should pay for what they get. But since the resource is limited and the demand exceeds supply, each can only get a fair share. If no consideration is given to objectives other than navigation, flood control and hydropower, then there is a shortfall of benefits to other regional objectives such as recreation. Objectives that now take it all must relinquish their share of the overallocation. At one point, the TVA report recommends that "TVA should provide releases where ways can be found to compensate residential customers for hydropower losses." It would be more appropriate for a regional development agency to say "...where it can enhance economic development and overall regional wellbeing."

Using power as a criterion for judging the feasibility of other uses is wrong for several reasons: (1) Reducing power benefits and thereby enhancing recreation benefits could increase total system benefits, as illustrated in Fig. 2. Unless the TVA is a mere power company it cannot ignore this fact. (2) Power values are distorted by power system characteristics and the wasteful use of energy. Assume power consumption is a sort of addiction in a group of consumers. Then it would be unfair to spend the resource budget of the group exclusively on power in lieu of other goodies that the non-addicts would cherish. Splitting the resource budget among the group would be a better deal. (3) A reduction in one benefit is usually required for a gain in another, unless the alternative use is insensitive to how much of the resource is spent. Thus, a reduction in one benefit tells only part of the story. (4) A regional development program requires a balanced approach that may demand valuing objectives at a higher than a possibly only partly representative monetary value.

Legal Mandate

A major reallocation may require a project re-authorization, but here a re-interpretation of the existing legal mandate is all that is needed. A reservoir operation policy is basically a technical interpretation of the legal mandate that accomplishes what is expected from the project. For example, the TVA advocates the position that its power program must be compensated if water is released without producing power for any purpose other than flood control and navigation. This position is based on section 9a of the TVA Act which states that the board is "authorized, whenever the opportunity is afforded, to provide and operate facilities for the generation of electric energy in order to avoid a waste of water power" and "so far as may be practicable to assist in liquidating the cost." These passages very clearly give the board 'authority' to decide what constitutes a waste of water and when it is practicable to make money. The Act clearly does not 'direct' the board to allocate water to hydropower, after navigation and flood control, under all circumstances, especially when there are other valid objectives to be served beside making power and money. The Act gives another hint of its intent in its concluding section 31, where it says that the Act "shall

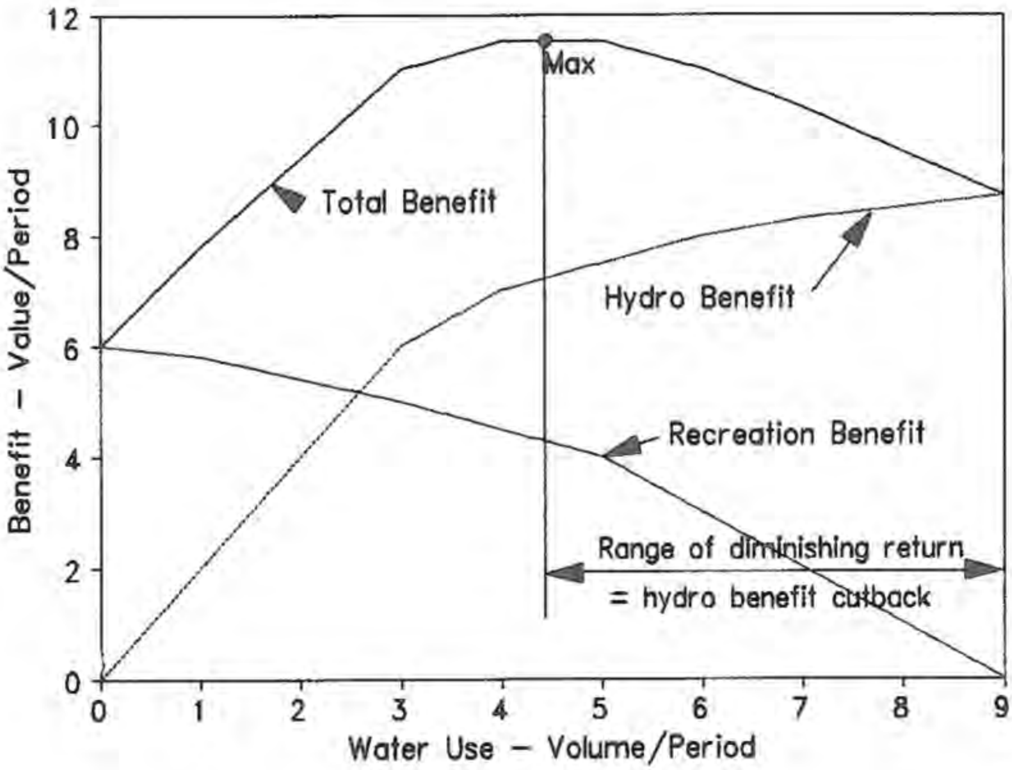

Fig. 2. Total benefit is the sum of hydro benefit and recreation benefit, both shown as function of water use during a period. The maximum total benefit occurs where the rate of diminishing benefit (recreation) is just equal to the rate of increasing benefit (hydro). The range of diminishing return extends from there onward (for higher water use) and is equal to the hydro benefit cutback that is required to maximize total benefit.

be liberally construed to carry out the purposes of Congress...," here not even mentioning hydropower as an overriding objective. To liberally construe the Act in context with the TVA program can only mean to pursue a holistic approach to multipurpose resource development aimed at the general wellbeing of the region. There can be no reasonable doubt that the Act fully endorses equitable and environmentally sound reservoir operations, even though it remains silent on specifics, as they may not have been recognized as important or opportune at the time.

Summary

In an environmental impact statement on contemplated reservoir operation changes, TVA comes to the conclusion that some minor adjustment in reservoir levels (alternative 1) is all that can be afforded (by the power interest) to meet the needs of the so far neglected recreation interest. This adjustment was hailed by the TVA board as the biggest step in 50 years and attacked by power watchdogs as a giveaway. The TVA concludes that the recreation interest must pay the cost that accrues to the power interest (less than 1 percent of the annual average power value) or the general taxpayer must pay. This conclusion is based on a long-standing misinterpretation of the TVA Act. Actually the sections 9a and 31 clearly enable the TVA board to conduct reservoir operations that meet TVA's regional development goals. Water operations that enhance regional economic development can hardly be construed as 'waste of water.' Fig. 2 illustrates how a cutback in hydro benefits can serve these goals. Consequently, those who received power over-allocations up to now must simply give them up, instead of receiving taxpayer subsidies in perpetuity. Actually a much larger reduction in hydropower benefits than the one proposed by TVA may be justified without compensation to the power interest.

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IMPLICATIONS AND IMPACTS OF TVA'S QUALITY INITIATIVE ON OPERATION OF WATER RESOURCES PROGRAMS

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Total quality management has become the fundamental business concept in today's world. In July of 1990, Marvin Runyon, Chairman of the Board of Directors of the Tennessee Valley Authority, announced that TVA would join the quality revolution. Plans were put in motion to develop a total quality initiative. First among those plans was to train 140 employees to conduct quality assessments using the criteria of the Malcolm Baldridge National Quality Award. Although TVA is not eligible to compete for the award, the criteria provide a good measurement tool for quality efforts. Assessors were trained last fall. TVA was divided into more than 150 business units for assessment purposes. Last winter, assessment teams began evaluating business units within the agency. So far, half of the business units have been assessed. The rest will be assessed this fall.

The Water Resources Division was assessed in March. The criteria do not attempt to evaluate the technical quality of work being done. Rather, they address the manner in which business is conducted to ensure that operational practices support quality work. During the course of the Water Resources assessment, about one-third of our employees were interviewed. The interviews focused on leadership, information and analysis, strategic planning, human resource utilization, quality assurance of products and services, quality results, and customer satisfaction. The information gathered in the interviews was consolidated and presented as a listing of strengths and opportunities for improvement.

Copies of the report were provided to all employees. Managers were asked to discuss the report with employees and to identify key opportunities to be addressed first. We were especially interested in examining any areas in which fundamental changes in how we do business would convert multiple opportunities into strengths.

Total quality management is often defined as "Do the right things right the first time." When we reviewed our opportunities for improvement in that light, we found a direction in which to begin our improvement efforts. Each part of the statement is critical. With respect to water resources activities, we are now trying to determine just what the right things are as perceived by our customers, just how the customers define the right results, and how we can put in place practices which ensure that errors don't arise.

We have established teams which are examining major areas of our work. One team is examining the way in which we operate the reservoir system to meet the needs of multiple users. A second is reviewing our efforts at improving the quality of the water in the system. The third is looking at how we serve our internal customers. Collectively, these evaluations will address about three-quarters of the work traditionally done in Water Resources.

The approach being applied in each area is called value chain analysis. It requires that we address such questions as:

[1] Tennessee Valley Authority, Water Resources Division, Evans Building 1A, Knoxville, Tennessee 37902-1499 (615/632-6770).

- How is value measured in this program?

- What key decisions and activities affect value?

- What uncertainties influence realized value?

- How do our current resources contribute to the value added?

- How do external support services contribute to value?

Since value is something determined by the user of a product or service (that is, the customer), this type of analysis will lead us to a customer-driven definition of what the right things are in terms of the work done by the water resources business unit. It will also tell us how best to increase the value of our programs to our customers.

Quality management is a dynamic process which requires continuous improvement in products and services. As we adjust our way of doing business, our customers and suppliers will become more involved in our work. We will maintain a better customer orientation, with our customers defining quality for us.

The process we are applying will help us achieve more cohesiveness in our programs, thus simplifying program delivery. As a result, our customers will find it easier to reach the right person and to get the right answers. Customers will also be more involved in setting program direction.

As we change what we do and how we do it, our customers and our suppliers will become part of the process of program delivery. Our working relationships with other agencies, with conservation and citizen action groups, and with individuals will change. Our improved focus is on delivery of water resources programs to the people of the region in the manner which most effectively meets the needs of the user.

WATER DEMAND FORECASTING IN THE UPPER DUCK RIVER BASIN IN CENTRAL TENNESSEE

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U.S. Geological Survey
Memphis, Tennessee

A study is in progress to determine whether the present water resources of the upper Duck River basin are adequate to meet future water demand without an additional storage reservoir on the Duck River. Water demand in the basin has increased substantially since 1980 as a result of industrial development. The Duck River is the major source of supply for industrial and public water systems of the area.

To simulate and to forecast water demand in the basin, socioeconomic and climatic data were input to the mathematical model, IWR-MAIN (Institute of Water Resources-Municipal and Industrial Needs). Calibration of the model was accomplished by comparing water use for 1980 and 1989 to water-demand predictions for those years.

The estimated future demand for water generated by the model will then be compared to the available surface- and ground-water resources in the basin. The surface-water data are being analyzed to define low flow and flow-duration characteristics of the Duck River and the ground-water data are being evaluated to determine the occurrence of ground-water available for future development. A comparison of the available resources and projected water demand are expected to indicate whether or not the Duck River, without further regulation, and aquifers in the basin are capable of supplying the water needed to meet the projected demand, or if additional impoundment of the river will be needed.

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THE STATUS OF TENNESSEE'S WATER QUALITY STANDARDS

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History of Standards

Tennessee first adopted water quality standards in 1967 and has amended them several times since. Three essential elements comprise water quality standards as defined by Section 303 of the Federal Clean Water Act (CWA), PL 95-217 et seq., namely, the antidegradation statement, the stream use classifications, and the water quality criteria. Tennessee's criteria specify baseline values for particular parameters of water quality necessary for the protection and maintenance of a prescribed use classification. The criteria define the instream quality necessary to support each classified use and establish limits on various chemical and physical parameters. In addition, the criteria delineate general considerations and objectives for establishing water quality standards, definitions of terminology related to the criteria, and a basis for interpretation of the criteria. The effective date of "Tennessee's Water Quality Criteria and Stream Use Classification for Interstate and Intrastate Streams" was February 2, 1987, and was last approved by the Environmental Protection Agency (EPA) on June 26, 1987. Tennessee's currently proposed Water Quality Standards consist of two chapters, General Water Quality Criteria, Rule 1200-4-3, and Use Classifications for Surface Waters, Rule 1200-4-4.

Review and Amendment of Standards

Modification of water quality criteria or stream use classifications is a function of the Water Quality Control Board. Section 303(c)(2)(B) of the CWA as amended February 4, 1987, states:

(B) Whenever a State reviews water quality standards pursuant to paragraph (1) of this subsection, or revises or adopts new standards pursuant to this paragraph, such State shall adopt criteria for all toxic pollutants listed pursuant to section 307(a)(1) of this Act for which criteria have been published under section 304(a), the discharge or presence of which in the affected waters could reasonably be expected to interfere with those designated uses adopted by the State, as necessary to support such designated uses. Such criteria shall be specific numerical criteria for such toxic pollutants. Where such numerical criteria are not available, whenever a State reviews water quality standards pursuant to paragraph (1), or revises or adopts new standards pursuant to this paragraph, such State shall adopt criteria based on biological monitoring or assessment methods consistent with information published pursuant to section 304(a)(8). Nothing in this section shall be construed to limit or delay the use of effluent limitations or other permit conditions based on or involving biological monitoring or assessment methods or previously adopted numerical criteria.

Tennessee maintains a policy consistent with federal requirements to review its water quality standards every three years. This process is known as the triennial review. Federal regulations require that the triennial review be a public participation process. The public is invited to comment on or suggest any revision to Tennessee's water quality standards. After the public has had an

[1] Tennessee Department of Environment and Conservation, Division of Water Pollution Control, Nashville, Tennessee 37247-3001 (615/741-6623).

opportunity to voice concerns with the existing standards and the proposed revisions, the revised standards are presented to the Tennessee Water Quality Board for adoption and later submitted to the EPA for approval. The Division of Water Pollution Control (WPC) conducted the triennial review in accordance with federal guidelines and the Tennessee Uniform Administrative Procedures Act during 1990-91.

The substantive changes proposed to Rule 1200-4-3 include: 1) the addition of a dioxin criterion for recreational stream uses (human health protection), 2) the addition of numerical criteria for toxic substances and the accompanying detection levels for these criteria, and 3) language which allows the development of a water quality criterion based on the toxic portion of the numerical criterion, so that the state may adopt a modified limit when necessary.

The substantive changes proposed to Rule 1200-4-4 include numerous changes to specific stream use classifications; corrections of typographical errors, inaccuracies in recreational use deletions, and inaccuracies in discharger locations or dischargers that have ceased discharging; and the designation of several trout streams as supporting a naturally reproducing population.

On January 17, 1991, the Water Quality Board voted unanimously to promulgate and adopt Tennessee's revised Water Quality Standards (Rule Chapters 1200-4-3 and 1200-4-4). These standards have been sent to the Office of the Attorney General and will be forwarded to the Secretary of State for final review. Once approved by the Attorney General and the Secretary of State, these standards will be submitted to the EPA Region IV Administrator for review. EPA will then have 60 days to either notify Tennessee of approval of these standards or up to 90 days to notify the state of disapproval of these standards.

A major impetus for promulgation of these water quality standards, however, will be the establishment of national numeric criteria in 1991 for states that have failed to comply with 303(c)(2)(B) (Federal Register, 1990):

This action may establish on a national basis, numeric water quality criteria for toxic pollutants that will become part of the water quality standards of states that have failed to comply with Section 303(c)(2)(B) of the CWA, thus, bringing those standards into compliance with the CWA, as amended.

Antidegradation

Each state must develop, adopt, and retain a statewide antidegradation policy in the water quality standards and identify methods for implementation through the state water quality management process. Federal requirements mandate that, at a minimum, the policy include the following components:

1. Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.

2. When the quality of waters exceed levels needed to support fish, shellfish, wildlife, and recreation in and on the water, that quality shall be maintained and protected unless the state finds that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located.

3. Where high quality waters constitute an outstanding national resource, such as waters of national and state parks and wildlife refuges and waters of exceptional recreational or ecological significance, that water quality shall be maintained and protected.

4. In cases where potential water quality impairment associated with a thermal discharge is involved, the antidegradation policy and implementing method shall be consistent with Section 316 of the CWA.

Use Classifications

Tennessee's criteria specify baseline values for particular parameters of water quality necessary for the protection and maintenance of a prescribed use classification. The state has established seven principal uses of the waters for which criteria of water quality are defined. These uses are 1) domestic water supply, 2) industrial water supply, 3) fish and aquatic life, 4) recreation, 5) irrigation, 6) livestock watering and wildlife, and 7) navigation. The criteria define the instream quality necessary to support each classified use and establish limits on various chemical and physical parameters. In addition, the criteria delineate general considerations and objectives for establishing water quality standards, definitions of terminology related to the criteria, a basis for the interpretation of the criteria, and Tennessee's antidegradation policy.

Tennessee's use classifications assign the criteria, as defined for each reasonable and necessary use, to all the surface waters of the state. For example, a particular stream or stream segment may be classified for any or all of the seven recognized uses. The specific uses assigned to this stream or stream segment determine the applicable instream water quality criteria for the protection and maintenance of that stream.

There are approximately 286 individual stream segments within the State of Tennessee which are not classified for recreational use in the 1987 water quality standards because of the proximity of domestic or municipal treatment facility outfalls. These stream segments total about 528 river miles. The Division's practice, however, has generally been to establish disinfection requirements on these domestic discharges. As a result, almost all domestic wastewater facilities in Tennessee are designed to be capable of disinfection. The Division is proposing to change the classification of all of these waters to include recreation. This classification upgrade will allow a regulatory basis to apply the numerical toxic limits for recreation to these waters. These limits are established to protect the health of consumers of fish taken from these waters.

Summary of Proposed Numeric Criteria

Tennessee's 1987 Water Quality Standards contain only 10 numerical limits for the use classification of domestic water supply. Since the first staff proposal for the 1987-90 standards was issued in May 1989, numerous reviews and comments were provided to the Division and revisions and additions to these proposed standards were made. The original proposal included numerical criteria for a total of 56 toxic pollutants, with 23 established limits for domestic water supply, 19 for fish and aquatic life and 44 for human health (recreation). The current version contains 18 numerical limits for domestic water supply, 25 for fish and aquatic life, and 73 for human health. This list of numeric criteria now contains a total of 86 toxic compounds. Table 1 is a summary sheet of Tennessee's proposed Water Quality Criteria.

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Table 1. Tennessee Water Quality Criteria - Summary Sheet. January 17, 1991.

TABLE 1. TENNESSEE WATER QUALITY CRITERIA - SUMMARY SHEET January 17, 1991

(#) COMPOUND	DOMESTIC WATER SUPPLY (µg/l)	FRESHWATER FISH & AQUATIC LIFE Criterion Maximum Conc. (CMC) (µg/l)	FRESHWATER FISH & AQUATIC LIFE Criterion Continuous Conc. (CCC) (µg/l)	RECREATION (10^{-5} risk factor for carcinogens) Organisms Only (µg/l)	REQUIRED DETECTION LEVEL (RDL) (µg/l)
INORGANICS					
1 Antimony	-	-	-	4310	1
2 Arsenic, total (c)	50	-	-	-	1
Arsenic (III) (c)	-	360	190	-	1
3 Beryllium (c)	-	-	-	1.3	1
4 Cadmium [1]	10	4 [3]	1 [3]	-	1
Chromium, total	50	-	100	-	1
5 Chromium (III)	-	-	-	670000	1
Chromium (VI)	-	16	11	-	10
6 Copper [1]	-	18 [3]	12 [3]	-	1
7 Lead [1]	50	82 [3]	3 [3]	-	1
8 Mercury	2	2.4	0.012	0.15	0.2
9 Nickel [1]	-	1400	160	4600	10
10 Selenium	10	20	5	-	1
11 Silver [1]	50	4 [3]	-	-	1
13 Zinc [1]	-	117 [3]	106 [3]	-	1
14 Cyanide	-	22	5.2	-	20
16 Dioxin [4]	-	-	-	0.000001	0.00001
VOLATILES					
17 Acrolein	-	-	-	780	1
18 Acrylonitrile (c)	-	-	-	6.7	1
19 Benzene (c)	5	-	-	710	1
20 Bromoform - Tribromomethane (c)	-	-	-	4700	1
21 Carbon tetrachloride (c)	5	-	-	44	1
26 Chloroform - Trichloromethane (c)	-	-	-	4700	0.5
27 Dichlorobromomethane (c)	-	-	-	4700	1
29 1,2-Dichloroethane (c)	5	-	-	990	1
30 1,1-Dichloroethylene (c)	7	-	-	32	1
32 1,3-Dichloropropylene	-	-	-	1700	1
33 Ethylbenzene	-	-	-	29000	1
35 Methyl chloride - Chloromethane (c)	-	-	-	4700	1
36 Methylene chloride - Dichloromethane (c)	-	-	-	16000	1
37 1,1,2,2-Tetrachloroethane (c)	-	-	-	110	0.5
38 Tetrachloroethylene (c)	-	-	-	88	0.5
39 Toluene	-	-	-	300000	1
41 1,1,1-Trichloroethane	200	-	-	170000	1
42 1,1,2-Trichloroethane (c)	-	-	-	420	0.2
43 Trichloroethylene (c)	5	-	-	807	1
44 Vinyl chloride (c)	2	-	-	5250	2

Table 1 (Continued). Tennessee Water Quality Criteria - Summary Sheet. January 17, 1991.

TABLE 1 (CONTINUED).	TENNESSEE WATER QUALITY CRITERIA				January 17, 1991
(#) COMPOUND	DOMESTIC WATER SUPPLY (µg/l)	FRESHWATER FISH & AQUATIC LIFE Criterion Maximum Conc. (CMC) (µg/l)	Criterion Continuous Conc. (CCC) (µg/l)	RECREATION (10^{-5} risk factor for carcinogens) Organisms Only (µg/l)	REQUIRED DETECTION LEVEL (RDL) (µg/l)
ACID EXTRACTABLES					
48 2-Methyl-4,6-dinitrophenol-4,6-Dinitro-o-cresol	-	-	-	765	50
49 2,4-Dinitrophenol	-	-	-	14000	50
53 Pentachlorophenol	-	20 [2]	13 [2]	-	5
55 2,4,6-Trichlorophenol (c)	-	-	-	6.5	5
BASE NEUTRALS					
57 Acenaphthylene (c)	-	-	-	0.3	2.3
58 Anthracene	-	-	-	0.03	0.7
60 Benzo(a)anthracene (c)	-	-	-	0.3	0.3
61 Benzo(a)pyrene (c)	-	-	-	0.3	0.3
62 3,4-Benzofluoranthene (c)	-	-	-	0.3	0.3
64 Benzo(k)fluoranthene (c)	-	-	-	0.3	0.3
66 Bis(2-Chloroethyl)ether (c)	-	-	-	14	1
68 Bis(2-Ethylhexyl)phthalate(c)	-	-	-	59	5
73 Chrysene	-	-	-	0.03	0.3
75 1,2-Dichlorobenzene	-	-	-	17000	2
76 1,3-Dichlorobenzene	-	-	-	2600	2
77 1,4-Dichlorobenzene - para-Dichlorobenzene	75	-	-	2600	2
79 Diethyl phthalate	-	-	-	120000	10
80 Dimethyl phthalate	-	-	-	2900000	10
81 Di-n-Butyl phthalate	-	-	-	12000	10
82 2,4-Dinitrotoluene (c)	-	-	-	42	1
86 Fluoranthene	-	-	-	54	10
87 Fluorene	-	-	-	0.03	0.3
88 Hexachlorobenzene (c)	-	-	-	0.007	0.05
89 Hexachlorobutadiene (c)	-	-	-	500	5
91 Hexachloroethane (c)	-	-	-	89	0.5
95 Nitrobenzene	-	-	-	1900	10
99 Phenanthrene	-	-	-	0.03	0.7
100 Pyrene	-	-	-	0.03	0.3

Table 1 (Continued). Tennessee Water Quality Criteria - Summary Sheet. January 17, 1991.

TABLE 1 (CONTINUED). TENNESSEE WATER QUALITY CRITERIA January 17, 1991

(#) COMPOUND	DOMESTIC WATER SUPPLY (µg/l)	FRESHWATER FISH & AQUATIC LIFE Criterion Maximum Conc. (CMC) (µg/l)	Criterion Continuous Conc. (CCC) (µg/l)	RECREATION (10^{-5} risk factor for carcinogens) Organisms Only (µg/l)	REQUIRED DETECTION LEVEL (RDL) (µg/l)
PESTICIDES					
102 Aldrin **(c)**	-	3	-	0.0014	0.5
105 g-BHC - Lindane **(c)**	4	2	0.08	0.63	0.5
107 Chlordane **(c)**	-	2.4	0.0043	0.006	0.1
108 4-4'-DDT **(c)**	-	1.1	0.001	0.006	0.1
109 4,4'-DDE **(c)**	-	-	-	0.006	0.1
110 4,4'-DDD **(c)**	-	-	-	0.008	0.1
111 Dieldrin **(c)**	-	2.5	0.0019	0.0014	0.05
112 a-Endosulfan	-	0.22	0.056	2.0	0.1
113 b-Endosulfan	-	0.22	0.056	2.0	0.05
115 Endrin	0.2	0.18	0.0023	-	0.1
117 Heptachlor **(c)**	-	0.52	0.0038	0.002	0.05
118 Heptachlor epoxide **(c)**	-	0.52	0.0038	0.001	0.08
119 PCB-1242 **(c)**	-	-	-	0.0005	0.5
120 PCB-1254 **(c)**	-	-	-	0.0005	0.5
121 PCB-1221 **(c)**	-	-	-	0.0005	0.5
122 PCB-1232 **(c)**	-	-	-	0.0005	0.5
123 PCB-1248 **(c)**	-	-	-	0.0005	0.5
124 PCB-1260 **(c)**	-	-	-	0.0005	0.5
125 PCB-1016 **(c)**	-	-	-	0.0005	0.5
PCB, total **(c)**	-	-	0.001	0.001	0.5
126 Toxaphene **(c)**	5	0.73	0.0002	0.008	0.5

[1] Freshwater aquatic life criteria for these metals are expressed as a function of total hardness (mg/l), as follows (values displayed above correspond to a total hardness of 100 mg/l):

$CMC = \exp(m_A[\ln(hardness)] + b_A)$ $CCC = \exp(m_C[\ln(hardness)] + b_C)$

	m_A	b_A	m_C	b_C
Cadmium	1.128	-3.828	0.7852	-3.490
Copper	0.9422	-1.464	0.8545	-1.465
Lead	1.273	-1.460	1.273	-4.705
Nickel	0.8460	3.3612	0.8460	1.1645
Silver	1.72	-6.52		
Zinc	0.8473	0.8604	0.8473	0.7614

[2] Freshwater aquatic life criteria for pentachlorophenol are expressed as a function of pH. Values displayed above correspond to a pH of 7.8 and are calculated as follows:

$CMC = \exp(1.005(pH) - 4.830)$ $CCC = \exp(1.005(pH) - 5.290)$

[3] Values presented are for the dissolved form of this metal.

[4] Value applies to total of toxicity equivalent factors (TEFs) of all isomers of dioxin and dibenzofurans.

(c) = carcinogen

STORMWATER NPDES PERMIT WORKPLAN FOR INDUSTRIAL INDIVIDUAL PERMIT APPLICATION

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Introduction

The so-called "nonpoint sources" of pollution are major contributors to the degradation of the quality of our nation's surface waters. In a 1989 report, the U.S. Environmental Protection Agency (EPA) stated that 65% of river pollution, and 76% of lake pollution, originate from nonpoint sources. Most stormwater discharges have been historically treated as nonpoint sources. However, after many years of attempting to deal with the issue, EPA has finally promulgated comprehensive regulations for stormwater under the National Pollutant Discharge Elimination System (NPDES) program (EPA, 1990). Included under the purview of the new regulations are stormwater discharges "associated with industrial activity." As a result, thousands of industries in Tennessee must soon file applications for stormwater discharge permits. This paper presents a generic workplan for completing an Individual Permit application for stormwater associated with industrial activity.

Overview of Permit Application Requirements

The NPDES regulations identify the types of industrial activities that require stormwater discharge permits. If a permit is required for a particular facility, or a portion of the facility, the regulations provide three means for permitting the discharge:

General Permit

If a General Permit has been issued which covers the facility, the facility may choose to file a "Notice of Intent" to be covered under the permit.

Group Application

Facilities which fall within a group of similar industries may qualify for inclusion in a Group pplication.

Individual Permit

A facility not qualified for coverage under a General Permit or a Group Application must apply for an Individual Permit.

Workplan for Individual Industrial Permit Application

The information and data requirements for an Individual Permit application are relatively extensive, and are to be reported on EPA's Form 2F. The following workplan describes, in general, the activities and analyses necessary for completing the permit application. The author has prepared a checklist, keyed to Form 2F, which provides more detailed guidance in conducting the application study and in completing the application form. The checklist is available from the author upon request.

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Step 1: Interviews, Site Inspection, and Information Collection

- Interview facility personnel to collect information on the environmental history of the site, facility operations, raw materials used, and intermediate and final products.

- Inspect the site to obtain information on the facility layout, the drainage system arrangement, and the potential sampling station locations.

- Collect all available relevant documents such as maps, drawings, permits, and environmental data and reports.

Step 2: Preparation of Site Base Map

- Review all available relevant information and prepare a base map of the site.

Step 3: Testing the Stormwater System

- Evaluate all relevant existing drawings, results of previous testing, and other information relative to the layout of the stormwater drainage system, or to nonstormwater connections to the stormwater system.

- Develop a plan for performing testing for nonstormwater discharge and for resolving any remaining questions about the layout of the stormwater drainage system.

- Perform appropriate field tests to verify that nonstormwater sources do not discharge to the stormwater system, and/or to resolve any questions relative to the layout of the stormwater drainage system. These may include dye tracer tests, smoke tests, water tests, temperature tests, or conductivity tests.

- Document the results of the testing.

Step 4: Information Evaluation and Project Planning

- Evaluate the data for completeness, and obtain any additional information needed.

- Prepare calculations of drainage areas, and prepare a composite map showing all required general site and vicinity information.

- Prepare a sampling and analysis workplan. This plan is a brief description of how samples will be collected, where they will be collected, the basis for the selection of the sampling stations, the analyte list, and the basis for the analyte list.

Step 5: Review of Workplan by the State

- Submit the plan to, or discuss the plan informally with, the State. Revise if necessary. It is desirable to obtain the State's preliminary approval of the sampling plan prior to plan implementation.

Step 6: Installation of Sampling and Rainfall Stations

- Install a rainfall monitoring station at the site.

    * Use a visually read graduated gage if rainfall is to be manually monitored.

    * Use an electronically logged tipping bucket or weighing bucket gage if rainfall is to be automatically monitored.

- At each sampling station:

    * Install a continuous sampler/flow meter that can collect grab samples and flow-weighted samples.

    * Or, set up for manual sampling and compositing. (Develop a hydraulic rating relationship, install a staff gage for direct reading of stage or an electronic logger for recording stage, establish the specific location for sample collection, and establish an appropriate sampling and compositing procedure.)

Step 7: Event Sampling, Sample Retrieval, and Sample Submittal

- Coordinate with facility personnel relative to rainfall monitoring and initiation of sampling activities.

- Sample one or more rainfall events, as appropriate. For automatic sampling, the number of events may depend on the analyte list due to sample volume requirements and sampler capacity.

- For manual sampling, construct the hydrograph for the event and develop sample proportioning (flow weighted) ratios.

- Analyze rainfall and runoff data to obtain event data (depth and duration), peak flow rate, and runoff volume.

- Collect composite and grab samples and submit the samples to a laboratory for analysis, or coordinate with facility personnel for sample collection and submittal, as appropriate.

Step 8: Laboratory Analysis and Data Review

- Obtain a laboratory analysis of the samples.

- Review the laboratory results for data quality.

- Prepare the laboratory results for inclusion in Form 2F.

Step 9: Completion of Form 2F

- Using the information and data collected above, complete the application form, Form 2F.

Summary

The above workplan presents a general approach to collecting the data and information necessary to complete the Individual Permit application. The level of effort required for a particular facility is highly dependent on several factors, including:

- The availability, accuracy, condition, and format of existing data and information about the facility, and the degree to which facility personnel are knowledgeable about the plant drainage system and environmental management practices;

- The chemical complexity of the facility operation, and the degree to which facility personnel are knowledgeable about the chemistry of raw materials, intermediate and final products, and wastes;

- The degree to which the stormwater system is accurately defined, and the extent of field testing required;

- The number and types of pollutants that must be analyzed; and

- The number and physical nature of the sample point locations.

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A CONCEPTUAL MODEL FOR WATER FLOWS IN THE FRACTURED ROCKS OF TENNESSEE [1]

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Many of the hydrogeologic characteristics of the Oak Ridge Reservation (ORR) of U.S. Department of Energy are typical of fractured rocks elsewhere in East and Middle Tennessee. The subsurface materials consist of a nearsurface stormflow zone, a vadose (unsaturated) zone, and a groundwater zone (Fig. 1). The stormflow zone approximately corresponds with the root zone of vegetation and is much more permeable than the vadose zone. Rainfall events produce a transient, perched water table in the stormflow zone, and water then flows downslope toward the streams. The specific yield of the stormflow zone on the ORR is about 0.025-0.040 (Moore 1991), but the main openings for water flows are macropores (>0.2 mm in diameter), which have a decimal fraction porosity of about 0.002 (Watson and Luxmoore 1986, p. 581). The connected macropores have various causes, including root channels, worm tubes, and aggregation of soil particles. Hydrograph analysis (Moore 1991) and infiltration tests under saturated conditions (Watson and Luxmoore 1986) indicate that the average hydraulic conductivity of the stormflow zone is about 9.0 m/d. Virtually all precipitation is absorbed by vegetated soils; overland runoff occurs mainly on saturated soils, where the stormflow zone has filled to overflowing.

Water level records for 17 stormflow monitoring tubes installed to depths of 80 cm show that all tubes had water inflows during some rainfall events, thereby indicating saturated conditions and a perched water table. However, tubes on steep slopes and in gullies generally had water inflows during small events whereas larger or more intense events were required to produce inflows to tubes near a drainage divide and on smooth and shallow slopes. These data and hydrograph analysis indicate (1) stormflow is transient but constitutes a large majority of base streamflow, (2) stormflow is discharged from partial contributing areas after all but the largest precipitation events, and (3) the local hydraulic gradient and the relative permeabilities of the stormflow zone and the vadose zone determine the relative amounts of stormflow discharge and groundwater recharge.

Flow paths in the vadose zone are nearly vertical; flow rates are mostly determined by the local saturated hydraulic conductivity. The average specific yield and hydraulic conductivity of the vadose zone are nearly the same as those of the groundwater zone (Moore 1989, pp. 30-50), and most water in the vadose zone probably flows through fractures in regolith. Fractures are pervasive on the ORR, and a large majority constitute a single cubic system (three orthogonal sets; Dreier et al. 1987; Sledz and Huff 1981). One fracture set is formed by bedding planes; the two joint sets are approximately strike parallel and dip parallel.

The water table on the ORR is near the regolith and bedrock contact in most areas. A convergence of evidence indicates that most groundwater is transmitted through a

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ORNL-DWG 91M-1513

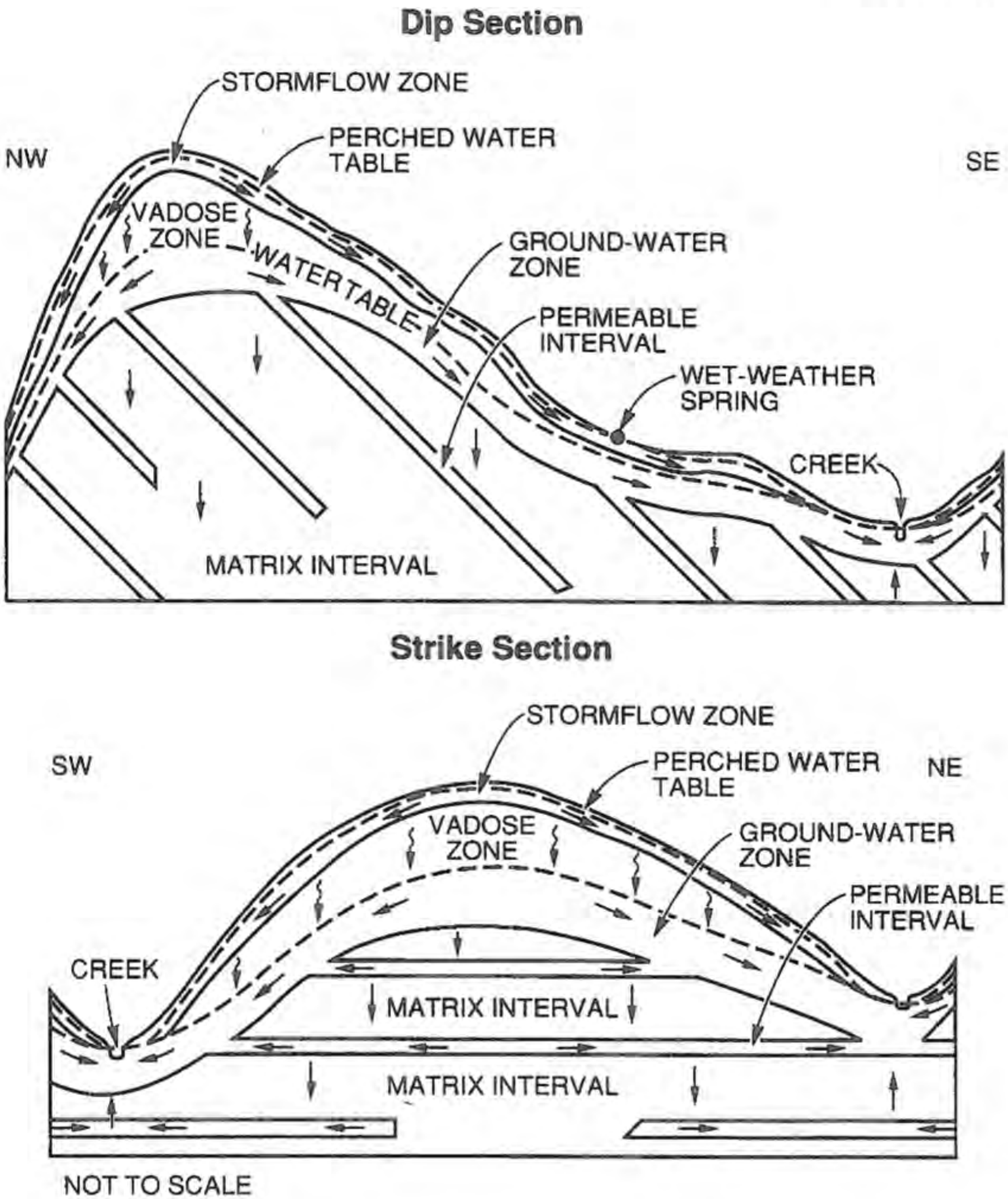

Figure 1. Hydrogeologic zones and directions of water flow.

network of pervious, connected fractures near the water table. The hydrologic importance of a permeable layer near the water table was first postulated by Webster (1976, pp. 10-11) and Webster and Bradley (1987, pp. 29-30, 79). This hypothesis was questioned by other workers (including the present author) for some years because slug tests show no difference in the average hydraulic conductivity of regolith and bedrock. New interpretations of the data indicate that the key features of this layer are spatial and temporal differences in saturated thickness and thus of differences in transmissivity. Regolith above this level has been formed by a large water flux, and the presence of unweathered bedrock at deeper levels indicates a smaller water flux. Seasonal changes in water table elevation change the saturated thickness of the permeable layer. The resulting changes in transmissivity explain an order of magnitude fluctuation in groundwater discharge rates (base streamflows) even though (l) contours of annual high and low water table elevations show little change in hydraulic gradient and (2) seasonal changes of water level in most wells are small compared with heights above stream level. Opposite changes in hydraulic gradient and saturated thickness from one physiographic location to another explain the common observation that "the water table is a subdued replica of land surface" (Stockdale 1951, p. 50) because the product of transmissivity and hydraulic gradient is constant at all locations along a flow path. Most groundwater near the water table flows in the direction of the maximum hydraulic gradient. The remainder follows fracture flow paths that lead to deeper levels.

Below the permeable layer near the water table, the groundwater zone consists of a few permeable fracture intervals in a relatively impermeable matrix. Surveys of 40 wells with an electromagnetic borehole flowmeter show that the thickness (vertical dimension) of the permeable intervals is about 25-250 cm and averages about 70 cm. The surveys also show that most of the water-producing fractures have nearly the same hydraulic conductivity over the entire thickness of a permeable interval. This evidence suggests that most water-producing fractures are joints, which span one to several beds and terminate at bedding plane fractures. Analyses of well logs and the depths of paired shallow and deeper wells show that the vertical spacing between permeable intervals increases from about 7 m near the water table to >35 m below a depth of 60 m. Transmissivity data from 760 slug tests, packer tests, and pumping tests are lognormally distributed for both permeable and matrix intervals. The geometric mean of transmissivity for permeable intervals is 0.23 m^2/d, and the average hydraulic conductivity for a thickness of 0.7 m is 0.33m/d. The geometric mean of transmissivity for matrix intervals is 0.0011 m^2/d, and the average hydraulic conductivity is 3.7×10^{-4} m/d. Average hydraulic conductivity is thus about 1000-times larger in the permeable intervals than in matrix intervals. For these conditions, according to the tangent law for heterogeneous systems (Freeze and Cherry 1979, p. 173), lateral flows of water occur in only the permeable fracture intervals whereas flows in the matrix intervals follow tighter fractures that are more nearly vertical (Fig. 1).

In a thin but areally extensive network of pervious fractures, groundwater may flow either downdip or nearly horizontally, along strike. Most groundwater probably flows along strike and thus follows relatively permeable flow paths to discharge locations in cross-cutting, tributary streams (Fig. 1). The remaining water may flow downdip to locations beneath main-valley streams and then seep upward through much less permeable matrix intervals to discharge locations in the streams (Fig. 1). Elongated cones of depression during pumping tests, and first arrivals of tracers in wells located along geologic strike from the point of injection have been interpreted in previous studies as indicating a rock mass that is more permeable in the along-valley direction than in the cross-valley direction. Instead, most of these data are probably explained by the orientations of the beds and the fracture networks; flow paths within these networks have a much larger average permeability than do flow paths across matrix intervals from one fracture network to another. Where fracture flow paths have not been enlarged by solution, there is no convincing evidence that the fracture networks are more permeable in the along-strike direction than in the downdip direction.

The hydrogeologic model of the ORR differs from generally accepted concepts of recharge, flow, and discharge for an ideal aquifer. However, the new model explains groundwater and surface-water data on the ORR whereas conventional concepts do not explain these data. Two key features of the new model are the occurrences of a stormflow zone and a layer of connected, pervious fractures near the water table. Both layers are thin and are drained or partly drained between recharge events. Also, the transmissivity of these layers is both spatially and temporally variable, and the hydraulic gradient is correlated with the slope of the layer. These conditions require careful consideration for digital modeling. A third key is the relationships between the rock matrix and pervious fracture networks at deeper levels. These relationships determine groundwater flow paths, flow rates, well yields, and the shapes of contaminant plumes.

The conceptual model of hydrogeology on the ORR should be applicable in many respects to other fractured-rock terranes of Tennessee and adjacent States. However, there may also be differences caused by characteristics of the stormflow zone, the vadose zone, and the groundwater zone. Land cover and soil characteristics affect the permeability and storage capacity of the stormflow zone and may thus determine the relative amounts of overland runoff and subsurface stormflow. The vertical permeability of the vadose zone affects the contributing area for stormflow discharge and determines the relative amounts of stormflow discharge and groundwater recharge. The transmissivity of the permeable layer near the water table affects groundwater flow rates, and the specific yield determines whether or not the layer acts as a recharge boundary during pumpage from deeper wells. Other important factors are (l) physiography and regolith thickness, which affect the hydraulicgradient, (2) the configurations of beds and permeable fracture networks, which affect the relative groundwater flux along alternative flow paths, (3) the relative hydrologic importance of bedding-plane fractures and high-angle joints, (4) the size and orientation of solution cavities, and (5) the occurrence of faults, which may form conduits or barriers to groundwater flow.

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UNCERTAINTIES IN ^{14}C DATING IN FRACTURED SEDIMENTARY ROCKS ON THE OAK RIDGE RESERVATION

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Several corrections are needed to date ^{14}C in ground water from fractured sedimentary rocks; because of uncertainties it is better to refer to such dates as ^{14}C dates rather than ground-water dates. Seven ground-water samples were collected from 200-ft-deep wells in Melton Valley on the Oak Ridge Reservation. The samples were analyzed for ^{14}C, ^{13}C, tritium, and a complete suite of cations and anions, with the goal of better interpreting flow paths in the deep ground-water zone.

The first correction to the data made use of ^{13}C to estimate the amount of dead carbon (no ^{14}C activity) introduced from dissolution of carbonate rocks. For example, the well in the recharge area had an uncorrected ^{14}C date of about 8000 years, but the ^{13}C value indicated nearly half of the carbon resulted from dissolution of carbonate rocks. The ^{13}C-corrected age, using a thermodynamic model, is only 2500 years. The oldest date in the discharge area was 39000 years, with a ^{13}C correction to 28000 years.

Another correction to the data is to determine whether the ground water contains a mixture of older and younger waters. The primary indicator of mixing is tritium. All but one well had measurable tritium (T), indicating the presence of water less than 30 years old. Five wells had 1 to 5 tritium units (TU), and one well had 100 TU. Recent rainwater on the Oak Ridge Reservation reaches over 1000 TU, because of stack releases from isotope processing.

The presence of tritium can be explained by understanding flow in fractured rock. The tritium may travel along fast flow paths in fractures. The ^{14}C, whose input began many thousands of years ago, has diffused from fractures into the matrix to reach a steady state concentration in the deep system. Thus, the leading edge of a solute plume could migrate 100's of m/yr as given by the ^{3}H data, while the peak contaminant concentrations (i.e., the center of the contaminant mass) would migrate at a rate of only cm/yr as given by the ^{14}C data.

These processes, matrix diffusion and fracture flow, can be modeled using a simple parallel fracture model. Little is known about fracture characteristics at the depths sampled, so a wide range of parameters was tested in a model of flow in parallel fractures with diffusion in the rock matrix. This testing was accomplished by using a Monte Carlo driver that selected values for aperture, spacing, velocity, and matrix porosity with a random number generator, conducting several thousand runs at a time. When measurements of bulk hydraulic conductivity and estimates of bulk effective porosity are used to constrain the number of successful runs (bulk, meaning an average over fractures and matrix), the range in parameters is limited.

The model reproduced ^{14}C data from a well in the recharge area to a well in the discharge area. The derived values for fracture spacing (>30 m) were consistent with estimates from

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a borehole flowmeter at somewhat shallower depths, while the derived apertures (<10 μm) have not been previously estimated. The same set of parameters explain the observed ^{3}H value in the recharge area only if ^{14}C is retarded to reduce its concentration. Retardation factors up to 10 have been hypothesized to explain ^{14}C-rock exchange in some systems. In the recharge area, the retardation factor would reduce the ^{14}C age from 300 to 800 years and in one discharge area well modeled, from 15000 to 4000 years. While the water is still old, these are large corrections. ^{3}H can be transported to the discharge area, but not without requiring retardation factors higher than previously reported.

In summary, the presence of both recent ^{3}H and old ^{14}C in the same well has implications for contaminant transport and groundwater age dating in fractured sedimentary rocks. The rapid migration of small amounts of contaminants may provide an early warning of transport pathways, provided the detection limit is low enough to monitor the leading edge of the plume. ^{14}C ages alone cannot be used to date groundwater in fractured rock, since they do not exclude the possibility of recent water traveling in fractures, and age correction for carbonate dissolution, matrix diffusion, and possibly retardation result in groundwater ages significantly younger than ^{14}C dates.

METHODS FOR IDENTIFYING AREAS OF DOWNWARD LEAKAGE FROM THE WATER-TABLE AQUIFERS TO THE MEMPHIS AQUIFER IN THE MEMPHIS AREA, TENNESSEE

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In a study of the water resources of the Memphis area, several methods have been used within the past few years to identify areas having high potential for downward leakage of water and contaminants from the water-table aquifers to the underlying Memphis aquifer. Leakage occurs where the confining unit between the water-table aquifer and the Memphis aquifer is thin or absent and the hydraulic gradient between aquifers is downward. Because these areas are of limited size, they are identified only rarely in test holes and wells; therefore, areas of downward leakage commonly must be identified by indirect techniques. Some methods found useful for identifying these areas are: (1) mapping the thickness of the confining unit, (2) mapping local depressions in the water table, (3) measuring downstream losses of water on major streams during periods of low flow, (4) detecting young water in the Memphis aquifer based on carbon-14 and tritium data, (5) determining local deviations from the normal geothermal gradient, and (6) recognizing local anomalies in water quality in the Memphis aquifer.The Memphis aquifer is the principal source of water supply for the Memphis area, supplying about 196 million gallons per day for public, commercial, and industrial uses. The possibility of contamination of this important aquifer is of much public concern. Recently (1986-88), synthetic organic compounds were detected in water from five municipal wells screened in the Memphis aquifer--three in the Allen well field in Memphis and two in the west well field at Collierville. The presence of synthetic organic compounds in water from these wells emphasizes the vulnerability of the principal aquifer in the Memphis area to contamination.

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USE OF ELECTROMAGNETIC BOREHOLE FLOWMETER TO DELINEATE GROUNDWATER PRODUCING FRACTURES

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Introduction

Ground water flow on the Oak Ridge Reservation (ORR) is dominated by permeable fractures within the relatively impermeable rocks. It is possible to detect the fractures which intersect a borehole using conventional logging tools (electrical, sonic, acoustic televiewer, caliper, temperature), but not with any certainty which of these fractures are permeable and are part of a connected network. This poses a problem for the groundwater modeler. Should all known fractures be included in the model? Only major fractures?

Electromagnetic Borehole Flowmeter

The system has three primary components: the flow probe, the packer assembly, and the electronics package. The flow probe includes an electromagnet, two electrodes on opposite sides of the cylinder, and an amplifier, all cemented in a water-tight epoxy and covered with a stainless steel jacket. Water moving through the hollow core of the flowmeter in the presence of the magnetic field created by the electromagnet induces a voltage directly proportional to the flow rate, which is measured across the two electrodes.

The probe will fit into a 2 inch diameter well. For wells 2-3.5 inches in diameter a plexiglass collar is fitted to the probe to force flow through the hollow core. For uncased wells or 3.5-10 inches wells a packer is used. The entire probe and packer assembly has no moving parts, so the probe is durable and rarely needs recalibration.

The probe transmits the flow-induced voltages through a waterproof cable to the electronics package at the surface. A portable computer converts the voltage into units of flow and records the raw and processed data. The entire system is compact and easily mounted in a van or truck. For more detail on the system see Young and others (1991).

Data Collection

The flowmeter is progressively positioned at intervals down the well and vertical flow is recorded while water is being pumped into or out off the well. Changes in vertical flow with depth indicate water entering or leaving the well. Assuming horizontal, unbounded flow to the well, the equations developed by Cooper and Jacob (1946) can be used to calculate an hydraulic conductivity profile (Fig. 1).

Results and Discussion

In most wells tested on the ORR, more than 70 percent of the total discharge is from less than 20 percent of the total screened interval. In the open holes tested to date, most of the flow enters and exits the well at a one or two

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

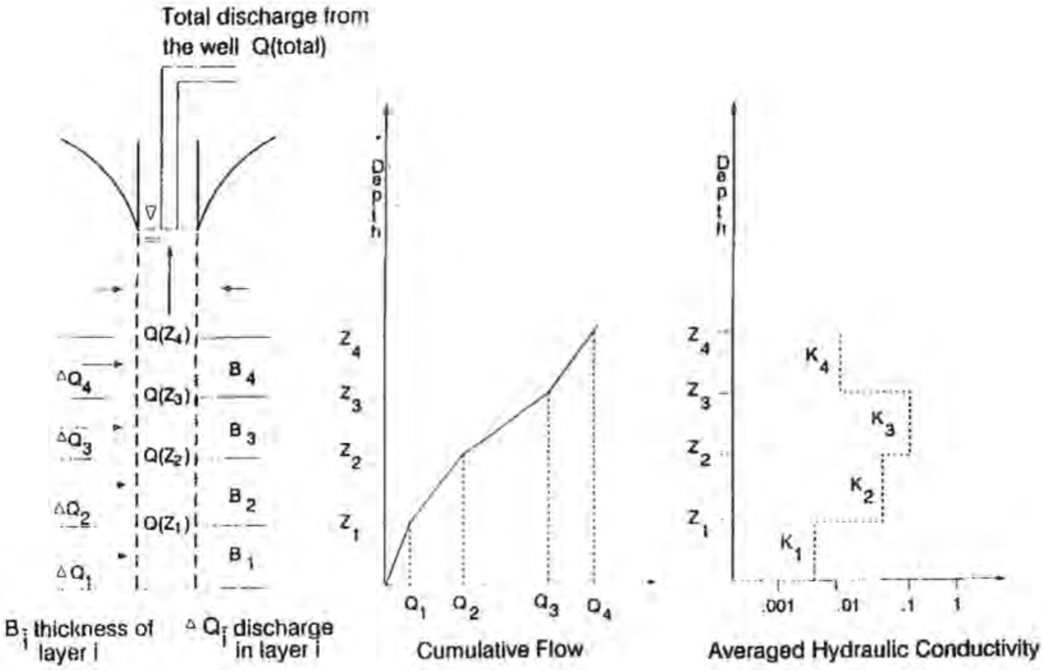

Fig. 1. Schematic of Horizontal Flow to a Well and the Profiles of the Cumulative Flow and the Calculated Hydraulic Conductivities.

fractures over a several hundred foot interval (Fig. 2). Over the same interval conventional logging tools show many more fractures (Fig. 3).

Although this data is preliminary and more wells need to be logged, our results to date suggest that the number of fractures in ORR rocks detected by geophysical means and by geologic mapping far exceeds the number of fractures that are significant hydrogeologically. Consequently, because flow appears to be dominated by a small number of highly permeable conduits, equivalent porous media and stochastic network fracture flow models are likely to work poorly, and every effort must be made to locate and map the few fractures that are hydrogeologically significant.

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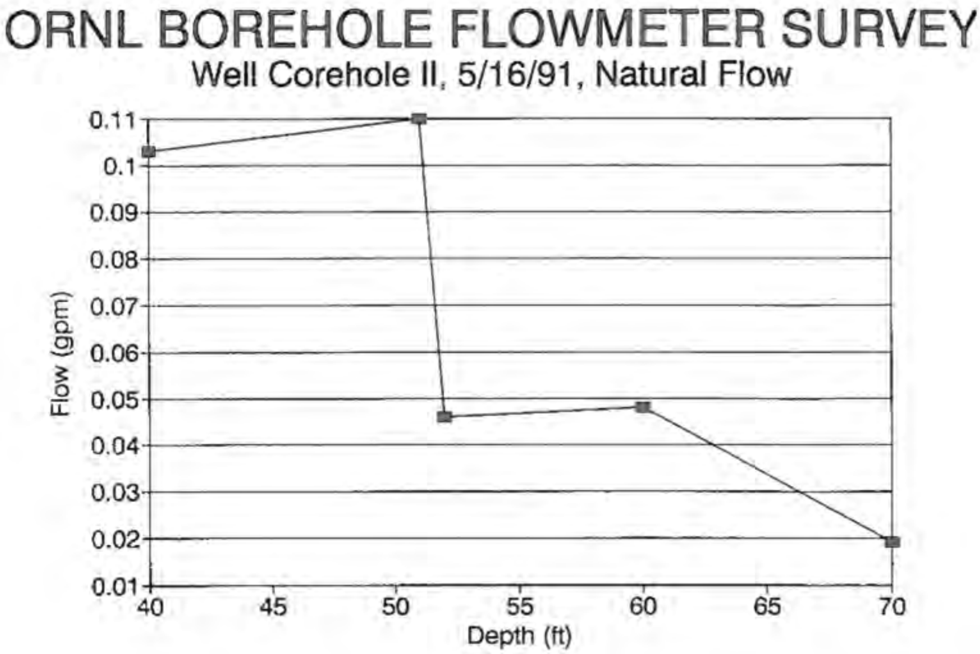

Fig. 2. Borehole flowmeter survey of corehole 2. A single flowing fracture was detected in this survey.

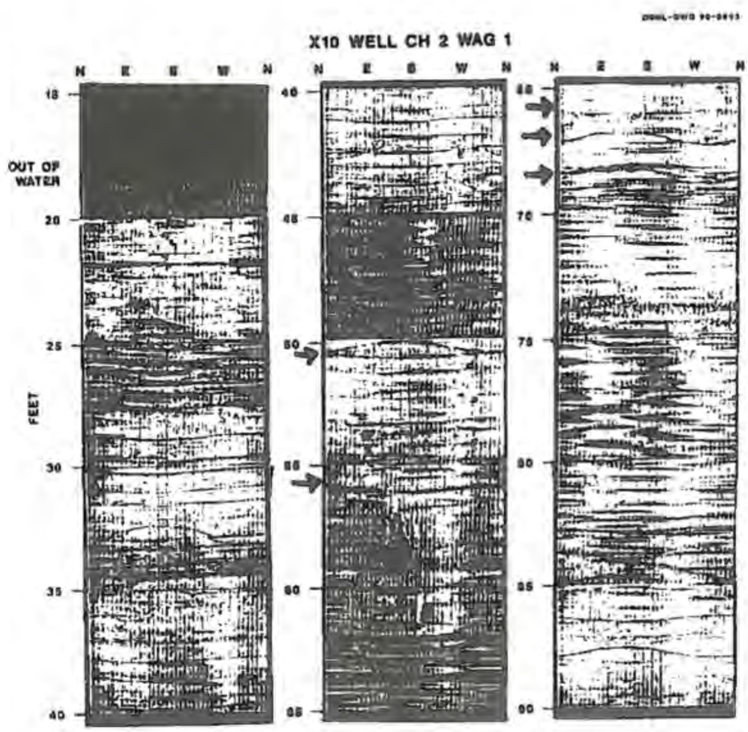

Fig. 3. Borehole televiewer log of corehole 2. Sinusoidal patterns are indicative of fractures (arrows).

BULL RUN VERTICAL VARIATION OF GROUNDWATER FLOW

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Purpose and Hypothesis

An investigation was conducted at the Tennessee Valley Authority (TVA) Bull Run Fossil Plant near Oak Ridge, Tennessee, to determine the strata of greatest groundwater flow and vertical variation of hydraulic conductivity. The information will be used as input into a three-dimensional flow model to determine the direction of groundwater flow, and to analyze the potential for migration of coal-ash leachate offsite. It was hypothesized that the overburden has very low hydraulic conductivity and most of the flow is through deep fracture zones in the bedrock.

Background

Bull Run Fossil Plant is situated in Raccoon Valley of the Valley and Ridge physiographic province and is located in Anderson County, Tennessee, on Melton Hill Reservoir (Clinch River Mile 48.0). The site is underlain by various lithologies of the Chickamauga Group, including limestones, shales, and siltstones. Chestnut Ridge is located north of the site and is underlain by cherty dolomite. Haw Ridge bisects the site. The rock formations are irregular and lie in relatively narrow linear bands oriented in the northeast-southwest direction. The area is characterized by a series of overlapping linear fault blocks that dip 30 degrees to the southeast. The results of 151 borings on-site indicate the elevation of top-of-rock varies from 235 m-msl near the intake channel to 253 m-msl on the east side of the site, or 2.7 to 16.5 m from the ground surface. No borings were conducted on top of Chestnut or Haw Ridges.

TESTS FOR VERTICALLY-AVERAGED HYDRAULIC CONDUCTIVITY

Well Installation

Single-well and borehole flowmeter tests were performed in nine wells, as shown in Fig. 1. Wells A, B, and C have solid casing which is 6.1 to 7.6 m deep. Below this is 1 m of screen in the overburden, the bottom of which extends to the top of solid rock (depth of refusal with hollow stem auger). An open borehole extends 10.7 to 21.3 m below top of the Conasauga Shale. The rest of the wells have solid casing to depths of 4.0 to 9.5 m, extending about 1.2 m below top-of-rock (no screened interval in soil). An open borehole through the Lower and Middle Chickamauga Limestone extends 5.8 to 23.8 m below the solid casing. The total depth of the wells varies from 11.3 to 30.5 m. Wells A, B, C, and E are 10 cm in diameter, while the others are 15 cm.

Single Well Injection/Pumping Tests

Single-well injection tests were performed at Wells A, B, H, and N. A clean (new) 0.8-m^3 tank was filled with potable water. Water was injected in the well at rates of 25 to 107 cm^3/s. The change in depth to water was monitored continuously by a pressure transducer. The data was analyzed using the Cooper-Jacob method (1946). This method assumes that the aquifer is unconfined; there is no delay in yield in the aquifer; flow is horizontal and uniform; the aquifer has infinite areal extent, is homogeneous, isotropic and of uniform thickness; the potentiometric surface is initially horizontal;

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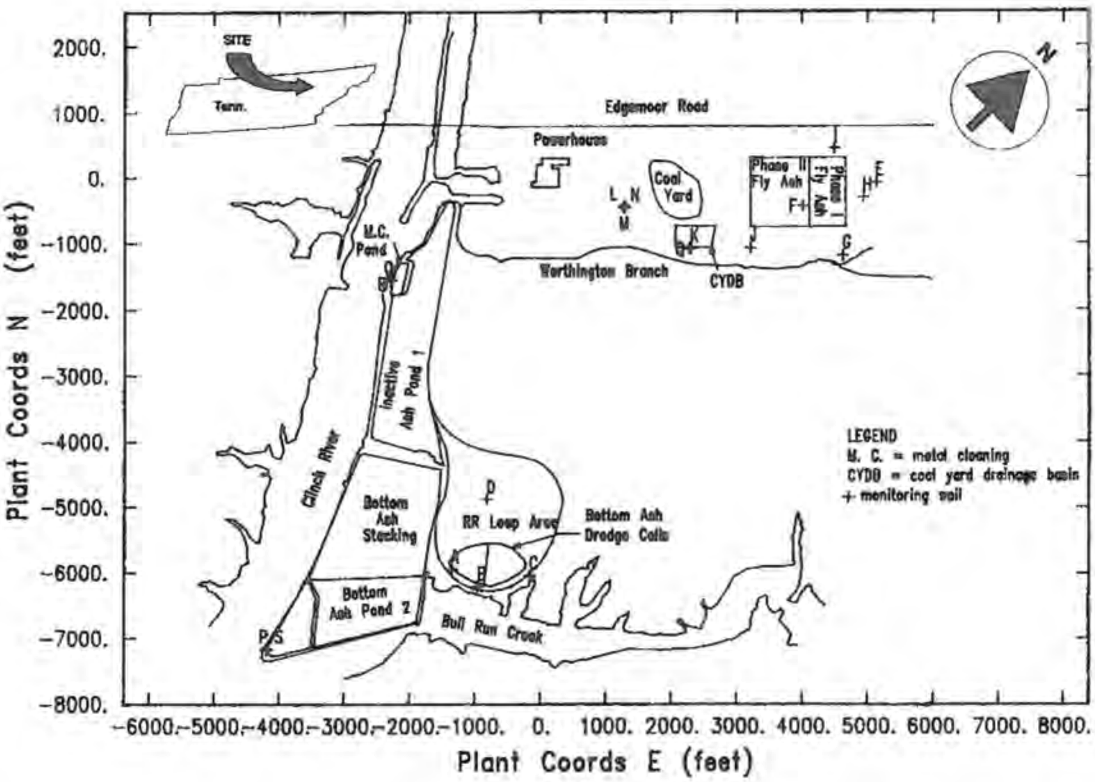

Fig. 1. Bull Run site map.

the pumping rate is constant; the well is fully penetrating the aquifer; and storage in the well can be neglected.

Pumping tests were performed in Wells E, I, and J. The field and analytical methods were the same as the injection tests, except water was pumped out of the well instead of into the well. Pumping rates varied from 13 to 95 cm^3/s.

Slug tests were performed in Wells C and G. The increase in the water level was about 10 feet. Water levels were recorded by the pressure transducer every 5 seconds during injection and recovery. The recovery curve was analyzed by the Hvorslev (1951) method using Thompson's (1987) TIMELAG program. This method assumes that the water level is "instantaneously" raised, flow to the well obeys Darcy's Law, and neither the screen nor the filter pack inhibit groundwater movement.

Results indicated hydraulic conductivity varied from $1x10^{-3}$ cm/s (Well J) to $9x10^{-5}$cm/s (Well G). No pattern emerged for the various areas of the plant site. The injection or pumping tests produced similar results as the slug tests.

BOREHOLE FLOWMETER TESTS

Equipment

The electromagnetic (EM) borehole flowmeter system was designed and built at the TVA Engineering Laboratory. The system has three primary components: the flow probe, the packer assembly, and the electronics package. The flow probe includes an electromagnet, two electrodes, and an amplifier, all of which are set into a high-strength water-tight epoxy matrix encased in a stainless steel housing. The packer assembly seals off the area between the flowmeter and the sides of the open hole. The electronics package translates the electronic signal to a flow value. For more information regarding the electronic borehole flowmeter system, see Young, et al. (1991).

Method

First, the flow probe and packer assembly were lowered to the bottom of the well and the "Telog" was set up. Next, the well was pumped (or injected into) at a constant rate until a quasi-steady-state was reached. The flowmeter was then raised in the well to measure flow at various depths. The packer assembly was fully inflated before each measurement, and deflated while being raised. An increase in flow in a particular region indicates the presence of a water-producing fracture or a permeable zone. Roughly three days were spent conducting the borehole flowmeter tests.

Results

Flow was not found in the bottom 2 m of any well. As the flowmeter was raised in the well, flow was typically located near the top of the open borehole in the well. Flow was produced from a 23 m-deep fracture in Well E. Except in Well E, all of the flow came from a zone of presumably weathered rock extending from a maximum 8 m below top-of-rock to a maximum of 4 m above top-of-rock (hollow stem auger refusal) (see Table 1). The thickness of this flow zone ranged from 0.9 to 9.2 m.

Table 1. Bull Run Borehole Flowmeter Results

	Elev. Top-of-Rock	Flow Zone Elev.		Distance From Top-of-Rock		Fracture Elev.
Well	(m-msl)	Bottom (m-msl)	Top (m-msl)	Bottom (m)	Top (m)	(m-msl)
A	240.1	235.7	241.8	4.4	1.7	
B	237.1	231.9	241.1	5.2	4.0	
C	237.8	236.5	241.1	1.3	3.3	
E	254.4	246.2	249.2	8.2	-5.2	237
G	251.2	244.8	247.9	6.4	-3.3	
H	253.9	247.2	251.8	6.7	-2.1	
I	261.3	254.8	-----	6.5	----	
J	244.6	238.5	239.4	6.1	-5.2	
N	247.2	244.2	-----	3.0	----	

In Wells I and N, flow continued to increase to the top of the open hole. Therefore, the top of the flow zone is not bounded by this test. The flow zone tended not to extend above top-of-rock in the wells in the Chickamauga Limestone, where as flow was recorded up to 5 m above top-of-rock in the Conasauga Shales.

Data Analysis

The hydraulic conductivity variation with depth was calculated from the results of the depth-averaged hydraulic conductivity tests and the flow variation with depth measured with the borehole flowmeter. The methodology described by Molz, et al. (1989), was utilized for this analysis. Typical results are shown in Fig. 2, which shows a cross section including Wells A, B, and C. The logarithm of the calculated hydraulic conductivity is plotted against elevation above mean sea level. The extent of the vertical axis at each well describes the vertical extent of the well. This figure illustrates that most of the groundwater flow will be in a permeable zone in the vicinity of top-of-rock.

Conclusions

The borehole flowmeter proved to be a useful and cost-effective tool to define the vertical variation of groundwater flow, locate water-producing fractures, and locate higherpermeability zones. Results indicated the majority of the flow was not through deep fractures in the rock as postulated. Rather, in all wells but one, all of the flow was produced from a less than 9.2 m-thick zone of presumably weathered rock extending from a maximum 8 m below to a maximum 4 m above the elevation of refusal by hollow stem auger. The hydraulic conductivity information will be used as input to a numerical groundwater flow model. The results of this test suggest that a two-dimensional horizontal-plane model of just the weather rock zone near the top-of-rock may be appropriate.

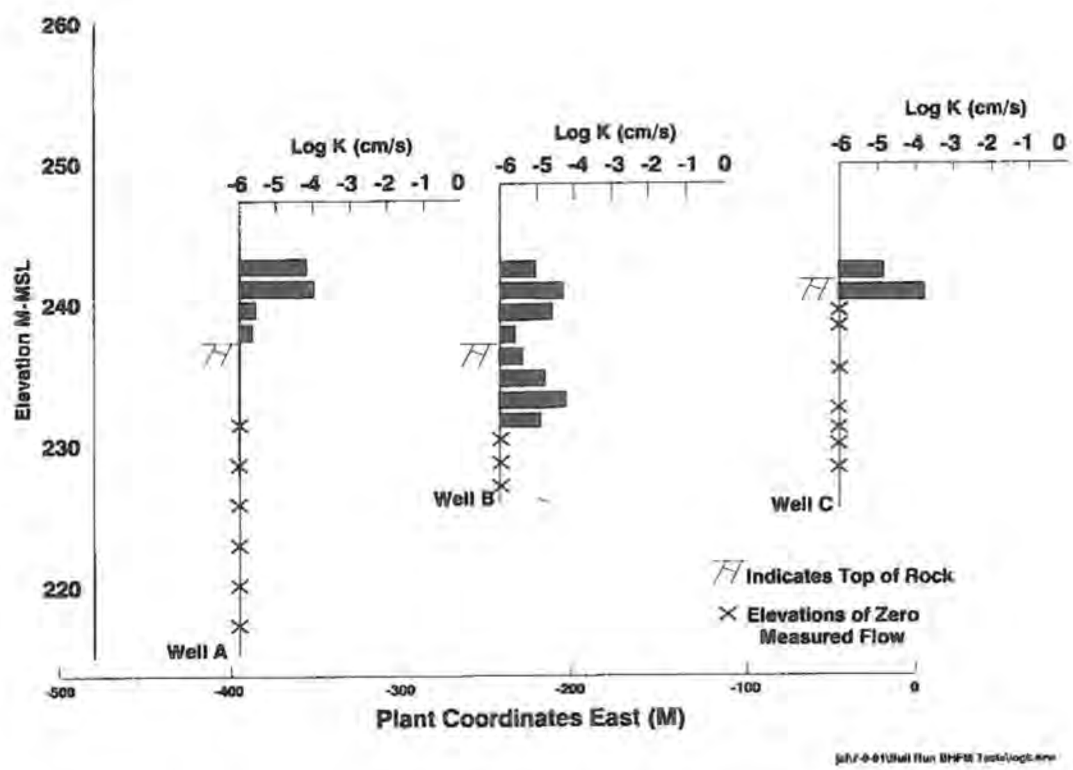

Fig. 2. Bull Run borehole flowmeter results. CROSS SECTION - 1847 North. Tested December 1990.

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TVA's VITAL SIGNS RESERVOIR MONITORING PROGRAM

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In FY 1990, the Tennessee Valley Authority (TVA) as part of its Water Resources and Ecological Monitoring Program initiated a "Vital Signs" Reservoir Monitoring program on 12 TVA reservoirs (the nine main stream Tennessee river reservoirs - Kentucky through Fort Loudoun and three major tributary reservoirs - Cherokee, Douglas, and Norris). The objective of the Vital Signs program is to provide basic information on the "health" or integrity of the aquatic ecosystem in each TVA reservoir. Other TVA reservoir monitoring programs also provide screening level information for describing how well each reservoir meets the swimmable (Fehring, 1991) and fishable (Hall and Dycus, 1991) goals of the Clean Water Act. This is the first time in the history of the Agency that a long term, systematic sampling of major TVA reservoirs has been conducted. The basis of the Vital Signs monitoring is the examination of appropriate physical, chemical and biological indicators in three areas of each reservoir. These three areas are the forebay immediately upstream of the dam; the transition zone (the mid-reservoir region where the water changes from free flowing to more quiescent, impounded water); and the inflow or headwater region of the reservoir. The information gathered is used in making evaluations of each reservoir's health and the overall health of the reservoir system, and to implement more intensive assessments where significant problems are identified. In addition, this monitoring helps establish a baseline against which to compare future water quality conditions and monitor trends in water quality for TVA's reservoirs.

Conclusions

The aquatic biological and water quality data collected in Water Year (WY) 1990, while pointing out some areas with potential problems, provided a preliminary indication that the "health" or integrity of the reservoirs monitored is good. The four reservoirs which had the greatest number of indicators of potential problems were:

1. Douglas Reservoir - low hypolimnetic DOs, high nutrient loads and algal productivity, few benthic taxa, low fish density and fish biomass, and poor fish community all indicate potential water quality problems, particularly in the transition zone area;

2. Wilson Reservoir - the low hypolimnetic DOs, sediment toxicity, poor fish community, and a decline in fish health suggest potential problems, particularly in the forebay area;

3. Watts Bar Reservoir - indications of sediment toxicity and elevated concentrations of mercury in sediment at the transition zone, low hypolimnetic DOs in the forebay, and the sparse number of benthic animals at the inflow locations are of interest; and

4. Fort Loudoun Reservoir - low summertime DOs in the hypolimnion of the forebay, low numbers of benthic macroinvertebrate taxa with dominance by tolerant animals, and low number of fish taxa (large percentage of carp at the inflow location) all suggest the water quality is less than ideal.

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Vital Signs Monitoring Highlights - 1990

The Vital Signs program employs several activities to examine reservoir health. They include physical and chemical characteristics of water and sediment (Meinert, 1991), acute toxicity screening of water and sediment (Moses and Wade, 1991), benthic macroinvertebrate sampling (Jenkinson, 1991), and fish community evaluations (Wilson, 1991 and Hickman et. al., 1991).

Physical/Chemical Characteristics of Water

Water temperature measurements made on the Vital Signs monitoring reservoirs in WY 1990 exceeded state criteria for fish and aquatic life on only one occasion. A surface water temperature of 30.4 °C was measured on Wilson Reservoir in June 1990. Dissolved Oxygen (DO) concentrations were occasionally less than 5.0 mg/l at the five foot depth (the depth used for state water quality criteria); however, DOs were never less than 4.0 mg/l at that depth, and never less than 5.0 mg/l for any sustained length of time.

The nine mainstem Tennessee River reservoirs, with the possible exception of the forebay area above Fort Loudoun Dam, lacked any prolonged periods of thermal stratification. However, the three tributary reservoirs (Cherokee, Douglas, and Norris) developed strong thermal stratification by early May.

Cherokee and Douglas developed large regions of anoxia in the hypolimnion during the summer months, with hypolimnetic dissolved oxygen concentrations below 1 mg/l from June through September. Of the mainstem reservoirs, Watts Bar, Wilson, and Fort Loudoun forebays developed small regions of hypolimnetic anoxia during later summer.

In the mainstem Tennessee River reservoirs, productivity (indirectly measured by chlorophyll-a concentrations) was highest at the forebay locations due in large part to the greater water clarity in the forebay areas than in the transition zones. The highest chlorophyll-a concentration (28 ug/l) on any of the mainstem reservoirs was found in Kentucky reservoir forebay. On the tributary reservoirs of Cherokee and Douglas, the most productive areas were not the forebays but the transition zones, due to nutrient limitations at the forebay locations. At the Douglas transition zone, a chlorophyll-a concentration of 36 ug/l was measured, which was the highest chlorophyll-a concentration observed at any Vital Signs monitoring location in WY 1990. Dissolved oxygen saturation values exceeding 150% and pH values exceeding 8.5, conditions that generally indicate high rates of algal photosynthesis, commonly occurred coincident with the high concentrations of chlorophyll-a observed at the transition zones on Cherokee and Douglas reservoirs. The productivity of Norris Reservoir was severely limited by phosphorus and was the lowest among the twelve Vital Signs reservoirs.

Phosphorus concentrations were somewhat higher at Fort Loudoun than at Watts Bar, but going downstream, they decreased to a minimum in Chickamauga Reservoir and then gradually increased to a maximum at the Kentucky Reservoir forebay. The phosphorus concentrations of the Tennessee River are increased by the inflows from the Elk (to Wheeler Reservoir) and Duck (to Kentucky Reservoir) rivers, which are naturally high in phosphorus. The transition zones on Cherokee and Douglas reservoirs had the highest concentrations of total nitrogen and total phosphorus among all the Vital Signs monitoring locations, which accounts for their high productivity.

Norris Reservoir had the highest light transparency (average Secchi depth 3.0 meters) and the transition zone of Douglas had the least light transparency (average Secchi depth 1.0 meters). Overall, turbidity, suspended solids and color were found to be highest, and Secchi depth lowest, during the January (high flows) and April (springtime algal blooms) Vital Signs sampling events. In addition, total phosphorus, which is carried into the reservoirs attached to the suspended sediment by these winter and spring rainfall runoff events was high in January and April. As flows decrease and concentrations of turbidity and suspended sediment decrease, conditions become favorable for the spring blooms of algae due to the availability of nutrients, warmer temperatures, and increased water clarity and depth of the photic zone.

With one exception, average concentrations of fecal coliform organisms were quite low at the reservoir sampling locations. A water contact recreation guideline of 200 organisms per 100 ml of water was used for comparison of the fecal coliform data. Nine of fourteen samples collected for fecal coliform organisms on Guntersville Reservoir were positive, with two of these occurrences, at the forebay, exceeding 200/100 ml.

Physical/Chemical Characteristics of Sediment

The median concentration of metals was higher at the forebays than at the transition zones. As expected, smaller particle sizes were found in sediments at forebays than at the transition zones, as well as lower total solids and higher volatile solids percentages. Cadmium was not detected in any of the samples. Mercury and lead were elevated in a small number of samples. The highest concentrations of mercury (1.9 ppm dry weight) were in samples from Pickwick Reservoir. Elevated levels of mercury (0.95 ppm) were also found in sediment samples collected at the Watts Bar transition zone. Lead (120 ppm) and nickel (63 ppm) at the Guntersville forebay, were higher than expected, and may deserve further investigation if confirmed by the 1991 sampling.

The sediment samples also were analyzed for eighteen pesticides and PCBs. With two exceptions, no pesticides nor PCB's were detected in the sediment samples. One sample collected at Pickwick forebay had a small, but detectable concentration of endosulfan sulfate (12 ppb), and one sample collected at the Norris transition zone had a low PCB concentration (550 ppb).

Acute Toxicity Screening of Sediment and Water

No acute toxicity to rotifers (Rotox^R) was demonstrated in tests using water column and sediment samples from the forebays and transition zones. However, sediments from three locations indicated some toxicity based on light emitting bacteria (Microtox^R), although all EC_{50} concentrations were greater than 100 percent sample. These locations, listed in order of greatest effect were the Watts Bar transition zone (downstream from the Clinch River) and Nickajack and Wilson forebays.

Benthic Macroinvertebrate Communities

Generally, more animals and more taxa were found in downstream Tennessee River reservoirs than in upstream or tributary reservoirs, with forebay and inflow benthic communities different from one another on all reservoirs. Mainstem areas with low DOs (i.e. forebays with summertime hypolimnetic anoxia and the tailwater streams downstream of these forebays) had generally fewer benthic organisms and numbers of species than areas where DO levels were always high.

Fish Community Evaluation

Open water fish abundance and species composition estimates using hydroacoustic and trawling techniques showed that most areas of both mainstem and tributary reservoirs were dominated by threadfin shad, with a few areas dominated by gizzard shad. Interestingly, bluegill was the primary species collected in the forebay and white crappie was the primary species collected in the transition zone in Douglas Reservoir. A large number of threadfin shad found in the forebay of Norris reservoir was unexpected given the oligotrophic nature of this area of Norris reservoir. The abundance of fish in open water areas tended to be higher in tributary than in mainstem reservoirs. Biomass of fish in these areas did not follow any particular trend, indicating an inconsistent pattern in the size of fish among mainstem and tributary reservoirs.

The quality of the fish community in near shore areas was evaluated using a number of ecological health and use characteristics. Overall, the quality of the fish community in mainstream reservoirs increased from upstream to downstream, with this trend most obvious at the inflow locations in each reservoir. This generally coincides with the increased species richness and abundance observed in the benthic macroinvertebrate community. Fish assemblage comparisons among tributary reservoirs (including Fort Loudoun) showed that Cherokee and Norris have the highest quality fish communities and Douglas the lowest.

Program Modifications

Based on a review of the 1990 Vital Signs data, several improvements are being considered for the monitoring program. An analysis of benthic communities (and sediment particle size data) suggest that the Guntersville transition zone should be relocated further downstream. Also, an analysis of benthic data and water quality data suggest that Chickamauga and Nickajack transition zones are located too far downstream. Relocation of the Chickamauga transition zone upstream and the deletion of the Nickajack transition zone are being considered. The water quality data analysis also suggests that the Pickwick transition zone should be relocated further upstream. Other minor improvements to the Vital Signs monitoring program being considered are the modification of the parameters currently being measured at inflow locations and changes in sediment collection methods to include composite sampling of both overbank and river channel sediment.

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Use of a Fish Bioenergetics Model to Evaluate Effects of Dissolved Oxygen Mitigation at Norris Dam [1]

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The management of tailwater fisheries, aquatic ecosystems, and hydropower can have conflicting objectives. For example, the installation and operation of hydroelectric facilities affect downstream biological resources by changing flow regimes, temperatures, and water quality. Special interest groups vigorously support and promote each of these resources: tailwater sport fisheries, which enhance the economic and cultural life of a region; natural aquatic ecosystems, which contribute to biological diversity; and hydroelectric power, which can boost economic growth. Conflicts among these interests may multiply in the next 3 years as the licenses of hundreds of hydroprojects in the nation expire and applications for relicense are evaluated for renewal.

When the physical costs to each resource can be presented in quantitative terms and the basis on which these costs are determined is available to review, all parties can benefit because many different solutions can be examined and their consequences quantified. This paper shows how a fish growth model influenced by environmental conditions such as water temperature and dissolved oxygen concentrations can be used to generate information about the costs and benefits of different hydropower development and mitigation scenarios. Models can provide defensible, objective, and accessible insight into outcomes of different development, mitigation, or non-development decisions. This research is conducted as part of the Environmental Mitigation Study of the U. S. Department of Energy's Hydropower Program.

METHODS

Models of Bioenergetics

Growth integrates all the environmental factors acting on an organism (Adams and McLean, 1985). Models of environmental factors affecting physiological functions can be useful for evaluating different environmental scenarios on fish growth. Bioenergetics models are examples of such models. Food ingested by an organism is used in metabolic processes, lost as wastes (excretion or egestion), or synthesized into new tissue. Food, metabolism, wastes, and tissue can be expressed in a common metric such as units (or rates of change) of energy, biomass, carbon, or nitrogen. A bioenergetic budget can be constructed of the distribution of the energy content in food into the energy used in metabolic processes, lost as wastes, or gained as new tissue (Adams and Breck, 1990). The study of the rates at which organisms ingest, use, transform, and lose energy is bioenergetics; the energy budget of an organism is known as the bioenergetic budget. Fishery biologists have used the bioenergetic approach to estimate fish growth

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or production, food consumption rates, and the effects of environmental factors such as water temperature and food availability on growth. A review of such applications is available in Adams and Breck (1990).

Brown Trout Bioenergetics Model

DO is necessary for the respiration of fish and low concentrations can lead to impaired growth and mortality. Research indicates that DO affects respiration, food consumption, swimming, and other activities (USEPA, 1986). The Cuenco (1985a, b, c) model of fish bioenergetics was used for this application because it, unlike other bioenergetics models, includes the effects of dissolved oxygen concentrations on bioenergetic processes. This model computes the balanced daily bioenergetic budget for fish and originally applied to estimate the growth of channel catfish under varying water temperature (TP), dissolved oxygen (DO), and feeding strategies (Cuenco 1985a, b, c). We modified it to simulate the effects of variable TP and DO on the growth of brown trout (Salmo trutta) for 1–year growing seasons. Growth is equal to food energy consumed multiplied by an assimilation factor minus energy used in respiration. The assimilation ratio is assumed to be constant; both food consumption and respiration rates are modified by TP, DO, and fish weight. The following model features, more fully described elsewhere (Cuenco 1985a, b, c), and assumptions and modifications for the current application should be noted:

Brown trout growth parameters. Many model parameters (e.g., exponent relating respiration to fish weight) are species-specific. Cuenco (1985a) presented all parameters for brown trout used in the current application with the exception of the parameters that relate critical DO concentrations to respiration rates (defined in the model as a function of TP and fish weight). The model assumes that there is a critical DO concentration (DOCRIT) below which food consumption and respiration are impaired and a second critical DO concentration (DOZERO) below which food consumption ceases. Both of these critical DO levels are assumed to be related to fish respiration rate, such that as respiration increases, both DOCRIT and DOZERO increase. The relationship between respiration and both critical DO levels is assumed to be linear. Thus one equation for a straight line relates DOZERO to respiration and another equation relates DOCRIT to respiration. We have assumed on the basis of a preliminary review of literature (USEPA, 1986; USFWS, 1986) that at TP = 12° C, DOCRIT = 10 mg/L and DOZERO = 4 mg/L, and at TP = 10° C, DOCRIT = 9 mg/L and DOZERO = 3 mg/L. We used these assumptions to define the relationship between respiration and critical DO values for brown trout.

Other modifications. Other modifications include the removal of a subroutine that calculated daily nonionized ammonia concentrations from daily concentrations of uneaten food and wastes generated by the fish because the model in this application simulates fish growth in a free—flowing river. Daily food availability, originally divided into a natural food component and an added food component, is set to equal fish consumption (e.g., unlimited food).

Modeled system and scenarios. The Norris tailwater was selected because considerable measurements of TP and DO are available for the tailwater both before and after DO mitigation measures were implemented. TP and DO data from a modeling study (TVA, 1986) of the effects of various management strategies, including turbine aeration to increase downstream DO concentrations of Norris Reservoir, a large, deep, multipurpose reservoir were used as inputs. Data were available for the reservoir releases and for a site 3 mi downstream of the powerhouse. The annual water temperature regime ranging from a maximum TP of about 20° C in autumn to a minimum of about 5° C in winter makes the tailwater well-suited for such coldwater fish as brown trout. State and local resource agencies maintain a trophy trout fishery in the tailwater. Trout growth for TP and DO data representing TP and DO at a station 3 mi downstream from the powerhouse was simulated (run 1). To represent the effects of DO mitigation, DO was increased by 2.3

mg/L for the 3 summer months during which DO fell below 4 mg/L in reservoir releases (run 2).

RESULTS

Figures 1a and 1b show, for runs 1 and 2, respectively, the progression of TP, DO, and simulated respiration, consumption, and critical DO requirements for brown trout with an initial weight of 100 g, over a 240 d growing season which begins on April 1 (day 93) and ends on November 30 (day 334). Under both scenarios trout grew until midsummer (maximum weight attained for run 1 = 185 g; for run 2, 197 g) then began to lose weight as energy used in respiration exceeded energy intake through food assimilation (end-of-season weight for run 1 = 113 g; for run 2, 134 g). This weight loss was due primarily to simulated suppression of consumption by low DO concentrations.

Figures 1a and 1b also show how critical DO concentrations (DOCRIT and DOZERO) increase with higher temperatures. This is expected, since DOCRIT and DOZERO are defined in the model as functions of respiration rate, which in turn is a function of water temperature and fish weight. Because the sensitivity of DO requirements to increases in TP is lower for larger fish, the runs in which growth remains positive and fish grow continuously result in lower DO requirements in the late summer and autumn. Whether fish whose weight is low because of poor growth have as high DO requirements as fish whose weight is low because they are very young is questionable. The simulated high sensitivity of critical DO levels to changing TP in the runs where fish lose weight late in the year may be a model artifact.

A comparison of Figures 1a and 1b indicates that 2–3 mg/L increases in DO during summer months enables the fish to maintain higher food consumption rates for about 20 days later in the year. The result of this is to permit a longer period of growth; with increased DO, end-of-season weight increases by about 20 g. (As a comparison, we ran the model (results not shown) with DO fixed at 15 mg/L to simulate growth in the absence of DO constraints. Consumption remains high throughout the year, permitting year-round growth, and fish weight at end-of-season climbs to 359 g.)

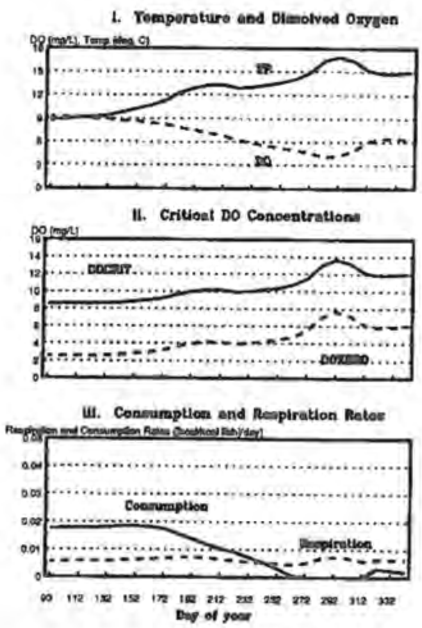

Fig. 1a. Conditions and Growth Components Before Mitigation.

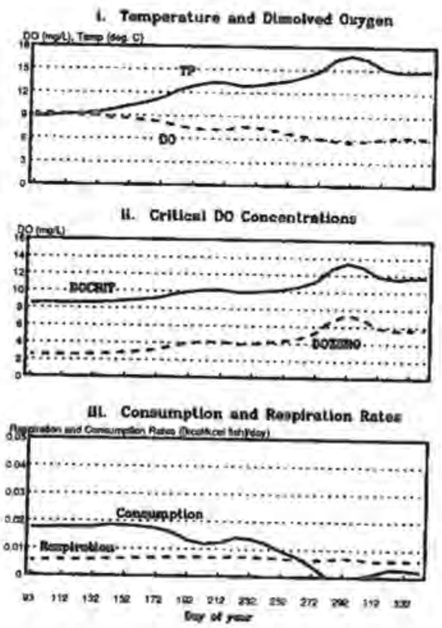

Fig. 1b. Conditions and Growth Components after Mitigation.

DISCUSSION AND CONCLUSIONS

Results such as presented in Figures 1a and 1b provide some useful information on the effects of DO mitigation on fish growth. First, they can enable identification of the most critical periods when fish physiological requirements for certain levels of environmental variables are highest. Figures 1 and 2 show how DO requirements change with changing water temperatures, which leads to fish consumption to fall in late summer. This suggests that it may be efficient to focus mitigative resources during specific seasons, e.g. summer and autumn. Such information may help managers to decide the extent of DO mitigation appropriate for current environmental conditions: for instance, exceptionally warm water temperatures would call for greater levels of air/oxygen enhancement, whereas cool water temperatures may allow for relaxed mitigation investment.

Second, fish growth under a range of mitigation levels can be examined. Benefits corresponding to various mitigation levels can be illustrated and trade-offs between power interests and fishery or ecological interests can be studied. We have simulated three scenarios — no mitigation, mitigation that adds about 2–3 mg/L to reservoir releases during the summer, and a hypothetical mitigation with saturation DO (15 mg/L). The information produced by these simulations is a step toward developing the development of a function like that displayed in Figure 2, comparing costs of mitigation with biological benefits. Such a function would be helpful particularly if costs of different mitigation levels become available.

Results are also useful to determine fish stocking strategies. It may be appropriate to stock large fish with lower DO requirements and lower sensitivity of DO requirements to increases in TP, in late summer. Those fish may have a better chance of gaining and retaining weight than small fish with high respiration rates and DO requirements and a high sensitivity of DO requirements to increases in TP. As the Norris tailwater is managed as a put-and-take trout fishery, stocking could be timed for best trout growth.

Systematic evaluation of uncertainty in model prediction resulting from uncertainty in model parameters and inputs could guide efforts at improving the model. Future extensions of this study may be to use a bioenergetic modeling approach to quantify the impacts on growth from varying flow regimes. Higher flow rates may incur higher activity metabolism costs and for some species activity metabolic costs far outweigh increased metabolic costs associated with increased water temperatures. In addition, we have taken only point estimates of TP and DO levels for a system which is in reality large and complex. A more useful and realistic model could be developed by accounting for spatially heterogeneous conditions, modeling fish movement within the system, and estimating parameters such as carrying capacity for spatial elements of the system. Other extensions of this study may include model parameterization for other fisheries species (e.g., striped bass) and for biological values other than fish growth (e.g., species diversity).

The relationship between DO, consumption, and respiration in this model is somewhat speculative and the results should be seen as qualitative. The quantitative, predictive ability of this model could be improved by systematic literature searches for empirical data on the effects of varying DO concentrations on bioenergetic processes and by model calibration and verification with appropriate fishery and water quality data sets. Long-term data sets with both water quality and biological data in hydropower tailwaters, however, are extremely rare. Therefore, federal agencies such as TVA as well as natural resource agencies, the hydropower industry, and research organizations can help by tying biological monitoring to water quality and other habitat mitigation programs. Opportunities to do this will arise in TVA's new reservoir operational improvements program and the upcoming wave of non–federal project relicense negotiations.

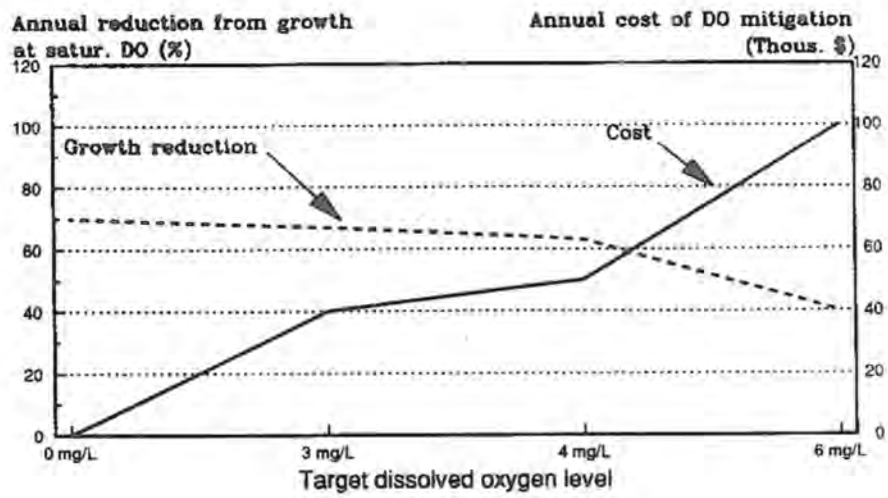

Fig. 2. Hypothetical Trade-Off Between Annual DO Mitigation Cost and Fish Weight Reduction.

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WETLAND MITIGATION: IS IT FOR REAL? A COMPARISON STUDY BETWEEN A MITIGATION SITE AND THREE NEARBY NATURAL WETLANDS

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Within the last decade wetland mitigation has received a lot of attention as a way to compensate for the destruction and degradation of wetlands in the United States. Although mitigation procedures are widespread throughout the country, there is little agreement as to the effectiveness of this practice to compensate for those wetlands that are to be destroyed or are already lost.

To date the Tennessee Department of Transportation has mitigated over 300 acres in Tennessee, and many more are planned (Brode 1991). When the Department of Transportation built a road through a wetland, in Huntingdon, Tennessee, they took a thirty acre tract of adjacent agricultural land out cultivation, selectively planted some wetland trees and, otherwise, allowed it to enter succession toward its' former wetland status. The purpose of this study is to determine whether the area used for mitigation has maintained the physical and biological components essential to support a succession of plant and animal communities comparable to adjacent bottomland hardwood wetlands.

This study will base its' assessment of the mitigation area on the following parameters. They are physio-chemical data of the soil, dominant plant species and plant biomass, small terrestrial vertebrate populations and diversity and avian species richness. These parameters which represent some important biological and physical aspects of a wetland, will be compared among the mitigation site and three nearby natural areas.

Physio-Chemical Data of the Soils

Soil samples obtained from each of the four sites will undergo the Bouyoucos Hydrometer method for the determination of sand, silt and clay composition (Bouyoucos 1951).

Plant Community Analysis

The plant communities in the mitigated site and each of the other three wetland areas, will be assessed using transect lines and circle plots. The transect method involves three lines running from the creek into the floodplain in each site. Each line is approximately 200 feet long, and there are 20 points along the line. At each point a meter stick is randomly dropped five times in a semi-circle around the investigator. Any plant that is hit is marked as present. This method will show dominance, frequency and density of the understory flora. Tree circle plots with a radius of 37.2 feet will be employed as a way to determine the number and total basal area of the trees in the wetland areas. A tree will be defined as a woody plant with a diameter at breast height greater than three inches (Kentula and Kusler 1990). A circle plot with 37.2 foot radius is a standard number, and it represents 1/10 of an acre or .04 hectares (Avery 1967).

Each of the four wetland regions will also undergo a plant biomass comparison. Several square meter plots in each wetland tract will be denuded of ground cover. This vegetation will then be dried and weighed to

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determine plant biomass per unit area in each type wetland.

Small Vertebrate Populations and Species Diversity

The small terrestrial vertebrate populations in the mitigated area and the three control areas will be sampled using three techniques. Sherman folding traps placed in trap lines will be used to catch small mammals. Twenty small mammal traps placed in lines will traverse each of the four study areas for a total of 80 traps. Small mammal trapping will be conducted for three consecutive nights monthly from June to November.

I will also use terrestrial drift fences with pitfall traps as another trapping procedure. The drift fences consist of 20 inch high aluminum flashing, and the pitfall traps are 5 gallon plastic buckets installed in the ground. Each wetland area has one drift fence installed. Each fence is L shaped and, each side is 25 feet long. The total fence length in each site is 50 feet. There are 5 buckets under each fence per site and 20 buckets total throughout the entire study area. Trapping will occur monthly for three consecutive nights from June to November.

I will also conduct walking searches of the four study sites. For this portion of the study, each site will be divided into a grid. In this manner all "herptiles" seen will be identified and their exact locations within each study site will be noted. Microhabitat data will also be recorded. These walking surveys will be repeated monthly from June to November 1991.

Avian Species Diversity

An indication of avian species richness in the four wetland regions will be determined by compiling a checklist of bird species seen and heard.

Discussion

Based on the data gathered from the three controls and the mitigation area, I will have some concept of the plant and animal life that the mitigation site supports presently and will support in the future. I will also get some idea by examining the physical composition of the soils, of some of the inherent functions and values of this mitigation site and the surrounding wetland regions. Some important functions and values which pertain to physical soil composition include ground water movement, erodibility, recharge and discharge rates, floodflow alterations and sediment toxicant retention (Adamus 1991). Upon examination of these conclusions, I should be able to determine whether this particular mitigation is a success or an inadequate substitute for a natural wetland.

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WOODS RESERVOIR RECONNAISSANCE LEVEL ASSESSMENT MANAGEMENT AND OPERATIONS WATER QUALITY PERSPECTIVE

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The Nashville District Corps of Engineers recently completed a reconnaissance level assessment of the management and operation of Woods Reservoir. This work was funded by the U.S. Air Force, Arnold Engineering Development Center (AEDC). The assessment was to look at the strengths, problems, and opportunities associated with the Woods Reservoir facility and related water management activities. A list of specific items to be considered was provided by AEDC. Specialists from the fields of Water Control Management, Hydrologic Engineering, and Water Quality prepared portions of the assessment, with this paper will concentrating on the latter area. Limited water quality data was collected by the Corps from several lake, inflow, and a tailwater station during 1990 to support this evaluation.

Located in south-central Tennessee, Woods Reservoir was formed in 1952 by the Elk River Dam at mile 170. The reservoir impounds portions of Coffee and Franklin Counties and is located entirely within the Eastern Highland Rim Physiographic Province. The reservoir has a drainage area of 263 square miles, also including portions of the Cumberland Plateau. At the normal summer pool elevation of 959.5 feet, Woods Reservoir contains 77,915 acre-feet of water and has a surface area of 3,910 acres. The reservoir is relatively shallow with a maximum depth of about 60 feet. The upper end of the reservoir has an unique network of island sand marshes which are ideal for waterfowl. Below the dam is four miles of tailwaters before the Tims Ford Reservoir is reached. The primary purpose of the reservoir is to provide cooling water and water supply for AEDC. Additional purposes are flood control and recreation.

General Water Quality Patterns

Hydrodynamic patterns in Woods Reservoir are influenced by both morphological conditions and the withdrawal of water by AEDC. The lake is physically divided into an "upper" and "lower" pool by the Morris Ferry Bridge at E.R.M. 176.4. Water is removed from the lake by pumps located at the Primary Pump Station (PPS) at E.R.M. 174.1 (lower pool). The "upper" pool is more influenced by watershed loadings while the "lower" pool is influenced by the AEDC water uses. Discharges from the AEDC complex return to the lake via Rowland, Bradley, and Brumalow Creeks.

The general water quality pattern for Woods Reservoir is similar to many southern lakes with seasonal thermal stratification. The hypolimnion gradually warms and loses dissolved oxygen (DO) with time until Fall destratification. The rate of warming is probably increased by AEDC cooling water discharges. Once the hypolimnion is devoid of oxygen, the bottom sediments release iron, manganese, and phosphorus into the water column. Both the 1990 data and past studies by others show Woods Reservoir to become strongly stratified and devoid of dissolved oxygen (DO) below the thermocline (20-25 foot depth).

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Due to the elevation of the PPS intakes, poor quality hypolimnetic water is withdrawn during stratified periods. After passing through the AEDC complex, the majority of this water is returned to the epilimnion of the lake via discharges to inflowing streams. The high productivity of Woods Reservoir may be partially due to the recycling of hypolimnetic phosphorus to the epilimnion via AEDC processes.

Existing Elk River Dam Operation

The design of the Elk River Dam allows for operational flexibility in response to lake conditions. The dam has two sluice gates, three tainter (spillway) gates, and one leaf (surface) gate. The current operating scheme is to release water through the sluice gates (El 897.75) until early or mid-summer when poor hypolimnetic water quality develops. According to AEDC personnel, this is done to flush the hypolimnion and reduce the build-up of iron and manganese. The tainter gates (El 935) or leaf gate (El 959) are then used to maintain the desired pool elevation for the rest of the stratified period. The leaf gate, which is a flap on top of the center tainter gate, is used the majority of the summer months to maintain low-range releases (20-105 cfs). A minimum release of 20 cfs is maintained at all times, which corresponds to the pre-reservoir 3-day, 20-year low flow.

Recommended Dam Operation

The operation in 1990 followed the general pattern described above. This operational procedure appears to worsen the rate at which DO is lost from the hypolimnion by releasing the cooler, oxygenated water present at the onset of stratification and replacing this water with warmer, more organically-enriched water.

A recommended change in the operation of the dam was made to hopefully improve the hypolimnetic water quality. Instead of trying to flush the hypolimnion by releasing through the sluice gates in the spring and early summer months, releases should be made via the leaf and tainter gates. The effects of this change would be to maintain a cooler, oxygenated hypolimnion for a longer period. By changing the release level, the rate at which the hypolimnion warms would not be as high. Instead of flushing the cooler water from the pool, the releases would flush the warmer epilimnetic waters.

This recommended operational change may result in four positive effects. One would be cooler water at the PPS, possibly reducing AEDC pumping/energy needs. Another positive effect is that the warmest water would be released from the lake, which might reduce epilimnetic temperatures somewhat. A third benefit is a less dramatic thermal change in the tailwater than what occurs now when releases are switched from the sluice gates to the leaf gates. The tailwater temperature showed an increase of 6°C as a result of gate changes. A more natural temperature cycle would be beneficial to aquatic life below the dam. The fourth effect would be maintaining DO in the hypolimnion longer into stratification, thereby, reducing anaerobic releases of iron and manganese. Hypolimnetic aeration could supplement DO levels to minimize anaerobic releases, if needed. This improvement would be passed on to streams receiving AEDC discharges. On the negative side, if cooler water is maintained in the hypolimnion into the Fall, destratification may be delayed somewhat (a week or two). A bimonthly lake survey was recommended to document the effects of the change in dam operation.

Hydropower Proposal

A review of two previous proposals to install hydropower generation facilities in the Elk River Dam was made in order to provide comments on possible effects on lake and tailwater conditions. These reports stated that hydropower would not produce any adverse effects on tailwater quality since the turbine intakes would be at the same elevation as the sluice gates. The field data collected during 1990 showed that significant reaeration would be lost if water passed through a a hydropower turbine due to reduced turbulence below the dam. Two measurements made during sluice releases showed low or no DO in the lake while the tailwater DO was at saturation. This loss of reaeration should be mitigated if hydropower generation is added to the dam. The existing tailwater appeared to be of high quality for fish and aquatic life habitat.

Other Issues

Other issues were considered during this study. Changes to the PPS raw water intake elevations were considered. Raising the pump intake elevations was not currently recommended because of adverse impacts on AEDC raw water temperatures for cooling water purposes and the possibility of improving water quality by changing the operation of the dam. A routine lake monitoring program was proposed for documenting year-to-year variations in water quality of Woods Reservoir. Brief aquatic macrophyte surveys were performed in the late summer and with only limited growths located. Prior to a decline in the late seventies, Woods Reservoir had extensive growths of aquatic macrophytes. The return of aquatic macrophytes is probably limited by light availability due to both algae and suspended solids. Fish tissue sampling for PCB's should continue until safe realized. Recommendations made concerning wastewater treatment systems at AEDC included eliminating two package-typeactivated sludge plants which receive infrequent flow and reducing hydraulic loading rates to the main trickling filter plant.

Conclusion

Based on the recommendations of the Corps reconnaissance level report, a phased implementation of various items needed to improve reservoir management will be made by AEDC over the next few years as resources become available. Some work will be performed in-house by AEDC, while other items will require follow-up by the Corps. This effort should improve AEDC's ability to manage the reservoir for flood control and also improve water quality conditions within the pool. A revised reservoir regulation manual, considering both water control and water quality, is the ultimate goal of this work.

DEVELOPMENT OF GEOGRAPHIC INFORMATION SYSTEM COVERAGES TO ASSESS RISK OF PUBLIC-SUPPLY WELL CONTAMINATION IN TENNESSEE

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During 1991, new geographic information system coverages were developed for use by State officials responsible for assessing risk of public-supply well contamination from hazardous-waste sites in Tennessee. The work was done in cooperation with the Tennessee Department of Environment and Conservation, Division of Water Supply. The coverages produced include (1) major aquifers, (2) karst areas, (3) public water-supply wells, (4) Comprehensive Environmental Response Compensation and Liability Act (CERCLA) sites, and (5) population centers. These geographic information system coverages can be combined to produce maps can be used to assess risk to wells and the population served by those wells.

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HYDROLOGICAL DATA ANALYSIS WITH A GEOGRAPHICAL INFORMATION SYSTEM [1]

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A Geographical Information System (GIS) is a powerful analytical tool with extensive hydrological applications. A GIS can produce high-quality maps and graphics, but more importantly, a GIS can link data to map features thereby allowing the spatial relationship of data to be explored. Map features can be plotted with different colors, symbols, or patterns based on their attributes to facilitate analysis. Such graphic display of data highlights spatially-related trends that are difficult to observe with a list of tabular data.

ARC/INFO, a commonly used GIS system, contains several subsystems including ARC, INFO, ARCEDIT, ARCPLOT, and others. ARC is the main program module in ARC/INFO. The capabilities of ARC include data conversion, digitizing, editing, file manipulation, coordinate projection or transformation, and analytical operations. INFO, the relational database manager, stores and manipulates tabular data associated with geographic features. ARCEDIT, an editor, can manipulate map features and feature attributes. ARCPLOT creates map graphics using features from any number of map coverages. Each coverage has a common theme; for example, one coverage may contain roads and another coverage may contain buildings.

The Oak Ridge Reservation Hydrology and Geology Study (ORRHAGS) uses ARC/INFO applications to help reach a conceptual understanding of groundwater flow for the Oak Ridge Reservation (ORR) in Oak Ridge, Tennessee. The ORR contains three Department of Energy (DOE) plants: K-25, a former gaseous diffusion plant; X-10, the Oak Ridge National Laboratory; and Y-12, a nuclear weapons facility. Each of these facilities collects groundwater data and each plant has developed its own database. To analyze data from the three ORR facilities, groundwater data were manipulated to conform to a standard format and structure in an integrated ORR-wide database for use by ORRHAGS researchers. The ORRHAGS database files are in fourteen related dBase IV files and contain information on groundwater chemistry and monitoring well construction. Water quality analyses date from the mid 1980's to 1989. The chemical files are divided by chemical class and include acid extractables, anions, base/neutral extractables, field parameters, metals, miscellaneous parameters, PCB's, pesticides, radionuclides, and volatile organic compounds (VOCs). Individual chemical samples are identified by the well name, plant, date of sample, whether it is a filtered sample, and whether it is a duplicate sample. The well construction data includes wells installed from the 1940's to 1990. Well data are in four files which include data on well construction, water level data, hydraulic parameters, and general geologic information. Individual well records are identified by well name and plant.

ARC/INFO was used to link well locations on the ORR and concentrations of groundwater

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[1] Research sponsored by the Oak Ridge Reservation Hydrology and Geology Study at the Oak Ridge National Laboratory, managed by Martin Marietta Energy Systems under contract DE-AC05-840R21400 with the U.S. Department of Energy.

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constituents. For example, in looking at the concentration of VOCs in groundwater, all wells with different concentration ranges can be displayed in different colors to illustrate spatial variations in concentrations. Plotted output can include the color-coded wells and geographical or man-made features. Other plots can include additional groundwater data, soil types, or geologic formations. The coverages used to illustrate contaminant plumes include layers of a reservation-wide digital base map, called the S-16A map, and a well location coverage with associated groundwater quality data.

The S-16A base map, developed by the Tennessee Valley Authority, was available in the GIS lab at the Oak Ridge National Laboratory, Environmental Sciences Division. Of numerous layers available from the S-16A, only a few with major features were used. ARCEDIT was used to modify some of the layers, because gaps are visible when only a few layers are plotted. The well location coverage was generated by the ORRHAGS project. Compilation of the well location coverage was complicated because four different coordinate systems were used to survey the ORR wells. These coordinate systems include an administrative grid, one for the K-25 Site, one for ORNL, and one for the Y-12 Plant. All plant grids were transformed into administrative grid so they would correspond to the administrative grid coordinates of the S-16A map. Because the grid systems were all developed independently, they have different origins and different deviations from true north. A separate coverage was created for each set of wells surveyed in the same coordinate grid. Every ARC/INFO coverage contains registration points called tics. ARC/INFO was capable of transforming the well coordinates if the tic coordinates were known in both the plant grid and the administrative grid. The tic coordinates from each of the three plant grids were transformed into administrative grid coordinates using a matrix operation that transformed each tic into Tennessee State Plane coordinates and then into administrative grid. Once the tic coordinates were calculated, ARC/INFO's transform command was used to perform an affine transformation for each well coverage. An affine transformation scales, rotates, and translates all coordinates in a coverage based on a least squares solution between the original tic coordinates and the new tic coordinates. Once the coordinates for each well coverage were transformed to the administrative grid, the coverages were combined into one coverage. The individual coverages were designed so that, when they were combined, each well would still have a unique numeric identifier. This numeric identifier was used to link the groundwater quality data to each well.

ARC/INFO's ability to link feature attribute data to well locations was demonstrated with a simple example involving VOC data from the Y-12 Plant. To reduce the volume of data for this example, dBase was used to filter the data to include only the data from the Y-12 plant in 1989 which were above the detection limits. Data for a select group of VOCs were extracted from the ORRHAGS database. One type of VOCs includes benzene, ethylbenzene, toluene, and total xylenes, which are all aromatic organic compounds that are typically associated with petroleum products. Another group of VOCs includes 1,1-dichloroethane, 1,2-dichloroethane, 1,1-dichloroethene, 1,2-dichloroethene, 1,1,2,2-tetrachloroethane, 1,1,1-trichloroethane, 1,1,2-trichloroethene, and tetrachloroethene, which are all chlorinated solvents used in degreasing and metal cleaning.

SAS, a statistical analysis package, was used to further summarize the data. The smaller set of VOC data was imported into SAS using a PROC DBF command. PROC DBF is a SAS command that automatically converts a dBase file into a SAS data set. Many wells on the ORR are sampled more than one time each year. SAS was used to calculate averages for the selected VOCs for each well. After the averages were calculated, all of the VOC values were summed for each well. In addition, the sum of the concentrations for the petroleum and chlorinated VOCs was calculated for each well. A SAS data set containing the unique numeric identifier from ARC/INFO was created. SAS was then used to merge the unique ARC/INFO identifier with the summary VOC data. SAS then generated a file which could be read by ARC/INFO. This file contained the

ARC/INFO well identifier and a sum of the averages for petroleum VOCs, chlorinated VOCs, and total VOCs.

ARC/INFO stores attributes for three feature types: points, lines, and polygons. All feature attribute tables contain an internal identification number and a user defined identification number (the unique numeric identifier). The wells were represented in ARC/INFO by points, so the unique numeric identifiers were stored in a point attribute table (PAT). The VOC data in an INFO data file was related to the PAT by each wells' unique number. After the data and attribute files were related, ARC/INFO was able to create maps based on the VOC data.

The ARC/INFO subsystem ARCPLOT was used to create map compositions for total VOCs near the Y-12 plant. These maps were used to examine the general shape of the total VOC contaminant plume, the variability of VOC concentrations from the chlorinated and petroleum VOC groups, the different VOC contaminant sources, and the type of VOCs released from each source. One color was used to show the total VOC concentrations, with darker shades representing higher concentrations. Several VOC concentration maxima were found and the general shape of the VOC plumes were shown. A large cluster of VOC-contaminated wells was located near the S-3 Ponds, on the west side of Y-12. These four one-acre ponds, which began operation in the early 1950's and have now been closed, were used for the disposal of liquid wastes from plant operations. Other VOC sources also exist near the S-3 Ponds (HSW 1991. Y/SUB/91-YP507C/1 Parts 1 and 2). Pie charts were used to show the location of other VOC sources and the type of VOCs the sources released. ARCPLOT's POINTSPOT command created pie charts that represented the relative concentrations of the petroleum and chlorinated VOCs. One color represented petroleum VOC concentrations and another represented chlorinated VOC concentrations. The pie charts showed that most wells near the S-3 Ponds contain more chlorinated VOCs than petroleum VOCs. ARCPLOT's SPOTSIZE command was also used to scale the pie sizes based on the total VOC concentration.

While VOC concentrations in groundwater was a fairly simple example, more sophisticated queries are possible. Additional data from the ORRHAGS database could be imported into ARC/INFO dealing with water quality data, well construction information, or geologic information. The ORRHAGS project is also working on additional coverages, for the ORR, including a geologic contact map and a soil types map. These new coverages will be polygon coverages with formation or soil data associated to their respective polygons. Once these coverages are created, ARC/INFO will be able to manipulate, analyze, and display the coverages' geographic information.

GIS analysis tools allow spatial relationships between map features to be identified and stored in the coverage's feature attribute table. Important analysis tools in ARC/INFO include topological overlay, buffer generation, and feature extraction. Topological overlay can create new map features and new feature attributes by overlaying two map layers. For example, the output from an overlay of the geologic formation and soil coverages would contain new polygons that have the data from both coverages. Polygons could then be identified that were in the Rome formation with clay-based soils. Spatial proximity or nearness of map features can be determined by using buffer generation. Areas and features can be identified when they fall within a buffer zone. Buffer zones are polygons that can be created around points, lines, or polygons. For example, wells within 500 feet of a facility may need to be identified so they can be sampled for VOCs. Feature extraction is a method of subsetting coverage features to be saved in an output coverage. One extraction method uses a polygon coverage to select a portion of a coverage. Another extraction method uses logical criteria to select map features. For example, using the polygon that represents the Y-12 Plant, all of the wells inside the plant area could be stored in a separate coverage. Using the logical criterion, an output coverage could be created that contained only wells whose depth was greater than 100 feet. Using the spatial analysis tools in ARC/INFO, important questions regarding the hydrology on the ORR can be analyzed. The flexibility and power of ARC/INFO allows many alternate scenarios to be evaluated. The ORRHAGS project will continue to use GIS to enhance the analysis of hydrological data.

AVAILABILITY OF GIS-BASED OR COMPATIBLE DATA FOR MODELING AGRICULTURAL NONPOINT SOURCE POLLUTION OF SURFACE WATERS IN TENNESSEE [1]

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Introduction

A critical gap exists between the input data required for hydrologic/ water quality models and geographic information systems (GIS) and the availability of those data for Tennessee. This problem has made our task of integrating a hydrologic/water quality model with GIS data more difficult. We offer this summary from our experience to help other engineers, scientists, and regulators proceed with realistic expectations.

A comprehensive model requires extensive watershed, hydrologic, and water quality data. Our selection of a study watershed was controlled by the scarcity of available streamflow and water quality data, essential for basic model calibration. Available quality-assured meteorological data come from a very coarse network and may not necessarily be representative of intermediate sites. Most model parameter values must be derived from areal coverages of the watershed, such as detailed land use, land cover, soil and geologic maps. State-wide GIS-based hydrologic/water quality modeling may become more appropriate in future years as geographic data bases for soil and land use are compiled and digitized using standardized classifications and scales. With only few exceptions, including the digitized soil map for Crockett County and the United States Geological Survey Digital Elevation Models (1:24,000), we know of no available geographic data bases suitable for local-scale modeling in Tennessee. Because of the need for consistent data across county lines, we recommend a centralized coordinated effort to design, compile, store, and make available environmental data bases in Tennessee.

Data Requirements

The main objective of our project is to integrate GIS technology with hydrologic modeling to evaluate the effects of Best Management Practices (BMP's) in watersheds in Tennessee. We have been using the hydrological model HSPF (Hydrological Simulation Program - FORTRAN)(Johanson *et al*, 1980) and the GIS Arc/Info. Current state-of-the-art hydrologic models such as HSPF are powerful tools for modeling streamflow and water quality in a watershed, based on existing and proposed conditions, but they characteristically require very fine temporal and/or spatial resolution (detailed) input data.

We have chosen to model sediment and nutrient loadings in a 31 square mile catchment. To do so, we must know the catchment's topography, hydrography, hydrology, climate, soils, and land uses. Since BMP's are employed on individual farms, we ideally would work at a scale sufficiently fine to detect these changes in land use. HSPF sub-routines calculate a

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water budget and generate runoff at various time scales. It estimates sediment and nutrients from a set of equations. It is only a model, so the geographic distribution of input parameters must be lumped together within contributing sub-areas. HSPF calculates input values for user-defined nodes in the hydrographic network, then reevaluates hydrologic/waters-quality factors as they are routed downstream (Johanson *et al*, 1980). The model will estimate missing parameters and will develop stream loadings based on a time series (preferably hourly) of climate data. Calibration of HSPF requires a time series gauging record of at least one year that includes the parameters of interest, in this case discharge, suspended sediment, and nutrient loadings.

Data Availability in Tennessee

Topographical and Geographical Base Maps

Topographic maps at 1:24,000 are published by U.S. Geological Survey (USGS) for the entire state of Tennessee. Digital Elevation Models (DEM's) have been derived from them for most of the state and Digital Line Graphs (DLG's) of hydrography, transportation, and boundaries have been completed for approximately one-third of the quadrangles. Errors exist in these digitized databases, so that users should exercise caution (Carter, 1989), but, for a price ($40 for the first quadrangle), GIS base maps may be generated and topographic parameters calculated.

Soils

Soils are mapped by county by the Soil Conservation Service (SCS). Significant variability exists among counties in the scale of maps and in the way in which soil series are associated.) Although SCS has a national GIS database (soil survey Geographic Data Base), digitized soils maps (scales ranging from 1:15, 840 to 1:31, 680) exist for less than 200 counties nationwide (Reybold and TeSelle, 1984). [Only Crockett County has digitized soils maps.] Digitizing detailed soils maps is extremely tedious; but, although the maps of soil associations are easier to digitize, associations may be based on attributes unrelated to the physical properties of soil that control runoff and sediment and nutrient loadings. A critical problem for watershed modeling in Tennessee is the incompatibility of soil maps where hydrologic units (inevitably) cross county boundaries. This problem is not unique to Tennessee (Bliss and Reybold, 1989). Soils data vary also. Some counties have Universal Soil Loss Equation factors published for soil series; and statewide moisture characteristics have been published (Longwell et al., 1963).

Geology

Geologic maps at several scales (as 1:24,000; 1:125,000; 1:250,000) exist for parts (individual mapping projects) to all (geologic maps of the states of Tennessee and North Carolina) of the Nolichucky River Basin. Dates of mapping, quality, and interpretability of the maps vary. Almost none of these geologic maps have been digitized in a form or scale that is appropriate for importing into a GIS for a model such as HSPF. Doing a consistent, accurate, and meaningful job of incorporation of bedrock geology into a GIS will require: field reconnaissance of existing mapped areas, standardization of mapping legends, grouping of mapped rock units into groups that are meaningful from the standpoint of the specific research to be done, and finally, digitizing and importing the final map into the GIS system.

Land Use

No digitized land use data at a scale relevant to BMP's are available state-wide. Satellite images (LANDSAT), in digital format, have a resolution of 30 meters, but require interpretation. USGS has land use/land cover maps at a scale of 1:250,000. In each case, it is possible to differentiate forest from crops, but not some crops from others. TVA has black and white air photo coverage of the Tennessee Valley and most SCS county offices have a set of photos covering the county but, except for a few very specific project sites, land use from air photos is neither interpreted nor digitized. Digitizing land use classes from low altitude air photos is an extremely time-consuming process.

SCS offices in each county frequently have hand-drawn land use maps (not digitized, not standardized scale). The lack of available land use data makes it necessary to input generalized estimates into the model (e.g., 20% row crops). This is an unfortunate under-use of the capabilities of the model.

Climate

Climate Stations are maintained in the state by the National Climatic Data Center and Tennessee Valley Authority (TVA). These agencies maintain separate records, so both must be contacted to locate the closest station. At TVA, temperature and evaporation data are under the jurisdiction of the Power Division, whereas precipitation data are acquired and managed by Hydrology. Unfortunately, this means that different stations record different parameters and few locations have the full spectrum of parameters required for water balance calculations. Data may be obtained in digital format, and TVA stations have periods of record exceeding ten years. Because of the local nature of precipitation cells and microclimatic conditions, a degree of spatial homogeneity of climate must be assumed, since the climate station network is inevitably too coarse to dependably represent the watershed. This problem is exacerbated in Tennessee by rugged topography.

Surface Water

Streamflows are monitored by USGS, TVA and the US Army Corps of Engineers. USGS data is stored in the database WATSTORE. Few stations in Tennessee have a multiple year continuous streamflow record and water quality. Tennessee Department of Health and Environment (TDHE) monitors water quality in the state and has records for 3,500 surface water stations in the database STORET. The vast majority of these records do not relate to ambient monitoring but to occasional targeted sampling. They may be entered into a GIS format using the lat/long coordinates. TDHE actively monitors water quality at 86 sites in the state, but samples are taken quarterly (formerly monthly) and there is no assurance that streamflow values are recorded or that the water-quality parameter we need (e.g. suspended sediments, nitrates) is determined. In the absence of water-quality data in the same time series as streamflow data, HSPF interpolates to generate the missing values. Our initial data problem arose in locating a study catchment with a gaging record with which to calibrate the model, because ambient monitoring stations on small tributary streams are rare.

Conclusions and Recommendations

Using a GIS to input topography, soils, and land use is a straightforward task only where those parameters have been reliably mapped and digitized at an appropriate scale. The reality in Tennessee is that hydrologic modeling requires extensive compiling and digitizing of existing data and synthesizing of missing data. Models that might be relatively simple to employ become massive, time-consuming, expensive undertakings. Assuming a long-term future of GIS and the increasing importance of water-quality investigations, Tennessee should acquire, digitize, and even commission the development of basic spatial databases such as soils, geology, hydrography, topography, land use, and climate records. The State GIS should centrally own the USGS digital databases (DEM's, DLG's) for the state so that they are readily and inexpensively available to users and so that updated, corrected versions could be quickly disseminated. This would constitute a significant improvement over the status quo, in which each user has to purchase from USGS and start from scratch in screening for accuracy. The majority of data in Tennessee, especially soils, are acquired and processed at the county level. For watershed modeling, unrelated to county boundaries, it is essential that counties use standard scales, associations, and formats.

Administrators, managers and technical personnel all must realize that computer modeling involves far more than simply executing a "canned" program and printing out the answer. As long as the required data remain so scarce, the quality and usefulness of models will be limited. If GIS are to be employed, an initial effort must be made to develop the required digital databases. With so many GIS users in Tennessee "reinventing the wheel," state-level coordination and pooling of digital data resources would help to remedy the situation.

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DEVELOPMENT OF A GIS BASED SYNTHETIC WATERSHED SEDIMENT ROUTING MODEL

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Introduction

For most watersheds, extensive water quality data are not available. Land use, topographic, edaphic and meteorological information is generally available; but without extensive water quality data, it is difficult to accurately calibrate and verify a continuous nonpoint source model such as HSPF. However, if the spatial and physical attributes of a watershed can be assembled into a geographic information system (GIS) data base, this information could potentially be used to generate synthetic water quality data by a simplistic approach. This paper focuses on the development of a GIS (ARC/INFO) based synthetic watershed sediment routing model. An important problem, particularly in a large watershed, is the transport of sediment produced in the subwatersheds to the outlet of the whole watershed. This problem is approached mathematically by a sediment routing equation that is based on the streamflow component of the total model. The synthetic model is applied to the 56.3 square mile North Reelfoot Creek watershed, located at the Northwest corner of the state of Tennessee. The results of this synthetic model are then compared with those from an integrated GIS-HSPF model and with the observed data.

Study Area

North Reelfoot Creek watershed (Fig. 1a) is typical of nonpoint pollution due to highly intensive agricultural activities. The creek is comprised of a main channel beginning approximately 4 miles north of Union City stretching roughly 17 miles to Highway 22 (The location of USGS gaging station).

The North Reelfoot Creek watershed is divided into two physiographically distinct regions. Area I on the western side is characterized by steep uplands with slopes ranging from 8 to 50 percent. Area II on the eastern portion, however, is fairly level uplands with slopes from 0 to 8 percent. The watershed is intensively farmed. In 1980, approximately 64 percent of the study area was planted in crops, 20 percent was grassland, and 12 percent was woodland. A very small portion is covered by wetlands, lakes, and roads. Area I covers 30.5 mi2 or 54.2% of the study area. Hillsides consist of cropland, woodland, grassland, and gullied area (Fig. 1b). Area II covers 25.8 mi2 or 45.8% of the study area. Hillsides are mildly sloped, consisting primarily of cropland and grassland. The primary agricultural crops grown in the watershed are soybeans and corn. Cotton and sorghum are also grown. Cropland acreage has declined to 44 percent today primarily as a result of the Reelfoot Lake Clean Water Program project.

The estimated 1980 gross erosion from this watershed was approximately 750,000 tons. About 230,000 tons of this sediment were transported to Reelfoot Lake, where it was deposited. As a result of sedimentation during the last several decades, Reelfoot Lake has decreased in size from 77.2 square miles to 19.3 square-miles. [1] One direct

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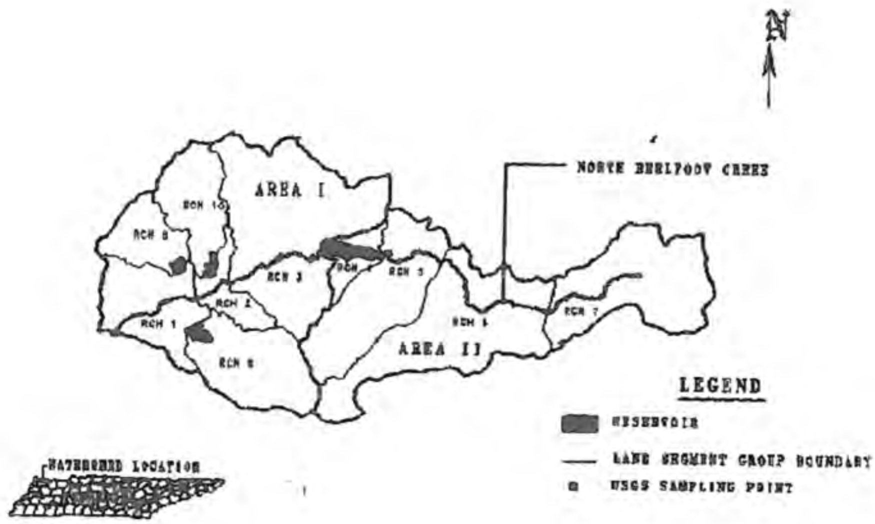

Fig. 1a. Location map and North Reelfoot Creek watershed.

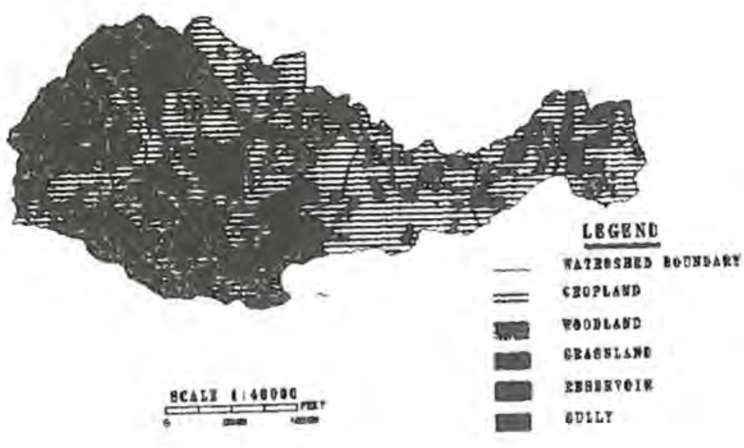

Fig. 1b. Landuse conditions (1988) of the study area based on aerial photos.

negative impact of sedimentation from soil erosion is the potential reduction in recreational benefits of the lake.

Integrated Nonpoint Source Model (GIS-HSPF)

A comprehensive nonpoint source model, Hydrological Simulation Program-FORTRAN (HSPF), [2] has successfully been calibrated and verified by Chew, et al., [3,4] to simulate the hydrological, hydraulic and sediment processes occurring on North Reelfoot Creek watershed. However, in order to enhance the overall modeling capabilities of HSPF, an additional study was recently completed by Sahoo [5] using more detailed spatial and physical attributes of the watershed assembled into an ARC/INFO GIS data base. One of the primary objectives of this study was to develop a GIS-based synthetic watershed sediment routing model to generate synthetic water quality data that will facilitate use of the HSPF model even on watersheds where minimal or no calibration data are available.

Synthetic Model (GISSRM)

Erosion and sedimentation by water embody the processes of detachment, transportation, and deposition of soil particles (sediment) by the erosion and transport mechanisms of raindrop impact and runoff over the soil surface. [6] The physical processes incorporated in the simplified model include: (a) Surface runoff arising from the rainfall and causing soil surface detachment and sediment transport in a subwatershed; (b) Sediment delivery due to the sheet and rill erosion to the outlet of a subwatershed (Stream channel bed and gully erosion are neglected); and (c) Deposition of suspended sediment that arises from the sheet and rill erosion in the reach between the outlet of a subwatershed and that of the whole watershed.

In quantifying these processes, the following methodologies were adopted: (a) Computation of runoff parameters by SCS rainfall-runoff model [7] or USGS regression equations; [8] (b) Construction of the subbasin storm runoff hydrographs by incomplete Gamma Distribution [9] or USGS dimensionless hydrographs for Tennessee; [10] (c) Channel routing by Muskingum method [11] for ungaged watersheds and reservoir routing by improved Euler method with parabolic interpolation; (d) The "Modified Universal Soil Loss Equation" (MUSLE) [12] for computing sediment yield due to sheet and rill erosion at the outlet of a subwatershed; (e) The Sediment Routing Model of Yang-Stall [13] for computing sediment transport in the main channel reaches.

Fig. 2 illustrates the flow chart of the GIS based synthetic watershed routing model (GISSRM). Most of the input variables are a function of the three important GIS coverages (i.e., topography, land use (Fig. 1b) and soil type). Additional meteorological data and information on cropping practices were taken from available literature and supplemented into the ARC/INFO database.

Combining soil and land use information, the important hydrologic variables such as hydrologic soil group, surface condition, roughness coefficient, SCS curve number and USLE parameters (LS, K, C, P) were derived for each subbasin.

Simulation Results

The synthetic model (GISSRM) was run for all the major single storm events for the period of record (1984-1989). Results were summarized on a monthly and annual basis since actual data on a storm basis were not available.
Comparison of mean annual observed and synthetic flows are shown in Figure 3a. Synthetic runoff values (cfs) fell between +11% to -20% of the recorded values.

Computed annual sediment loads fell between -31% to +17% of the recorded values. Figure 3b suggests that the model overestimates loads for years with low sediment yields and underestimates loads for years with high yields. Part of the

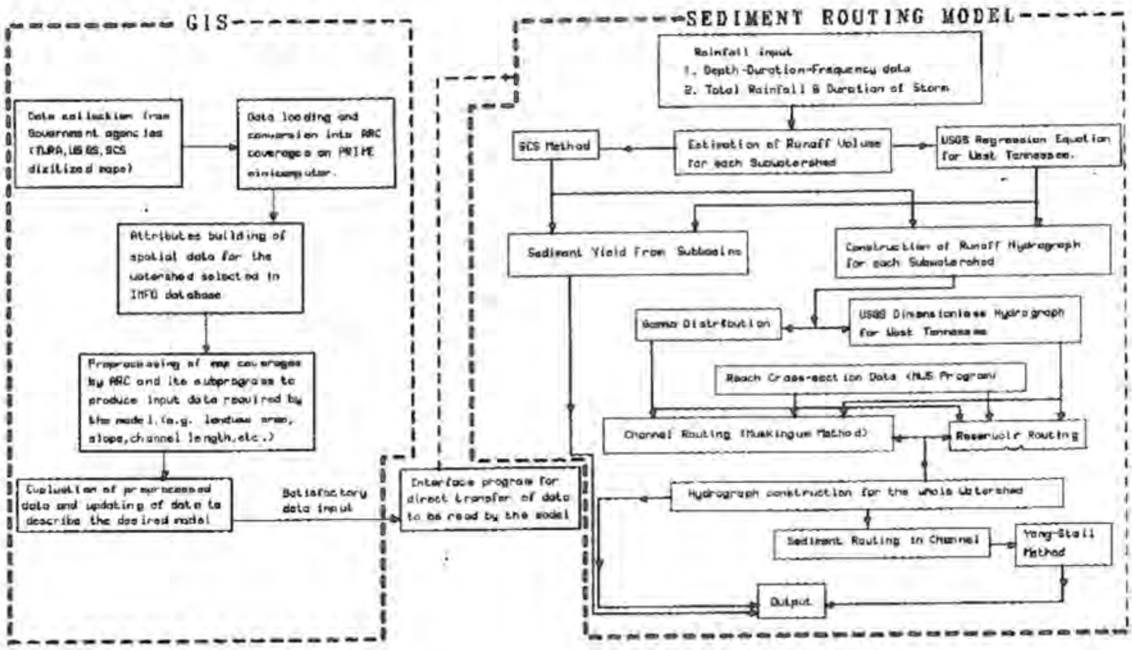

Fig. 2. Flow chart of a GIS-based synthetic watershed sediment routing model.

underestimation may be explained by the fact that more extreme storm events could strongly influence channel and gully erosion which also contributes to the production of suspended load.

The sediment yield from subwatersheds in tons/acre/annum computed from this model were also compared with those obtained from an integrated GIS-HSPF model. Subwatersheds in Area I known to have gulleys present showed larger underestimated differences than the other subwatersheds in Area II.

The expected average annual sediment loads for the watershed were computed in the synthetic model by both the runoff frequency approach (i.e. USGS regression equation) and the rainfall frequency approach (SCS CN method). The computed values were 112,000 tons by the runoff and 132,000 by the rainfall frequency methods, respectively. These estimates were reasonably close to the annual observed data for the year 1985 (98,897 tons), in which the total rainfall of 49 inches is nearly equal to the mean annual rainfall of 50 inches.

Summary

The use of a GIS data base in both the continuous-process (HSPF) and event-driven (GISSRM) models was found beneficial in enhancing the modeling efforts and model performance. In addition to improving sediment simulation, the GIS approach minimizes time requirements and human error when accurate, digitized data are available.

The integrated geographic information system nonpoint source model was calibrated using both the observed data from the USGS gaging station (GIS-HSPF(R)) and the synthetic data computed by the GISSRM model (GIS-HSPF(S)). The synthetic

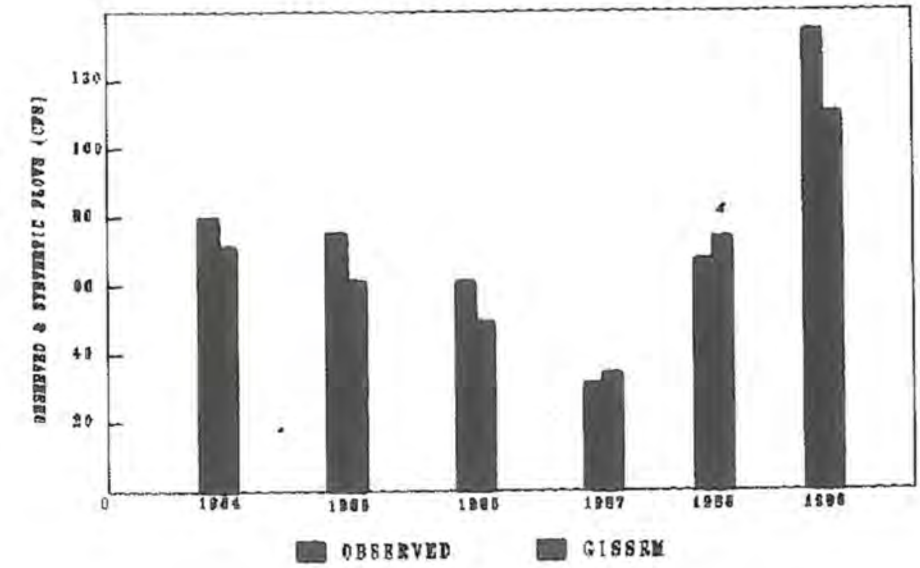

Fig. 3a. Comparison of annual mean flows (cfs).

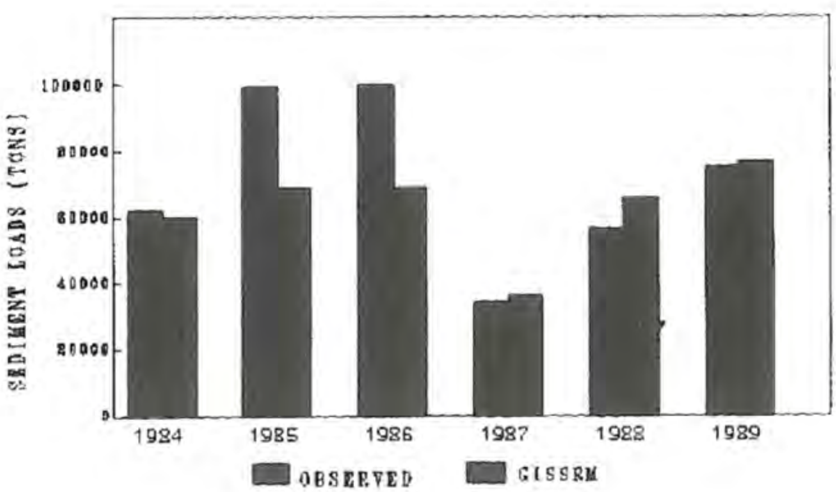

Fig. 3b. Comparison of annual sediment loads.

simulation yielded nearly the same hydrologic/hydraulic response as the real data approach. However, the synthetic sediment data approach exhibited an average error of 18.5% in annual sediment yield when compared with the observed data while the real data appraoch had only 6% error.

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EFFECTS OF FLOWPATH VARIATION ON THE HYDROGEOCHEMICAL RESPONSE OF WALKER BRANCH WATERSHED TO STORMS [1]

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Precipitation and stream discharge have been monitored continuously since 1969 in the East and West Forks of Walker Branch Watershed, a 97.5-ha forested catchment underlain by dolomite (Knox Group) and typical of large portions of the Ridge and Valley Province of eastern Tennessee. Watershed topography is characterized by broad ridges with steep slopes and narrow stream valleys. Soils (primarily Ultisols) are acidic, low in exchangeable bases, and generally deep (up to 30 m) on ridges declining to 1-2 meters along perennial stream channels. On average, annual precipitation totals 137 cm and annual runoff about 71 cm, of which about one-half occurs as baseflow. Water budgets for the entire watershed indicate approximately 15% of the discharge originates outside of the watershed, with the West Fork gaining approximately 35% of its annual flow from outside its topographic boundaries and the East Fork, which has perennial reaches but is intermittent at the base of the catchment, losing flow. The differences in annual runoff between the catchments are primarily the result of larger baseflow on the West Fork. Analysis of storm hydrographs indicates that the East and West Fork watersheds generate similar amounts of storm area-specific runoff.

Intensive studies of soil hydrogeochemical processes on a hillslope in Walker Branch have indicated high rates of surface infiltration, considerable vertical variation in hydraulic conductivity resulting in zones of perched saturation during storms, and the importance of flow through macropores and mesopores in regulating hydrology and solute chemistry during storms (Jardine et al. 1990, Luxmoore et al. 1990, Wilson et al. 1991). To determine patterns in hydrogeochemical response at different spatial scales, the West Fork Watershed has been instrumented with an array of lysimeters, piezometers, groundwater wells, and flumes that partition it into a nested set of catchments ranging in size from a 0.5-ha upper slope subcatchment to the entire 38.4-ha West Fork Watershed (Fig. 1). The flume on the 0.5-ha catchment captures both surface and subsurface flow in the top 2.5 m of the soil profile. Groundwater levels, flow, and solute concentrations have been intensively monitored across this network during several storms in 1989 and 1991. Each of these storms was large enough to generate surface flow in the ephemeral stream network in the upper portions of the West Fork Watershed. Results from the 1989 studies are presented in Mulholland et al. (1990).

Hydrometric Results

The surface hydrologic response to precipitation was biphasic, consisting of a small increase in flow in the perennial stream within a few hours after the onset of rainfall and a much larger flow response in ephemeral and perennial streams throughout the watershed commencing 12 h to several days after rainfall. The lag period prior to the second, larger hydrologic response was

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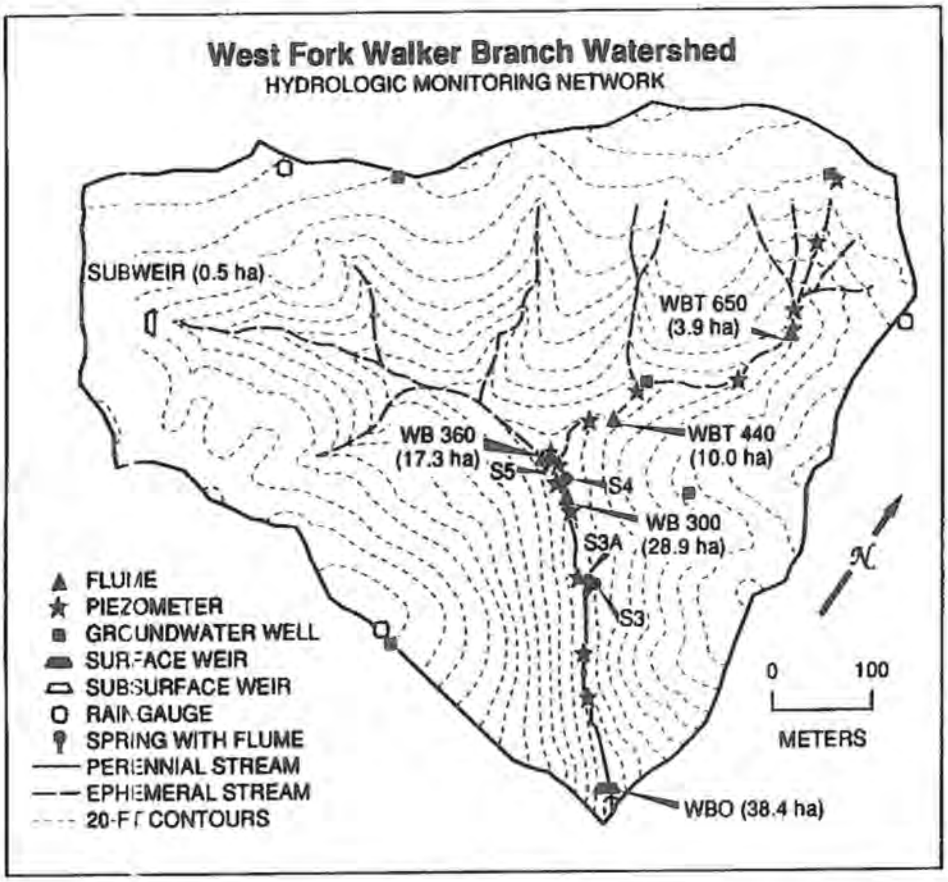

Fig. 1. Map of the West Fork of Walker Branch Watershed indicating sites of hydrometric measurements during storms.

related to rainfall intensity and antecedent soil moisture condition, with longer lags for lower intensity events and drier antecedent conditions. The second response involved a spatially sequenced initiation of flow beginning in the upper slope subcatchment (shallow subsurface flow only) and working its way downgradient. This whole-watershed response was preceded by the development of extensive zones of perched saturation, first in the upper few meters of soil on the upper slope and then in the ephemeral stream valleys. Water levels in the permanent groundwater zone in upslope portions of the watershed responded very little to individual rainfall events, suggesting that storm runoff was largely decoupled from deep groundwater dynamics over much of the watershed.

Storm runoff measured in the perennial stream at the base of the watershed varied from 30% to 55% of precipitation, indicating contributions from large portions of the watershed. Storm runoff also increased with increasing catchment size for most storms, suggesting that relatively long subsurface flowpaths were important in contributing stormflow in the lower portions of the watershed. However, storm runoff was similar across all catchment sizes during a large January storm with very wet antecedent soil moisture conditions, indicating that shallow flowpaths dominated at this time.

Water Chemistry Results

In general the effects of storm runoff on major ion chemistry in the perennial stream were: a dilution of base cations (dominated by Ca and Mg), a dilution of alkalinity, and an increase in SO_4 concentrations. These effects were largely the result of runoff from upper portions of the watershed via subsurface and ephemeral stream flow characterized by very low levels of base cations, low alkalinity, and relatively high SO_4 concentrations.

The spatial distribution of sources and sinks of different solutes in storm runoff from the watershed is evident from variation in flow-proportional concentrations across catchment sizes. Spatial patterns in flow-proportional solute concentrations were of four types. For Ca, Mg, and alkalinity, rainfall concentrations were low and concentrations increased with increasing catchment size. Most of the increase in concentrations of these solutes occurred in the perennial stream at the largest watershed scale, indicating that bedrock was the dominant source of these solutes. Concentrations of Si, K, Na, and Cl were also low in rainfall and increased with increasing catchment size, but the majority of the increase occurred with the smallest catchment size (shallow subsurface flow from the upper slope subcatchment), indicating that the upper soil was the dominant source of these solutes. Concentrations of SO_4, Al, and to some extent dissolved organic carbon (DOC) were low to moderate in rainfall, increased sharply and peaked at the smallest catchment scale, and declined with increasing catchment size thereafter. This pattern indicates the importance of the upper soil as a source of these solutes and suggests a sink along deeper flowpaths through the soil. Concentrations of NH_4, NO_3, and PO_4 are relatively high in rainfall (or precipitation passing through the forest canopy), decline sharply to almost undetectable levels at the smallest catchment scale, and increase somewhat at the largest catchment scales. This pattern indicates an extremely strong sink for these biological nutrients in the upper soil layers and a secondary source low in the watershed (probably bedrock for P and unknown for N).

Solute concentration patterns over storm hydrographs at different sites (catchment scales) help identify geochemical mechanisms dominant at those scales. Concentrations of Ca, Mg, alkalinity, and Si are distinctly diluted during high flow in the perennial stream, indicating that a kinetically-controlled process such as weathering was largely the source of these solutes at the larger catchment scales. Although Si concentrations were also diluted at high flow in the ephemeral streams, concentrations of Ca and Mg, although low, were relatively constant indicating that a rapid process such as ion exchange largely controlled release of these solutes to runoff through soils. Concentrations of SO_4 and DOC increased at high flow at all sites further indicating the importance of upper soil sources and sinks along deeper flowpaths through the watershed. DOC concentrations followed a clockwise hysteresis pattern at all sites indicating either source depletion or a change in dominant flowpaths from rising to falling limbs of the hydrograph. Jardine et al. (1990) suggested competitive sorption reactions controlled DOC and SO_4 dynamics in soils during storms.

Geochemical Tracers of Hydrologic Flowpaths

Because of the spatial variability in solute sources, some solutes are useful as tracers of the relative importance of different hydrologic flowpaths in generating storm runoff in the perennial stream. Ca and Mg are useful in identifying the contribution of deep groundwater because the bedrock is the only sizeable source of these solutes in runoff. Stream runoff was separated into soil zone flowpaths, with Ca concentrations of upper soil runoff (@ 2 mg/L), and bedrock zone groundwater flowpaths, with Ca concentrations equal to those measured in a large, relatively constant flow spring (S3) prior to storms (26.8-29.7 mg/L). Results of this separation indicated that bedrock zone groundwater flowpaths accounted for an average of only 6% (range: 3-10%) of the storm runoff at an upper perennial stream site (catchment size of 28 ha), but that bedrock zone groundwater flowpaths accounted for about 15% (range: 4-30%) of the storm runoff measured in the perennial stream at the base of the watershed.

Christophersen et al. (1990) have proposed an end-member mixing analysis that uses pairs of solutes as tracers for determining the geochemically-relevant flowpaths contributing to streamflow. The approach defines a few geochemically different types of water resulting from processes in spatially distinct zones (e.g., upper soil horizons, lower soil zone, groundwater) and ascribes streamflow at any one time to a mixture of different proportions of these waters, with changes in stream solute concentrations being due to changes in the mixed proportions. Using Ca and Si as tracers, streamflow at the base of the watershed appears to be a mixture of only two water sources (flowpaths) since data plot roughly as a line on the Ca-Si axes. A bedrock zone groundwater flowpath with Ca/Si concentrations similar to that of spring S3, and a soil zone flowpath with Ca/Si concentrations similar to either upper soil runoff or ephemeral stream runoff account for the perennial stream Ca/Si storm chemistry. However, using Ca and SO_4 as tracers, there is evidence of at least three water sources (flowpaths) contributing to streamflow (bedrock zone groundwater, upper soil zone flow, deeper soil zone flow). An analysis using Ca and naturally-occurring ^{222}Rn further suggests the existence of three important flowpaths contributing streamflow.

Samples for measurement of $^{18}O/^{16}O$ ratios were collected across the nested catchment sites during a March 1991 storm to determine the contributions of antecedent water and event water to storm runoff along different flowpaths. These data may indicate the importance of soil water and groundwater mixing compared to bypass flow processes (via macropores) in generating stormflow and determining water chemistry across different spatial scales in the watershed.

Our results to date indicate that stormflow generation is a threshold type of process in Walker Branch, with limited surface response until considerable zones of perched saturation develop in the upper soil and trigger a large flow response across the watershed via the ephemeral stream network. There appear to be at least three dominant geochemically-distinct hydrologic pathways: (1) upper soil zone flow, (2) deep soil zone flow, and (3) bedrock zone groundwater flow (Fig. 2). The relative importance of these flowpaths vary spatially along the perennial stream and through time.

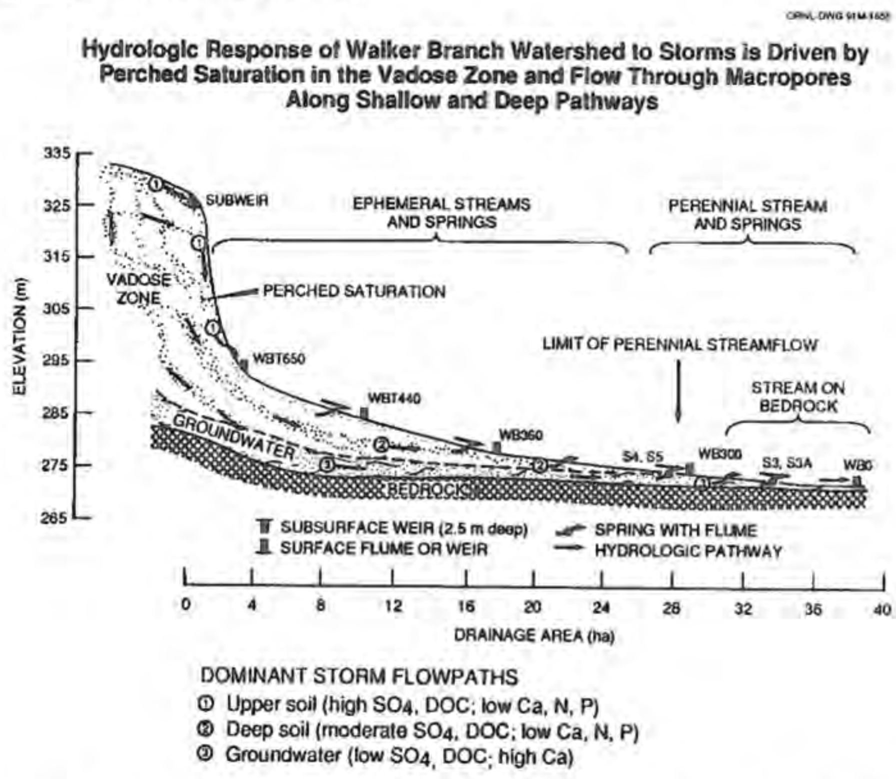

Fig. 2. Dominant storm flowpaths and major chemistry differences for each in Walker Branch Watershed.

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TRANSPORT OF CONTAMINATED SEDIMENT DURING FLOODS IN WHITE OAK CREEK NEAR OAK RIDGE, TENNESSEE [1]

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Introduction

Parts of the White Oak Creek (WOC) watershed have become contaminated during the last 47 years of operation of Oak Ridge National Laboratory (ORNL). The 16 sq. km. catchment consists of a short embayment between White Oak Dam and the Clinch River, a small lake (7 ha), and two main tributaries (Melton Branch and White Oak Tributary) which converge 1 km upstream of the lake. The contaminants presenting the highest risk to human health and the environment are particle reactive and are associated with the soils and sediments in the floodplains and channels of WOC and in White Oak Lake (WOL). During floods, the erosion and resuspension of these sediments can result in the transport of contaminants within the catchment and out of WOL into the Clinch River. It is not possible to predict the transport of contaminated sediment during storms because the existing database and monitoring program were not developed to address this issue. In order to evaluate the probability of contaminated sediment transport during floods, and to develop strategies for controlling off-site transport, a data collection program and a modeling investigation have been initiated. The data collection program is required to establish a conceptual model of contaminated sediment transport in WOC, to provide the data required to calibrate and apply the computer model, and to generate a database that will be used in the future to evaluate the effectiveness of completed clean up activities. The computer model will be used to simulate the transport of contaminated sediments during floods up to the 100-year event with existing and future land use conditions.

Transport of Contaminated Sediment in White Oak Creek

It is not currently possible to predict the transport of contaminated sediments within or out of WOC during floods. The existing database and monitoring system for the movement of sediments and contaminants are not capable of providing the type of information required to extrapolate contaminant transport from small floods to larger events. In addition, the difference in magnitude between commonly observed floods (i.e., 1 to 5 year events) and moderate to extreme floods (50 to 100 year events) would make it difficult to estimate contaminant transport during larger floods by extrapolating from common floods even if a sufficient database were available. Instead of extrapolation, a computer model is used. In order to select an appropriate computer model, a preliminary data collection program is being used to construct a conceptual model of contaminated sediment transport in WOC during floods. The conceptual model will establish the significant sources and transport processes that must be known to conduct a modeling investigation. Once a computer model has been selected, a comprehensive sampling and analysis program will be developed to collect

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the information required to calibrate and apply the model.

Preliminary Data Collection

Sediment and contaminant transport during floods will be sampled in the preliminary data collection program using six monitoring stations in WOC. The initial locations of these stations (Fig. 1) were selected to identify sources of contaminated sediment and areas where sediment accumulates. At each station, an automatic pumping device collects periodic samples of streamwater and suspended sediment. The samplers are controlled by stage monitors so that the samples are only taken during floods that exceed a specified magnitude. Manual sampling with depth-integrating samplers will be used to correlate automatic point samples with the actual sediment discharge calculated from measurements of the vertical and horizontal distribution of suspended sediment. Containers have been installed in the streambed to collect bulk samples of bed load.

Samples are analyzed for suspended sediment load, grain size distribution and various chemical contaminants. In addition to in-stream sampling of sediment transport, methods are being developed to measure erosion in the floodplain and along channel banks, and to estimate sediment yield from hillslopes that drain into the channel system. The preliminary data collection is expected to continue for two more years. Once sufficient data is available, the computer model will be selected and a comprehensive sampling and analysis program developed for calibration and application of the model.

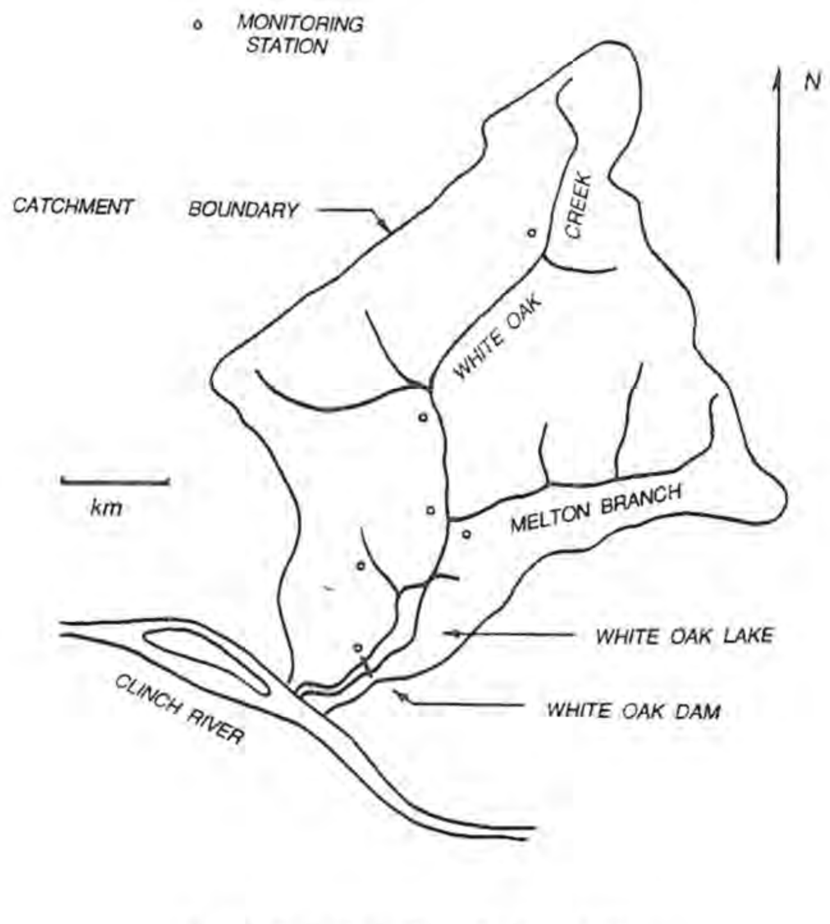

Fig. 1. Location of monitoring stations.

Modeling Contaminated Sediment Transport

A computer model will be used to simulate the hydrologic response and the transport of contaminated sediments in WOC during flood magnitudes ranging from the 1 year to the 100 year event. The initial simulations will be based on the existing land use and climatic conditions to evaluate the current probability of contaminant movement. If the risk is unacceptable the model will be used to evaluate the short term and long term effectiveness of proposed approaches for reducing the chance of contamination moving off-site. Estimates of uncertainty in the results will also be included.

This application requires a catchment scale model with good components for surface and near surface hydrology, channel routing, and the transport of sediment and contaminants. A model structure is needed that will maximize the potential for accurate extrapolation well beyond the range of observed events. However, if the amount of calibration data that can be collected during floods in the near future is limited, a compromise will be required between a complex, physically based model with many parameters and a relatively simple model with a limited number of parameters to be calibrated.

Based on these criteria the Hydrologic Simulation Program-Fortran (HSPF) model is an example of the type of model that could be selected. This model incorporates the rainfall-runoff components previously known as the Stanford Watershed Model along with components for sediment transport and water quality modeling. An extensive set of documentation for HSPF is available through the Environmental Protection Agency (EPA, 1984).

Assuming that a model similar to HSPF is selected, a 5 to 10 year sampling and analysis program will be developed to collect the data required to calibrate the model. There are over 50 parameters involved in simulating contaminated sediment transport in WOC with HSPF. Values for these parameters will be set by calibrating the model in three stages: hydrologic response, sediment dynamics, and contaminant transport. The hydrologic response components are calibrated for WOC using observed data for precipitation, stream discharge, potential evapotranspiration, channel characteristics, and soil and land use conditions. The calibration of the sediment transport components requires data collected during a range of discharges for erosion by overland flow, scour and deposition in the floodplain and channel, concentration and particle size distribution of suspended sediment, and the median particle diameter of the bed material. The water quality components allow the simulation of any constituent for which data is available for the sediment-water partition coefficient (Kd), temperature and pH. Much of this information is already available. Lab experiments can determine missing Kd values for the specific radionuclides, metals and organic constituents and the mineralogy of the sediments that these contaminants may encounter in WOC.

The objective of the calibration phase is to set parameter values using observed events to maximize the potential for accurate results of simulated extreme events which may be 2 or 3 orders of magnitude larger than some of the calibration events. Based on a limited number of case studies which compare the simulated response of a calibrated model to observed events (often referred to as verification), it is generally possible to limit errors to 20% to 40% for the hydrologic response of floods within an order of magnitude of the calibration events. The potential errors in the simulations of sediment dynamics are expected to be twice the errors in the hydrologic response, and the errors in the water quality simulations are expected to exceed errors in the sediment dynamics results. Estimates of uncertainty in the results will be critical in this application due to the limited amount of calibration data and the extrapolation to events several orders of magnitude larger than some of the calibration events. Techniques for estimating the uncertainty of each modeling component (hydrology, sediment dynamics and contaminant transport) are being developed for the model structure, calibration techniques and field data.

Applications

After HSPF is calibrated the initial application will be to simulate the transport of contaminants within the WOC catchment and off-site into the Clinch River for flood magnitudes between the 1 year and 100 year events. The probability of specific magnitudes of contaminant transport will be estimated using the exceedance probabilities of the discharge and the amounts of sediment and contaminants available for transport under the various antecedent conditions in WOC that currently exist. The model will then be used to evaluate the effectiveness of proposed approaches to reduce these risks that are being considered in the Environmental Restoration Program at ORNL. In addition to short term impacts, the model can be used to evaluate the long term effectiveness of specific restoration activities by assuming a variety of future land use and climatic conditions.

In addition to evaluating the risk of off-site contaminant transport at ORNL, the results will be relevant to other water resources issues in Tennessee. The transport of contaminated sediment is an important issue in the management of hazardous waste sites, urban storm water and navigable rivers. The ability to predict the movement of contaminated sediments resulting from a flood or specific management or development plans is currently limited by incomplete understanding of the physical and chemical processes involved in the transport of contaminated sediments, and the lack of adequate databases and modeling expertise. The results of this study should help overcome these limitations.

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COMPARISON OF CONTAMINANT CONCENTRATIONS ON SURFACE SEDIMENTS AND IN SURFACE WATER IN WHITE OAK CREEK EMBAYMENT

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Department of Energy activities at oak Ridge National laboratory have released ^{137}Cs and other contaminants to White Oak Creek which drains directly into the Clinch River and Watts Bar Reservoir. The largest annual releases occurred in the mid-1950s, but have been significantly reduced since the 1960s. Contaminated sediments have accumulated in the White Oak Creek Embayment (WOCE), an arm of Watts Bar. Highly contaminated sediment, containing ^{137}Cs level corresponding to peak release values, had been buried deep in embayment sediments. However, recent sediment data show that these high ^{137}Cs levels are now observed at the sediment surface. This study, performed in order to further characterize contamination of WOCE sediments and surface water, is part of the site characterization and contaminant screening study for WOCE.

Sediments in WOCE are uncontrolled, subject to erosion and transport processes. Available data suggest that less contaminated material has been gradually resuspended into the water column and transported downstream, a process influenced by storm events and rapid changes in water level associated with reservoir operations.

Hydrodynamic conditions at the WOCE mouth change rapidly over short time periods (minutes). If daily water level fluctuations are the dominant transport process, contaminant concentrations in out-flowing water should correspond to those observed on upstream surface sediments. However, contaminant concentrations in these water samples vary from nondetectable, to comparable with surface sediment values. These results suggest that transport of contaminated surface sediments out of WOCE may be most influenced by storm events.

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[2] U.S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

DETERMINATION OF SEDIMENT ACCUMULATION AND MIXING RATES USING ^{137}Cs and ^{210}Pb IN WATTS BAR RESERVOIR [1]

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Activities at the Department of Energy's facilities on the Oak Ridge Reservation over the past 50 years have released contaminants to local streams and consequently to the Clinch River and Watts Bar Reservoir. More than 60 sediment cores were collected in Watts Bar Reservoir (Olsen et al. 1991) and analyzed for the vertical distribution of ^{137}Cs; seven of the cores were also analyzed for the vertical distribution of unsupported ^{210}Pb.

^{137}Cs and unsupported ^{210}Pb are excellent tracers of sediment accumulation, mixing and transport. Both are rapidly adsorbed to particulate matter and both are relatively easy and inexpensive to measure by gamma spectrometry (Cutshall et al. 1983). The history of ^{137}Cs release into the Clinch River is reasonably well-documented with peak releases occurring in the mid-1950s (Olsen et al. 1991) (Fig. 1). Unsupported ^{210}Pb ($^{210}Pb_{xs}$) is a naturally occuring radionuclide. It is produced in the atmosphere by the decay of the inert gas ^{222}Rn and unsupported by its parents in the ^{238}U series. $^{210}Pb_{xs}$ enters water surfaces directly through direct deposition, and indirectly via erosion of watershed soils.

The objective of this work was to examine the processes responsible for the vertical distribution of ^{137}Cs and $^{210}Pb_{xs}$ in the sediments by using a numerical model of sediment accumulation, mixing, decay and molecular diffusion. Analysis of both ^{137}Cs and $^{210}Pb_{xs}$ permits comparison of model predictions of both point- (Cs) and non-point source (Pb) contaminants.

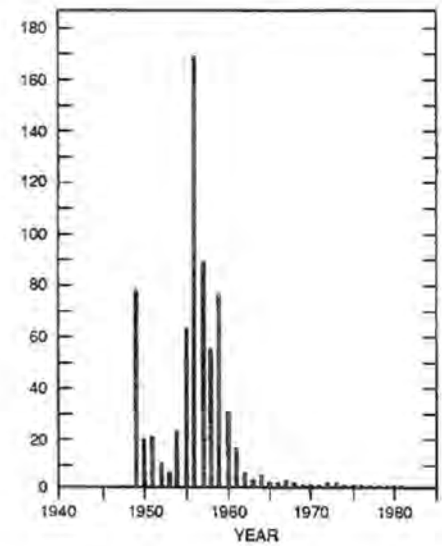

Fig. 1. ^{137}Cs Release History for White Oak Lake (ORNL)

Model Description

The model used is a numerical approximation of the advection and diffusion of contaminated particles from the water-sediment interface to depth. The model calculates the contaminant concentration C (pCi/cm^3-wet sediment) at depth z (cm) at

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time t (yr) (Peng et al. 1979, Olsen et al. 1981, Anderson et al. 1987):

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial z}(D_s\frac{\partial C}{\partial z})-S(\frac{\partial C}{\partial z})-\lambda C$$

where C the contaminant concentration (pCi/cm^3-wet), S is the sedimentation rate (cm/yr) and lambda the radioactive decay coefficient (yr^{-1}). D_s (cm^2/yr) is the sum of the mixing rate (D_b) due to physical processes and bioturbation, and the effective mixing (D_{eff}) due to molecular diffusion (D_m) (D_s=D_b+D_{eff}). Sediment mixing (D_b) is simulated as occurring in two discrete zones (Fig. 2). The upper-most mixed zone is assumed to be homogeneously mixed to depth z_h. The lower mixed zone has an exponentially declining mixing coefficient. The effective mixing (D_{eff}) due to molecular diffusion (D_m) is

$$D_{eff}=\frac{D_m\theta^2}{1+K_d(1-\theta)\rho_s/\theta}$$

where K_d is the measured distribution coefficient ([activity/g dry sediment]/ [activity/ml pore water]), rho_s the dry density of sediments (g/cm3), rho_w the density of water (g/cm3). The porosity of the sediment is defined as:

$$\theta=\frac{\%W/\rho_w}{\%W/\rho_w+(1-\%W)/\rho_s}$$

where %W is the measured percent water by weight.

The model is solved using a finite difference technique. In each timestep (delta t) a homogeneous sublayer (delta z) is deposited (delta z = delta t * S) at the water-sediment interface. The previously deposited sublayer is decayed, mixed with the underlaying sublayers and subsequently advected downward. Selection of the timestep follows the Courant stability criterion: delta t < .5 * (delta z)^2 / D_s.

Model parameters obtained from the literature are the distribution coefficients ($K_{d\text{-}Cs}$=5200, $K_{d\text{-}Pb}$=43700 ml/g), molecular diffusion coefficients ($D_{m\text{-}Cs}$=378, $D_{m\text{-}Pb}$=158 cm^2/yr) and decay coefficients (half-life$_{Cs}$=30.1, half-life$_{Pb}$=22.3 yr) (Anderson et al. 1987). Average porosity values were calculated for each core based on the measured water content and density of dry sediments (Table 1). The release history of ^{137}Cs over White Oak Lake Dam as reported from 1948 to 1986 (Fig. 1) was used as the source term for the ^{137}Cs simulations. The total amount of ^{137}Cs available to be deposited in a sediment core was calculated to be equal to the decay corrected inventory of the core. Similarly, the total amount of $^{210}Pb_{xs}$ to be deposited in a sediment core was calculated to be equal to the decay corrected inventory of the core. Sedimentation rates were assumed uniform over time and were calculated from the timing of the peak release of ^{137}Cs over White Oak Lake Dam and the depth of the peak contamination in each sediment core. Concentration levels of ^{137}Cs in sediment grab samples taken with an

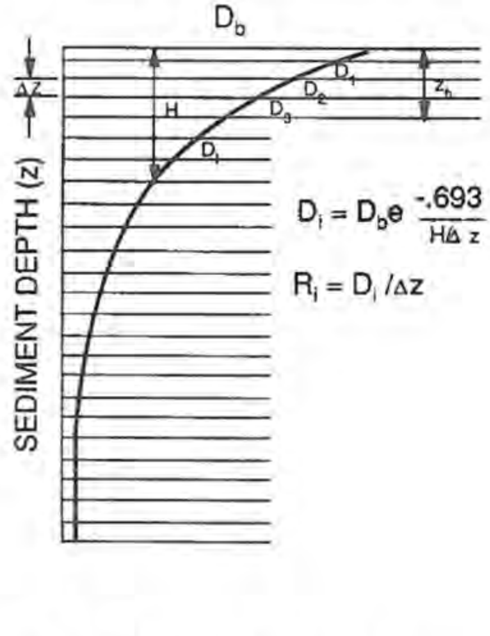

Fig. 2. D_b = depth-dependent mixing coefficient (cm^2/yr); Δz = sublayer thickness (cm); R_i = transfer rate due to physical mixing at sublayer boundary, D_i/Δz(cm/yr); H = depth at which D_b equals one-half of the surface value (cm); z_h = depth of upper-most layer that is completely homogenized (cm).

Eckman Dredge from 1954 through 1958 (Cottrell 1959) in Watts Bar Reservoir justify the rate calculations: decay-corrected peak contaminant concentrations are between 89% and 128% of those found by Cottrell.

Contaminant distributions of ^{137}Cs within cores were evaluated through comparison of model results and the height and shape of the ^{137}Cs peaks by calibration of three parameters: a) the depth (z_h) of the uppermost homogeneously mixed zone, b) the mixing rate (D_b) and c) the depth (H) at which D_b equals one-half of the surface value (Fig. 2).

Using the same parameter sets as determined for the ^{137}Cs simulations, $^{210}Pb_{xs}$ simulation results were compared with $^{210}Pb_{xs}$ core profiles.

Table 1. Radionuclide data and model parameters for selected cores from Watts Bar Reservoir.

ORNL DWG 91M-10316

River mile	^{210}Pb pCi/cm^2	^{137}Cs pCi/cm^2	Total depth cm	Average porosity	S cm/yr	Cs-D_{eff} cm^2/yr	D_b cm^2/yr H=4cm z_h= 3*S	D_b cm^2/yr H=8cm z_h= 0cm
567.5	68.7	1386	103	0.57	2.6	0.019	20.	10..
565.5	59.9	715	87	0.62	2.2	0.026	25.	12.5
562.5	67.2	612	95	0.62	2.4	0.029	25.	12.5
556.8	49.4	270	67	0.64	1.6	0.033	10.	5.
538.3	40.8	250	48	0.74	1.2	0.061	10.	5.
533.8	58.5	407	87	0.59	2.2	0.035	30.	15.
530.9	46.7	275	67	0.48	1.6	0.018	10.	5.

Results and Discussion

Various combinations of values of the calibration parameters give good agreement between the depth and concentration of the ^{137}Cs peak. As an example, Core 567.5 is presented (Fig. 3). First, the simple process of continually and fully mixing the most recently deposited three-year thick sediment layer (z_h) provides an adequate fit. Second, a mixing rate (D_b) of 20 cm^2/yr at the surface and an exponentially declining mixing rate with a half-depth (H) of 4 cm improves the fit. Third, a combination of the above two parameter sets results in improvement in fit. Fourth, a mixing rate (D_b) of 10 cm^2/yr and a half-depth (H) of 8 cm (Table 1) results in a good fit of the simulated depth and concentration of the ^{137}Cs peak and the observed peak. Similar sets of mixing parameters (Table 1) (rates within published ranges) resulted in good fits for each of the seven cores.

Calibration of the three adjustable parameters shows that when sedimentation rates are high the mixing rates need also to be relatively high to ensure peak height matching. Mixing, primarily, causes the peak to flatten and widen. Secondarily, the peak moves deeper into the sediments (see also Olsen et al. 1981). The degree of peak movement is dependent on the combination of the mixing rate and half-depth values (Fig. 3).

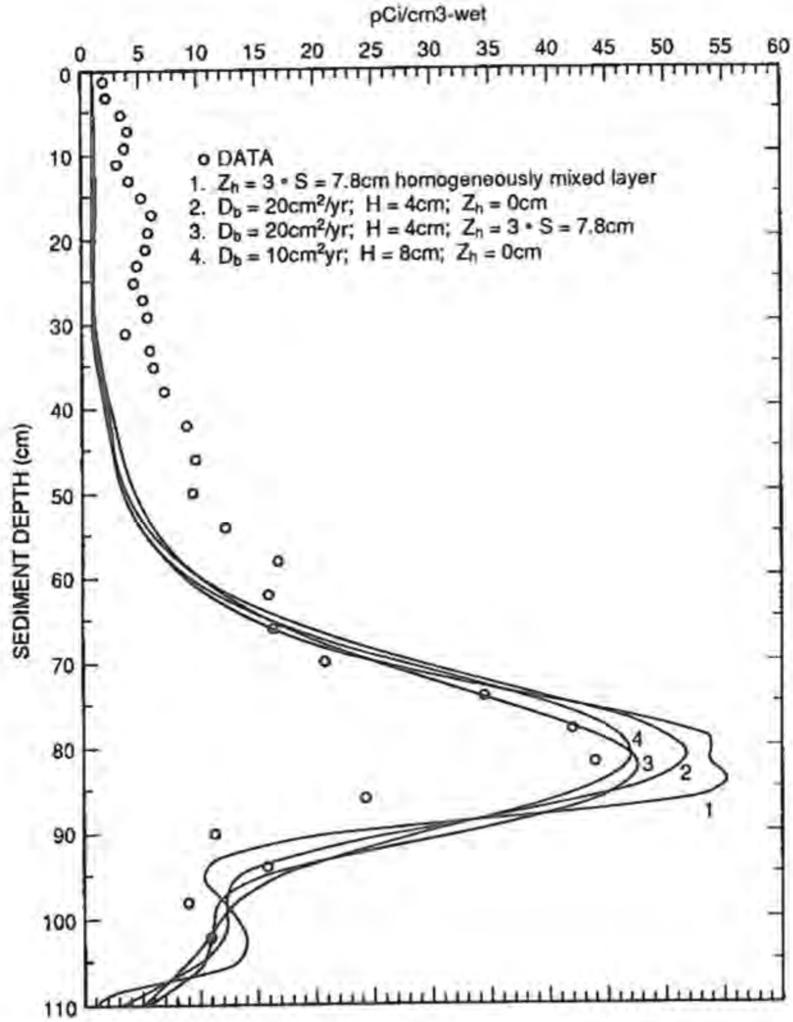

Fig. 3. Example of ^{137}Cs Concentration (pCi/cm^3-wet) in a Sediment Core: Core 567.5.

The effective mixing (D_{eff}) due to molecular diffusion and the distribution coefficient, causes less contaminant mobility than the physical process of mixing, simply because the calculated effective mixing rates for the

different profiles are orders of magnitude smaller that the calibrated mixing rates needed to match the peak ^{137}Cs concentrations (Table 1).

Although the peak ^{137}Cs contaminant depth and concentrations can be matched, the inventories over the last 15 years are consistently two- to three-fold lower in the modeled cores compared to the measured inventories implying secondary sources of the contaminant. Secondary sources may be contaminated sediments in the Clinch River and numerous embayments (e.g. White Oak Creek embayment) that are slowly eroded and transported downstream (see also Cottrell 1959).

The results of the simulations of $^{210}Pb_{xs}$ profiles under the same scenerios point to the importance of temporally varying sedimentation rates and fluxes. $^{210}Pb_{xs}$ fallout in the Oak Ridge, TN area, measured over two years, was .47±.02 pCi/cm^2-yr (Olsen, pers. comm.) yielding an expected inventory of 10.4 pCi/cm^2, if atmospheric input was the only source to the sediments over the 39- yr simulated time period.Measured inventories in Watts Bar Reservoir are 4 to 7 times higher (Table 1), indicating that watershed erosion contributes to the inventory. Moreover, $^{210}Pb_{xs}$ inventories are directly related to the sedimentation rates of each core. The $^{210}Pb_{xs}$

profiles cannot be considered monotonic (Fig. 4); $^{210}Pb_{xs}$ profiles would be monotonic if the unsupported ^{210}Pb concentration in each sediment layer would be initially identical and then decline with age (and depth) in accordance with the usual radiactive decay law. Mixing does not affect the simulated $^{210}Pb_{xs}$ profiles; only when the upper-most sediment layers are homogeneously mixed do we see a minor impact (Fig. 4).

Two types of event-based processes may help explain the observed profiles. Watershed erosion may be assumed to cause non-steady sediment fluxes, and varying water velocities may cause post-depositional mobility and focussing of sediments containing $^{210}Pb_{xs}$. Post-depositional mobility of ^{137}Cs and $^{210}Pb_{xs}$ is a process that requires further investigation.

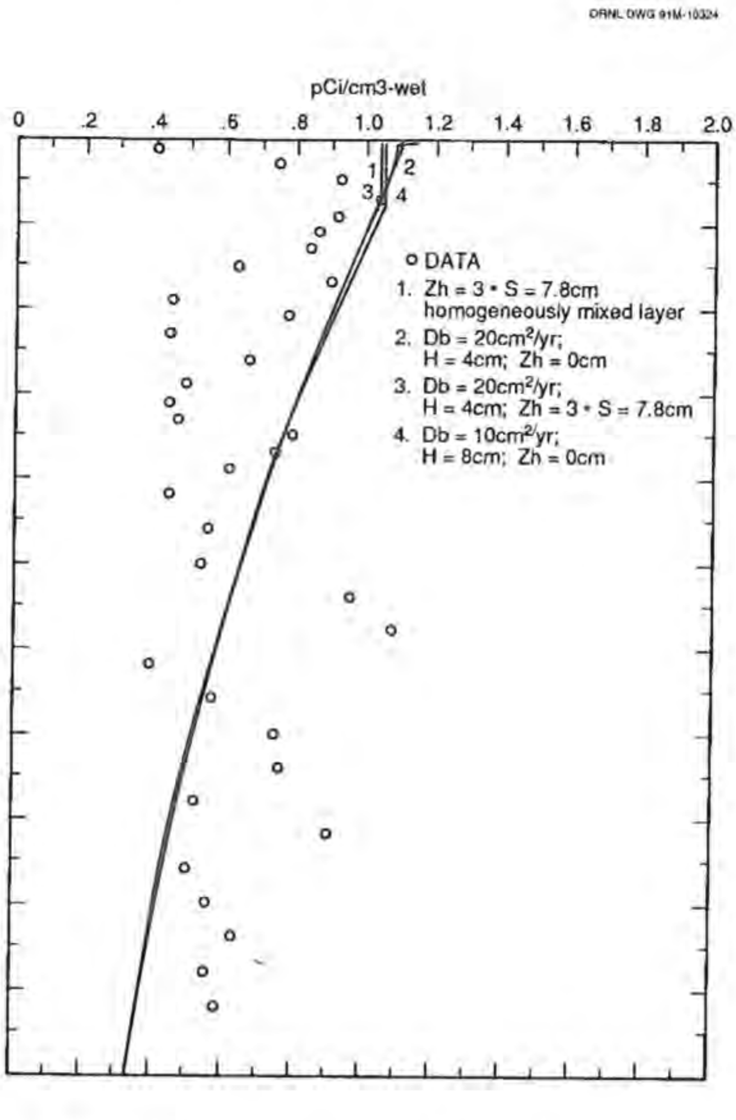

Fig. 4. Example of $^{210}Pb_{xs}$ Concentration (pCi/cm^3-wet) in a sediment core: core 567.5.

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PATTERNS OF SEDIMENT ACCUMULATION IN WATTS BAR RESERVOIR BASED ON ^{137}CESIUM [1]

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The U.S. Department of Energy has recently undertaken an environmental restoration program designed to achieve remediation of hazardous materials released from the Oak Ridge Reservation (ORR). Contaminants include radionuclides, metals, and organic compounds that were released over the past 50 years from Oak Ridge National Laboratory, the Oak Ridge Gaseous Diffusion Plant, and the Y-12 Plant located on the ORR.

One component of this program is the Clinch River Resource Conservation and Recovery Act Facility Investigation (CRRFI) which focuses on portions of the Clinch and Tennessee Rivers that may have been adversely affected by contaminants released from the ORR. As part of a preliminary scoping study for the CRRFI, Olsen et. al. (1990) measured ^{137}Cs activity in 58 sediment cores and 187 surface sediment samples collected from the Clinch River and Watts Bar Reservoir. ^{137}Cs was chosen because (1) its release history from ORR is reasonably well known, (2) it is easy and inexpensive to measure by gamma spectrometry, and (3) it is rapidly sorbed to riverborne particulate matter and thus serves as a tracer for the transport and accumulation of other particle-reactive contaminants.

Olsen et. al. (1990) focused on estimating the amount of ^{137}Cs retained by Watts Bar Reservoir. Using these data, we have performed additional analyses designed to investigate the relationships between several indicators of ^{137}Cs accumulation and various reservoir characteristics. This presentation describes the results of these analyses. In addition, we discuss an independent estimate of the amount of ^{137}Cs retained in Watts Bar Reservoir using the Olsen et. al. (1990) data.

METHODS

Data Collection

Two types of coring devices were used to obtain 58 sediment profiles. A gravity corer was generally used in areas where the water depth exceeded 10 m. This device consists of a tube attached to an anchored cable which is then allowed to free-fall to the bottom. The inertia of the corer provides the force necessary to penetrate the sediment. In areas where the water depth was less than 10 m, a vibracorer was used. This device consists of a vibrating head attached to an aluminum irrigation pipe. Sediment penetration results from the thixotropic action of the vibrating head. Vibracoring is limited to shallower areas because pipe lengths greater than the depth of the water column are needed with this device. Upon retrieval, sediment profiles were carefully extruded from the corer and sectioned into either 1-, 2-, or 4-cm thickness increments. These sections were placed into plastic-lined aluminum cans, sealed, and returned to the laboratory.

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[1] Research sponsored by Office of Environmental Restoration and Waste Management, U.S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

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In addition to the cores, 187 surface sediment samples were collected. A Ponar bottom-grab sampler was used to collect these samples. Upon retrieval, the samples were placed into beakers, sealed, and returned to the laboratory. The surface sediment samples were used to develop a map of sediment characteristics and to identify sites best suited for coring.

In the laboratory the core and surface sediment samples were analyzed for ^{137}Cs activity using solid state detectors attached to a computerized gamma spectra acquisition system (Larsen and Cutshall 1981). After counting, each sample was weighed to determine wet weight, oven-air dried (60° C) for several days, and weighed again to determine dry weight. These weights were used to calculate activity concentrations.

Statistical Characterization

Four measures of ^{137}Cs accumulation were used in our statistical characterization. The total activity of each core segment was divided by the cross sectional area of the corer and summed down the core to give a core inventory (pCi cm^{-2}). The peak concentration (pCi g^{-1}) within each core was found by dividing the core segment activities (pCi) by the corresponding dry weights and finding the maximum concentration within the core. Since ^{137}Cs has a well defined release history from the ORR, we calculated a sedimentation rate (cm yr^{-1}) based on the depth of the peak concentration and the elapsed time since the peak discharge occurred from the ORR. Finally a surface concentration of ^{137}Cs (pCi g^{-1}) was obtained by calculating a mass weighted average of the activity concentrations in the top 6 cm of each core.

We used analysis of variance and regression analysis to test for relationships between the ^{137}Cs variables described above and core characteristics such as sediment type and water depth. Exploratory analyses of the data revealed that the two cores taken in the Clinch River had significantly higher peak concentrations and inventories than did the cores from Watts Bar Reservoir. This is most likely due to the fact that significant dilution of the suspended particulate matter containing ^{137}Cs occurs below the confluence of the Clinch and Tennessee Rivers. Consequently, we decided to exclude the Clinch River cores from our statistical analyses. In addition, the six cores collected in the major embayments of Watts Bar Reservoir (Caney Creek, Piney River, and White Creek) were found to have markedly lower concentrations and inventories of ^{137}Cs. The embayment samples were also excluded from our analyses because these samples are located in areas off the main channel of the reservoir.

Estimation of ^{137}Cs Inventory

Olsen et. al. (1990) subdivided the reservoir surface area into polygons based on sedimentary characteristics determined from the surface sediment samples and bathymetry obtained from navigation charts. They used a geographic information system to estimate the amount of ^{137}Cs in the reservoir by averaging the core inventories in each polygon, multiplying these averages by the polygon areas, and summing the polygon inventories.

We also calculated a reservoir inventory based on the Olsen et. al. (1990) polygons. We looked for cores collected in each polygon and determined whether or not there was agreement between the polygon sediment type and the core's sediment type. We also compared the sediment type of the polygon with that of any grab samples collected in the polygon. If there was a core (or cores) collected in the polygon and the sediment types agreed, we chose that core or cores to characterize the polygon. If there were no cores collected in the polygon, we examined sediment type and water depth of any grab samples collected in the polygon. We then chose nearby cores having sediment type, water depth, and location similar to grabs collected in that polygon. If there were no grab or core samples in the polygon, we chose nearby cores having similar sediment type as the polygon. Polygon inventories were calculated by averaging the inventories of the cores assigned to each polygon.

RESULTS AND DISCUSSION

Statistical Characterization

Analysis of variance (ANOVA) showed no significant differences between cores collected by vibracorer and gravity corer for peak concentration ($r^2 < 0.01$; $P = 0.75$), surface concentration ($r^2 = 0.02$; $P = 0.36$), inventory ($r^2 = 0.05$; $P = 0.15$) and sedimentation rate ($r^2 = 0.01$; $P = 0.55$). These results imply that the type of corer does not introduce a bias into the data and therefore allows us to combine measurements from the different sampling gears in subsequent analyses. However, the data were not collected to test this hypothesis.

Linear regression analysis showed that a substantial amount of variance in ^{137}Cs inventory could be explained by the peak concentration ($r^2 = 0.72$; $P < 0.001$). This implies that a large portion of the ^{137}Cs inventory in a core is associated with the peak concentration. We also found a strong relationship between the inventory and the sedimentation rate ($r^2 = 0.78$; $P < 0.001$), implying that areas having higher sedimentation rates will typically have higher ^{137}Cs inventories.

Based on the chemical affinity of ^{137}Cs for fine-grained sediments, we hypothesized that peak and surface concentrations, inventory, and sedimentation rate would be higher for fine-grained sediments than for coarser grained sediments. Each core was assigned to one of three sediment types (soft mud, sandy mud, or eroded soil) based on visual inspection of the core during field collection. An ANOVA on sediment type found significant differences between sediment type for inventory ($r^2 = 0.34$; $P < 0.001$), peak concentration ($r^2 = 0.47$; $P < 0.001$), surface concentration ($r^2 = 0.42$; $P < 0.001$), and sedimentation rate ($r^2 = 0.34$; $P < 0.001$). In all four cases, the soft mud had higher levels than both sandy mud and eroded soil.

Linear regression was used to test for relationships between the four measures of ^{137}Cs accumulation and distance from release source as measured by river mile. We also investigated across-channel effects on ^{137}Cs as measured by distance from shore and water depth. In all cases we did not find that significant amounts of variability in the ^{137}Cs variables were explained by these explanatory variables. It is important to note that the Olsen et. al. (1990) data were not collected to explicitly test these types of effects.

Estimation of ^{137}Cs Inventory

Using the total core inventories, we estimate that Watts Bar Reservoir contains 267 Ci of ^{137}Cs. This is approximately 80 percent of the decay-corrected total of 335 Ci ^{137}Cs released into the Clinch River from White Oak Lake. Olsen et. al. (1990) estimate that the reservoir contains 304 Ci of ^{137}Cs which is approximately 91 percent of the total release. Given the uncertainties in assigning cores to polygons, we feel that these estimates are not significantly different. In order to assess the potential exposure of ^{137}Cs to aquatic biota, we calculated an inventory in the top 16 cm of sediment. We estimate 24 Ci or 7 percent of the total inventory of ^{137}Cs resides in the top 16 cm of sediment.

Accumulation zones for both total and surface inventory estimates occur along the old Clinch River and Tennessee River channels where the impoundment of water has reduced currents and permitted accumulation of sediment and particle-associated contaminants. Nearshore areas in the upper reaches of the reservoir also exhibit high inventories. The sediments in the major embayments contain relatively low inventories of ^{137}Cs suggesting local sediment sources rather than the influx of sediment from the main body of the reservoir.

SUMMARY AND CONCLUSIONS

The lack of difference between samples collected by gravity corer and vibracorer is important since it permits us to combine the data for other analyses. The strong relationship between inventory and peak concentration is important since this indicates that most of the ^{137}Cs retained in the reservoir is associated with the peak discharge from the ORR and that this peak has been effectively trapped by the sediments. The fact that the reservoir contains large areas of fine-grained sediments based on the surface sediment samples, and that these sediments exhibit higher inventories, sedimentation rates, peak, and surface concentrations also supports the hypothesis that most of the ^{137}Cs is trapped in the Watts Bar sediments.

It is important to note that our statistical analyses are exploratory in nature and are based on a data set collected for a different purpose. A major objective of Olsen et. al. (1990) was to estimate the amount of ^{137}Cs retained by Watts Bar Reservoir. Their cores were collected in areas thought to be sediment accumulation zones and do not represent a random sampling of the reservoir. We subsequently used their data for analyses outside of their primary objective. This may account for the lack of relationships we found between our measures of ^{137}Cs accumulation and variables associated with core location. However, we feel that this is an important result in that the data collected in future phases of the CRRFI will use a statistically based sampling design.

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WATER QUALITY OF CLINCH AND POWELL RIVERS, EAST TENNESSEE

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Water-quality characteristics of the Clinch and Powell Rivers in East Tennessee have been under investigation since June 1989 by the U.S. Geological Survey in cooperation with the Tennessee State Planning Office. Water-quality data are being collected at two sampling locations on each river: an upstream location near the Tennessee-Virginia stateline and a downstream location just upstream of Norris Reservoir.

Suspended-sediment concentration and suspended-sediment discharge were determined monthly from June 1989 through February 1990 and during several storms (June 1989 through April 1991) at the four sites on the Clinch and Powell Rivers. Concentrations of suspended sediment in the Powell River ranged from 2 to 614 milligrams per liter, and in the Clinch River, from 2 to 450 milligrams per liter. Calculated instantaneous suspended-sediment discharge ranged from 3.5 to 18,500 tons per day for the Powell River and 2.4 to 23,200 tons per day for the Clinch River.

Water in the Clinch and Powell Rivers was a calcium bicarbonate type water with dissolved-solids concentrations generally less than 200 milligrams per liter. Nutrient concentration at each of the four sites varied with stream discharge. Concentrations of total organic nitrogen generally were less than 2.3 milligrams per liter as nitrogen and concentrations of total phosphorus generally were less than 0.24 milligrams per liter as phosphorus. Measurements of selected metals for the Clinch and Powell Rivers indicate that highest concentrations occurred during periods of storm runoff. Total iron concentrations exceeded 10,000 milligrams per liter in some water samples collected during storms.

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GROUNDWATER QUALITY IN TENNESSEE

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In 1989, the U.S. Geological Survey, in cooperation with several State agencies in Tennessee, began two studies to investigate the quality of water in the principal aquifers in the State. In one study, water samples were collected from a statewide network of 90 wells and springs used primarily for public supply; in the second study, samples were collected from a statewide network of 150 private domestic wells in order to determine the quality of water used for domestic water supply. These samples were analyzed for fecal bacteria, nitrate, pH, dissolved or total solids, sulfate, manganese, iron, selected trace metals, and other constituents. The samples also were analyzed for the presence of selected organic compounds.

Results indicate that, except for bacteria, ground water throughout Tennessee generally meets State drinking-water standards. Fecal coliform and streptococci bacteria were detected in 41 percent of the water samples. The most frequent occurrence and highest concentrations of bacteria generally were in ground water samples collected from the carbonate aquifers in Middle Tennessee. Nitrate concentrations equal to or exceeding State drinking-water standards were detected in water from five wells. Acidic waters were detected in the unconsolidated aquifers in West Tennessee. Synthetic organic compounds were detected at several sites. Iron and manganese concentrations generally did not exceed drinking-water standards except in water samples collected from the alluvial aquifers of West Tennessee and the Pennsylvanian sandstone aquifer in east-central Tennessee.

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QUALITY OF GROUND WATER ON TENNESSEE POULTRY FARMS [1]

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There are approximately 125 million broilers grown on more than 800 Tennessee poultry farms. These farms vary in size from as little as ten acres to several hundred acres. Each year a typical broiler house averages approximately six grow-outs with an average of 20,000 birds per grow-out. Each broiler house has the potential to produce 240 tons of broiler litter annually. Assuming a nitrogen content of 60 pounds per ton, each broiler house is capable of suppling the nitrogen requirements for approximately 60 acres of corn production.

In most cases, the broiler litter is utilized by the producer as a fertilizer on pasture, small grain or row crops, although some producers sell or give broiler litter away. Since many producers do not have adequate land resources to apply all litter at recommended rates, the potential exists for excessive application and subsequent pollution of surface and ground water.

Research on poultry farms in Georgia (French, et al., 1988) and Delaware (Ritter, 1989) has found nitrate-nitrogen levels in water wells (ground water) to be as high as 95 parts per million (ppm). Also, high bacteria counts were found in some wells.

On many broiler farms, well water is used in the domestic residence as well as in the poultry house(s). The Environmental Protection Agency (EPA) has set a 10-ppm nitrate-nitrogen level as the drinking water standard for municipal water supplies. Nitrate-nitrogen levels exceeding 20 ppm may adversely affect broiler growing performance (Barton, et al., 1989).

There is presently no information available on the potential impact that land application of broiler litter has on ground and surface water in Tennessee. The objectives of the study were:

1. To determine the levels of nitrate-nitrogen, bacteria and other ground water quality parameters on Tennessee broiler farms.

2. To relate water quality data to rates of litter application, soil types, well depth and well construction.

Geographic Location

Four geographic regions of Tennessee with heavy broiler production and distinctly different geology were selected for study. The Ridge and Valley region included McMinn, Polk, Bradley and Hamilton counties. This region is underlain by folded and faulted limestone, shale and sandstone of Ordovician and Cambrian age. The Cumberland Plateau region includes Morgan, Fentress and Grundy counties. The region is underlain by relatively level bedded

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[1] This project was made possible in part through the University of Tennessee Agricultural Extension Service (UTAES) cooperating with the Tennessee Valley Authority.

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Ordovician and Cambrian age. The Cumberland Plateau region includes Morgan, Fentress and Grundy counties. The region is underlain by relatively level bedded sandstone, shale and coal of Pennsylvanian age. The Highland Rim region includes Coffee, Franklin, Grundy and Lincoln counties. This region is underlain by level bedded limestone of Mississippian age. The Central Basin includes Bedford and Lincoln counties. It is underlain by level bedded limestone of Ordovician age. Commonly the soils of the Central Basin are shallow to rock. Karst topography is found in parts of the Ridge and Valley, Highland Rim and Central Basin.

Well Selection

The first step in the ground water study was to identify broiler growers in each of the four test regions using private water supplies (wells) and willing to participate in the survey. Seventy-one broiler growers using well water for broiler production were identified by the county Agricultural Extension agents and the four integrated broiler firms operating in these regions.

A survey form was developed to assist in obtaining information about the farm well(s) and litter handling practices on the farm. The form included information on the size of the broiler operation, well water usage, well physical characteristics, litter storage and land application of the litter.

Sample Collection

During the months of June and July, 1990, water samples were collected on 71 broiler farms in the four test regions previously specified. The sampling procedure was as follows:

- Locate a water faucet near the wellhead.
- Allow water to run through the faucet at least 5 minutes to purge the expansion tank and associated plumbing.
- Flame sterilize the faucet with a butane torch for three to five minutes.
- Collect 250 milliliters of water from the faucet in a pre-sterilized container.
- Store sample in an ice bath and return to water quality laboratory within 12 hours of the sampling time.

Water samples were taken from 105 wells, five springs and one municipal water system, for a total of 111 samples. These water systems were being used in the farming operation and/or in the home on a daily basis.

Laboratory Analysis

Water samples were assayed for total coliform, fecal coliform and aerobic bacteria (APHA, 1975). Salmonella was analyzed according to the Conventional Procedure outlined in the Bacteriological Analytical Manual (FDA, 1978). Nitrate-nitrogen was determined using ion chromatography (APHA, 1975).

Water Test Results

The laboratory analyses for fecal coliform indicated that 30 samples had 1 to 49 colonies per 100 ml, 2 samples had 50-99 colonies per 100 ml and 13 samples had greater than 100 colonies per 100 ml. A total of 45 of the 105 well water samples (43 percent) had fecal coliform bacteria present which indicates possible contamination from human and/or animal waste sources. In addition, eight well water samples (8 percent) tested positive for Salmonella. Eight water samples (8 percent) were found to exceed 10 parts per million (ppm) nitrate-nitrogen. Four of the five springs tested positive for fecal coliform and one was positive for Salmonella. Table 1 shows averages and ranges of selected test parameters for all water samples tested.

Table 1. Summary of 1990 Laboratory Analyses for 111 Samples.

Test	Average	Range
Total Coliforms (Col./100 ml)	51.60	0 - >100
Fecal Coliforms (Col./100 ml)	38.82	0 - >100
Aerobic Bacteria (Col./ml)	1,783.68	0 - 31,000
Nitrate as Nitrogen (mg/l)	3.11	0 - 53

Characteristics of Broiler Operations Surveyed

The following is a summary of production characteristics and practices noted during the survey:

Broiler Operation

- Only 16 percent used soil tests to determine application rate.
- Frequency of broiler litter removal varied greatly from producer to producer.
- Stockpiled litter is usually stored for no more than three to four weeks.
- Broiler litter is used as a fertilizer on pasture, hay, small grain and row crops.
- Broiler litter may be given away, sold, or fed to beef cattle.
- Many broiler growers did not know how much litter they applied to the land.
- Many broiler growers do not have access to sufficient land resources to spread their litter at recommended rates.

Wells

Some wells were:

- Located in areas susceptible to potential contamination from surface water.
- Located very close to septic tank leachfields.
- Located inside chicken houses.
- Located within 25 feet of litter stockpiles.
- Constructed with the top of the casing below ground level.
- Constructed with no seal on top of the casing.

Well depth ranged from 50 to 850 feet and averaged 148 feet. Seventy-five percent of wells had a concrete cap surrounding the well opening. According to broiler producers surveyed, 16 percent of wells became cloudy after rainfall. Only 30 percent of the broiler growers in the survey had tested their well water in recent years, but most were concerned about the quality of water on their farms.

Conclusion

Wells are often located in areas susceptible to potential contamination from surrounding factors, such as septic systems, cattle and hog feedlots, chicken houses and surface drainage. Although over application of nitrogen on nearby fields may occur, sample data do not indicate widespread nitrate contamination. The primary contaminant identified in the study was fecal coliform. The origin of the fecal coliforms, human or livestock, was not determined. Many wells with bacterial and/or nitrate contamination were located in close proximity to both the poultry house and the household septic system.

Beginning June 1, 1991, additional well inspection and water testing will be conducted to investigate source(s) of contamination on water wells that had (1) more than 10 colonies fecal coliform per 100 ml, (2) more than 10 ppm nitrate-nitrogen and/or (3) Salmonella.

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GEOCHEMICAL CHARACTERISTICS OF A LEACHATE PLUME EMANATING FROM THE SHELBY COUNTY LANDFILL AT MEMPHIS, TENNESSEE

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A study of the Shelby County landfill area during 1989-91 revealed that local ground-water quality has been affected by a leachate plume emanating from the landfill. This plume extends northward from the landfill in the direction of ground-water flow in the alluvial (water-table) aquifer. Ground-water samples from downgradient wells screened in the alluvial aquifer (and upper part of the underlying "confining unit") contained concentrations of major inorganic constituents (sodium, iron, calcium, magnesium, potassium), trace inorganic constituents (barium, strontium, boron), and dissolved solids that were generally 2 to 10 times greater than concentrations in samples from upgradient and background wells. In the alluvial aquifer, generally small but detectable concentrations of benzene, toluene, and xylene were detected in most samples; however, concentrations rarely exceeded State or Federal maximum contaminant levels for drinking water. Small concentrations of the halogenated volatile organic compounds vinyl chloride and 1,2-trans-dichloroethene also were detected in samples from downgradient alluvial aquifer wells.

Elevated concentrations of some inorganic and organic constituents were detected in samples from wells in the Memphis aquifer adjacent to the Shelby County landfill. Those inorganic constituents that had elevated concentrations in the leachate plume in the alluvial aquifer (such as sodium, strontium, and boron) also were detected in water samples from the Memphis aquifer at concentrations two to eight times greater than concentrations in background samples. Benzene, toluene, and xylene were detected in small concentrations (commonly less than 1.0 microgram per liter) in water samples from most Memphis aquifer wells, indicating that the source of these constituents was not necessarily the leachate plume. The halogenated volatile organic compounds vinyl chloride and 1,2-trans-dichloroethene were detected in samples from Memphis aquifer only at wells located in the area of the leachate plume in the alluvial aquifer, indicating possible leakage from the overlying alluvial aquifer.

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INVESTIGATIVE STRATEGY TO DETERMINE THE EXTENT AND RATE OF CONTAMINANT TRANSPORT IN A STRIKE-DOMINATED KARSTIC FLOW SYSTEM

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Karst development associated with solution voids which follow structural weaknesses is common within the strike belts of carbonate rocks in the Tennessee Valley. The movement of contaminants and groundwater through faulted, fractured and solution-weathered carbonate rock is poorly understood and is most strongly influenced by the orientation of the most prevalent deformational features. Traditional methods of positioning monitoring wells in such environments will not produce a realistic portrayal of the extent of groundwater contamination unless a detailed understanding of the structural framework of the aquifer is obtained. Careful analysis of regional geologic trends must be considered in conjunction with site specific hydrologic and subsurface data to design a representative monitoring network.

A monitoring well network was needed at a landfill site in the Valley and Ridge of northeast Tennessee suspected of contaminating several nearby springs and domestic wells. The landfill is located on the northwest limb of an asymmetric, fault-bounded syncline, upon the clayey residuum of the lower Knox Group. Numerous bedrock exposures in the site vicinity revealed the fractured nature of the limestone and dolostone, as well as several cave openings. Deformational features observed in the bedrock are related to nearby northeast-southwest trending thrust faults, and include intricate folding, fracturing, and tear faults which are typically oriented perpendicular to strike. Sinkholes, dolines, and caverns in the vicinity appear to be oriented along strike, probably due to solution along structural weakness associated with bedding-parallel slip developed during folding. A thorough understanding of the relationships of these structural features was required in order to develop a reasonable understanding of the direction(s) of groundwater movement, and thus contaminant transport, to maximize the effectiveness of the monitoring network.

Relatively few studies have addressed the flow of groundwater through karst environments in which the dominant conduit system is largely controlled by geologic strike. This study presents a systematic approach to such a system which included field mapping, dye tracer studies, geophysics, and monitoring groundwater elevations concomitant with rainfall data. Synthesis of the data produced a conceptual model for contaminant transport, and established a reliable monitoring network for the landfill.

Field Surveys

Field reconnaissance of the area around the landfill allowed an understanding of the local hydrogeology and the location and geometry of the cave systems. A series of springs, located in water gaps located both southwest and northwest of the landfill, were the apparent local discharge points for groundwater. Three caves were explored within the watershed and found to be developed by solution of the carbonate rock along bedding. Two of the caves were found to lie along strike of one another, with a portion of the landfill located between them.

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It was strongly suspected that landfill leachate could be entering the groundwater through this potential conduit. Review of aerial photographs, and topographic and geologic maps revealed several small tear faults along the southwest limb of the syncline. These features were suspected to be potential areas of cross - strike flow, and warranted closer study.

Tracer Tests

Three dye tracer tests were conducted with only one proving successful. Dye injection was unsuccessful when it was attempted within the caves, in an effort to demonstrate their potential as recharge points. It is believed that the dye became lost in the unsaturated portion of the cave, and never made it into the groundwater. A successful dye tracer test was conducted by injecting dye into an abandoned well located at the landfill perimeter. This test utilized fluorescein dye and a network of charcoal "bugs" in the nearby springs and surface water streams. Dye was detected in one of the springs located along strike. This confirms that groundwater flow at least in part follows geologic strike. The test reveals the average linear velocity from the injection point to the spring to be about 40 feet per day.

Geophysical Surveys

Transient electromagnetic sounding method (TEM) and spontaneous potential (SP) surveys were chosen as geophysical tools at the site to investigate the subsurface for the presence of zones of lower conductance (i.e. voids) or areas exhibiting streaming potential indicative of flowing groundwater. The TEM survey revealed a highly irregular bedrock surface which outlined potential areas of preferential flow along the soil-bedrock interface. The survey indicated one bedrock "high" across the southeast portion of the landfill, which was hypothesized as a potential groundwater divide. TEM also indicated areas of possible subsurface voids southeast of the landfill which could serve as major conduits. The SP survey corroborated the presence of a groundwater divide near the middle of the landfill by indicating a local SP anomaly in the vicinity of the bedrock high identified by TEM. This information was essential in explaining the observed directions of contaminant flow at the site.

Continuous Hydrologic Monitoring

Pressure transducers and data loggers were installed in several existing monitoring wells in an effort to obtain information on the dynamics of the groundwater flow system. These data were augmented by similarly recording of leachate levels in the landfill, and with rainfall data measured at the site. The data indicate that the landfill was effectively intercepting infiltration of rainfall for particular areas in the landfill vicinity. Monitoring wells installed outside the influence of the landfill exhibited rapid groundwater responses to rainfall events as did the levels of leachate measured in the landfill. Several wells at the site located southeast of the landfill also exhibit rapid response to rainfall events, suggesting that recharge unaffected by the buffering influence of the landfill occurs rapidly in the karst system.

Analytical Sampling

Various groundwater sampling events were conducted throughout the investigation which delineated the present nature and extent of groundwater contamination. Other than the monitoring wells, sampling points were chosen based on their proximity to the landfill and their geologic setting. Since previous investigations had suggested a groundwater divide is located beneath the landfill, monitoring points had to be located to potentially intercept contaminants on either side of this divide. Since discharge of groundwater in karst flow systems is typically through seeps, springs, and surface water bodies, the numerous springs located along strike both northeast and southwest of the landfill were chosen as monitoring points. One spring was chosen in proximity to a tear fault to detect any contaminants moving across strike along that feature. Volatile organic compounds (VOCs) found within the leachate (particularly tetrachloroethylene), or their daughter products (i.e. trichloroethylene, 1,1 dichloroethane, vinyl chloride), were detected in groundwater samples from all the existing monitoring wells and in all the springs located northeast of the landfill. VOCs were not detected in the springs located across strike or southwest of the landfill. However, a domestic well located near the springs located to the southwest consistently indicated organic contaminants.

Monitoring Well Placement and Results

Review of the initial field data revealed the following:

- The local geology consists of solution weathered carbonate rocks with observed openings oriented along strike, with some tear faults which could promote across-strike flow.
- Tracer tests confirmed groundwater movement along strike.
- TEM and SP geophysical surveys revealed areas of preferential flowpaths and the approximate location of a groundwater divide.
- Hydrologic monitoring demonstrated the effect the landfill has on groundwater recharge.
- Analytical sampling indicated the observed limits of contamination extended both southwest and northeast of the landfill, in a nearly linear orientation.

The data were utilized to determine the optimal number and location of monitoring wells. An upgradient well was installed on the slope located above the landfill. One monitoring well was positioned such that across-strike flow via a solution weathered slot identified at the soil - bedrock interface from the geophysical survey could be monitored. Another well was located downgradient of the landfill in a water gap developed along the trace of a tear fault identified from geologic mapping. A well doublet, consisting of a deep and shallow well, was installed along strike of the cave system located immediately northwest of the site. A sixth well was installed over one-half mile downgradient of the site, southwest of the groundwater divide identified in the field investigations. The series of springs located in the water gaps on either side of the landfill continued to be used as monitoring points.

The monitoring wells and springs proved to be located in satisfactory locations to properly monitor the extent of shallow groundwater contamination associated with the landfill. Figure 1 illustrates the relative limits of VOC contaminants detected by the current monitoring network. Questions still remain, however, on the vertical extent of contamination beneath the landfill.

Contamination has been detected at depths up to 150 feet in the landfill vicinity. However, the presence or absence of contamination at any given location appears to be dependent on whether or not the individual conduit encountered through drilling is pervasive enough to encounter conduits effected by the landfill leachate. Drilling additional deep wells in a discontinuous aquifer system such as this does not appear to be a practical means to determine the vertical extent of contamination, since the chance of intersecting the proper conduit are very small (Quinlan and Ewers, 1985). Since springs typically serve as the points of discharge in karst flow systems (Seaber et al., 1988), these points should prove to be adequate monitoring points.

Discussion

Development of a monitoring program in faulted, fractured, karstic flow systems requires a detailed understanding of the local geologic and geomorphic setting to optimize the effectiveness of the system. Dye tracer studies, geophysical surveys, and continuous potentiometric data are useful tools to aid in determining the orientation of features which may affect groundwater movement. Care must be exercised in determining the location of geologic features (i.e. fractures, faults,

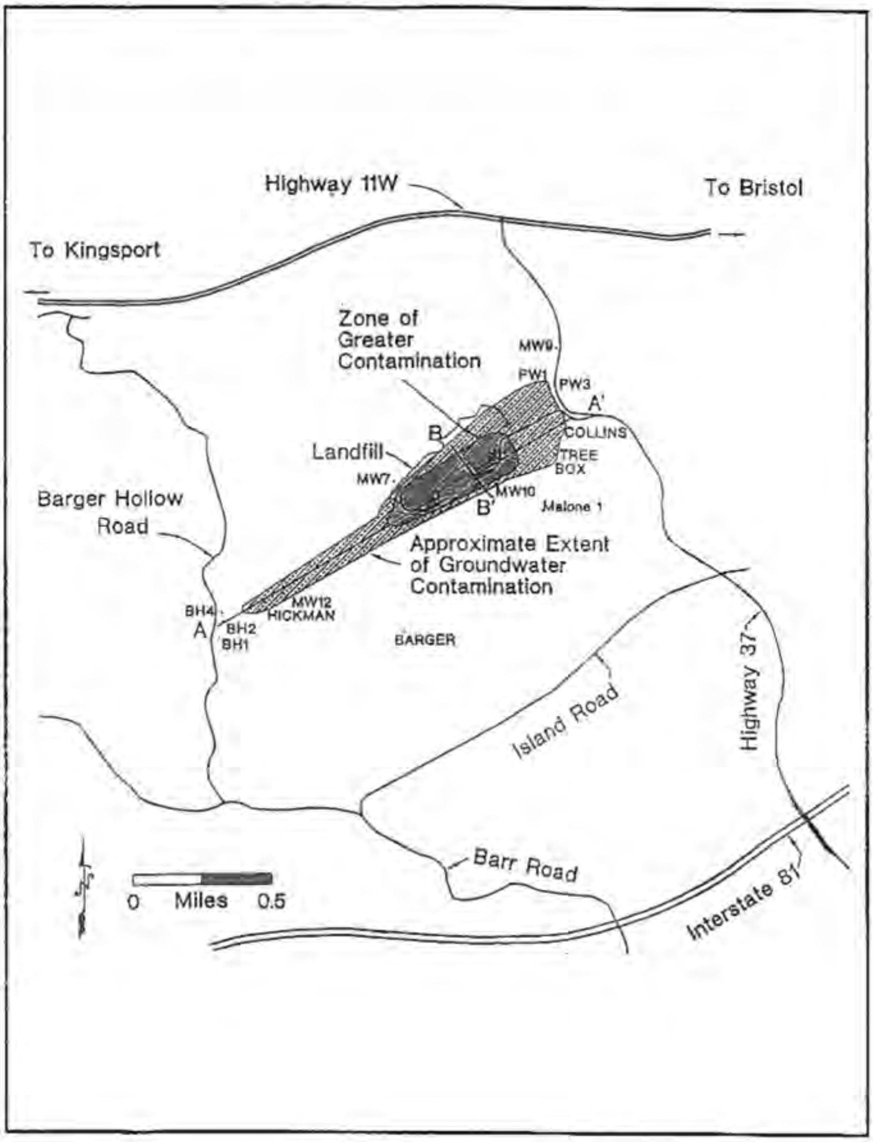

Fig. 1. Plan view map showing current extents of known contamination.

bedding planes) that may promote preferential flow. Such features should be examined thoroughly, with respect to their orientation and for the presence of enhancement by solution. This study demonstrated that solution along bedding is apparently the most dominant process which affects flow at this location. Although along-strike flow is surely a major element of most karst systems in fractured and faulted terranes, they must each be considered on an individual basis. Geologic techniques which aid in providing a conceptualization of the local hydrogeology should be an essential element of any similar study to produce a capable monitoring network.

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AN ASSESSMENT OF THE IMPACT OF CLASS V INJECTION WELLS ON CARBONATE GROUND WATERS

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Introduction

Part C of the Safe Drinking Water Act (Public Law 93-523) authorized the U.S. Environmental Protection Agency (EPA) to establish regulations to assure that potable ground water is not endangered by the underground injection of waste. Guidelines for underground injection and the classification of injection wells come under Part 146.04 of the Federal Underground Injection Control program (U.S. EPA, 1981). This program created five classes of underground injection wells. Classes I through IV include such categories as radioactive and hazardous waste injection and disposal of brines from the oil and gas industry. Class V wells are generally defined as those which inject only non-hazardous fluids into or above strata that contain underground sources of drinking water (USDW). USDWs not only include aquifers which are currently serving as drinking water supply sources but also aquifers which are of acceptable quality for possible future use. Class V wells include any type of injection well not covered in the UIC definition of Classes I, II, III or IV. EPA has classified Class V injection wells into six groups based in part on the expected quality of the injected fluid. Any sinkhole modified to accept waste, including storm water runoff, is considered a Class V injection well.

The U.S. EPA has funded twenty-four projects nationwide under its Shallow Injection Well Initiatives Program to help evaluate the impact of Class V injection wells on ground water and to establish best management practices. The authors of this paper were chosen to help evaluate Class V injection well practices in the karst of Tennessee.

Objectives

The primary goal of the proposed study was to determine if Class V injection wells have created a ground water pollution problem. Evaluating the effects of service station bay drains that lead to septic tanks, pits, or dry wells and storm water runoff wells were a primary target of the investigation.

Additional objectives of the research are:

1) review case histories of contamination from Class V injection wells in karst through a literature review,

2) evaluate the effectiveness and applicability of UIC-Class V injection well regulations in states having karstic limestone terranes and provide suggestions to modify regulations for better protection of human health and the environment,

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3) sample selected runoff waters entering sinkholes and analyze chemical constituents in nearby wells and springs to determine contaminant levels. Analyses for BTEX, MTBE, TPHC, ethylene glycol, zinc, and lead were chosen to evaluate the impact from service station bay drains and urban storm water runoff,

4) perform a benthic macro-invertebrate study at the sites being sampled chemically to document contaminant effect on stream biota,

5) demonstrate the applicability of dye tracing to show the connection between selected pollution sources and contaminated wells and springs.

Study area

Two geologically different karst terranes in Tennessee were chosen so that the results would have applicability throughout much of the karst in the United States. Around Cookeville, the Mississippian-aged carbonates of the Eastern Highland Rim Province are flat-lying, allowing ground water to move along a wide range of orientations corresponding to joint and photo-lineament trends (Ogden et al., 1989). In the Valley and Ridge Province around Johnson City, the Ordovician-aged carbonates are complexly folded and faulted, and ground water moves predominantly along stratigraphic strike within solutional-enlarged bedding planes. Most of the ground water flow paths in and around Cookeville have been documented by Faulkerson and Mills (1981) and Hannah et al., (1989). These traces have delineated the boundaries of three spring water basins that receive storm runoff from Class V injection wells. No ground water tracing had been conducted in Johnson City until initiation of this project.

Methods

Samples were collected where water enters Class V injection wells and at the springs influenced by these waters. As a control, samples were also gathered from a sinking stream and a spring with a predominantly forested recharge area. Samples were analyzed for constituents expected from service stations as well as from agricultural practices. Dissolved oxygen (DO), pH, conductivity, and temperature were measured in the field with a Hydrolab field monitor. Laboratory analyses used as indicators of contamination from agricultural activities and septic tanks included nitrate, chloride, fecal coliform, and fecal streptococcus bacteria. Zinc, chromium, lead, methyl tertiary butyl ether (MTBE, a gasoline additive), benzene-toluene-ethylene-xylene (BTEX), total petroleum hydrocarbon (TPHC) and ethylene glycol levels were measured as indicators of waste products and leaks from service stations and parking lot runoff.

To enhance the interpretation of the impact of Class V injection wells on spring waters, benthic macroinvertebrate samples were collected at riffle areas and pools at both the injection points and the springs. Samples were collected with a modified kick net and a Surber sampler (0.09 m^2). All organisms were preserved in a 10% formalin solution, enumerated, and identified to the lowest taxonomic level possible.

Ground water tracing was conducted using fluorescein and rhodamine dyes with activated charcoal detectors. Optical brighteners and cotton detectors were also used for tracing. A control packet was placed at a spring known not to be hydrologically connected to the tracer input site during each test.

Results

Service Station Bay Drain Survey

Approximately 75 sites were visited in the Johnson City and Cookeville areas to determine service station bay drain disposal practices. This survey yielded the following results: 1) most service stations claim to have their bay drain connected to the city sewer, 2) others have no idea where the drain leads to, 3) only a few say that the drain leads to a septic system or drain well. These results have made it very difficult to document if ground water quality degradation is occurring. Personnel from regulatory agencies with the authority to perform detailed on-site inspections will be needed to determine actual disposal practices.

Ground Water Tracing

Four ground water traces from Class V injection wells in Johnson City were conducted. These results have documented the ground water flow paths to a spring along Knob Creek that drains much of the north portion of town. Six traces were conducted in the Cookeville area. Ground water travel times were very rapid, being in the order of several thousand feet per day.

Water Quality Sampling

Measurements of MTBE, BTEX, TPHC, ethylene glycol, and metals taken during the wet season were not useful in demonstrating water quality degradation. At most sites these parameters had levels below detection limit. Samples will be subsequently taken during the dry season to determine if dilution effects were the reason for these low levels.

Benthic Macro-Invertebrate Survey

A macrobenthic survey was conducted on springs and sinking streams in the Cookeville and Johnson City areas that are affected by Class V injection wells. Macedonia Springs was the control spring for the Cookeville area while Taylor Springs served as the control in the Johnson City area. Riparian zones tended to be constant in the Cookeville area while Johnson City sites had the most variation.

Winter samples were picked and separated to the order level and some families. The winter findings suggest lower numbers of orders, but higher numbers of individuals in the Class V impacted sites. Springs heavily influenced by Class V injection wells had higher counts of chironomids, with only 4-5 orders being represented. However, substrate analyses were not performed which could significantly affect the number of orders found. Table 1 shows the number of individuals per taxa at each sampling site.

State Survey of Class V Injection Well Regulations

A telephone survey of sixteen states with significant occurrences of karst limestone bedrock was undertaken in order to: 1) communicate with regulatory staff responsible for underground injection control (UIC) or ground water protection programs, 2) obtain copies of the states' UIC regulations pertaining to Class V wells, 3) document case histories of contamination from Class V wells, and to 4) gain ideas and information on alternatives for preventing ground water contamination by Class V injection wells.

Ten of the sixteen states interviewed reported having no rules dedicated to Class V wells. Most of these do, however, give special approval to ground water return flow wells for heat pump and air conditioning systems. Several commented that misused or abandoned Class V wells are regularly discovered during investigations of unrelated complaints and violations. Minnesota prohibits any use of wells for injection purposes (except return flow wells) and requires landowners to seal them as they are discovered. Illinois is another state which uses a public information campaign to control Class V injection wells. The Missouri Division of Geology and Land Survey issues a joint permit with the Division of Environmental Quality for large commercial or institutional heat pump withdrawal/injection wells. Ohio and Arkansas have conducted inventories of Class V wells in their states for the purpose of developing appropriate regulations. Ohio's regulations, which will contain special provisions for karst terranes, will become available this spring. The states of Alabama and Tennessee have a registration requirement for Class V injection wells. The regulators acknowledge that, with limited tracking and enforcement capability, they are notified of only a small fraction of disposal wells in use.

Florida and West Virginia have two of the most comprehensive regulations covering Class V wells that have been reviewed to date. West Virginia's regulations specifically

Table 1. Number of Individuals per Taxa at each Sampling Site.

	Sampling Site										
TAXA	*Taylor Spring	Stinky Creek	Crystal Springs	Shoe Spring		*Macedonia Spring	City Spring	Big Spring	Pigeon Roost	Ament Resurgence	Essex Spring
Chironomidae	56	40	110	115		42	14	143	234	67	43
Coleoptera	2	23	37	25		35	36	12	0	4	151
Gastropoda	76	1	41	26		9	78	0	0	0	95
Isopoda	2	2	75	5		107	38	6	1	3	27
Nematoda	1	11	6	9		2	2	6	1	40	2
Crustacea	6	2	3	210		45	69	1	2	1	51
Ephemeroptera	0	0	0	0		228	28	0	0	0	1
Plecoptera	0	0	0	0		98	17	0	0	0	0
Trichoptera	0	0	0	0		89	0	0	0	0	0

*Control Springs

mention two types of Class V wells often found in carbonate formations: 1) wells for waste disposal into solution cavities and, 2) sinkholes used for the disposal of sewage or any other waste. Florida, which contains shallow ground water in karst aquifers, has developed six groups of Class V injection wells and reserves the right to apply Class I design standards if the situation warrants.

One concern aroused during the interviews was that the recently issued NPEDS municipal stormwater regulations will increase the use of Class V injection wells for controlling urban runoff. With many states having such loose regulatory control over Class V wells, there are implications for adversely affecting ground water quality with re-routed stormwater drainage.

Summary and Conclusions

Our results have shown that many more Class V injection wells occur in the study areas than anticipated. Regulatory authority will be needed to access actual bay drain disposal practices. Wet season water quality sampling did not indicate water quality degradation based on measurements of MTBE, BTEX, TPHC, ethylene glycol, and metals. Dilution effects are believed to contribute to these results. In contrast, benthic macro-invertebrates were stronger indicators of water quality. Springs receiving recharge from Class V injection wells showed a less diversity and density of benthic macro-invertebrates than the control springs.

Most state regulations do not specifically address Class V injection well practices in karst terranes. The extreme vulnerability of karst aquifers dictates that this be changed. Some combination of the West Virginia and Florida's UIC statutes offer a relatively flexible framework for regulating Class V injection wells and protecting karst aquifers.

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ASSESSMENT OF NITRATE EXPORT FROM A HIGH ELEVATION WATERSHED

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Nitrate leaching from forest soils can be detrimental to both the forest ecosystems and stream water quality. Nitrate moving through the soil transports plant nutrients and acidifying agents, hydrogen and aluminum, and can export them to streams. In the high elevation spruce-fir forests in the Great Smoky Mountains National Park (GRSM) nitrate has been found to be leaching from the rooting zone. Streams associated with these ecosystems are poorly buffered. Therefore rapid export of nitrate from the soils to the streams could lead to episodic acidification. The purpose of the Noland Divide watershed study is to assess the levels of nitrate export from the watershed to the streams and the potential impacts of the export to the ecosystem.

From 1986-1989, the Integrated Forest Study conducted by Oak Ridge National Laboratory monitored atmospheric inputs to forest sites. Their findings demonstrated that at the Noland Divide site in GRSM 1) there are very high atmospheric influxes of nitrogen, 2) that the soils are nitrogen saturated and 3) as a result of 1 and 2, nitrate is leaching out of the rooting zone. (Lindberg and Johnson, 1988) The acid soils were found to hold soil solutions with free aluminum concentrations approaching toxic levels (Johnson et al., 1989). These results indicated considerable sources of acidification for the watershed.

The large quantities of hydrogen ions and aluminum present in these acid soils are mobilized by nitrate. These cations are thenrapidly transported out of the forest system and deposited to the stream where they acidify the water (Tamm, 1991). During winter or drought periods, large amounts of nitrate can accumulate in the soil to then be released during a rain event, causing episodic stream acidification (Figure 1) (Foth H.D. 1990).

Of concern for the Great Smoky Mountains is that through predicted ecosystem changes, nitrate fluxes will increase, there by exacerbating the water quality hazards. Currently the spruce and fir forest is in decline. The Balsam Wooly adelgid has decreased the fir basal area by greater than 30% and emaciated the remaining live crowns (Busing, 1988). Spruce has exhibited declining growth trends in both ring size and crown health during the last 20 years (Adams et al., 1990; Durr, 1990). Furthermore, soil warming due to fir canopy decline and global climate change may accelerate the nitrification of plant materials, enhancing the accumulation of nitrate in the soil. Finally, continued atmospheric deposition of nitrate contributes to the accumulation in the soil.

The Noland Divide Watershed Study is addressing several concerns for water quality and nitrogen cycling. The objectives of the study are:

1) To assess the flux of nitrate and aluminum through the watershed

2) To assess the current and potential impacts of acidification to the stream resulting from episodic events.

3) To develop a more complete view of the N process occurring below the rooting zone.

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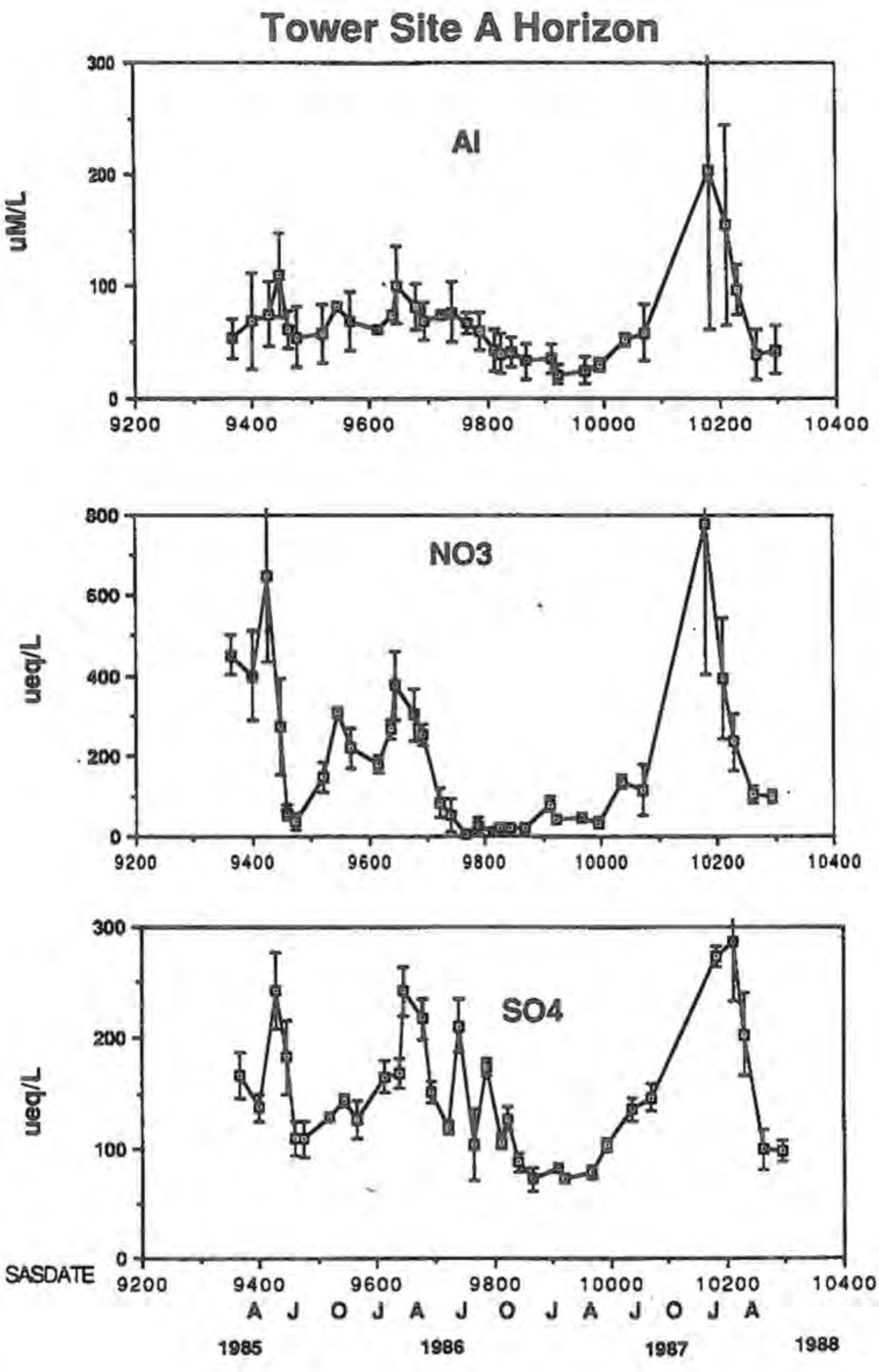


Fig. 1. Soil solution Al (total), NO_3^-, and SO_4^{2-} in A horizon of the Smokies Tower site. (Standard Errors are shown.)

The Site

The study site is located a 1695m, 5560 ft on Noland Divide near Clingman's Dome in GRSM. The watershed area is about 17 ha. Water movement from the watershed is via two braided streamlets. The area is underlain with Thunderhead Sandstone of the Great Smoky Group (King et al. 1968) The soils are weakly developed existing in humid, moist climates and are acidic ranging from 3.8 in the A horizon to 4.7 in the B_{w3} (Johnson et al, 1989).

Old-growth Red Spruce (Picea rubens) dominate the overstory with some mature Yellow Birch (Betula alleghaneinsis). A dense understory vegetation is composed of Fraser Fir (Abies Fraseri), Red Spruce, blackberry (Rubus canadensis L.), witch hobble (Viburnum alnifolium Marsh.), blueberry (Vaccinium erythrocarpum Michx.), sorbus (Sorbus americana (Marsh.) DC), and Rhododendron (Rhododendron maxima) (Johnson et al, 1989)

Previous research conducted in GRSM revealed that stream chemistry is strongly related to the forest soil chemical properties and that nitrate and aluminum can strongly contribute to changes in stream pH (Silsbee and Larson, 1981). Accordingly GRSM streams were found to experience episodic acidification events (Olem, 1986; Cook et al., 1990)

The Methods and Equipment

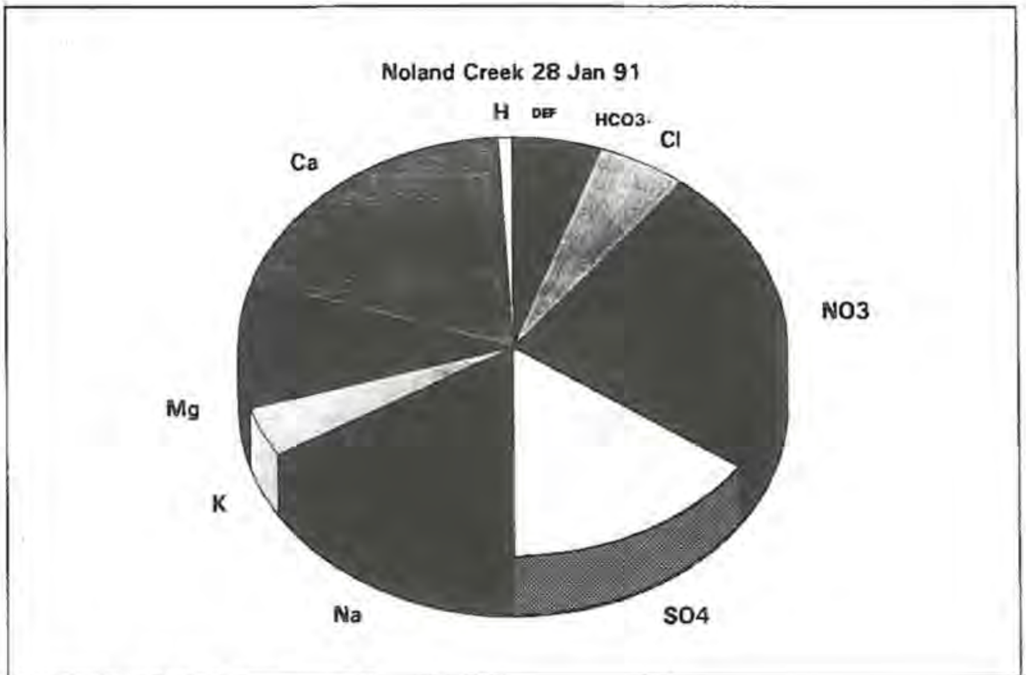
Nitrogen fluxes in the watershed are being evaluated through regular collection and analysis of precipitation, soil solution and stream water samples. Precipitation and soil solution sampling are a continuation of collections begun by the Integrated Forest Study. Precipitation collectors are located in both an open site, without canopy cover, and a throughfall site, under the canopy. Precipitation samples are being collected twice weekly and analyzed for pH and conductance. Weekly samples are sent to a laboratory for analysis of major cations and anions. Rainfall data is also gathered twice weekly from bulk collectors and chart recorders.

Soil solutions are being collected through tension lysimeters at three depths in the throughfall site, underneath the forest floor, the A and the B horizons. Solutions samples are being taken monthly and analyzed for pH, conductance, and major cations and anions. Soil temperatures are also read monthly for the same depths.

Stream chemistry and discharge are being gauged continuously and stream water samples are being collected weekly. Using several discharge equations, we estimated the low flow and peak flow for the two streamlets. A 3 foot H-flume was selected as the most appropriate gauging device because of the wide range of flows it accurately measures and its "self cleaning" properties. Stream chemistry is being monitored with a Hydrolab H20, a data transmitting water quality monitor. Temperature, conductance, and pH are being continuously measured through the H20 and the data are transmitted and stored in a datalogger. This system will provide records of episodic changes in stream chemistry related to storm events. Weekly stream samples are being collected and analyzed for major cation and anions.

Results and Discussion

Results from the precipitation and soil solution samples are comparable to previous findings from the IFS study. Precipitation samples show low pH, 3.9 - 4.9. Soil solutions also display low pH, 3.8 - 4.7, and high levels of nitrate and aluminum. Nitrate is continuing to export from the rooting zone. Consequently, preliminary analyses of Noland creek stream water bear out expectations of high nitrate levels. Stream samples collected after a January snow melt showed nitrate (57µeq/L) and sulfate (36µeq/L) as the predominate anions (Figure 2). These concentrations are relatively high when compared to other stream systems. Stream sampling and discharge monitoring were initiated during summer of 1991, therefore further results are not yet available, but earliest findings will be reviewed in the presentation.



Measure	pH	ANC
Conc.	5.72	0

Measure	DEF *	HCO3- *	F	Cl	NO3	SO4	PO4
Concn	9	3	1	12	57	36	0

Measure	NH4	Na	K	Mg	Ca	H
Conc.	0	39	9	23	45	2

All values above except pH are as microequivalents per liter. Bicarbonate was estimated from the pH of the sample and assumed atmospheric carbon dioxide content of 350 ppm using Henry's Law and the dissociation constants for the carbonic acid-bicarbonate equilibrium. Anion deficit (DEF) was calculated by difference.

Fig. 2.

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MATHEMATICAL REPRESENTATION OF AN AGRICULTURAL WATERSHED FOR ANALYSIS OF NONPOINT SOURCE POLLUTION USING HSPF

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HSPF which is a sophisticated hydrological water quality model, has been employed to guide the selection of agricultural best management practices used for reducing non-point source pollution. Long Creek watershed, located in the Nolichucky River Basin, in northeast Tennessee, has been selected as a test watershed for developing techniques and approaches that are planned for use in simplified model applications by personnel with limited training in HSPF operation.

Mathematical representation of a complex watershed with multiple water quality constituents in a sophisticated model requires an immense amount of data on the characteristics of a given watershed. Principle data needs for the model encompass six major areas: (1) location and weather characteristics; (2) land-use and land-cover characteristics; (3) soils properties; (4) land forms and geology of the area; (5) information on stream reaches in the watershed; and (6) historical water quality and water quantity records. Due to the continuous simulation associated with HSPF, data requirements for many of the parameters vary temporally, and consequently a times-series input is needed. Also, many common descriptive parameters used with single-event hydrologic models have to be treated as functional rather than descriptive parameters in HSPF.

Weather Information

Weather data, consisting of precipitation and temperature records were obtained for Jefferson City from the National Oceanic and Atmospheric Administration in machine readable, digital format. Jefferson City was the closest NOAA weather station with hourly records to the Long Creek watershed. The data consisted of a daily summary of precipitation and the maximum and minimum daily temperatures. The format of the NOAA supplied weather data was modified slightly and temperature data was dissaggregated into hourly values using a HSPF supplied routine. Hydrologic calibration of the model used a 3-year continuous simulation (January 1969 through December 1971).

Land Use, Land Cover

Land use and land cover information was obtained from 1:24,000 scale photographs and from site investigations. The information was ultimately incorporated into a GIS system for analysis and decision purposes. This consisted of conversion of descriptive data to functional parameters. The photos were obtained from the Tennessee Valley Authority map office in Chattanooga, TN. Color infrared photographs are planned for availability soon and should allow for a more detailed assessment of land use and cover.

Two significant factors in the land use, land cover parameters are seasonal variability of the vegetation, and farming practices that modify the cover characteristics on a frequent basis. Functional parameters for land use and cover can be input to the HSPF model on a monthly basis, or through a special actions block. Normal seasonal changes are accounted for on a monthly basis, and

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distinct farming practices that significantly change functional parameters are recorded in the special actions block. For example, this would include such things as modification to the infiltration capacity, Mannings' roughness value, and upper zone storage capacity, due to plowing or disking.

Slopes in the Watershed

Average slope is an important watershed characteristic needed for modeling. For the HSPF simulation of Long Creek watershed, slopes were obtained from Digital Elevation Models (DEMs) available from the United States Geological Survey (USGS). The DEMs were loaded into the GIS system and divided subareas that contained similar slopes (ie. 0 to 1%, 1% to 5%, 5% to 10%, 10% to 15%, and greater than 15%). Since land segments in HSPF can be characterized by only a single slope, this was a major factor in the sub-basin arrangement for numerical representation.

Soils Characteristics

Soils information available for input into HSPF was obtained from the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) in the form of soil surveys and other publications. For representation of a large watershed the level of detail reflected by the non-digitized soil surveys proved to be too data intensive. Therefore, for the Long Creek simulation, soil associations were used. These use the more general types of soil and seemed adequate for this type of simulation. Digital maps of soils are being prepared by the SCS, but were not yet available.

Stream Reaches

General stream reach characteristics such as reach length, reach surface area, average depth in reach, approximate reach volume, and a stage - discharge relation are necessary input parameters for HSPF. This quantitative description of each reach is merely an approximation of the real reach and the level of detail will vary with the size and complexity of the watershed being modeled. Long Creek was divided into 12 reaches for the simulation, each reach having several types of contributing land segments. The reaches were networked so that the main stem of the creek was divided into 4 sub reaches with the remaining 8 sub reaches connecting directly to one of the main stem reaches.

Streamflow Records

Observed streamflow based on gaged records were used to compare with model output. This was done for both streamflow (in cfs) and for volume balance (cf). If the modeled streamflow was not significantly different from actual streamflow for the simulation period the model was assumed to be calibrated. For validation purposes a second, separate time period is simulated, if the model results were not significantly different the model was then said to be calibrated and validated. For the Long Creek watershed HSPF was calibrated using 1969 through 1971 data and was validated using 1974 through 1976 data. Streamflow gage records used for comparison purposes were acquired for the Long Creek watershed from TVA for the years of record 1965 through 1977.

Water Quality Records

Modeled water quality must be calibrated in much the same manner as streamflow. Water quality records were obtained from STORET by TVA for this project. Water quality data for the Long Creek watershed was continuous for the calendar year 1976. Isolated and infrequent water quality data exist at other times. The model was calibrated using the 1976 water quality data, and validation attempted using the isolated and infrequent data points.

Summary of Data

When all the previously described quantitative data properties are spatially overlaid, segments that are relatively homogeneous can be identified. The map shown in figure 1 illustrates how the Long

Fig. 1. Reach Division of Long Creek Watershed, for model input.

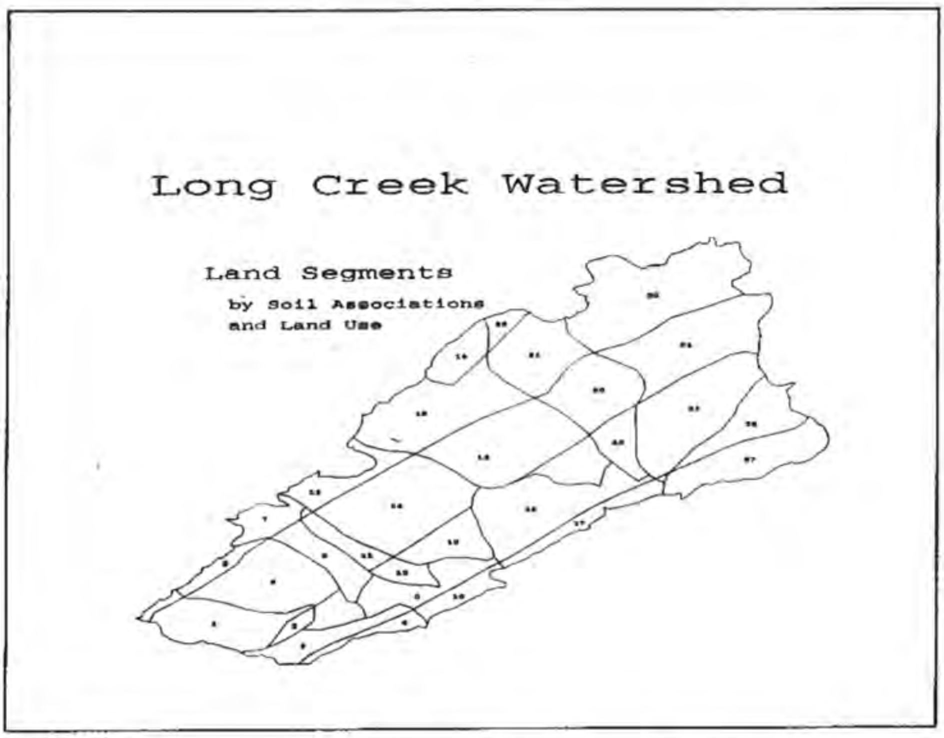

Fig. 2. Land segmentation of Long Creek watershed, for model input.

Creek watershed was divided into reaches for the HSPF simulation, and figure 2 illustrates the division of land segments for the HSPF simulation. Each land segment represents a relatively homogeneous set of parameters values including: soils characteristics, land cover, land use, tillage practices, and surface slope. Similarly each stream reach (as defined in the model) represents a relatively uniform section of actual stream reach which represents relatively uniform characteristics for: channel shape, channel slope, channel composition, cross-sectional shape, and Mannings' roughness values for the channel and banks.

Selection of a Spatial Resolution

Selecting a spatial resolution for modeling requires a compromise. Low resolution (large areal coverage) would not provide sufficient detail to evaluate the effects of a single Best Management Practices on an individual-site basis. Alternately, high resolution (small areal coverage), while providing sufficient detail for individual site Best Management Practices, would be too data-intensive to be practical on a large watershed. Therefore, a moderate resolution was initially selected on the Long Creek simulation and single Best Management Practices were applied on a aggregated-site basis (applied to a complete land segment).

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STATISTICAL METHODS FOR ESTIMATING STORM-RUNOFF LOADS IN THE NASHVILLE METROPOLITAN AREA, TENNESSEE

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Methods for estimating storm-runoff loads for streams in the Nashville Metropolitan area are needed by the city to comply with U.S. Environmental Protection Agency regulations for discharge of storm runoff. To develop these methods, the U.S. Geological Survey in cooperation with the Metropolitan Government of Nashville and Davidson County undertook a study in 1990 to relate storm-runoff loads to land use. Quantity and quality of runoff were monitored at five sites draining areas of distinctly different land use. Sampling was conducted during one storm at four sites and during three storms at the remaining site. Concentrations for selected storm-runoff constituents were determined from a flow-weighted composite sample taken from discrete samples collected during the first 3 hours of the storm. Storm-runoff loads were computed as the product of storm-runoff volumes and the concentrations in the composite samples.

Accuracy of the U.S. Geological Survey regional regression models for estimating single-storm loads for watersheds in the Nashville area was assessed by comparing regression-derived estimates with the field data. Standard error or prediction (SEP) for the nine constituent models examined ranged from 107 to 10,000 percent. Although loads were not accurately predicted by the models,six of the nine models accurately predicted relative site-to-site variability, indicating that they could be used to predict fundamental relations between watershed characteristics and storm-runoff quality. The storm-load regression models were adjusted using the Nashville data, with a modification of simple linear regression. The adjustment procedure provided the largest reduction in prediction error for total recoverable copper (SEP reduced from 10,000 to 26 percent for the adjusted model), lead, and zinc. For the dissolved-solids model and the total and dissolved-phosphorus models, adjustment did not reduce the SEP to an acceptable level (less than 150 percent).

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NORTH MOUSE CREEK WATER QUALITY STUDY

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Background

North Mouse Creek is located in southeastern Tennessee. It flows generally north to south, and drains an area of 93.7 square miles (sq. mi.) at its confluence with the Hiwassee River. An intensive water quality survey was performed on the reach between creek miles 26.6 and 18.4 in the summer and fall of 1989. The drainage area in this study reach increases from 35.0 to 48.1 sq. mi. Most of the land in the North Mouse Creek valley within and upstream of the study area is used for agriculture. The Creek is therefore primarily impacted by runoff from non-point sources. A small portion of the contributing watershed within and near the City of Athens and the town of Niota has undergone urban development.

The intent of the study was to determine the assimilative capacity of North Mouse Creek. The study consisted of conducting intensive field sampling activities in order to collect data for calibrating a water quality model of the creek. The calibrated model was then used to determine the capacity of the creek to assimilate waste loads from a proposed sewage treatment plant.

Dissolved Oxygen Cycle

The most critical factor in assessing the current and expected future water quality of North Mouse Creek is the concentration of dissolved oxygen (DO) in the water. As such, the field surveys conducted during the study were intended to identify and measure the parameters having the greatest impact on the DO cycle.

The primary natural source of DO for a stream is the absorption of atmospheric oxygen or reaeration. The reaeration rate coefficient K2 is primarily a function of the hydraulic characteristics and temperature of the stream. Because of the importance of stream reaeration, and because of the variability of the theoretical, empirical, and semi-empirical methods which can be used to estimate K2, reaeration in North Mouse Creek was measured in the field using a variation of the USGS steady-state propane gas tracer method.

There are currently three primary sources of oxygen depletion in North Mouse Creek: 1) the oxidation of organic matter, known as carbonaceous biochemical oxygen demand (CBOD); 2) the benthic or sediment oxygen demand (SOD); and 3) the transformation of organic nitrogen to ammonia, nitrite, and finally to nitrate. A water quality sampling and analysis program was designed and implemented to measure both CBOD and the nitrogen parameters. SOD was measured directly in the creek using aluminum chambers designed by the EPA.

Algal biomass in a stream can also affect the concentration of dissolved oxygen. Algal respiration depletes oxygen, and algal photosynthesis produces oxygen. Analysis of diurnal DO data and the water quality samples from North Mouse Creek produced little evidence of algal activity, therefore, the algae cycle was not included in subsequent modeling efforts.

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Hydraulic Characteristics

Water quality in a stream is heavily dependent upon discharge, depth and width. In addition, time-of-travel and longitudinal dispersion data were required to support subsequent sampling activities. For both of these reasons, it was necessary to determine the essential hydraulic characteristics of the creek.

North Mouse Creek discharges were measured using an electromagnetic velocity meter. Discharge measuring stations were selected based on considerations of uniformity of flow conditions, and the combination of highest velocity and smallest depth available within a given reach. The stations selected were used repeatedly throughout the field surveys.

Creek widths were based on the discharge measurement data, supplemented by additional observations over the entire length of the study reach. Little variation in creek width was observed over this reach. Creek depth, however, changes significantly, as the creek is characterized by a series of pools and riffles. The selection of reach average depths was a critical factor in calibrating the water quality model.

Because of the varied nature of flow in different reaches of the creek, it was not possible to determine average reach velocity (and hence travel time) from a series of point velocity measurements. The travel time was instead measured in the field by detection of Rhodamine WT dye. This was accomplished by instantaneously injecting a slug of dye into the creek, and measuring relative dye concentration at successive downstream stations.

The measured fluorescent dye wave at each station was also used to compute the longitudinal dispersion coefficient. Longitudinal dispersion is caused by the variation of velocity with vertical and lateral position, and can affect pollutant movement in a stream.

Reaeration

To measure the reaeration rate coefficient K2, three surveys were performed. The techniques used for these surveys were based on those developed by the USGS (USGS, 1987). For each survey, commercial grade propane gas was injected into North Mouse Creek at a uniform rate for a duration sufficient to establish a gas concentration plateau at the injection location. As the plateau moves downstream, its concentration decreases due to the desorption of the gas to the atmosphere and longitudinal dispersion.

The rate of propane gas desorption was measured directly for each reach of the creek by sampling and subsequent determination of the propane plateau concentration at consecutive downstream locations. This method allowed direct determination of the rate of oxygen absorption, which is proportional to propane desorption. The gas injection was accompanied by a slug release of conservative dye, so that the reach-by-reach effects of longitudinal dispersion could be determined. The dye was also used to locate the central portion of the propane plateau, and thereby guide the timing of propane sampling. The gas injection location was selected far enough upstream to provide complete transverse mixing of the gas and dye at the first sampling point.

Sediment Oxygen Demand

The SOD is a function of both the local benthic and hydraulic characteristics, which are likely to vary considerably over relatively short distances. The direct measurement of SOD is confined to discrete locations over very small areas. In this study, SOD measurements were specifically conducted to determine the maximum and minimum magnitude of benthic oxygen uptake likely to occur over the study reach. In this way, the expected range of SOD (and to some extent the "average" SOD) over each reach was determined.

Field measurements were conducted using the EPA's standard SOD chambers. The chambers allow a portion of the stream bottom to be isolated, and contain recirculating pumps to simulate streamflow conditions. In addition, each chamber has a port for a DO sensor, which provides direct measurement capability of the DO inside the chamber. Each SOD test consisted of positioning two open bottom chambers and one closed bottom chamber on the stream bottom. The procedures used in the field were those developed by Region IV of the EPA (EPA, 1986).

Water Quality Sampling and Analysis

Water quality samples were taken throughout the field survey period, primarily to develop a better understanding of the physical, chemical, and biological factors which predominate in North Mouse Creek. This can best be accomplished by using time-of-travel data to ensure successive samples are taken from essentially the same parcel of water as it moves downstream. Therefore, samples were collected during all of the field surveys using the fluorometric dye tracer to guide in the timing of the samples. The samples were preserved and submitted to two area laboratories for analysis. Of primary interest were those parameters related to the in-stream CBOD and the nitrogen, phosphorus, and algal cycles. The CBOD data reported by these laboratories were used to compute the deoxygenation rate coefficient K1.

Computer Modeling

The EPA's QUAL2E-UNCAS computer model was selected to assess North Mouse Creek water quality under current and proposed future conditions. The model is capable of simulating all of the processes of importance to the study, which included reaeration, deoxygenation, SOD, CBOD, and the nitrogen cycle.

The model was used in several ways throughout the study. After conducting a preliminary time-of-travel study using the tracer dye technique, the model was used on a "bench-top" scale to assist in development of the intensive field surveys. The results of the filed surveys were used to calibrate the model for the stream. This was accomplished by using the field data as a guide in adjusting the model parameters to yield the best match between the observed and computed values. During calibration, it became apparent that reaeration and SOD were the predominant oxygen balance terms for the stream.

The calibrated model was then used to simulate the creek under design conditions of the 3-day, 20-year low flow without the proposed sewage treatment plant. These efforts showed the creek currently has the capacity to assimilate additional waste loads. The creek was then simulated under design conditions with proposed treatment plant discharges. An iterative process was used to determine the best use of the available assimilative capacity.

Finally, uncertainty analyses were performed in order to assess the expected variation in plant effluent characteristics, and to approximate the risk of water quality violations resulting from that variation.

Conclusions

North Mouse Creek was found to be a typical, agriculturally impacted rural stream. The field surveys provided no evidence of any particularly unusual physical, chemical, or biological processes which would impact present or future water quality. The dissolved oxygen balance in the existing system was found to be driven primarily by reaeration and sediment oxygen demand, with the nitrogen cycle and in-stream CBOD being relatively minor oxygen sinks. Computer modeling performed with the QUAL2E-UNCAS model showed that the creek has sufficient capacity to assimilate effluent from the proposed sewage treatment plant.

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A COMPARISON OF METHODS FOR ESTIMATING EVAPOTRANSPIRATION USING STANDARD WATER-BUDGET MODEL AND REMOTELY SENSED DATA COMPUTATIONS

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Two different methods were used to estimate evapotranspiration (ET) rates at similar sites in south-central Tennessee for June 1990, one at the Arnold Air Force Base, and one in the Duck River basin, which lies on the Arnold Air Force Base boundary. Because satellite data were available, a method utilizing the normalized difference vegetation index (NDVI) of remotely sensed thematic mapper (TM) satellite data were used for ET estimation on the Arnold Air Force Base site. This method estimates actual ET based on vegetation characteristics expressed by the NDVI values. For the Duck River basin, where historical hydrologic data were available, the Thornthwaite[2] water budget model was used to estimate ET. The Thornthwaite water budget model assumes that actual ET is equal to potential ET if precipitation equals or exceeds potential ET. If precipitation is less than potential ET, the Thornthwaite model computes an adjusted actual ET. ET values computed by the two methods were compared to determine if the results were similar.

Results indicate that the NDVI method has a slightly lower actual ET estimate as compared to the estimate obtained from the Thornthwaite model. Because the NDVI method accounts for all of the variability in the vegetation canopy (including bare soil and non-vegetated areas), it probably is a more accurate representation of the actual ET of the area than the lumped estimate derived by the water budget model.

More stringent testing of the applicability of the NDVI method is required to more firmly establish the validity of the method in watershed modeling. Concurrent investigations are evaluating the method in different geographic areas and climate conditions.

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[2] Use of the trade name in this abstract is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

STATUS OF AN AERATING LABYRINTH WEIR FOR MINIMUM FLOW AND OXYGEN IMPROVEMENT IN SOUTH HOLSTON DAM TAILWATER

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Background

Weirs constructed below hydropower dams can improve minimum flows between generating periods and increase tailwater dissolved oxygen (DO) content during generation. TVA has developed two distinct functional designs: a timber crib weir for minimum flow only (Figure 1) and a labyrinth weir for minimum flow and aeration (Figure 2). A target minimum flow is sustained by slow drainage of the weir pool between periodic refills. With the labyrinth weir, aeration occurs during generation via overtopping. Both weirs are designed to maximize the value of the tailwater while minimizing backwater on the upstream turbine, unsafe hydraulic conditions, and environmental disturbance.

South Holston Weir Description

TVA is currently constructing a labyrinth aerating weir downstream from South Holston Dam. For flow control, this weir is equipped with a pipe and valve arrangement that maintains constant minimum flow as the pool drains. For aeration, the weir features an extended crest length that reduces the unit discharge along its overflow sections. Reduced unit discharge minimizes the intensity of the downstream roller to safe levels and reduces the overflow nappe to a thickness that will aerate effectively. Aeration is achieved primarily by entrainment of bubbles impinged by the nappe as it enters the downstream plunge pool.

The weir now under construction will have a drop height of 4.5 ft over a crest length of 2100 ft and is designed to aerate an average generation flow of 2500 cfs. The crest length will result in a unit discharge low enough to produce safe plunge pool conditions and effective aeration. Unit discharges of 7 cfs/ft over low head weirs have resulted in fatal rollers, while unit discharges of 0.5 cfs/ft create thin sheets of water with trivial downstream recirculation. A range of unit discharges from 0.5 to 3.5 cfs/ft were tested full-scale during design of the South Holston labyrinth weir (Hauser, 1990). Plunge pool hydraulics below a vertical weir segment were measured and observed by the author, who walked and swam in the recirculation zones with safety gear. Results suggested 2 cfs/ft as a threshold above which flow conditions become mildly troublesome to free swimmers. The South Holston weir will operate at 1.2 cfs/ft during normal turbine operation and around 2 cfs/ft during flood operation (less than 1 percent of the time). Plunge pool depths will average 2.5 ft with a maximum of 4.5 ft to allow an adult to walk instead of swim for self-rescue of rescue of small children.

Aeration is achieved primarily by bubbles entrained as the overflow nappe impinges on the plunge pool. Aeration efficiency is affected by drop height, unit discharge, plunge pool depth, and oxygen deficit (Nakasone, 1987). According to aeration literature, the South Holston weir should increase DO by 3 to 4 mg/L DO in the overfall when upstream DO is 2 mg/L and unit discharge is 1.2 cfs/ft, with a 4.5 ft fall

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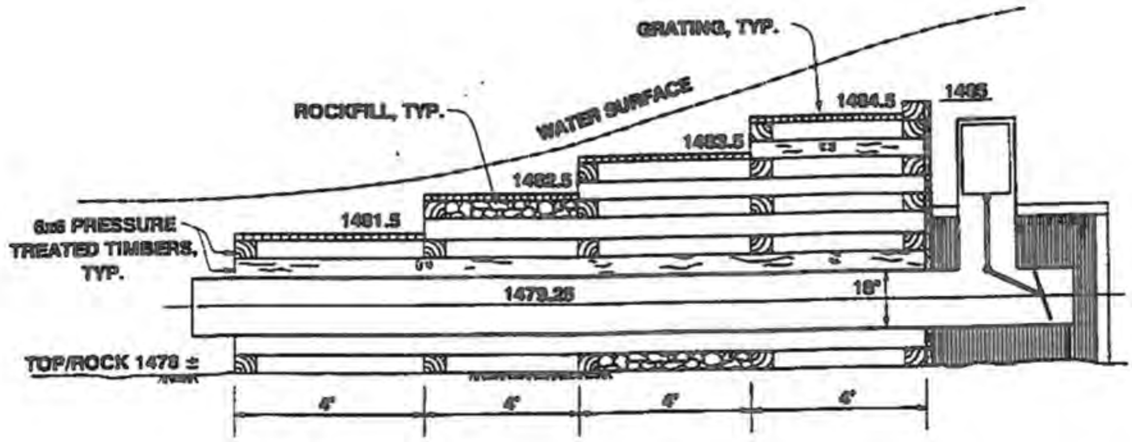

Fig. 1. Section view of timber crib weir.

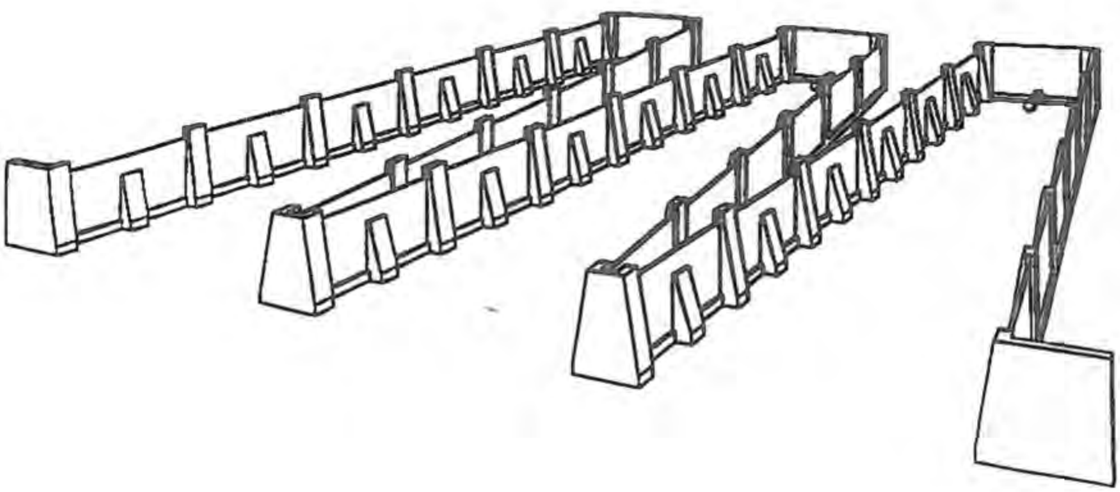

Fig. 2. Perspective view of three-bay labyrinth weir.

height. Additional aeration may occur down the length of the labyrinth legs due to reentrainment of bubbles along the flow path, based on measurements at an existing labyrinth weir installation.

The labyrinth shape was planned after the crest length was determined. The labyrinth must fit reasonably into the river channel, provide good bubble zones, and achieve uniform overflow conditions along the weir crest. Weir segments normal to river flow are non-overflow to avoid nappe convergence in corners that might increase recirculation intensity. To avoid long labyrinth legs, numerous bays were desirable. The number of bays was limited by the channel width and the bay width needed for full bubble zones along the sides of each labyrinth bay. Non-overflow segments were minimized to reduce costs. Crest length and these shape constraints determined bay length and leg angle. Water surface profiles in headwater bays were computed to check for nonuniform overflow conditions that might produce dangerous hydraulics along the weir.

The South Holston labyrinth weir is being constructed of concrete and wood. Weir walls will be pressure-treated, tongue-and-groove wood members placed horizontally atop lower members and supported by reinforced concrete piers anchored into bedrock. Piers will be slotted vertically to receive wall members in a stoplog arrangement. Intermediate concrete buttresses at midpoints between the slotted piers will support lower wood members. A concrete leveling pad between each slotted pier will include T-pipes to ventilate behind the nappe. Pipes and valves like the timber crib weir will be included for minimum flow control. Most concrete components are in place now, and construction is expected to be complete in late 1991.

Conclusions

Advantages of these weirs are evident in hydraulic and aeration performance, weir safety, and ease of construction. The pipe and valve assembly is a proven low maintenance way to regulate flow. The porous timber crib eliminates dangerous hydraulics, and is easily constructed with inexpensive materials. Overflow conditions are navigable without danger. Disadvantages of weirs like the timber crib are that it is attractive to the public as a fishing pier in a location of rapidly varying water levels, in spite of efforts to prohibit such use. Cost-effectiveness of a timber crib weir for minimum flow rivals that of turbine pulsing and usually exceeds that of small turbine additions or turbine bypass options.

The labyrinth weir achieves minimum flow and aeration objectives with a single structure. Aeration and safety increase as the crest is lengthened. Aeration is passive, so all releases are aerated regardless of origin. Aeration is downstream of the hydro plant, avoiding efficiency losses and cavitation problems of in-plant methods. Extended crests efficiently pass flows with less inundation and head loss on the upstream turbine. The labyrinth weir cannot be used as a fishing pier. Disadvantages of the labyrinth weir are that is it non-navigable, and it requires excessive crest length to safely aerate high flow applications. Aerating weir costs are equivalent to combinations of other methods for minimum flow and DO improvement.

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CONCRETE BLOCK WEIR AND ORIFICE DISCHARGE CHARACTERISTICS FOR STORMWATER DETENTION OUTLET CONTROL

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Introduction

With the increase in urbanization occurring throughout the country the use of Stormwater Detention Facilities (SDF) as a part of an overall urban stormwater management control strategy is becoming increasingly important. The growing use of SDF and the proliferation of various design approaches employed to configure the discharge structures used in these SDF led to the establishment of a Task Committee within The American Society of Civil Engineers (ASCE) to review and report on progress in the area of outlet control structures for SDF (ASCE, 1985). In their report, ASCE outlined areas that needed special attention to improve design information for detention pond discharge structures. The study presented in this paper develops laboratory data and rationale to support the use of concrete block construction of outlet control structures for SDF, and discusses the use of regular weirs, compound or *stacked* weirs, orifice, and combined weir/orifice type configurations for outlet control structures. The use of concrete block structures in conjunction with detention storage appears to be growing because of apparent practical, economic, and esthetic advantages over other types of structures.

Concrete Block Discharge Structure Configuration

Figure 1 illustrates how a concrete block discharge structure could be configured. The components of a concrete block discharge structure are as follows:

Orifice Opening

This type of opening controls the discharge for one storm event, e.g. 10 year storm. In the configuration shown, an orifice is used to regulate the first-stage storm flow. A handy way to produce the orifice openings is to build in concrete blocks laid on their side. The required area can be achieved by providing the proper number of block openings around the discharge structures.

Regular Weir

This type of weir opening has a constant width throughout its height. Using regular weirs in conjunction with lower orifice opening(s) is a way to control the discharge for a second storm event, e.g. 25 year storm, thus producing a multiple-stage discharge structure. It is important that the block voids on all weir surface openings be filled with concrete and trawled to a smooth surface to ensure proper flow performance.

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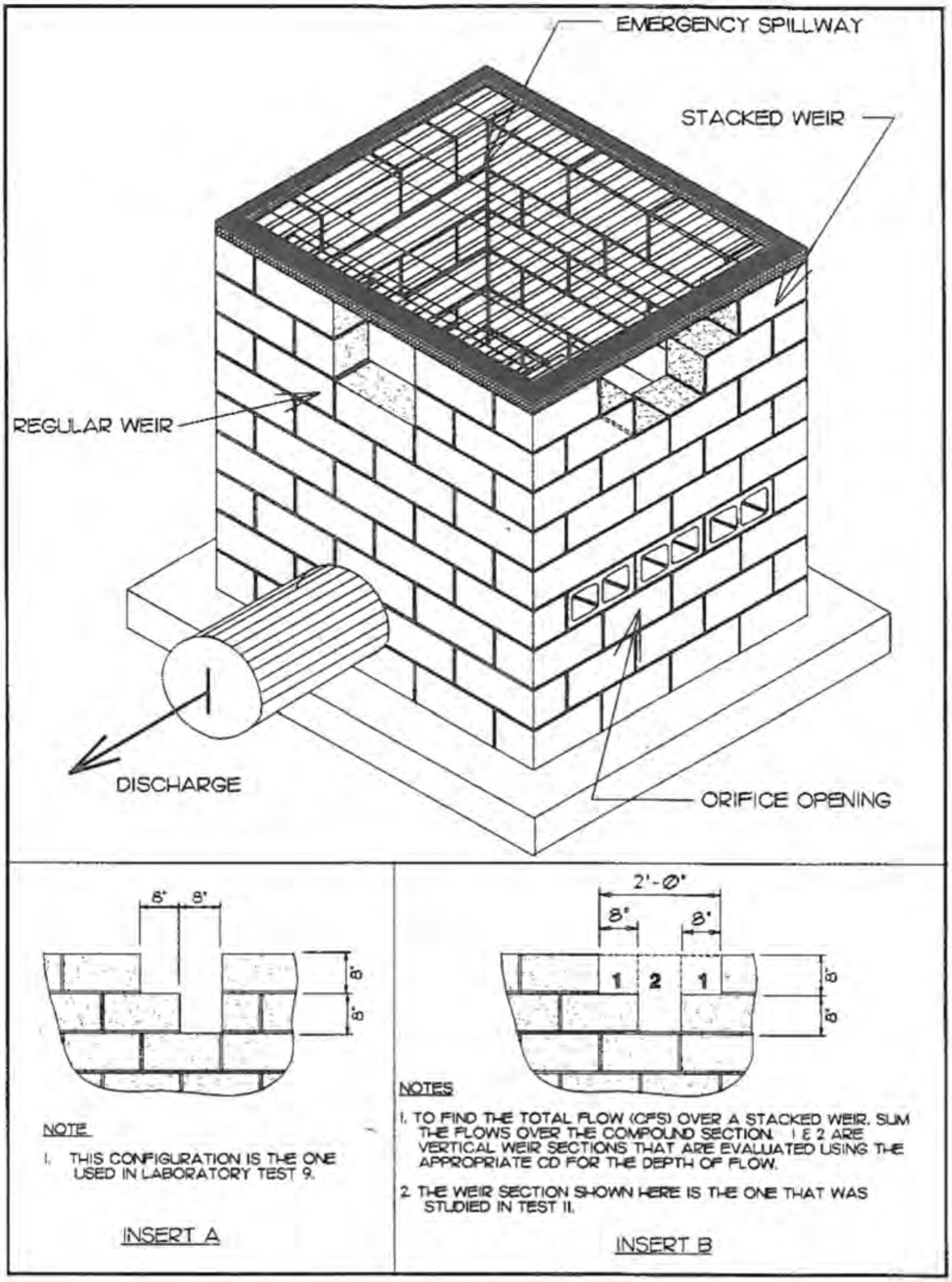

Fig. 1. Typical concrete block discharge structure.

Stacked Weir

Figure 1 shows a *stacked* weir that could be used to control the discharge for two storm events. In cases when a *stacked* weir is used for multiple-stage stormwater control, the orifice opening may be omitted. State-of-the-art practice currently favors control of two (rather than three or more) events (ASCE, 1985). Figure 1 Inserts A & B show possible configurations for *stacked* weirs.

Emergency Spillway

The emergency spillway protects the integrity of the earth dam that is most often used to produce a detention pond. The top grating is removable to allow for easy maintenance. One type of emergency spillway is an opening at the top of the riser structure as shown in Figure 1. An alternate route for the flow of water is recommended in the unlikely event the pipe leading from the discharge structure becomes blocked. The alternative route should be an emergency channel spillway capable of passing the entire flow for the maximum design storm event, e.g. 100 year storm.

The major factor affecting the performance of SDF discharge structures, such as the one shown in Figure 1, is the rate at which the various openings discharge water. Technical literature discusses various methods for designing SDF. These approaches range from simplistic approximate methods to well developed computer storage routing. All of these methods have fundamental shortcomings when it comes to the design of concrete block SDF discharge structures. No matter how complicated the mathematical approach used in the routing process, the approach .... "utilizes standard weir and orifice equations and applies them to very complex and composite control structures" (ASCE, 1985). However, lack of published orifice and weir discharge coefficients for openings formed from concrete blocks leaves the hydraulic engineer with little choice but to design the detention storage and outlet control opening(s) using "guesstimate" discharge coefficients. Inaccurate coefficients could result in either expensive, over-designed or ineffective, under-designed ponds. This paper will present laboratory test results for determining weir and orifice discharge coefficients and will show the sensitivity of pond storage to chosen coefficients.

Laboratory Setup

A series of twelve full-scale laboratory tests were conducted to evaluate the performance and hydraulic characteristics of various orifice and weir configurations commonly used in single- and multiple-stage stormwater detention outlet control structures constructed with concrete block. The study was performed in the University of Tennessee Civil Engineering Department Water Resources Laboratory. Figure 2A shows an example plot of the data obtained for a weir only laboratory test (Test 10).

An approximately five foot square 8" concrete block wall was constructed in the laboratory flow reservoir. The block wall was configured such that various arrangements of weir and orifice openings could be installed. Water was introduced upstream of the block wall through a calibrated 3" X 6" venturi meter and 8" diameter schedule 80 PVC pipe. The venturi was calibrated to measure water flow up to the total laboratory pump capacity of 3 cubic feet per second (CFS). A rock diffuser wall was constructed to dissipate turbulence between the point where water was introduced and the concrete block wall. A stationary staff gage was installed just downstream of the diffuser for obtaining head readings over the orifice and weir configurations. The twelve tests consisted of four orifice only tests, four weir only tests, two stacked weir tests, and two combined weir/orifice tests. Four of the tests also included the installation of an elevated channel bottom (raised floor) flush with the invert elevation of the orifice opening. Correction was made for a small amount of seepage through the wall by calibrating the leakage rate to the head of the particular test. The basic derived weir and orifice relationships that relate C_d to flow rate and head are shown in Equations 1 & 2. The C_d values presented in this paper were developed using power regression analysis of the laboratory data ($Y = aX^b$) as shown in the example weir test given in Figure 2A. These

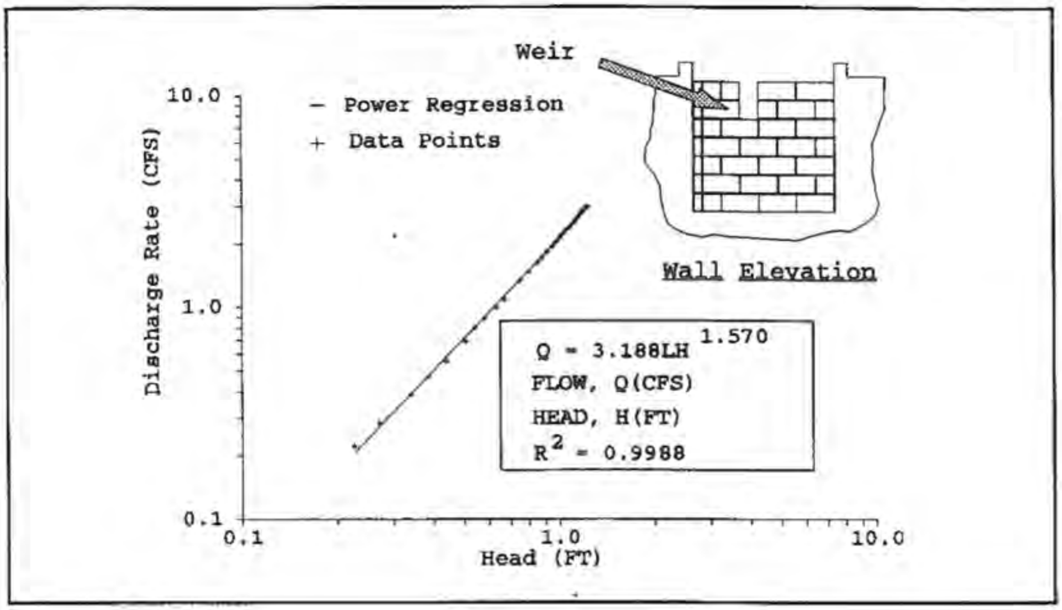

Fig. 2A. Discharge rating curve for 8" wide x 16" high weir only (Test 10).

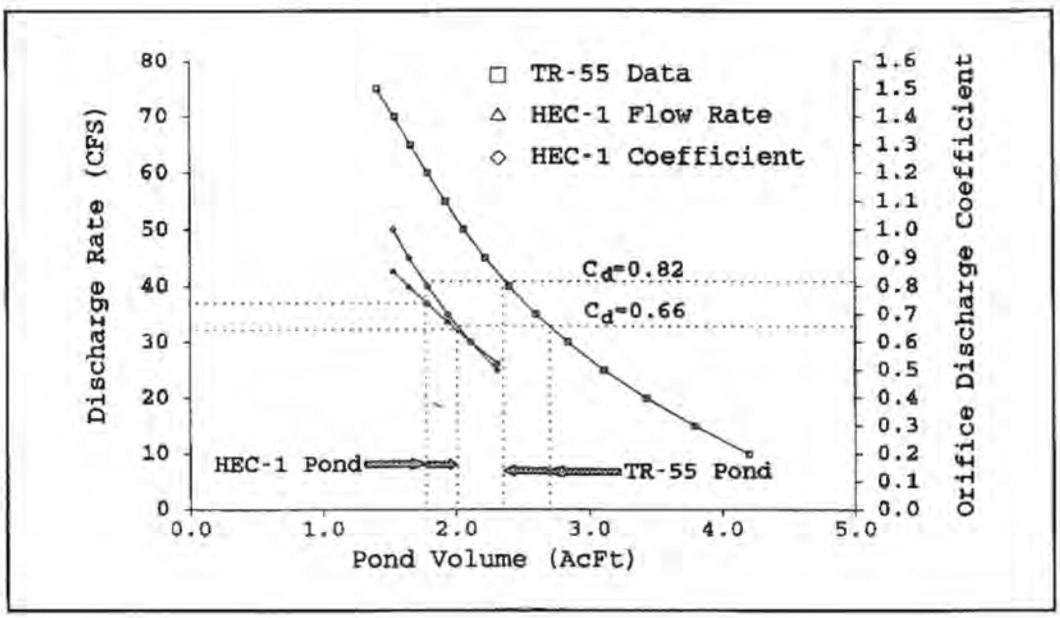

Fig. 2B. TR55 & HEC1 pond design comparison for assumed orifice discharge coefficients.

C_d results were then used to check the performance of *stacked* weirs and weir/orifice arrangements to determine if their performance differed from that which would be predicted with the laboratory tests.

Equation 1 - Orifice

$$Q=C_dA\sqrt{2gH}$$

Q = Flow (CFS)
C_d= Coefficient of Discharge
A = Area (Ft^2)
g = Acceleration of Gravity (32.2 Ft/Sec^2)
H = Head (Ft)

Equation 2 - Contracted or Suppressed Weir

$$Q=C_d(L-0.1nH)H^{3/2}$$

Q = Flow(CFS)
C_d= Coefficient of Discharge
L = Weir Length(Ft)
n = Number of Contractions
(0 for Suppressed Weir)
H = Head(Ft)

Laboratory Results

Orifice

Table I shows the results of the orifice only laboratory tests performed in this study. The geometry of a concrete block orifice approaches that of a *short tube* and an associated improvement in flow performance over a thin plate orifice. A standard short tube has a C_d of 0.82 (King et al., 1976). The typical concrete block orifice has a ratio of length to mean diameter of approximately 1.3. Schoder et al. (1927) predicts a C_d of 0.78 for an orifice of this configuration. In direct contradiction to Merritt (1968) and Schoder (1927), the introduction of a rough bottom (flush bottom suppression) at the invert elevation of the orifice appears to reduce, not increase, C_d. This reduction in C_d indicates that the degree of roughness and localized turbulence associated with the full scale experiment may have has more impact on C_d than suppression of the *vena contracta*.

Weirs

Laboratory test results on the performance of 8", 16", and 24" wide weirs indicates that King et al., (1976) can be applied to these broad-crested weirs to obtain accurate C_d values for concrete block weirs. Discharge coefficient results of the weir only laboratory tests are shown in Table II and are compared with average broad-crested weir C_d obtained from King, (1976). In all cases, with SDF facilities constructed using concrete block, the reduction in flow caused by end contractions (i.e., 0.1nH in Eq. 2) can be neglected.

Stacked Weirs

Flow through a *stacked* weir may be evaluated by using a method of *vertical strips*. Figure 1 Insert B (Test 11) shows discrete strips for determining the flow over a *stacked* weir. The flow for each strip is calculated using the proper C_d for the associated head of this section. For example,

Table I. Laboratory Determined Coefficients of Discharge Orifice Only Tests

Results of Lab tests at the depth indicated.	Test 1 Single Orifice	Test 2 Double Orifice	Test 3 Single Orifice Flush Bottom	Test 4 Double Orifice Flush Bottom
Discharge Coeff. @ 1.0 FT Head	0.679	0.676	0.643	0.599
Discharge Coeff. @ 1.5 FT Head	0.674	0.667	0.641	0.610
Discharge Coeff. @ 2.0 FT Head	0.670	0.662	0.640	0.612
Discharge Coeff. @ 2.5 FT Head	0.668	——	0.641	-----
Discharge Coeff. @ 3.0 FT Head	0.668	-----	0.641	——

Table II. Laboratory Determined Coefficients of Discharge and Comparison with Handbook Values for Weir Only Tests

Weir Head (H)	8" Wide Weir Test 10	16" Wide Weir Test 7	24" Wide Weir Test 12	King Broad-crested Weir
H=0.62 FT	2.920	2.893	2.922	2.951
H=0.80 FT	3.015	3.003	-----	3.120
H=1.23 FT	3.188	——	-----	3.240

using the C_d values developed in the weir only test, the predicted discharge performance of the two *stacked* weirs tested 3.3% lower for Test 9 and 2.7% lower for Test 11, as shown in Figure 1 Inserts A & B, than for the actual measured discharge rates. While these differences appear significant, they are usually considered to be acceptable in the design of SDF discharge structures and ponds.

Weir/Orifice Combinations

Figure 3 shows the weir/orifice configuration that was evaluated in Test 5. Test 6 included the addition of a flush channel bottom at the invert elevation of the orifice. ASCE identified this type of discharge arrangement, often used on multiple-stage outlet structures, as one needing additional research (ASCE, 1985).

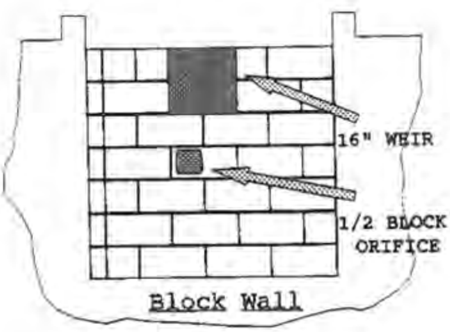

Fig. 3.

A prediction of the discharge rate for the combined weir/orifice tests was obtained by using the C_d developed during the orifice only and weir only tests. The predicted discharge from Test 5 was 3.8% lower than the actual measured discharge rate; the predicted discharge from Test 6 was 4.5% lower than the actual measured discharge rate. Some increase in actual discharge as compared to calculated discharge would be expected due to the higher approach velocity for these tests compared to that of the orifice only and weir only tests. The differences can be considered acceptable in the design of SDF discharge structures and ponds.

Sensitivity of Detention Pond Design Storage to Weir and Orifice Coefficients

Figure 2B shows a plot of the relationships between orifice C_d, discharge rate (CFS), and detention pond volume in acre feet (AF) for a typical urban drainage area (20 acres; SCS curve number 92; time of concentration 0.3 hr; 25 year storm) evaluated with TR-55 (U.S. Department of Commerce, 1986) and HEC-1 (US Army Corps of Engineers, 1987). TR-55 does not consider the geometry of the pond being designed, nor the configuration of the discharge structure, in selecting the required pond storage volume. In the manual method of TR-55 the required pond volume depends on the ratio of peak outflow to peak inflow (q_o/q_i) for a given SCS storm event. Pond volume is affected by assumed C_d selection. Figure 2B shows how sensivitive pond volume is to proper C_d selection. In the typical urban drainage area, using a C_d of 0.82 (typical short tube; King, 1976) will cause detention pond volume to be underestimated by 12.6% when compared to the pond volume estimated by TR-55 using the test developed C_d of 0.66. However, when designing by TR-55 this 12.6% difference may not be significant since TR-55 is only considered to be accurate for a range of $\pm$ 25%, and for this reason TR-55 should only be used for preliminary design (U.S. Department of Commerce, 1986).

The HEC-1 determined detention volumn plots in Figure 2B show the impact of pond stage-storage relationships and discharge structure geometry on the design volume of detention storage. For the same a typical urban drainage area described earlier, the HEC-1 volume required by storage routing is approximately 25% less than the TR-55 design volume. The relationship between the two HEC-1 curves depends on the geometry of the detention pond and discharge structure being evaluated. Using a C_d of 0.82 will cause HEC-1 designed detention pond volume to be underestimated by 13.6% when compared to the pond volume calculated by HEC-1 using the test developed C_d of 0.66. Design using any method that routes storm flow through a detention pond, such as HEC-1, requires the use of accurate stage discharge information in order to ensure correct and cost effective design. Satisfactory stage discharge relationships can only be achieved using the proper C_d values.

Discussion and Applications

Modular standards have been used in the masonry industry since 1946, and like most other block, the hollow unit masonry units used in this study were manufactured in accordance with ASTM C-90. However, this apparent standardization does not prevent the individual block manufacturer from varying its block configuration. For design purposes an accurate measurement of the opening area is needed prior to commencing detailed design. Once the block dimensions have been determined, the weir and orifice C_d values provided in Table I, Table II, and King (1976) can be used for design. The orifice opening should be located above the pond bottom (e.g. 16") to allow for some sediment storage. Water trapped below the orifice will easily dewater itself by seeping through the concrete block wall(s) after a storm event. The designer is advised to provide some type of trash rack(s) to prevent debris from blocking orifice openings.

Discharge structures need to be inspected by the hydraulic engineer during construction to ensure that the design is being followed. Maintenance and inspection of the structure is simplified by installing a top grating, see Figure 1, in sections for easy removal. It is recommended that all concrete block structures have reinforcing steel installed in order to ensure structural adequacy. At a minimum, discharge structure walls should have horizontal joint reinforcing every other course, a continuous top bond beam (minimum of 2-#5 bars), and vertical steel (minimum of 1-#5 bar) at each corner doweled into the foundation and lapped into the bond beam.

With the increased use of detention ponds for urban stormwater management, it is recommended that the design engineer consider rigorous storage routing methods, such as provided in HEC-1, to prevent over-designed pond volumes. A small amount of increased design time spent on more rigorous routing methods may be cost effective, resulting in more reasonably sized ponds, and less expensive development area dedicated to stormwater management. Whenever possible, the designer should consider the use of deeper, rather than shallow, ponds for detention. Deep ponds allow higher heads which require smaller discharge structures and take up less land space. Site locations and safety considerations will often constrain optimum pond configuration, but it is incumbent on the design professional to take advantage of all the information and design methods available to ensure efficient and cost effective SDF.

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DISCHARGE AND WATER QUALITY MONITORING REQUIRED FOR NPDES STORMWATER REGULATIONS COMPLIANCE

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Introduction

The Waste Area Grouping 6 (WAG 6) is one of the waste disposal sites operated by the Martin Marietta Energy Systems (MMES) for the Department of Energy at Oak Ridge, Tennessee. Surface water drainage from a 35.4 acre watershed at the western boundary of WAG 6 is being measured at a point identified as Monitoring Station 3 (MS 3). The drainage basin of MS 3 is shown in Fig. 1. Two branches drain the watershed, joining just upstream of MS 3 and flowing into the White Oak lake. At present, two separate flow measuring flumes are installed on the two branches, upstream of their confluence. The flumes are small, and incapable of measuring large flood flows. The upgrade of MS 3 has been prompted by the recent operation of two Tumulus pads and the addition of an Interim Waste Management Facility (IWMF) to the watershed. Both facilities store contaminated waste in engineered casks on concrete pads, covered by an engineered clay cap.

The Tumulus pads are in operation at present, and will be filled to capacity and capped within about two years. Waste disposal at the IWMF site will start as soon as construction is completed. Monitoring of flow at MS 3 must be performed in order to fulfill the NPDES and other permit requirements of WAG 6. The IWMF may become a separate NPDES site, pending the result of a permit application. The access road for transport of waste to IWMF crosses over MS 3 and adequate drainage structures should be provided at this crossing to allow unobstructed flow of storm water. The two sites marked as covered area in Fig. 1 consist of waste sites covered with impermeable flexible membrane liners. Future plans include capping these sites with an engineered clay cap. The remainder of the watershed surface is covered with natural vegetation, with a network of ground water monitoring wells and access roads.

Design Constraints

Because of the mixture of waste material in WAG 6, and strict regulations applicable at the site, certain design restrictions were to be observed, as listed below.

1. The monitoring station should measure the 25-year, 6-hour storm runoff accurately.
2. Very low flow rates which occur the majority of time should also be accurately measured.
3. Flow measurement device(s) should allow free passage of sediments.
4. Excavation for installing the flow measurement and monitoring devices should be kept to an absolute minimum.
5. Flow should pass under the IWMF access road, with minimum possible ponding upstream of MS 3.
6. Flow measurement should be automated, to eliminate the need for continuous attendance, and to allow automatic water sampling for quality assessment.

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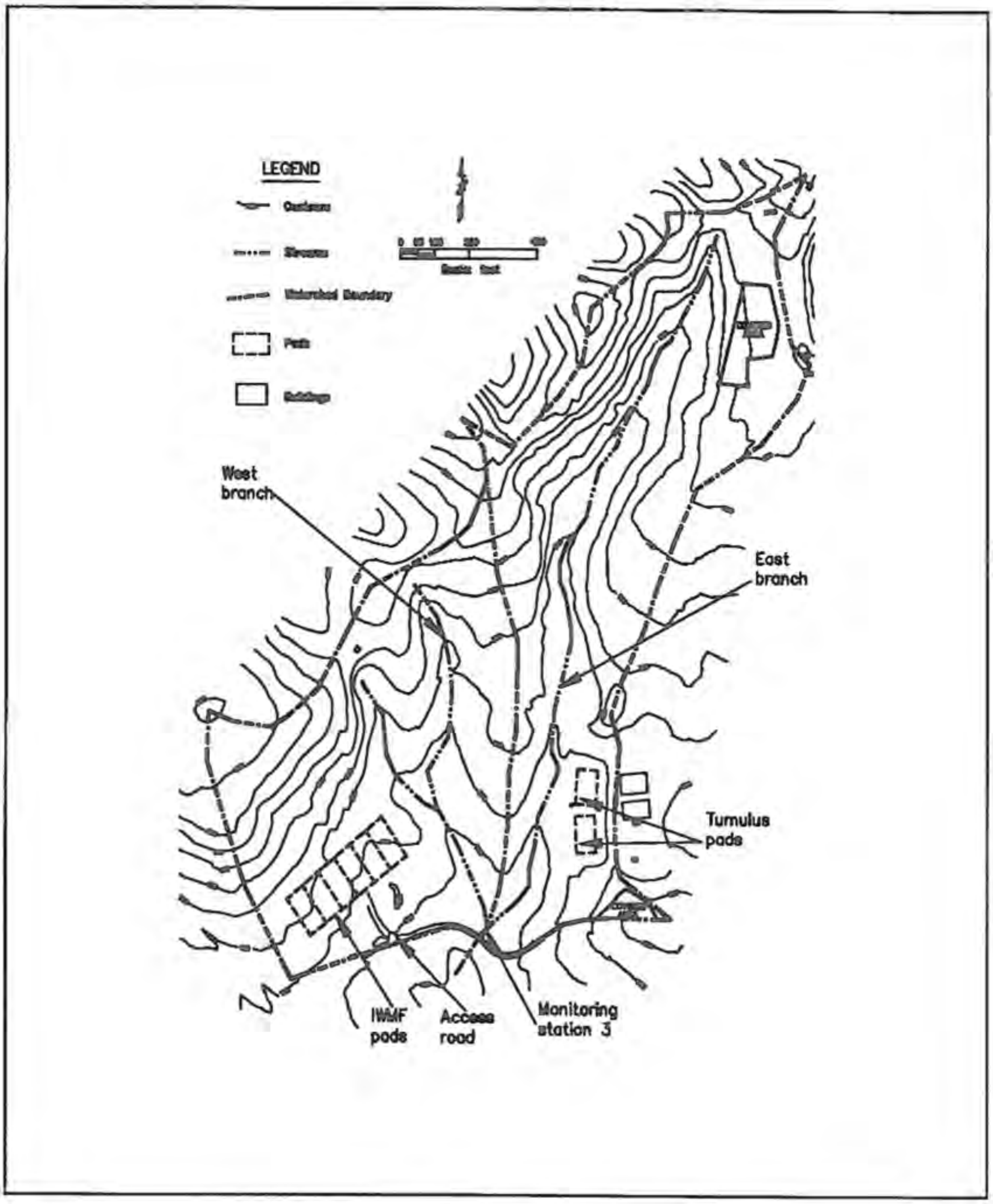

Fig. 1. The monitoring station 3 watershed.

7. Any computer model used must be verified and documented.

HYDROLOGIC ANALYSIS

Development of Design Storms

Because of the relatively small size of the watershed, rainfall distributions were determined with increments of 2 minutes. In order to develop the needed design rainfall distributions for 6-hour storms at such a resolution, storm distributions were developed using the U.S. Weather Bureau Technical Paper No. 40 (USWB, 1961), the National Oceanic and Atmospheric Administration Technical Memorandum NWS HYDRO-35 (NOAA, 1977), and the Soil Conservation Service 24-hour rainfall distribution (SCS, 1973). Based on this information, rainfall distributions for recurrence intervals of 2- to 50-years were developed for a 6-hour design storm, with a 2-minute time interval.

Selection of Runoff Model

The Corps of Engineers HEC-1 model was used to develop the outflow hydrographs at MS 3. This model was selected because of its full documentation and wide use in the industry. The model is also versatile in selection of the methods for calculating the discharge hydrograph. For this study, the SCS curve number method was used for calculating the runoff volume, and the SCS dimensionless unit hydrograph method was used to determine the basin outflow hydrograph.

Determination of Watershed Parameters

The SCS method requires the determination of the average watershed slope, the hydraulic length, the lag time, and the curve number. A detailed CAD topographic map of the site was used, together with the SCS grid method, to compute the basin slope, length, and the lag time for both the East and West branches (shown in Fig. 1). After examining the present watershed surface characteristics and the expected future activities on WAG 6, a uniform curve number was selected for the watershed area. The results are shown in Table 1.

The covered areas (Fig. 1) were treated as impermeable surfaces. The Tumulus pads were assumed to be capped with an engineered clay liner with a vegetated cover. The construction schedule for the IWMF is designed to have two of the six pads operational at any one time. No new pad will be cast until an older one is filled and capped with clay. This assumption was used in the model.

Table 1. Summary of hydrologic parameters of watershed

Parameter	West Branch	East Branch
Drainage Area (square miles)	0.03085	0.02440
SCS Curve Number	72	72
SCS Lag Time (hours)	0.15	0.22
Average Watershed Slope	0.11	0.13
Hydraulic Length (feet)	1260	2350

The Results

The peak discharges of the outflow hydrographs at MS 3, determined using the techniques described above, are shown in Table 2. This table indicates that the flow measuring device at MS 3 should be capable of measuring 71.4 cfs (peak of the 25-year storm runoff) according to the DOE design standards (DOE, 1989). Future closure activities on the watershed surface are likely to reduce this peak flow rate since most closure activities will involve replacing impermeable surfaces with clay and top soil.

DESIGN OF MONITORING EQUIPMENT

Water quantity and quality

In light of the given constraints, a review of the capabilities of the existing flumes indicates that a 4.5-ft H flume will be a suitable device for flow measurement at MS 3. The H flume is known for its accuracy in the entire range of its measurement. A 4.5-ft H flume can accurately measure flow rates from 0.0031 cfs to 84.0 cfs. Details of size, installation, and rating tables of this flume are given by USDA (1962).

Automatic grab samplers with refrigerated sample storage will be used at the MS 3 site. Such samplers are commercially available, and can be programmed to suit a wide variety of permitting and monitoring requirements.

Installation of the H Flume

For accurate flow measurement, the H flume requires a minimum of 22.5 ft of approach section and a free flowing nappe. However, studies show that flume accuracy drops only 3% at 50% submergence, and only 1% at 30% submergence. Thus, the flume could be installed to operate under submerged conditions in large floods, in order to reduce upstream ponding. However, two additional factors govern this decision. One is the elevation of the downstream White Oak Lake, on which there is limited information; the other is that a lower installation of the flume would conflict with the requirement to minimize excavation at the site. Therefore, the final elevation of the flume invert will have to be optimized to best satisfy these conflicting constraints.

Table 2. Summary of Peak Flow Rates

Recurrence Interval (yrs)	Peak Flow Rate (cfs)
2	15.1
5	19.4
10	52.0
25	71.4
50	88.2

In order to avoid unnecessary excavation at MS 3 site, the final design consisted of a box culvert, to be placed under the road, and to act as the H flume approach section. The flume itself would then be placed at the downstream end of the culvert. Dictated by the H flume size, the box culvert would have a width of 8.55 ft, a height of 4.5 ft (inside dimensions), and an approximate length of 40 ft. The approach section should have a longitudinal slope of 2%. Both the H flume and the approach section should have a bottom slope of 1:8 transverse to the flow direction, to facilitate discharge measurement and sampling requirements at low flows. Details of installation of the flume are given by USDA (1962).

CONCLUSION

In order to provide an upgrade for the Monitoring Station 3 (MS 3) at Waste Area Grouping 6, a hydrologic model of the area was developed. The peak runoff flow rate from the 35.4 acre area for a 25-year 6-hour storm was found to be 71.4 cfs. An H flume which can accurately measure this discharge as well as the low flows at MS 3 was selected for the station. A box culvert with cross sloping floor would serve as both the approach section for the culvert and sampling site for water quality, as required by the expected permit specifications at the site.

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PROPER SELECTION OF CONTROL PRACTICES TO REDUCE SOIL EROSION AND SEDIMENT-RELATED NONPOINT SOURCE POLLUTION FROM CONSTRUCTION AREAS [1]

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Introduction

Soil erosion is a naturally occurring process and can be caused by wind, water, ice and gravity. Problems arise, however, when erosion and sedimentation rates exceed natural values which can result from land-disturbing activities such as construction. The causes, water-quality effects, and solutions of accelerated soil erosion and sediment-related problems due to land-disturbing construction activities is the topic of this paper.

Background

Erosion can be caused by raindrop impact which results from the vertical force exerted on the soil surface. This pounding effect allows soil aggregates to break up and the resulting splash can carry with it some of the loosened particles. As the water collects on the land surface the forces of gravity initiate overland flow, and additional erosion can be produced due to a horizontal shearing force from the flowing water that can also detach and carry loosened soil particles. A thin erosive flow of water leads to sheet erosion. When these shallow flows start to concentrate, rill erosion is caused due to changes in flow within the low spots of the soil surface. Gully erosion is a complex process that can be formed by several rills combining or a rill can be transformed into a gully. A gully is similar to a rill but is larger and difficult to stop once formed and may require heavy equipment and special techniques to stabilize. (Goldman et al, 1986).

Commonly, based on the principles of fluvial geomorphology, natural streams or storm water conveyance channels erode and deposit sediment to stabilize themself to handle approximately a 2-year frequency storm (Stem, 1975). However, when increases in velocities and flow occur along a drainageway, it must stabilize to a new equilibrium condition. Urbanization and construction activities generally increase the velocities and flows of storm water entering a drainageway and creates a state of nonequilibrium. This can lead to channel and/or streambank erosion due to the stream's need to restabilize itself.

Sedimentation is one end result of the soil erosion process. The greater the velocity of the flow--the greater the size and density of particles capable of suspension and transport. As the velocity decreases, the suspended sediment will began to deposit with the larger and denser particles preceding the finer and less dense particles. Due to their fine size, silts and clays require very low velocities and longer time to gravimetrically settle while sand and other larger aggregates can settle rather quickly during higher velocities.

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Sediment Related Environmental Impacts

Alteration of the land surface can often lead to negative effects to watercourses that handle storm waters. Land-disturbing activities that alter the protective land cover exposes the soil surface and makes it vulnerable to erosion and sediment problems. Excessive suspended sediment in surface waters can: (1) limit light penetration and inhibit photosynthesis which is necessary for the maintenance of the basic aquatic food chain and can also effect game fish that rely on sight to feed; (2) cause abrasion to fish gill linings thus promoting disease and parasites; (3) act as a vehicle and transport many pollutants such as nutrients, heavy metals, oxygen demanding substances, bacteria, oil, PCB's, pesticides, and other synthetic organic compounds; and (4) increase the complexity and costs associated with water treatment. Excessive sedimentation can: (1) smother or alter habitats for aquatic insects and small organisms living on the stream bottom to the point of sterilization; (2) lead to loss of surface area and volumetric storage of watercourses that carry storm water; and (3) cause increases in peak flow and total runoff from a disturbed site. (University of Wisconsin-Madison, 1990; Virginia Soil and Water Conservation Commission, 1980).

Basic Principles of Soil Erosion and Sediment Control

Through basic and applied research and experience (trial and error) many effective methods for significantly reducing the rate of erosion and sediment transport have been determined. Some of the most effective steps in retarding the erosion process and controlling sediment transport are as follows: (1) fit the site being development to the terrain; (2) physically retard the velocities and flows of the runoff; (3) minimize the area and/or duration of exposure to the elements; (4) protect denuded area from erosive forces by using vegetation, mulch, and/or matting; (5) retain existing vegetation whenever feasible; (6) divert runoff away from denuded areas; (7) trap the sediment from sediment-laden runoff on site; and (8) frequently inspect and maintain control measures. (University of Wisconsin-Madison, 1990; Virginia Soil and Water Conservation Commission, 1980).

The last principle–inspect and maintain control measures--is an essential step in helping to retain sediment on site. One common problem in erosion and sediment control is in the neglect of control devices once in place. Where maintenance is neglected, failure can occur to the extent that resulting environmental impacts effects are as severe as if no control practices were applied.

Common Control Practices

Basically, the larger the exposed areas, the longer the time the area is unprotected by vegetation, and the steeper the slopes--the greater the potential problem. Many methods do exist to prevent and/or minimize soil erosion and sediment problems from occurring. Some of the most effective and common techniques are listed below (Livingston et al, 1988; Virginia Soil and Water Conservation Commision, 1980; Wang and Grubbs, 1990)

Sediment barriers are used to trap suspended sediment before it can enter a receiving stream or lake. They can also be used to slow velocities on slopes until a protective cover can be established. The most commonly used types of sediment barriers are straw bales and silt fences.

Diversions are used to intercept and convey surface runoff. Normally these devices are used to divert storm water from unprotected slopes and/or divert sediment-laden waters to designated control areas. Some commonly used methods of diversion are swales, dikes, and flumes.

Sediment traps and basins are holding area for sediment-laden runoff from disturbed areas. These controls help to retain runoff long enough for much of the suspended sediment to settle out. Normally these traps and basins are pond-shaped but they can also be constructed within ditch conveyance channels.

Slope protection controls are used to help protect denuded areas from erosion due to elements of nature. The most common applications are sod or seeding along with straw, mulch, riprap, erosion blankets and/or mats. Protecting slopes within a storm water conveyance channel sometimes requires additional protection. Various forms of check dams are commonly used in conveyance channels to help slow velocities to minimize channel erosion and provide for some trapping of sediment. Check dams are usually removed when channels and upland areas are vegetated and stable.

Waterways, streams, and outlet protection techniques are applied to prevent scour and minimize erosion by reducing the velocities of concentrated flows and/or providing protective cover for areas where velocities cannot be easily controlled. Some common materials/methods applied are riprap, induced vegetation, temporary stream crossings, check dams, geotextiles and mats.

Vegetate as soon as possible. The first priority in controlling erosion is to prevent displacement of the soil. Vegetation applied immediately after grading is highly effective in erosion control. Since vegetation is climate dependent, it is feasible to schedule construction such that vegetation can be established upon grading. Temporary seeding may be used in cases until disturbed areas can be brought to final grade.

Current Research and Problems

Research on sediment-related nonpoint source pollution indicates that many current field practices are not effective. In many instances, the proper materials or methods for soil erosion and sediment control are provided, but improper placement and/or maintenance prevent full effectiveness of the practices. Practices applied to conditions they were not designed for is another common problem (Kouwen, 1990). Training for inspectors, contractors and others associated with land-disturbing construction activities on the proper selection, placement, and maintenance of proven technologies can help reduce sediment-related nonpoint source pollution.

Tennessee has a widely varied terrain and several influencing factors must be considered. Accounting for such factors as expected rainfall, rainfall durations, rainfall energy, soil erosion index, and topographic and geological features can improve the determinations necessary for selection of erosion/sedimentation control devices.

Conclusions

Current technology appears sufficient to control soil erosion and sediment problems if proper application and maintenance is implemented. Failure of controls is usually linked to improper installation and/or untimely or insufficient inspection and maintenance of applied controls. Better training in the selection, installation and proper maintenance of control devices is one key step toward achieving maximum efficiency of Best Management Practices in controlling nonpoint source pollution from land-disturbing activities.

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SOIL GAS SURVEYS AS A SOURCE OF PRELIMINARY DATA IN THE CHARACTERIZATION OF HAZARDOUS WASTE SITES [1]

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The characterization of hazardous and toxic waste sites can escalate into a costly undertaking. Soil borings and monitoring wells are used to obtain data on subsurface contamination during site investigations. Placement of these borings and wells is usually done with little knowledge of subsurface conditions. This "hit or miss" approach can result in mis-characterization of the site as "clean" or an results in increased costs as soil borings are used to "chase a plume". It is becoming increasingly popular to perform a soil gas survey prior to installing soil borings or monitoring wells. Soil gas surveys combined with geophysical surveys provide a preliminary look at subsurface conditions. Soil borings and monitoring wells can be placed to obtain the most beneficial data during site investigations based on the results of these surveys. The cost of these surveys is minimal compared to the savings obtained from not installing soil borings or monitoring wells which yield little or no valuable information.

Soil gas surveys do not replace the need for soil sampling and groundwater sampling. The soil gas surveys provide qualitative or quantitative data on volatile organics in the vapor phase. These vapors reside in the pore spaces between the soils. The vapors may emanate from the groundwater or from contamination on the soil particles. The surveys provide a relative concentration of contaminants which are then verified by soil and groundwater sampling.

Methodology

The process of conducting soil gas surveys is straightforward and relatively simple. Two types of surveys are currently being used. The passive survey involves placing inverted canisters containing activated carbon filaments in the ground. The canisters are placed approximately six inches below the surface, left over a period of time (usually two weeks), and removed. The filaments are then analyzed using gas chromatography/mass spectrophotometry (GC/MS). This method provides a flux of contaminants over time. The other method currently used is the active method. This involves placing a tube below the surface of the ground. A vacuum is drawn on the tube and organic concentrations are determined using field instrumentation. A total concentration can be obtained by using a organic vapor analyzer (OVA) or a photoionization detector (PID). Individual compound concentrations can be determined using a portable gas chromatograph equipped with a flame ionization detector (GC/FID) or a electron capture detector (GC/ECD). The active method provides a real-time method of determining hot spots and plumes.

Sampling points are usually established on a grid system. Typical grid spacings are 25 to 50 feet. In areas where contamination is highly suspected, grid spacing is usually smaller. For a general survey, spacings of 50 or 100 feet are acceptable. The grid can be

[1] Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

[2] U.S. Army Corps of Engineers, P.O. Box 1070, Nashville, Tennessee 37202.

placed out on a site plan and the results of the survey can then be recorded on the plan. By incorporating known geology and hydrogeology, as well as results from any geophysical surveys, plumes and hot spots can be mapped directly onto the site plan. An example of a passive survey map is shown in Figure 1.

Case Studies

The Nashville District has been using soil gas surveys as the first step in site characterization during hazardous and toxic waste investigations. Both passive and active survey methods have been employed. At each site, soil borings and groundwater monitoring wells were installed based on the results of the soil gas survey. Results of the survey were confirmed with the borings and wells.

A soil gas survey was conducted as part of a construction site clearance (CSC) at Ft. Benjamin Harrison, Tennessee. The purpose of the CSC was to determine if any contamination existed at a site which was scheduled for construction of a learning resource center. The known site history indicated that a paint shop and holding area had been located at the site. The exact location of these facilities was not known. After removal of these facilities, soil fill was placed over the site. The site was covered in grass and no surficial indications were present that any contamination might exist. A passive soil gas survey was performed at the site. The canisters were installed on 50 foot centers and left in the ground for two weeks. The results of the survey indicated that Trichloroethylene as well as Benzene, Toluene, Ethylbenzene, and Xylene (BTEX) were present. A soil boring was installed in the area of suspected contamination and trichloroethylene was found in the saturated zone. Monitoring wells and additional soil borings were installed in areas of contamination as well as "clean areas". These results confirmed that trichloroethylene and petroleum hydrocarbons were present in the groundwater above regulatory limits. Another CSC was performed at 801st Motor Pool at Ft. Campbell, Kentucky. This time, an active soil gas method was used. Borings were advanced to a predetermined depth and a soil gas probe was inserted approximately one foot below the terminus of the borehole. A vacuum pump was used to extract vapors and analysis was done using a Organic Vapor Meter (OVM). Sampling points were not done on a grid but were concentrated in areas where existing underground storage tanks were present and where future construction activities would take place. Results of the survey indicated that higher soil gas concentrations existed around the tanks; however, none of the soil gas concentrations indicated significant levels of volatile organics. Soil borings and hand auger samples were then conducted in the area. Significant petroleum contamination was found in some areas. This was not indicated by the soil gas survey. The low soil gas readings were probably attributable to the heavy clay content of the soils in the area.

A site investigation was conducted at the former American Car and Foundry property near Winfield Lock and Dam, West Virginia. This property was formerly used as a railroad car washing facility. The site was extensively contaminated with a variety of compounds. A passive soil gas survey was performed. Approximately 400 canisters were installed over the 22-acre site. Because the site was known to be heavily contaminated in areas, additional canisters were installed to measure the loading rate. One of these canisters was removed and analyzed every couple of days until it was determined that the canisters had been in the ground for a sufficient amount of time. This soil gas survey provided excellent maps of plumes which existed at the site. A variety of compounds were found during the survey. Soil borings and monitoring wells were then installed in the contaminated areas. Table 1 shows the correlation between some of the soil borings and the soil gas survey.

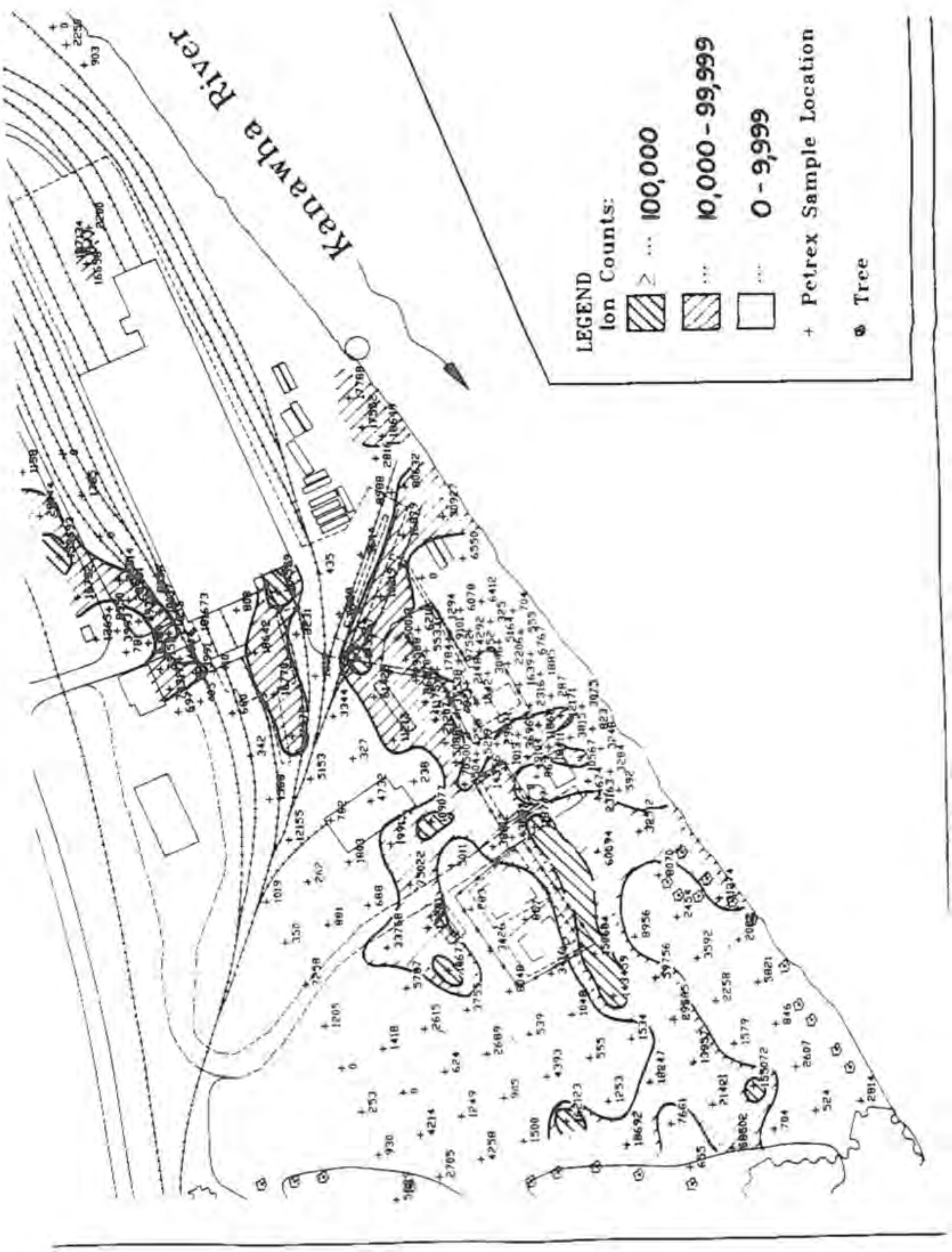
Kanawha River
LEGEND
Ion Counts:
≥ ... 100,000
... 10,000 - 99,999
... 0 - 9,999
+ Petrex Sample Location
Tree

Fig. 1.

Table 1. Comparison of Soil Gas vs. Sampling Results

Parameter (ppm)	Relative Flux Soil Gas	Soil Boring RS-4
Chloroform	med	120
Combined DCE, TCA, Freons & CC14	low	97
Trichloroethene	med	150
Total Chloro-benzenes	high	528
Dichloropropene	med	10
Napthalene	med	140
Tetrachlorethene	med	140

high ≥ 100,000 ion counts
med 10,000 - 99,999 ion counts
low 0 - 9,999 ion counts

Conclusions

Soil gas surveys provide a cost-effective means of characterizing a site. The surveys are not stand alone tools; however, acceptable data can be obtained when results are confirmed with actual field sampling. Each type of survey has its advantages and disadvantages. Passive surveys provide more accurate results in soils where clay layers exist; however, real-time data nd actual concentrations cannot be obtained. Active soil gas surveys provide real-time data and other soil gas sampling points as well as soil and water sampling points can be decided in the field.

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CONDUCTING THE 1992 NATIONAL RESOURCE INVENTORY IN TENNESSEE, A MULTIDISCIPLINARY SAMPLING APPROACH TO ACCESSING THE CONDITION OF NATURAL RESOURCES WITHIN THE STATE

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The National Resource Inventory (NRI) is conducted every 5 years by the Soil Conservation Service (SCS) to gather comprehensive information on the status, condition, and trends of the country's soil, water and related resources. Each SCS state office conducts the NRI under guidance from the National Office. SCS has conducted inventories under various Congressional directives since the formation of the agency over 50 years ago. The legislative authority for conducting NRIs is the Rural Development Act of 1972 (Public Law 92-419) and the Soil and Water Resource Conservation Act of 1977 (Public Law 95-192). The 1990 Farm Bill contains specific directives for extending the scope of the NRI by relating it to water quality protection and improvement objectives.

The NRI was first conducted in 1982 with the second inventory occurring in 1987. Currently SCS is preparing to perform the 1992 inventory or NRI92. Nationally approximately 300,000 primary sample units (PSUs) containing approximately 900,000 data collection points will be inventoried. In Tennessee data will be collected in just under 7,000 PSUs containing approximately 21,000 sample points.

The NRI sampling design is based on standard statistical techniques of stratification, area sampling, and clustering. Stratification subdivides the nonfederal land into strata that are each more homogeneous than the population as a whole (Goebel and Dorsch, 1984). Strata are developed on a county basis and defined using the public land survey system (PLSS). In Tennessee a pseudo PLSS was created for the inventory. Two-stage area samples are taken within each stratum. The first stage sampling unit, or PSU, is an area of land of up to 160 acres in size. At the second stage sampling, 1 to 3 sample points are randomly selected within the PSU. Sampling rates vary across strata depending upon such factors as land use and soils patterns, Major Land Resource Area (MLRA) distribution, and county size.

Originally the Iowa State Statistical Laboratory (ISU) randomly selected PSU locations in Tennessee using a pseudo Public Land Survey System grid. The resulting 160 acre squares were drawn on county highway maps because the county was the fundamental sample frame for the inventory and the county highway maps were commonly available. Additionally each PSU contained 3 randomly selected points referenced to the southwest corner of the PSU. SCS field personnel transferred the sample locations onto aerial photography or soils map sheets. These photographs became the guide maps for SCS personnel to make field visits to collect data on the various resources. No effort was made to provide or collect exact geographic coordinates of the sample sites since this data was not needed to collect or analyze the data at the time.

Data elements which will be collected beginning in August 1991 and ending in March 1993 on the entire PSU area include: MLRA, hydrologic unit (8 digit code), size of PSU, universal soil loss equation (USLE) R factor, remote sensing imagery data, areas in

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farmsteads and urban land uses, and water areas (such as large streams, small streams, large waterbodies, and small waterbodies). Point data will include soil information which will allow linkage to the
large soil database maintained by SCS, highly erodible land (HEL) classification, prime farmland, participation in the Conservation Reserve Program (CRP), earth cover, landuse with secondary uses and cropping histories or forest type as appropriate, distances to habitats, irrigation, erosion data, wetlands data (using the Cowardin Wetlands and Deepwater Habitats system), installed conservation practices and treatment needs, potential cropland, and where crops are produced, conservation tillage data. As is evident from the data to be collected, many disciplines will be involved in collecting the data and providing quality control. The disciplines will include agronomy, biology, engineering, forestry, geology, statistics, and soil science.

The advent of geographic information systems (GIS), greater demands on SCS field personnel, and advances in remote sensing technology, mandates supplementing the NRI by georeferencing the sample site locations. NRI92 includes compiling the PSU locations along with included sample points on 7 1/2 minute quadrangles and digitizing these locations in a GIS. A major benefit of the georeferencing task will be enhanced abilities to analyze and display data along with an expanded potential to link with other databases. This data can be made available to users outside SCS, however SCS policy forbids public disclosure of the location of PSUs to protect the individual'sright to privacy and avoid compromising the site's integrity and reliability for future datacollection purposes. Several methods are being explored to share the data while meeting these objectives, the most simple of which is a nondisclosure agreement with the recipient of shared data (Shafer, Maizel, and Cimmery) . The collected data has many applications to water quality issues. An example could be in determining which pesticides to monitor in groundwater. If the aquifer recharge area is known, then the GIS could be used to select PSUs within the defined area and estimates could be made on the extent of individual crops grown on the area, the soil properties where these crops are grown and chemicals utilized, for the tillage systems in use at the time of the inventory. This data could then be input to an appropriate model such as DRASTIC to evaluate the potential for groundwater contamination. Numerous other applications can be conceived such as estimation of the need for erosion control to achieve a reduction in sedimentation. The data could render a detailed a detailed estimate of the kinds of control practices needed and coupled with current cost data, the cost of on site control could be compared to off site actions such as dredging or ditch clearing and environmental costs of allowing lesser degrees of erosion control. NRI data can be made available through the state office of the SCS.

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RESERVOIR INTERPOOL PLANT HABITAT DYNAMICS III. DISTINCTIVE WETLAND ECOSYSTEMS IN THE TENNESSEE VALLEY

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Extent and Biotal Character

Twenty-six river impoundments above Chickamauga dam are cataloged by the Tennessee Valley Authority with a total winter drawdown zone or mudflat (area between summer and winter pool shores) of some 42,000 ha. Continuing watershed supplies of alluvium and continuing erosion of summer shores (boat wave force as a primary cause) bring about continuing increases in the breadth of the drawdown zone mudflats. Many shores retreat more than a meter a year. These 26 reservoirs have a reported accumulative summer shoreline, or edge, of 9200 km. The summer shore and inland plant community types tend to be of hydric to hydromesic forest species unless displaced by anthropogenic activities. Transitional marshes and swamps are not common.

The mudflat substrates are of two broad categories. The first are truncated residual soils which are generally low in fertility and highly vulnerable to boat wave erosion. The second are non-point-source alluvial, or occasionally colluvial, mostly fine sediments. These mineral sediments empirically exhibit good fertility, but are inherently unstable. The substrates support scattered terrestrial plant community types when exposed. A pioneer plant/weed community can be found on those residual soils which are in the drawdown zone but not inundated every summer season or only covered briefly; more common on tributary reservoirs. On the October-March exposed transported sediments, usually inundated throughout the ordinary aestival growing season, a particularly adapted assemblage of seasonal plants may develop.

The brumal plant community types on sediments are of two life history categories. The first, often at the summer shore, is composed of several perennial wetland species, mostly graminoid and of relatively large stature (Grasses, Sedges, Reeds) which seldom form closed canopies. The second is of periodic seed-to-seed, October to March, species which may locally form closed stands with six to eight co-dominant species of graminoids and herbs.

Excessive precipitation events and certain management practices may bring about temporary surpluses of pool water which exceed the normal pool levels. For example, the area of total affected full flood zones for the mainstream reservoirs (above normal pool), are Chickamauga 218 ha; Watts Bar 1902 ha; Ft. Loudon 364 ha. These overshore zones may be inundated in winter, but are more commonly so in the late spring. The flood pool "highshore" may be discerned by hydric forest species distribution and is demarcated by the trash line.

Brumal Moisture and Temperature

Brumal precipitation (1 October to 31 March) measured near monitored sites has averaged over 75 cm during each of the three sequential periods of this study. The seedbed surfaces are usually moist, often saturated, after drawdown. During the 88 seven day

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periods of this mudflat ecological study there were only 9, seven or more consecutive diel periods when no measurable rain fell at a particular Watts Bar mudflat site (mile 580). Short absences of precipitation, however, may bring about notable surface drying of large extents of these surfaces.

Surface wet or dry, these fine, tan to brown substrates have rapid radiational cooling. The sparse cover of most brumal plant communities does not appear to interfere much with this energy loss; yet plant development does not appear particularly sensitive to cold atmospheric conditions.

The drawdown zone mudflat sediment surfaces are, by their genesis, relatively even and usually abutting the winter pool. Temporary wetting or drying of the surface does not affect the saturated, anoxic gray zone at about the subterranean elevation of the drawdown pool. This gray zone, which underlies the seasonal plant rooting zone some 10 to 20 cm, is denoted by color, the occasional inclusion of undecomposed organic litter, an avoidance by perennial plant roots and a pH around 6.0. Where lithospheric conditions allow, the zone is empirically continuous with the winter pool and slope-elevated as much as a meter due to texturally dictated water retention and capillarity.

In the study period, continuous near surface air temperatures below 0° C for 48 hours occurred only six times. Fragmented ice forms along the pool shore and over shallow mudflat puddles, and mineral surface ice needles may form, but the heat stored in the winter pool - gray zone continuum (lowest measured 4° C) is continuously liberated to mitigate pool ice and penetrating substrate frost.

Time varying heat transfer from winter pool to reservoir mudflat has been analyzed and temperature profiles of mudflat sediments have been obtained for bench mark data. Time dependent finite difference heat conduction equations have been implemented using Lotus - 123 for graphing and iterative solutions. Figure 1 is an example of a regime with a constant below freezing air temperature and the consequential lessening of the temperature fall of the mudflat root zone as heat is transferred from the gray zone. Since heat energy transfer is directly proportional to the temperature difference, in very cold periods the mudflat root zone will be much warmer than the air a few centimeters above.

The energy balance of the growing zone of the mudflat flora is modified by this brumal heat transfer to the benefit of the growth strategies of the evolutionarily adventive seasonal flora.

Water Sources and Characteristics

During the October-March drawdown periods, water is supplied adjacent to the exposed sediment habitats from sources upstream in the watershed and may wet the mudflats in brief flood inundation and by vigorous wave action. Water is supplied to the drawdown zones from incident precipitation. Water is supplied to the mudflats from superior, abutting landscapes by surface and storm flow runoff and from the shallow ground water zone, often truncated by summer pool level wave erosion scarps.

The waters from these several sources subject the extant biota of the mudflat to varying and often distinct chemical and physical conditions. Watershed inputs tend to reflect stable temperatures and pH dependent on regional climate and regional biogeochemistry. Precipitation is consistently, moderately acid and reflects meteorological temperatures. Runoff and storm flow vary seasonally with increment, vegetative cover type, levels of biological activity, and reflect on-shore substrate temperature profiles. There are empirical nodes of very basic pH readings (pH 9-10) when algae show vigorous winter development in the over-sediment flow.

The origin of these impacting waters is often distinguishable by simple on site pH and temperature interpretations. Regional water at the shore changes temperature more slowly and tends to have pH's with a central tendency that is slightly basic (e.g.,7.5: 6.4 - 8.3 pH extremes). Soil biosphere storm flow in winter is generally more variable in pH

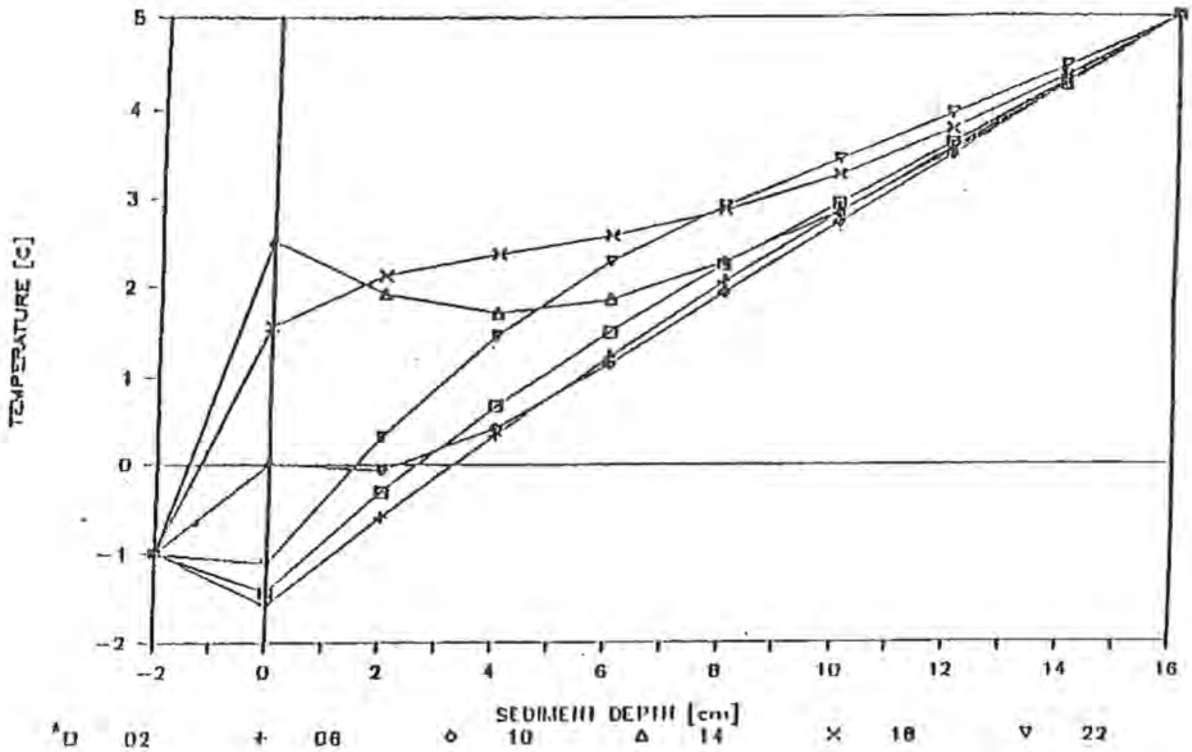

Fig. 1. Sediment temperature profiles. Symbols indicate 2400 hour times* for an average air temperature of -1°C and grayzone, heat sink temperature of 5°C for a mudflat sediment thickness of 16 cm.

than reservoir pool water, with uneven pH's from 6.2 to 8.5. Readings tend to be below neutral when storm flow channels are active and air temperatures have been depressed (cold winter rainstorms on base-poor species forested slopes), even though the soils of forest slopes tend to be less acidic in winter than summer. Storm water surges are more affective when summer shore wave-cut transitions are more abrupt. Visible surface runoff from well vegetated slopes is seldom important.

Shallow ground water emersions are semi-permanent but local on the mudflats, and can be typified as low in pH (5.6 to 6.0) and more consistent in (often lower) temperatures than storm flow waters surfacing across the sediment.

Characteristic Flora and Fauna

In the upper Tennessee River Valley, various investigators have identified an upper drawdown zone flora which can be approximated as an open, weedy community of a few dozen species. These form inconsistent, active, off-season assemblages, often closely related to summer season sources on adjacent shoreland or upstream disturbed areas. Cocklebur (Xanthium sp), Trumpet Vine (Campsis radicans L.), Ragweed (Ambrosia sp), Smartweed (Polygonum sp), Dock (Rumex sp), Toothcup (Rotala ramosior L.), False Pimpernell (Lindernia sp), Water willow (Justicia americana L.), Butterweed (Senecio glabellus Poiret) and Lizard's Tail (Saururus cernuus L.) are common, often aspect-dominant, herbs. These resident, ruderal plants are most often in the on again-off again pool zone.

Scattered across the sediments, and commonly dominant just below the summer shore, are conspicuous graminoids including Eleocharis, Fimbristylis, Scirpus,Phalaris, Cinna, Cyperus, Juncus, and Eragrostis. These sediment substrated flats, when vegetated, also show seasonal taxa such as Alopecurus, Ludwigia, Mullugo, Myosurus Sibara, Veronica and Rorippa. Alopecurus carolinianus Walter (foxtail), can form closed stands. The seasonals are qualified by the ability to mature on site and maintain a seed bank reserve.

The drawdown mudflats and the ordinarily abrupt margin of the summer shore present a new, extended brumal edge habitat for fauna in east Tennessee. Sign and spoor indicates a number of mammals, birds, reptiles, amphibians and invertebrates (snail, worm and clam) frequent this habitat. Comprehensive surveys of particular faunal groups are not apparent, but we have conducted a survey of the avifauna along the tributary Cherokee reservoir drawdown for three winter months of 1991.

Sixty one species of birds were noted as utilizing a 1.6 km long transect encompassing the winter-flood zone shores. In comparison, 82 total species were recorded in the adjacent Knox County (TN) Christmas Bird Count (Tennessee Ornithological Society) some two weeks before the Cherokee survey began. Twenty-nine of the 61 species found in our study were regular users of the terrain from the normal pool shore outward. Birds associated with rivers and lakes were the most conspicuous: Ring-billed gulls, Canada geese, Mallards, American coots, Buffleheads, Great blue herons and Killdeer. A large flock of Americangoldfinches habitually frequented the winter pool shore.

Conclusions

Manipulated reservoir pool levels result in substantially new, wetland habitats for study in the upper Tennessee River Valley. These habitats are slowly being colonized in evolving flora and faunal associations largely derived and composed from adjacent forest, streamside and pasture components. The presence of the winter reservoir pool heat sink, the erosive expansion of the mudflats between summer and winter pools and the lack of a biota evolutionarily adapted for Southern Appalachian regional wetlands leads to a dynamic, non directional status for these physically and bio-chemically adrhythmic drawdown areas.

Major contributors to this study include E.B. Bartlett, R.C. Kramel, E.M. Maclin, H.A. Rial-Meador and J.C. Rodgers.

PERCEPTIONS OF SELECTED TENNESSEE COUNTY LEADERS ON THE LEVEL OF SEVERITY AND PROGRAM PRIORITY OF 14 WATER QUALITY ISSUES

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Population perceptions are an important factor in dealing with issues of public concern. Throughout its history, the Agricultural Extension Service has sought public opinion as a part of the planning process. In response to a national objective to plan proactive programs dealing with local water quality concerns, the Tennessee Agricultural Extension Service conducted a mail questionnaire of leaders across the state.

The purpose of the survey was to provide county level information for local planning and program development. However, the results also provide some insight into opinions across the state. Based upon the study findings, significant relationships were found between the county leaders' perceptions and their geographic region, audience classification and place of residence.

Procedure

Fourteen water quality issues were identified through a review of current literature and discussions with knowledgeable professionals. The issues included topics concerning erosion, misuse of chemicals, improper disposal of chemicals, and current water quality issues.

The issues were developed into a mail survey administered through the Agricultural Extension Offices in each county. Extension personnel were asked to identify county leaders from 13 groups ranging from county government officials, to bankers, and senior 4-H club members.

Respondents were asked to rate the level of severity, and program priority for Extension work of the 14 water quality issues. Issues were rated as to the level of severity on a one to five scale (critical, major, minor, no problem, uncertain). The same issues were also rated as to their importance to Extension work on a one to four scale (high, average, low, uncertain). A total of 3,257 questionnaires were returned from Tennessee's 95 counties.

Specific objectives of the study include:

1. To compare Tennessee county leaders' perceptions of the level of severity and program priority of 14 water quality issues.

2. To determine the rank of 14 water quality issues regarding the level of severity and program priority as perceived by Tennessee county leaders.

3. To determine if county leaders from Tennessee's three major geographic regions differ in their ratings of 14 water quality issues.

4. To determine if county leaders from Tennessee Extension-related audiences differ from non-Extension-related audiences in their perceptions of 14 water quality issues.

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5. To determine if county leaders living in rural communities differ from leaders living in urban communities (Standard Metropolitan Statistical Areas) in their rating of 14 water quality issues.

Results

Based upon the results of the survey, significant relationships were found between the county leaders' perceptions and their geographic region, audience classification and place of residence.

The rank of the level of severity and program priority of the 14 water quality issues as perceived by county leaders statewide is illustrated in figure 1. The five issues rated as both critical or major concerns and meriting high priority for Extension work were:

1. Understanding the effects of current practices on future supplies of safe water.

2. Lack of citizen awareness of the nature and importance of water resources.

3. Improper disposal of leftover chemicals, empty containers, used motor oil, etc.

4. Lack of knowledge and use of water conservation methods.

5. Soil erosion on farms.

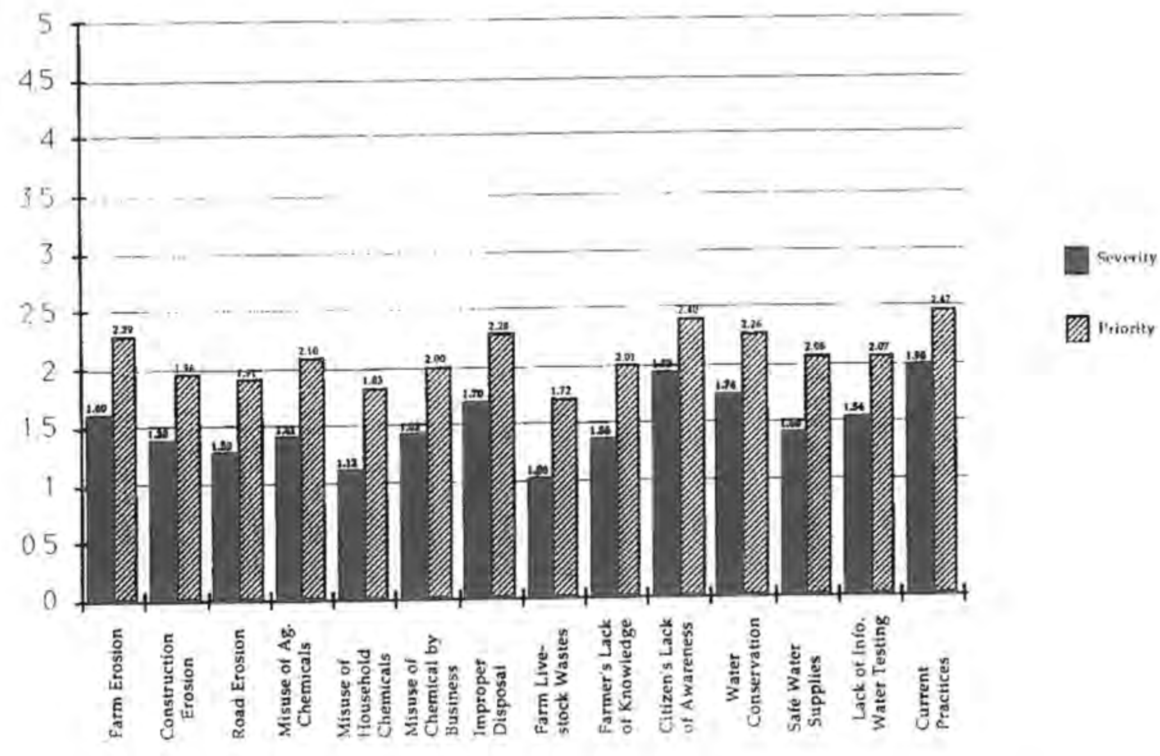

Fig. 1. Selected Tennessee leaders' ratings of the level of severity and program priorities of 14 water quality issues.

The study compares the leaders geographic region of the state (based upon the three grand divisions) and their perception of the level of severity and program priority of the 14 issues. The county leaders geographic region and their perceptions of the issues were significantly related in 11 of the 14 water quality issues. Nearly one fourth (23.9 percent) of the county leaders in West Tennessee rated soil erosion on farms as either "major" or "critical". County leaders in the middle region of the state were more likely than leaders in the eastern or western region of the state to rate misuse of household chemicals, misuse of chemicals by local business, improper disposal of leftover chemical, empty containers, used motor oil,etc., as either "major" or "critical". County leaders from the Eastern geographic region of the state were more likely than Middle or West Tennessee county leaders to rate the severity of the soil erosion on construction sites, farm livestock wastes contaminating water, lack of citizen awareness of the nature and importance of water resources, lack of knowledge and use of water conservation methods and inadequate supplies of safe water as either "major" or "critical" problems.

Study findings further indicated that Extension-related audiences were significantly more likely than non-Extension-related audiences to perceive the stated water quality issues as problems. County leaders from Extension-related audiences perceived 12 of the 14 water quality issue as more severe problems than non-Extension-related audiences.

Study findings indicate that county leaders in urban counties were significantly more concerned about water quality issues than county leaders in rural counties. The county leaders' place of residence was significantly related to their perceptions of the severity of 7 of the 14 water quality issues.

Discussion

Based upon the study findings, three of the of the top five issues statewide were related to awareness, understanding and lack of knowledge about water quality issues. Extension is currently providing educational programs, mass media presentations, publications and exhibits which provide information about water quality. Future plans include more intensive efforts to increase water quality awareness and knowledge with specific emphasis on issues indicated as "major" or "critical" by counties.

Study findings indicate that Extension-related audiences were significantly more likely than non-Extension-related audiences to perceive these water quality issues as problems. This would tend to imply that Extension-related audiences are more aware of water quality issues. It is recommended that Extension increase efforts to reach non-traditional audiences to increase awareness of water quality issues. Educational efforts with Extension-related audiences should continue.

The study findings further indicated that urban county leaders were significantly more concerned about water quality issues than rural county leaders. This would tend to imply that urban county leaders have specific water quality concerns related to the nature of living in an urban setting. Therefore, it is recommended that Extension develop educational programs to address specific water quality concerns in urban areas. These programs should be designed to create awareness and assist urban audiences in actively pursing improvement of water quality in their setting. Additional programs should be designed to meet the concerns of rural settings. These programs should feature water systems and the rural to urban link in water quality concerns.

Future Plans

The survey will be repeated in 1992 to evaluate the impacts of current educational programs. A follow-up study evaluating the effectiveness of various methods of reaching clientele should be conducted in an effort to improve program effectiveness.

NETWORKING OF GEOGRAPHICAL INFORMATION SYSTEM DATABASES

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The United States Army Engineering District, Nashville, Corps of Engineers is developing a Geographical Information System for internal use and contracted GIS studies. This program is being developed in multiple phases.

In Phase II of our district plan we are looking to network the Nashville District GIS Program with other federal, state, regional, and local GIS systems to share technology and most important databases. Networking would remove the high labor cost of each GIS user of developing many of their own databases. It would also allow each program to gain access to data otherwise not readily available.

Our networking proposal would enable all entities involved to benefit financially by reduction of labor costs in database development.

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INTEGRATED RESERVOIR MANAGEMENT COMPUTER SUPPORT SYSTEM

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Increasing demands on the Tennessee Valley Authority (TVA) integrated water control system require even more sophisticated data collection, data processing, and data dissemination support to meet today's expectations from our customers to best manage the available resources. The TVA Reservoir Operations Section has recently installed a new generation of computer workstations designed to meet his challenge. The workstations are tied together through a Local Area Network (LAN) which allows the sharing of a central core of data, while providing each user with their own central processing unit (CPU), and allows workstations in remote locations to share in the same network.

The system performs a myriad of chores, including data collection, data validation processing of watershed models to estimate runoff, streamflow and reservoir routing computations, and report generation and transmission. All functions are directed toward providing operations personnel a timely picture of the current reservoir status and hydrologic conditions and the opportunity to formulate and evaluate operation plans for the future. Once operating decisions have been made, the support system is instrumental in preparing reports an messages to other federal, state, and local agencies and for media dissemination to the public. The system will also furnish the information to be provided via a toll-free direct information line available throughout the Valley.

[1] Tennessee Valley Authority, 400 West Summit Hill Drive, Knoxville, Tennessee 37902 (615/632-2977).

KENTUCKY LAKE DATA BASE FOR PC USERS

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Cookeville, Tennessee

Introduction

The Kentucky Lake PC users' data base includes many non-STORET data which have been obtained from several sources including TVA, USGS, NOAA, and water utilities. The data base includes hydrological data, meteorological data, water quality data, and some data pertaining to barge traffic and aquatic plants. Virtually no aquatic life data are presented. The beginning date is 1944 when the reservoir was filled and most data sets terminate in 1989 or 1990.

Data are arranged in usable spreadsheet forms on individual diskettes along with a cover sheet listing the diskette contents and two software programs for displaying the data. One of these software programs is called VIEW and it allows the user to see the contents of the diskette and to see the contents of any file at the press of a key. VIEW is free for private use but may not be sold or marketed. The other software program included on the diskette is AS-EASY-AS which is a fairly powerful spreadsheet/plotting system which is compatible with many other spreadsheet systems. AS-EASY-AS was chosen because it is very easy to learn to use and is relatively inexpensive. The user may try AS-EASY-AS for 30 days at no cost. However, if continued use is desired, the user must pay $50.00 plus $5.00 shipping and handling to TRIUS, Inc., 231 Sutton Street, Suite 2D-3, North Andover, MA 01845. A diskette with the full version of the AS-EASY-AS shareware is included.

Users having spreadsheet and plotting programs on their PC's such as LOTUS 123, Symphony, Harvard Graphics, Sigma-Plot, etc. will find the data easily accessible and ready for specific uses.

Hydrological Data Summary

The hydrological data base consists of data generated by TVA and USGS. The TVA data contains operational information for Pickwick and Kentucky Dams. This information includes total daily flows out of each dam, the turbine flow component and the gate flow component. It also includes the midnight reservoir elevations and sometimes the associated storage volumes.

The USGS data base consists of daily flow records for 1944-1989 (or the period of record) obtained from gages at Savannah on the Tennessee River, at Hurricane Mills on the Duck River, at Lobelville on the Buffalo River, at Denver on Trace Creek at Bruceton on the Big Sandy River, at Grand Rivers on the canal between Kentucky and Barkley Lakes, and at Paducah on the Tennessee River below Kentucky Dam. The USGS records are presented in a form very similar to pages from the USGS published <u>Water Resources Data</u>. Using the standard USGS format requires that the user restructure the spreadsheet for specific uses other than viewing.

[1] Tennessee Technological University, Civil Engineering Department, Box 5015, Cookeville, Tennessee 38505 (615/372-3454).

Meteorological Data Summary

The meteorological data consist of daily rainfall values at five locations between Pickwick and Kentucky Dams for the period from 1950 to 1990; NOAA data from the stations at Memphis, Nashville and Paducah containing mean daily air and dew point temperatures, wind speed and incident solar radiation.

Water Quality Data Summary

The water quality data included here are non-STORET data obtained from USGS, TVA, and water utilities. Most of the water quality data taken by TVA and state agencies are cataloged in the EPA maintained and operated STORET system. Procedures for accessing the STORET system are available from TVA in Chattanooga.

The temperatures and DO values in water released from Pickwick and Kentucky Dam turbines during 1950 to 1989 are on the water quality diskettes. Water chemistry for raw water withdrawn by the Camden and New Johnsonville utilities is available on a daily basis; Camden from 1987-1990 and New Johnsonville from 1983-1990. These data include temperature, turbidity, pH, and alkalinity. Water quality data collected by the USGS at the Pickwick Dam, Buffalo River, Duck River, Big Sandy River and at Paducah, KY are available. These data cover various periods of record. The water quality data also contain monitoring records of temperature and conductivity in water below Pickwick Dam from 1976-1982. One disk also contains records from a continuous monitor operated by TVA at the TN-KY state line during 1988 and the plant effluent temperatures at New Johnsonville between 1985 and 1987.

The parameters available for USGS data are shown in Table 1.

Table 1. Water Quality Parameter List for Station Water Quality Files Buffalo, Big Sandy, Paducah, Pickwick, Duck

Parameter	Code	Units
Sampling Depth	3	ft
Temperature	10	celsius
Discharge	60	cfs
Turbidity (JTU)	70	JTU
Turbidity (NTU)	76	NTU
Conductivity	95	micromho per cm
Dissolved Oxygen	300	mg per L
5 day BOD	310	mg per L
pH	400	dimensionless
Alkalinity	415	mg per L
Total Nitrogen	600	
Total Organic N	605	
Total NH3-N	610	
NO2+NO3	630	
Total Phosphorus	650	
Dissolved P	653	
Organic P	660	
Total Hardness	900	
Ca as CaCO3	910	
Mg as CaCO3	920	
Sodium (Na)	929	
Chlorine	940	
SO4	946	
Total Manganese	1055	
Dissolved Manganese	1056	
Total Selenium (se)	1147	
Chlorine "a"	32211	

EFFECT OF GROUND-WATER WITHDRAWALS UPON SPRING DISCHARGE AT THE STATE FISH HATCHERY, ERWIN, UNICOI COUNTY, TENNESSEE

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U.S. Geological Survey
Knoxville, Tennessee

The effect of pumping a recently constructed production well upon the discharge of several springs near Erwin, Tennessee, was determined in 1990 as part of a hydrogeological reconnaissance of the area conducted in cooperation with the Erwin Utilities Board and the Tennessee Wildlife Resources Agency. The well operated by the Erwin Utilities Board is about 1,800 feet northeast of a system of springs issuing from the Shady Dolomite (Early Cambrian age). These springs are used to provide the Tennessee Wildlife Resources Agency fish hatchery at Erwin with a continuous supply of water. Water levels at two springs, an observation well, and the recently constructed production well were monitored for a 4-month period. Rainfall and discharge also weremonitored at two sites at the hatchery for a 3- to 4-month period, one below the hatchery raceway and one on the bypass channel used to divert excess water around the raceway. Mean daily discharge ranged from 1,080 to 1,440 gallons per minute at the site below the raceway, and from 180 to 580 gallons per minute at the site on the bypass channel. Flow at these two points represents the total discharge of the springs. A 7-day, two-stage pumping test at 200 and 410 gallons per minute at the production well indicated that the well and the springs are hydraulically connected through fractures in the dolomite and that pumping reduces spring discharge by a rate almost equal to the pumping rate.

[1] U.S. Geological Survey, Water Resources Division, 1013 North Broadway, Knoxville, Tennessee 37917 (615/521-8909).

TENNESSEE AND CUMBERLAND RIVERS ENVIRONMENTAL DECISION SUPPORT SYSTEM

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Jack Brown
United State Corps of Engineers
Nashville, Tennessee

The Tennessee Valley Authority (TVA) Environmental River Resource Aid (TERRA) is a computer workstation graphics display that helps track environmental variables in the power service area. TVA's power service area includes 51 dams, a pumped-storage project, 12 coal-fired plants, and 4 nuclear plants on the Tennessee, Cumberland, Ohio, and Green Rivers. TERRA interfaces with various databases to provide near real-time data for reservoir and power system planning and scheduling. Displays of measured and forecasted temperatures are used to guide operation of power plants and dams that control water to meet thermal and other environmental constraints.

The poster session will explore the current development of TERRA in coordinating efforts between TVA's Reservoir Operations and Power Control Center, and the Corps of Engineer's Nashville District. The coordination and tracking of water flow, temperature, and dissolved oxygen (DO) through the summer of 1991 will be highlighted on a SUN Sparcstation 2 computer workstation.

Figure 1 shows the area covered by TERRA, including both the Tennessee and Cumberland River Systems. Figure 2 shows forecasts from a TVA Tennessee River temperature model for system water temperatures for July through September. The model output is used to forecast and compare water temperatures at power plant intakes on the system. Figure 3 shows an example of intake water temperatures at Browns Ferry Nuclear Plant. An action level at 84°F shows when special river flow or cooling tower operation is needed to meet the environmental thermal limits.

Temperature and water quality modeling is done by the Corps of Engineers, Nashville District, for the Cumberland River. Results of this modeling for critical points in the system include the release DO at Old Hickory Dam (upstream of Nashville) and the intake temperature at Cumberland Fossil Plant downstream of Cheatham Dam. Forecasted data for Old Hickory Dam release DO and Cumberland Fossil Plant intake temperatures are shown in Figures 4 and 5. The 5 mg/L line on the Old Hickory figure shows the state DO standard. The 85°F line on the Cumberland Fossil Plant figure shows the intake temperature above which the plant cannot operate at full load.

The previous figures are examples of data presentations that show as window displays on the TERRA workstation graphics. TERRA uses a "point and click" approach to show graphics or other available analysis "tools." Other decision-making tools include text files (such as NPDES reporting data), spreadsheets, simulation models, expert systems, etc.

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[1] Tennessee Valley Authority, Engineering Laboratory, P.O. Drawer E, Norris, Tennessee 37828 (615/632-1880).

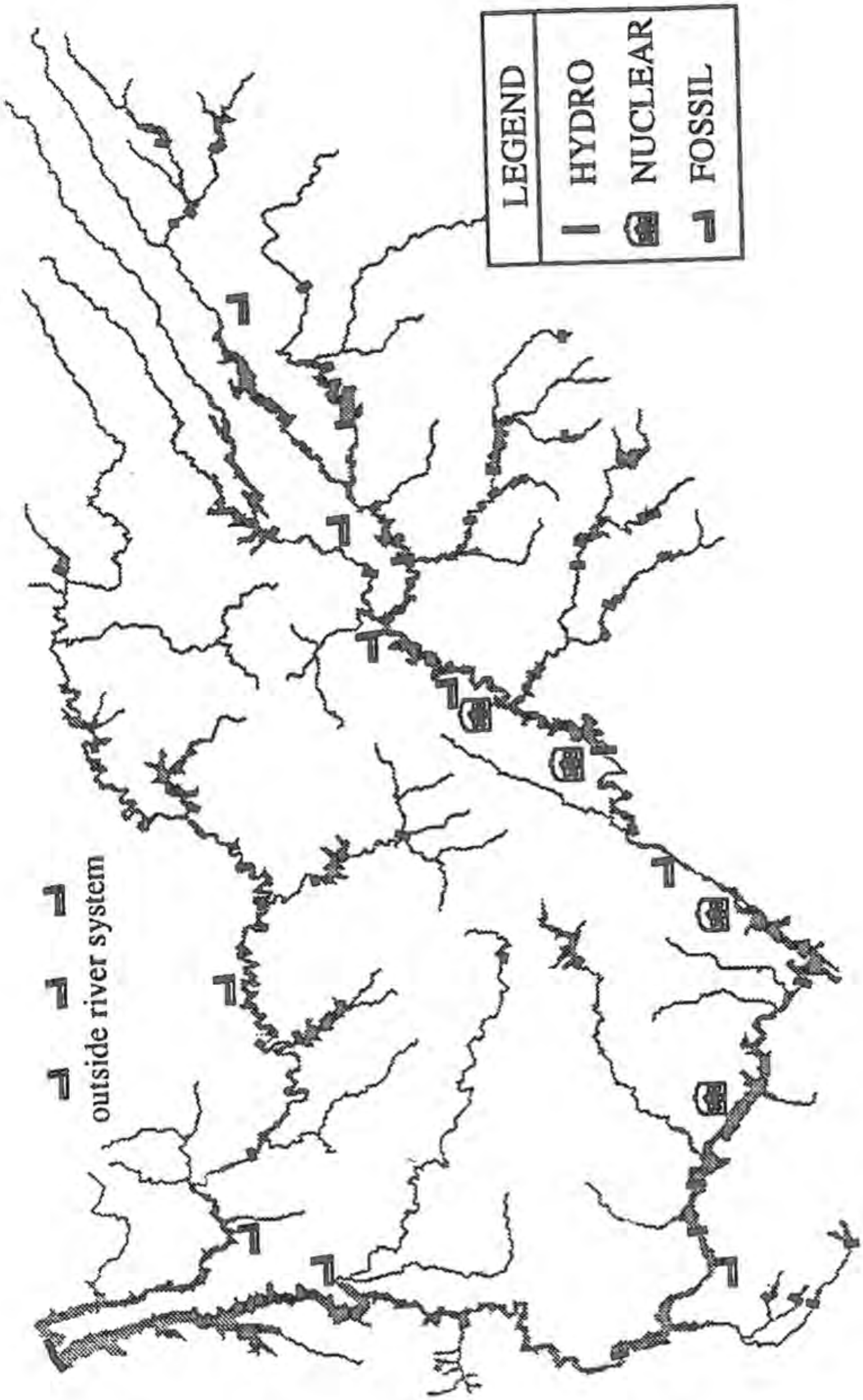

Fig. 1. TVA environmental river resource aid display area.

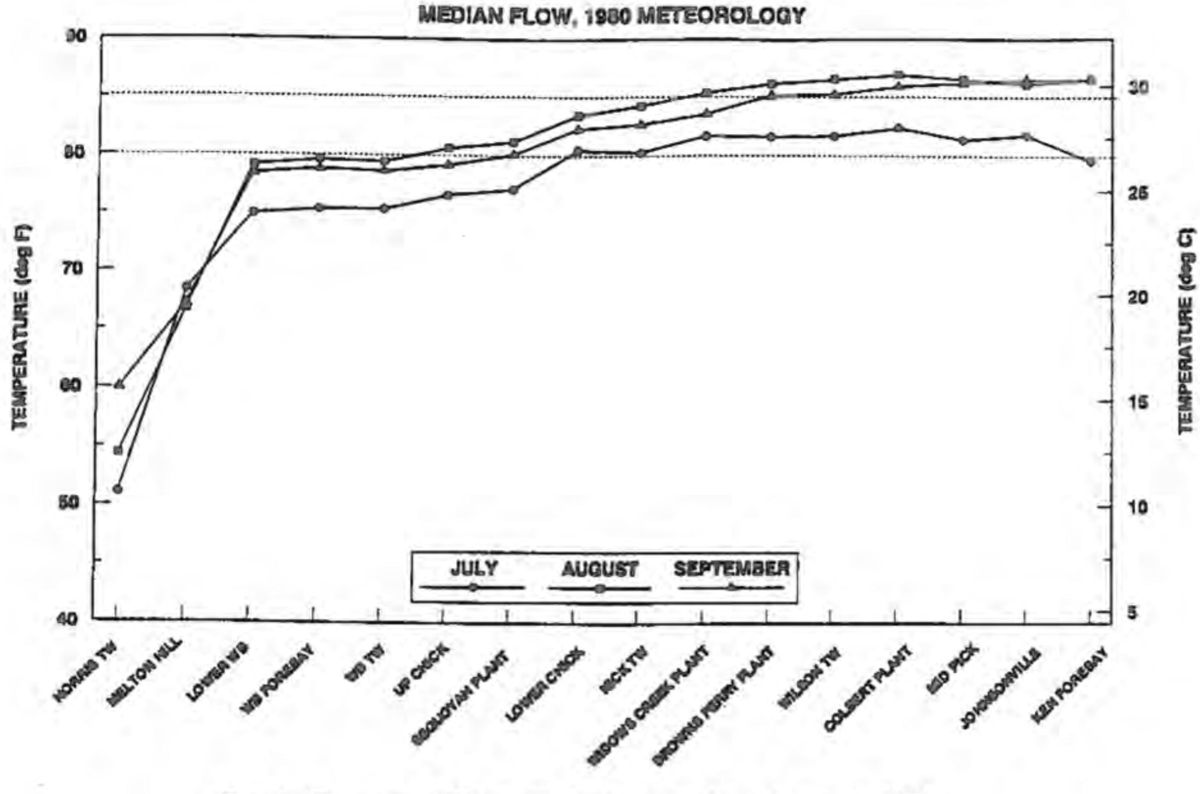

Fig. 2. Tennessee River, water temperature forecast, 1991.

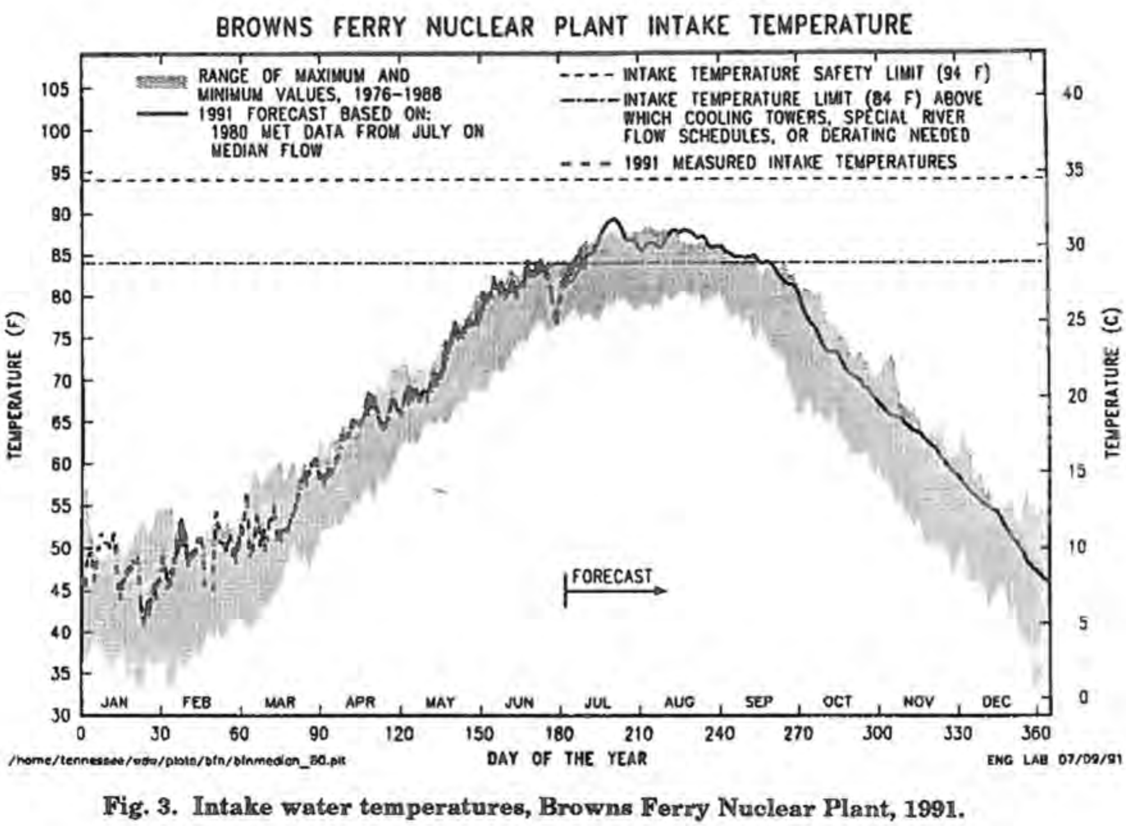

Fig. 3. Intake water temperatures, Browns Ferry Nuclear Plant, 1991.

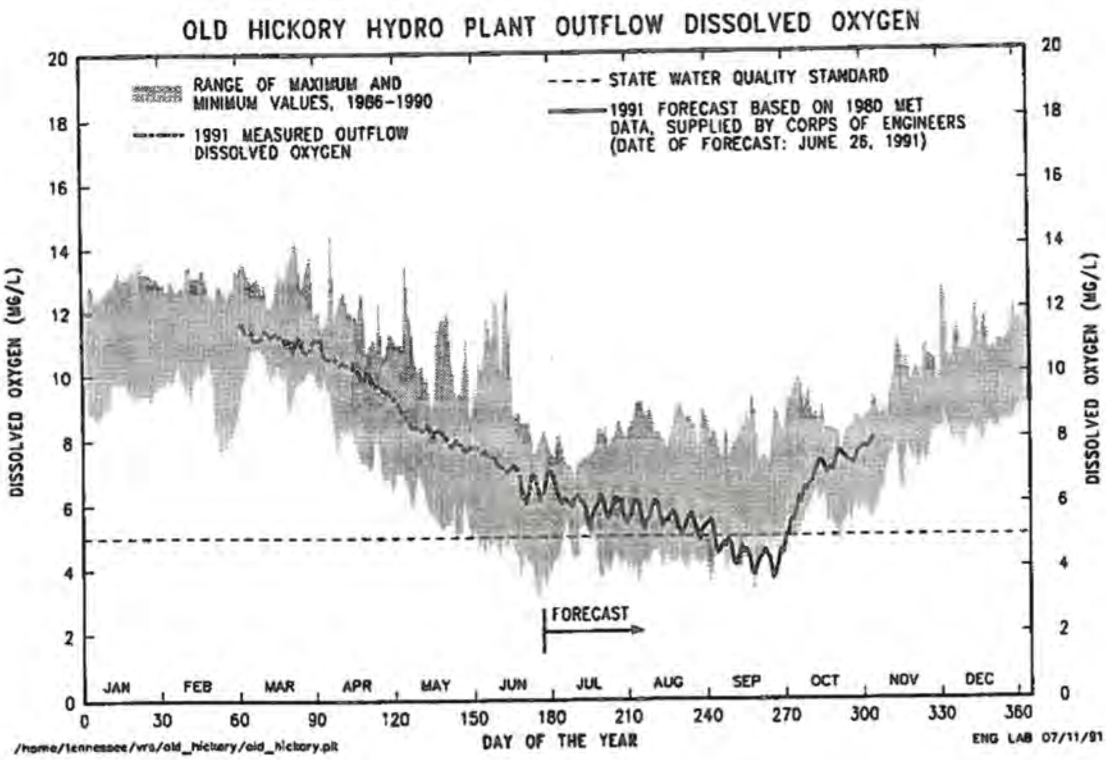

Fig. 4. Outflow dissolved oxygen, old Hickory Hydro Plant, 1991.

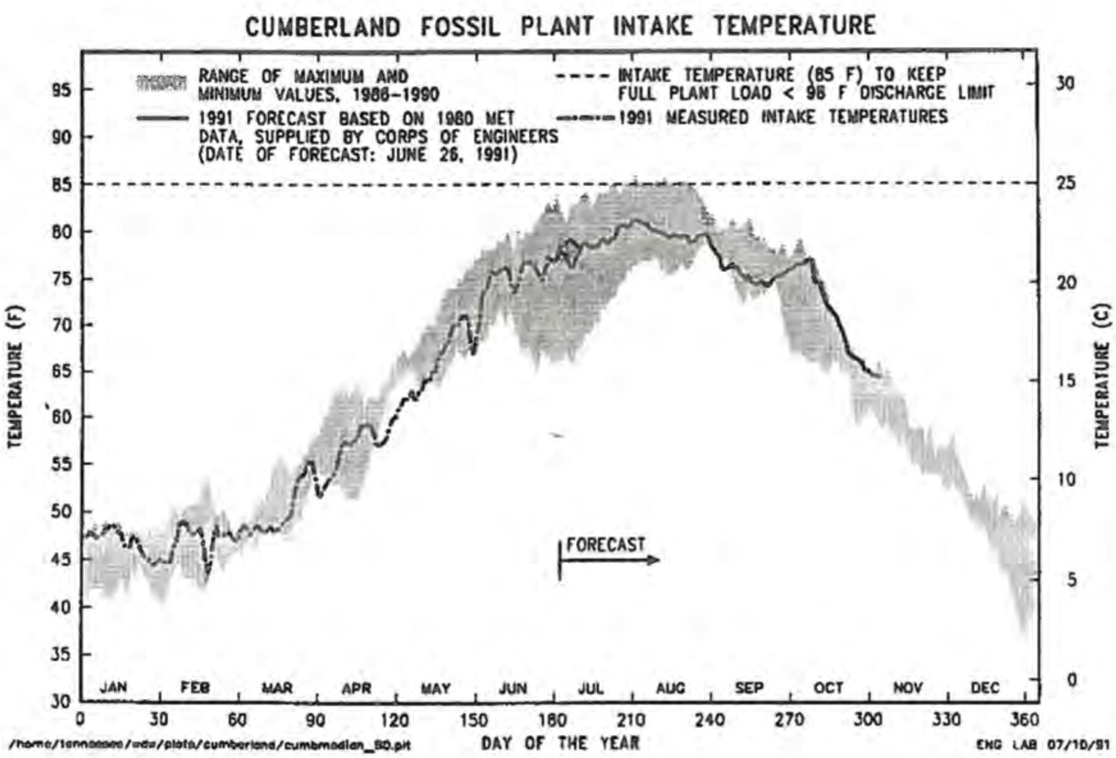

Fig. 5. Intake water temperatures, Cumberland Fossil Plant, 1991.

MICROBIAL UTILIZATION OF ADSORBED CONTAMINANTS IN GROUNDWATER SYSTEMS

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John T. Novak
Virginia Tech
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Introduction

Both the migration rate and the concentration of hazardous chemicals in groundwater play a major role in determining how far these materials migrate, how risk factors are assessed, and what remedial action can be taken. These analyses require a thorough understanding of the biogeochemical behavior of the hazardous chemicals in soil-water systems. Anthropogenic contaminants may enter the subsurface through spills and land disposal of wastes. Several factors may affect the fate and transport of contaminants in the subsurface. Water constituents may exist in aqueous solution, as non-aqueous phase liquids, or be associated with a variety of alternate phases, such as inorganic or organic particles. Sorption or complexation of certain waste components to these alternate phases may result in limiting their transport and/or bioavailability.

Currently, the management strategies employed to reclaim contaminated soil and groundwater are difficult to implement. Pump and treat technology is frequently used to cleanup contaminated groundwaters. This has limited effectiveness because of the low aqueous solubility and high affinity for aquifer solids of many target compounds. Pumping may remove the dissolved contaminant fraction, however, the sorbed residual faction can continue to serve as a reservoir for groundwater pollution over a long period of time.

The ultimate fate of many organic compounds in soil systems is dependent upon microbiological processes (Alexander, 1981; Dashman and Stotzky, 1986). Few biodegradation studies have related adsorption of hydrophobic compound to solid surfaces to the biological utilization of the sorbed compound. If a microorganism cannot use the adsorbed form of a chemical, it may be expected that the organism will first metabolize the chemical that is in solution and that the subsequent rate of transformation of the target compound will be limited by the rate of desorption.

The purpose of this study was to investigate the availability of sorbed 2,4,6-TCP for biodegradation by acclimated bacteria. The target compound was chosen because it is on the U.S. Environmental Protection Agency (EPA) list of priority pollutants, is a known carcinogen, and its presence in soil and groundwater has increased in recent years.

Methods and Materials

Batch laboratory microcosms were used to evaluate sorption and biodegradation of a chlorinated aromatic compound [2,4,6-Trichlorophenol (TCP)] in mineral and organic soils. Four soils were used for study:

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[1] University of Tennessee, Department of Civil Engineering, 219A Perkins Hall, Knoxville, Tennessee 37996-2010 (615/974-0722).

1) course sand, 2) kaolinite clay, 3) low organic, and 4) high organic. The sand and clay were purchased as reference materials. The organic soils were collected from previously uncontaminated site. The high organic soil consisted of 57% sand, 15.8% clay and 27.1% silt and was classified as a sandy loam. The low organic soil consisted of 19.8% sand, 25.9% clay and 54.2% silt and was classified as a silty loam. The fraction of organic matter associated with the high organic soil was determined to be 2.2% by weight while that of the low organic soil was determined to be 0.4% by weight.

Erlenmeyer flasks, containing 10 g sorbent (wet) and 90 ml buffer, were tightly capped and autoclaved on five different days to insure sterilization before dosing with 2,4,6-TCP and acclimated microorganisms. Radiolabelled 2,4,6-TCP was spiked into each sterilized system, sealed with a Teflon/silicon septum and cap, and mixed on a shaker to suspend the soil. In addition, the same quantity of labelled 2,4,6-TCP was added directly to scintillation vials for direct scintillation counting to determine initial substrate concentrations. Initial 2,4,6-TCP concentrations ranged from 100 to 1200 µg/l. The role of adsorption in biodegradation was determined by adding acclimated organisms to each microcosm after apparent equilibrium was achieved (> 60 days). A microbial culture capable of utilizing 2,4,6-TCP as the sole external carbon and energy source was isolated from the subsurface soil. The predominate microorganism was identified as *Pseudomonas aerugenosa* (>99%). Autoclaved microorganisms were introduced into additional microcosms to serve as controls. These controls provided corrections for abiotic uptake. Microcosms were incubated at room temperature (20°C) in the dark.

Biodegradation rates were determined by measuring $^{14}CO_2$ (mineralization) and ^{14}C remaining in the microcosm over time. Aerobic conditions were maintained in solution during incubation via the transfer of O_2 contained in the headspace gas. Transfer of O_2 in the gas phase to solution phase was facilitated by sample shaking at 100 cycles/min on a mixing bath. Measured dissolved oxygen levels in biodegraded microcosms were sufficiently high (> 2 mg/L) so as not to limit aerobic metabolism.

Results and Discussion

Each sorbent investigated in this study had different physical characteristics, particularly organic matter content, which influenced its sorption capacity. Experiments were undertaken to determine if the extent of sorption of 2,4,6-TCP to solid phase sorbents affected mineralization rates.

Mineralization rates were calculated at each sampling time in each microcosms to determine the effect of sorbent on rates. Rates reached a maximum within hours, then began to decrease rapidly during the first few days of incubation for all sorbents (Fig. 1). After ≈ 5 days, the mineralization rate continued to decrease but at a much reduced rate.

Mineralization rates in sand and clay microcosms were statistically the same as sorbent-free microcosms and appeared to be first order. The mineralization rates in microcosms containing organic matter differed from sorbent-free, sand and clay microcosms. The rate during the first few days of incubation was similar to that in microcosms containing organic-free sorbents due to mineralization of aqueous phase 2,4,6-TCP. However, the rate of decrease in mineralization slowed significantly in high and low organic matter soil microcosms after ≈ 5 days of incubation. This change in rate was attributed to an influx of substrate into solution from the sorbed state. This influx elevated the low substrate concentration in solution. If bacteria can mineralize only dissolved substrate, then the desorption of 2,4,6-TCP into solution would make more substrate bioavailable. The increased solution concentration should cause an increase, or a slower decrease, in the overall mineralization rate. The slowing of the rate of decrease in mineralization was much more apparent in the high organic soil. This soil sorbed >30% of the 2,4,6-TCP initially added to the microcosm which then became bioavailable as it desorbed.

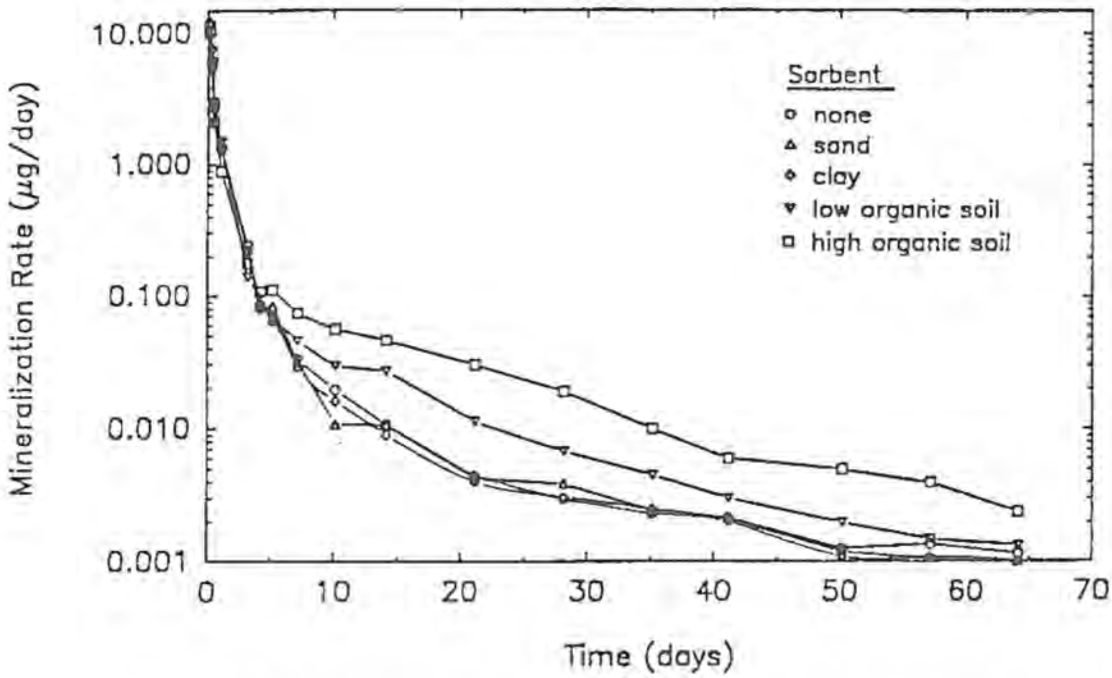

Fig. 1. Effect of sorbent on the mineralization of 100 µg/L of 2, 4, 6-TCP.

The ability of *P. aerugenosa* to utilize sorbed 2,4,6-TCP was evaluated by monitoring radioactivity associated with centrifuged solids obtained from subsamples taken from microcosms over time. The mass of 2,4,6-TCP in the centrifuged solids was quantified by extraction in scintillation cocktail augmented with methanol. The acclimated bacteria clearly were able to utilize the 2,4,6-TCP associated with each sorbent (Fig. 2). The 2,4,6-TCP associated with sand and clay appeared to be constant over time. However, the variation associated with the measurement of such low concentrations was quite large.

Removal of 2,4,6-TCP from high and low organic soils appeared to occur in two distinct intervals, fast and slow. Within the first few days after inoculation, 30-50% of the sorbed 2,4,6-TCP was released from the organic soils. The sorbed concentration then decreased at a much slower rate for both organic soils.

It could not be determined if the bacteria degraded the 2,4,6-TCP while it was sorbed to the soil or if the 2,4,6-TCP first desorbed before being acted upon by the organisms. Using results obtained from the biodegradation of sorbed toluene in soil (Robinson et al., 1990) and preliminary results obtained in this work, it was speculated that the bacteria were acting on the contaminant substrate in the aqueous phase only. It was assumed that as 2,4,6-TCP was removed from solution by mineralization, a concentration gradient resulted and 2,4,6-TCP desorbed back into solution. Once in the liquid phase, ^{14}C-substrate could be degraded as liquid phase substrate. If true, both fractions of 2,4,6-TCP would eventually be biodegraded in the aqueous phase but at a rate controlled by desorption.

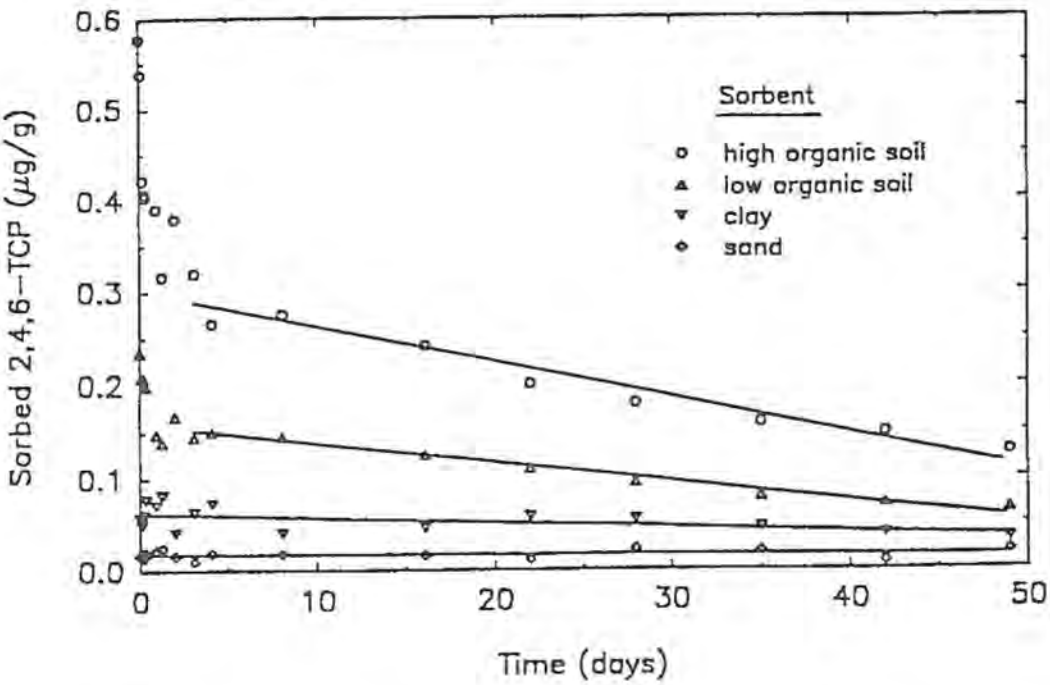

Fig. 2. Utilization of sorbed 2, 4, 6-TCP by acclimated bacteria. Initial aqueous 2,4,6-TCP concentration = 100 µg/L.

Summary and Conclusions

The introduction of different sorbent types will increase the complexity of a system. Environmental systems are heterogeneous and contain a variety of surfaces to which a contaminant can react. Each of these surfaces has a different binding capacity.

The bioavailability of a contaminant in a subsurface environment will vary with the physical state in which it exists.

Biodegradation of 2,4,6-TCP associated with sand and clay was very rapid. Sand and clay had only a minor effect on the biodegradation rate. Mineralization rates in organic soil microcosms were elevated over sand and clay microcosms after ≈ 5 days of incubation due to an influx of 2,4,6-TCP into solution from an initially sorbed state. Microbial utilization of sorbed 2,4,6-TCP from organic soils was initially fast followed by a slow, declining rate. Slow removal was believed to be desorption controlled.

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AGRICULTURAL EXTENSION SERVICE WATER QUALITY DISPLAY

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Water quality has been identified as a national initiative for the Extension Service by the U.S. Department of Agriculture. That is, water quality is a significant concern in American society which Extension educational programs can contribute to resolving.

The water quality program in Tennessee is conducted with the leadership of an interdisciplinary committee. The program addresses five issues identifies through a survey of locally nominated leaders from across the state:

(1) creating awareness of water problems, their consequences and strategies to address them;

(2) developing adequate supplies of safe water for domestic, agricultural and community uses;

(3) enhancing water quality through recommended agricultural production practices;

(4) improving water quality through recommended chemical use; and

(5) enhancing water quality through recommended waste disposal practices.

The poster presentation will discuss the educational programs addressing these issues and display the materials developed to support these programs.

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DEVELOPMENT OF A NEW ENVIRONMENTALLY IMPROVED HYDROTUBINE

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Low concentrations of dissolved oxygen (DO) in the discharges of hydro plants represent one of the most significant environmental concerns confronting the hydropower industry. The autoventing turbine (AVT) represents a promising method for solving this concern. The concept of an AVT involves air to be aspirated into the water as it passes through the turbine whenever concentrations of DO are less than desired. An applied research project is being conducted to develop experimental and numerical methods to allow for reliable design and deployment of this new "environmentally improved" hydroturbine.

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[1] Tennessee Valley Authority, Engineering Laboratory, Norris, Tennessee 37828.

SURFACE WATER HYDROLOGY FOR A CONTAMINATED FORESTED WATERSHED [1]

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D. M. Borders, B. Frederick, and G. K. Moore
The University of Tennessee
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A. T. Bednarek
The University of Notre Dame
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Introduction

The Whiteoak Creek Watershed, consisting of Whiteoak Creek (WOC) and its tributaries, Whiteoak Lake (WOL), and the WOC Embayment (WOCE) on the Clinch River, is the primary surface drainage for the Oak Ridge National Laboratory (ORNL) on the Department of Energy's (DOE's) Oak Ridge Reservation (ORR) in eastern Tennessee (Fig. 1). Stream flows have been monitored in the watershed by the U. S. Geological Survey (USGS) and several divisions of the Laboratory for over 40 years. The stream network consists of small perennial and intermittent, first- to third-order streams. In addition to natural runoff and groundwater recharge, WOC receives waste effluents and process water discharges from the ORNL facilities. These effluents and discharges represent a significant portion of the annual stream flow.

Twenty-seven surface water monitoring stations (Fig. 2) are located within or in the immediate vicinity of the WOC watershed. Several of these monitoring stations are not operational at the present time. Analyses of the stream flow monitoring data indicate spatial and temporal patterns which are useful in predicting hydrologic trends and which can serve as indicators for the need to initiate upgrades of the hydrologic monitoring system in the watershed. Hydrographs prepared to compare flows at selected gaging stations and to isolate contributions from different areas show that differences in stream flows measured in WOC above the confluence with Melton Branch (MBR), WOC's primary tributary, and at the USGS station located near Haw Ridge (upstream of the confluence) were negative about 50% of the time during a period of drought (May 1987–April 1988) (Borders et al. 1989). For a wet period (October 1989–September 1990), the differences were positive about 90% of the time. These comparisons highlight the major contribution of precipitation to the water budget of the watershed.

Site Description

The WOC rises from springs on the southwest slopes of Chestnut Ridge and, with its tributaries, drains much of Bethel and Melton Valleys (which include ORNL) to the Clinch River. The waters of WOC are

[1] Research sponsored by the Office of Environmental Restoration and Waste Management, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

[2] Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee 37831-6038 (615/574-7844).

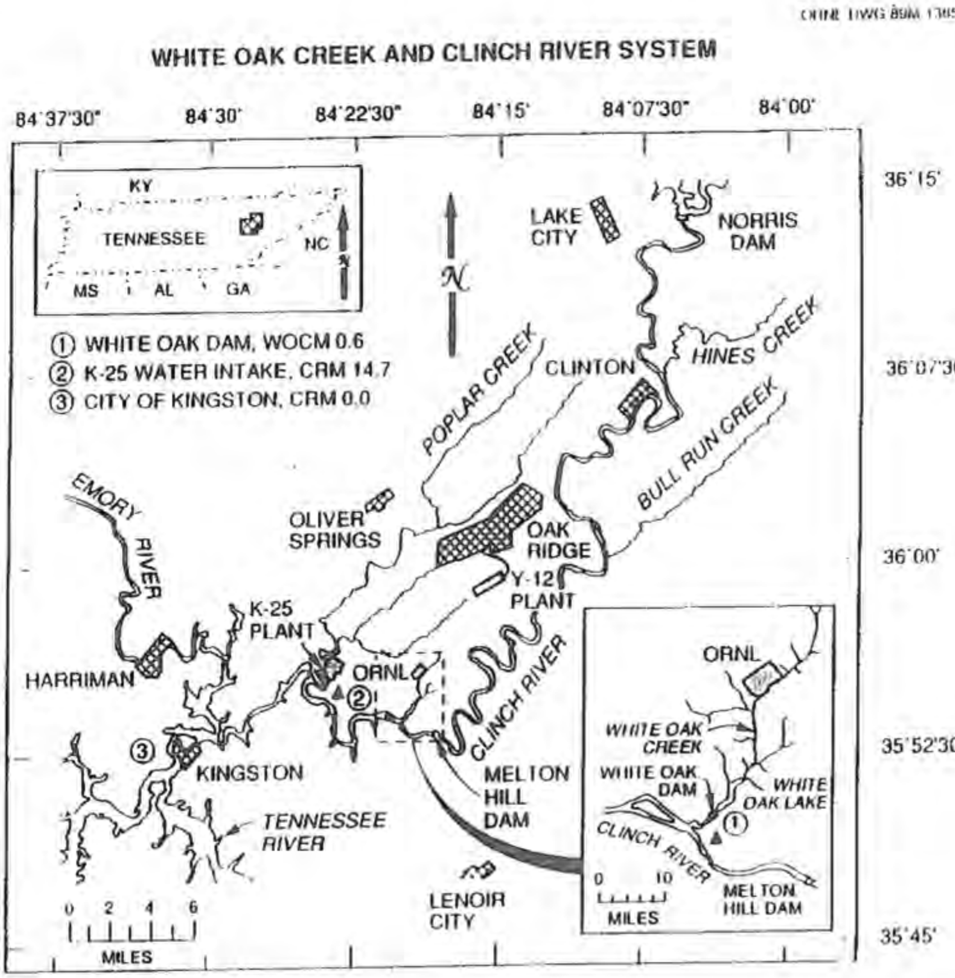


Fig. 1. Map showing the location of the White Oak Creek Watershed in Oak Ridge, Tennessee.

impounded by Whiteoak Dam (WOD), constructed 1.0 km (0.6 miles) upstream from the Clinch River in 1943, to form Whiteoak Lake (WOL). WOL serves as a holding pond for ORNL waste effluents. The drainage areas upstream from the Clinch River and Whiteoak Dam (WOD) are approximately 16.8 km^2 (6.5 miles^2) and 16.0 km^2 (6.15 miles^2), respectively. Elevations in the watershed range from 226 m (741 ft) above mean sea level (MSL) at the mouth of WOC to 413 m (1356 ft.) above MSL at the top of Melton Hill, the highest point on the ORR.

WOD is a low-head structure (weir and a concrete-box culvert) with a normal lake elevation of 227.1 m (745 ft). The reservoir is only 0.9 m (3 ft) above full-pool elevation [226.6 m (742 ft)] in the Clinch River. A recent survey indicates that the volume of WOL at normal pool level is ~43,890 m^3 (1.55×10^6 ft^3) (Cox et al. 1991). In 1983, modifications were made to the flow system at the dam to increase the flood discharge capacity to approximately 56.6 m^3/s (2000 ft^3/s). It has been estimated that the 100-year flood peak discharge is approximately 44.6 m^3/s (1564 ft^3/s) (Tschantz 1987).

Groundwater occurs in all four major geologic formations that underlie the WOC drainage basin. The dolomite of the Knox Group on Chestnut Ridge and the Chickamauga Limestone Group underlying Bethel Valley apparently are the principal water-bearing units. They discharge larger amounts of water, per unit drainage area, to the streams than the other geologic units. The springs that occur along the southern slopes of Chestnut Ridge are the principal sources of the base flow of the upper portion of WOC. The Rome Formation on Haw Ridge and the

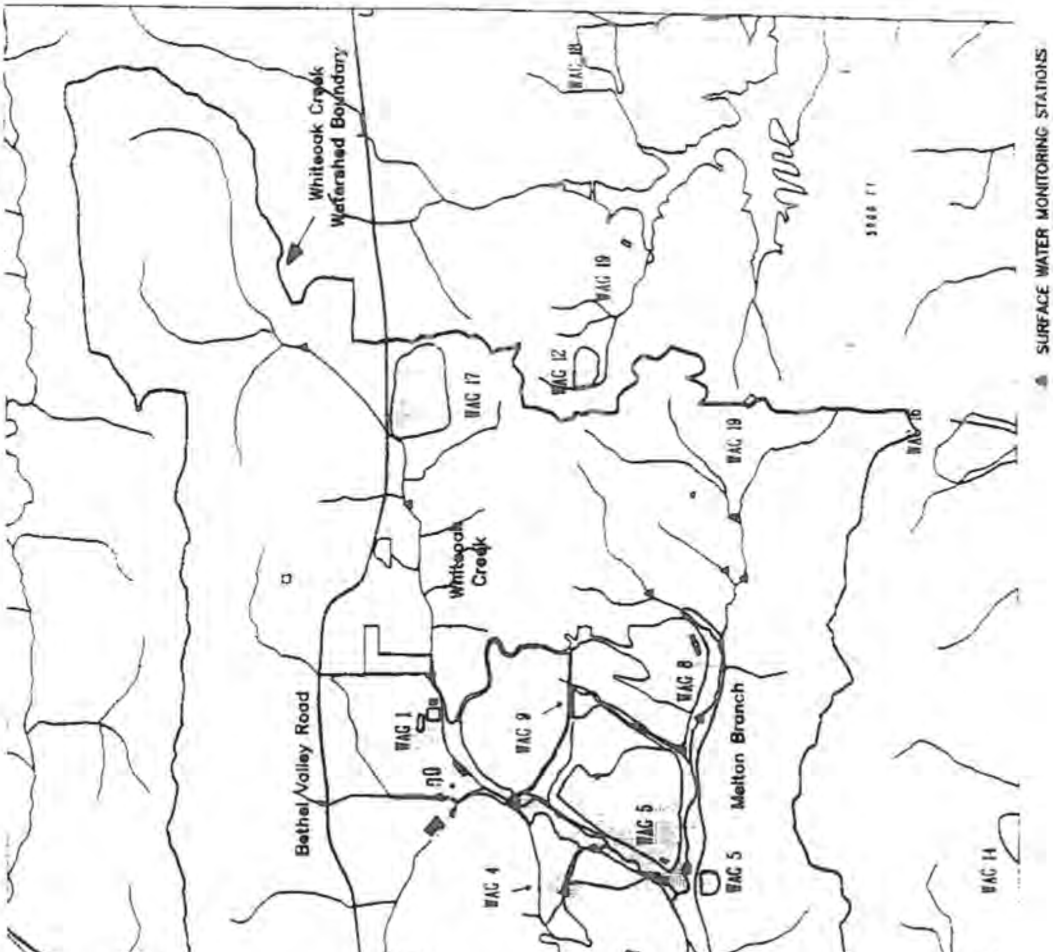


Fig. 1. Locations of surface water monitoring stations in the White Oak Creek Watershed.

Conasauga Group underlying Melton Valley discharge smaller quantities of water to the streams. Water occurs in the weathered rock of all units near land surface (McMaster 1967).

All of ORNL's known active and inactive waste management areas, contaminated facilities, and potential sources of contaminants have been divided into 20 waste area groupings (WAGs), eleven of which lie at least partially within the WOC watershed (Fig. 2). Water in WOL contains measurable quantities of dissolved ^{3}H and ^{90}Sr, which are released through the monitoring station at WOD. The WOC flow system also receives effluent from nonpoint sources, the Solid Waste Storage Areas (SWSAs) and Low Level Waste (LLW) pits and trenches, through both surface and groundwater flow. Sediments within the WOC flow system have sorbed chemical and radioactive contaminants. Consequently, these contaminants have accumulated in the WOC floodplain and WOL sediments. The sediment in the lake bed contains an estimated 650 curies of radioactive isotopes, primarily ^{137}Cs, ^{60}Co, and ^{90}Sr. During periods of heavy rainfall, both dissolved radionuclides and resuspended contaminated sediment are released from the lake into the Clinch River.

Hydrologic Data

The collection of hydrologic data in the WOC watershed began with facility planning studies in the early 1940s and has developed into a long-term program of environmental research studies and monitoring activities required to cope with the Laboratory's unique waste management needs. The hydrologic data available for Water Year 1990 (October 1989–September 1990), were derived largely from ongoing studies of the ORNL Environmental Restoration Program (ERP) and from the continuing monitoring program conducted by the ORNL Environmental Surveillance and Protection (ESP) Section of the Office of Environmental and Health Protection (OEHP). Much of the data presented have been collected, compiled and formatted by ORNL's Environmental Sciences Division (ESD) Hydrology Group. Current monitoring, for the most part, is associated with the National Pollutant Discharge Elimination System (NPDES) permit for ORNL operations (EPA 1986).

Climate

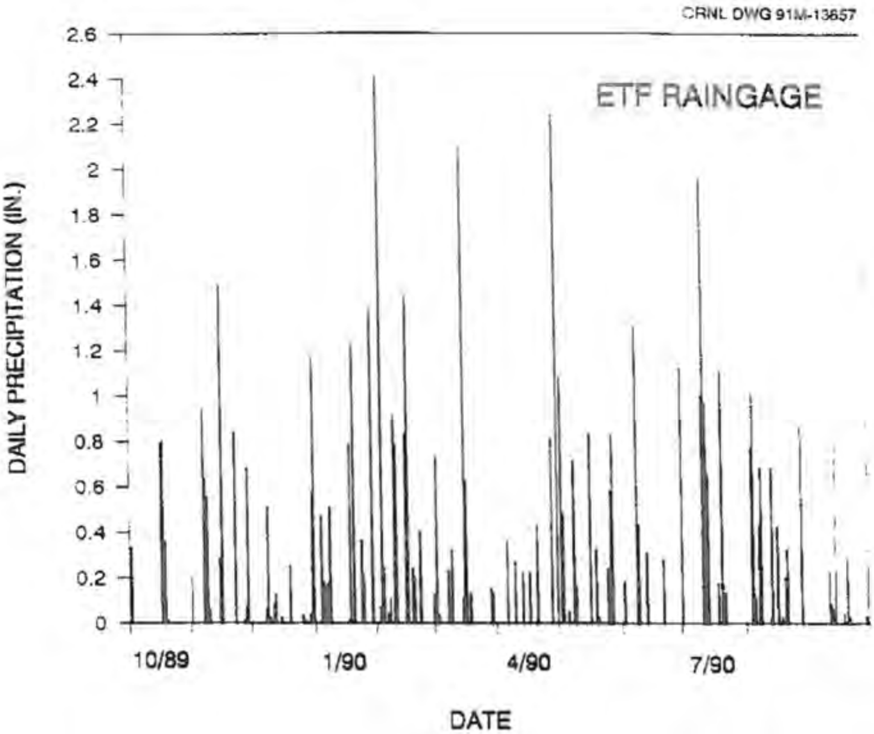
Precipitation, temperature, humidity, wind speed, and wind direction data are available for several stations located in the vicinity of the WOC watershed. The period of record varies from station to station. The National Oceanic and Atmospheric Administration, Atmospheric Turbulence and Diffusion Division (NOAA/ATDD) monitoring station located in Oak Ridge, about 15.4 km (9.6 miles) north of the center of the watershed, is the closest long-term meteorological station with records dating from 1947 to the present.

Precipitation is probably the most important climatic factor in hydrologic studies. Precipitation establishes the quantity and variations in runoff and stream flow and it is the source for replenishment to the groundwater system. Mean, maximum, and minimum annual precipitation for stations near ORNL during the period 1954-1983 was 132.6, 190.0 and 89.7 cm (52.2, 74.8 and 35.3 in.), respectively (Huff and Frederick 1984). Monthly precipitation at the NOAA/ATDD station generally ranges from 13.46 to 15.75 cm (5.3 to 6.2 in.) during the wettest months (January–March), and from 7.37 to 9.65 cm (2.9 to 3.8 in.) during the driest months (August–October). The mean annual runoff for streams in the ORNL area is 56.6 cm (22.3 in.). The remainder of the mean annual precipitation, about 76.2 cm (30 in.), is consumed by evapotranspiration.

Annual precipitation for Water Year 1990 at nine sites in the vicinity of the WOC watershed ranged from 137.1–149.8 cm (53.97–58.99 in.). Figure 3 shows daily precipitation recorded at the ETF station located in WAG 6, north of WOL, and the NOAA/ATDD station for Water Year 1990.

Surface Water

Data on surface water flow and quality are collected at several sites in the WOC flow system as part of the Environmental Surveillance and Protection (ESP) monitoring



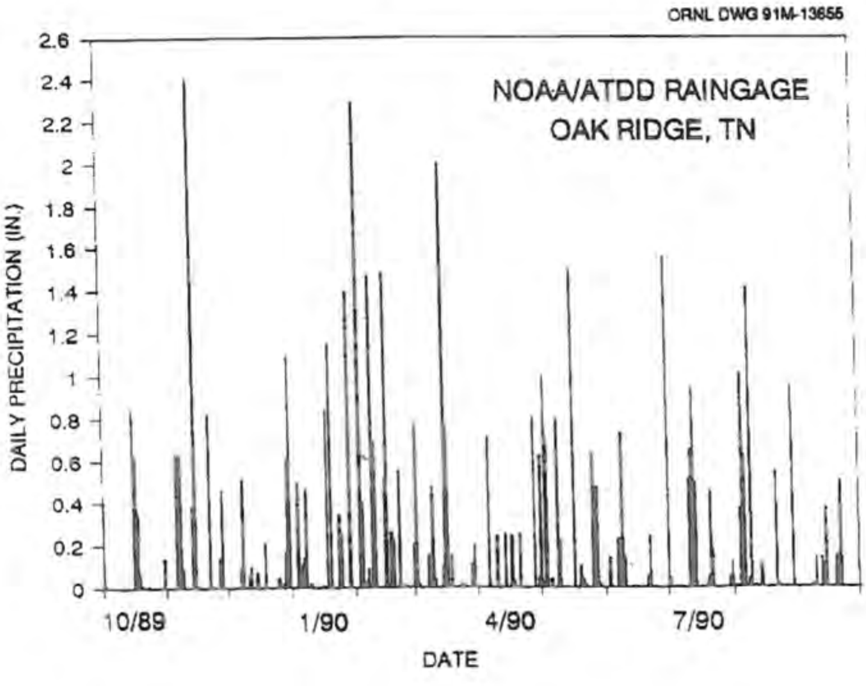


Fig. 3. Precipitation during Water Year 1990 at the ETF raingage in the White Oak Creek Watershed and the NOAA/ATDD raingage in the City of Oak Ridge.

and compliance program associated with the NPDES permit, in numerous studies of the Environmental Restoration Program (ERP), and in a number of independent studies. The Biological Monitoring and Assessment Program (BMAP) also collects some periodic water quality data, as required by the NPDES permit (Loar 1990).

Data on stream flows in the vicinity of WOC are collected by ESD, ESP, and the USGS. Three sites (WOD, WOC, and MBR) are operated by ESP as part of the NPDES permit requirements and eight sites are currently operated by the USGS as part of ERP studies to isolate individual contributions from upstream hydrologic units and for application in modeling studies. An additional ESP site (WOC Headwater monitoring station) has been established on WOC, upstream of Bethel Valley Road and the ORNL facilities, to monitor background water quality and flow in the headwaters area.

Stream flow data are also being collected by ESD's Hydrology Group at nine sites. These sites include monitoring by ESD at the four ESP stations in order to assist with evaluation and mitigation of problems with discharge measurement. Independent monitoring of discharge at five additional surface water stations includes two sites on tributaries that drain the pits and trenches area northeast of WOL, one site that drains SWSA 4 to the south into WOC, and two sites (Ish and Raccoon Creeks) outside the WOC watershed to the west of State Highway 95. Figure 4 shows daily average discharge from WOD, the outfall from the WOC system, for Water Year 1990.

Flow in WOC in the main ORNL plant area is augmented by the disposal of water imported for plant processes, potable supplies, and sanitary use. The nature of the flow is complex because of the effects of storm drainage, leakage into and out of an extensive system of underground pipes, and the increased permeability of disturbed subsurface materials along pipe lines and within construction sites. Of the total amount of imported water (~4×10^6 gallons per day), 38% is lost to the atmosphere as evaporation. The remaining 62% is

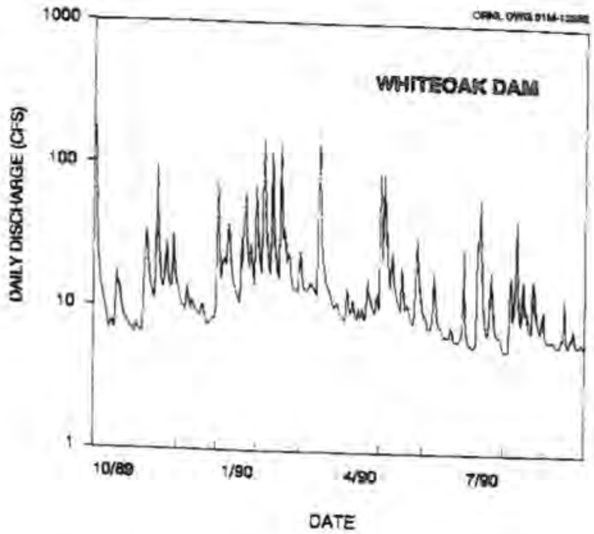


Fig. 4. Daily discharge at the White Oak Dam weir, the outfall for the entire White Oak Creek Watershed into the Clinch River.

subsequently discharged to the WOC surface water system (Kasten 1986).

Early discharge data collected by the USGS at WOD (1953-55; 1960-64), WOC (1950-53; 1955-64), and MBR (1955-64) indicate average annual discharges of 13.5, 9.62, and 2.50 cfs respectively. Stream flow data collected by ESD's Hydrology Group for Water Year 1990 indicate average annual discharges of 17.20, 13.93, and 2.86 cfs at the same three sites. The discharges at WOC (45%) and WOD (27%) are significantly greater than the discharge at MBR (14%). These differences are most likely due to the incongruity and briefness of the three periods of record and the increased contribution of process water discharges to WOC since 1964.

Summary

Characterization of the hydrology of the WOC watershed is necessary to better understand the trends in both temporal and spatial patterns of the watershed. Hydrologic data collected on the WOC watershed during Water Year 1990 are provided to support that need as well as to provide the sources of data needed for long-term assessment of remedial restoration activities. Dynamic hydrologic data collected on the surface and subsurface of low systems, which affect the quality or quantity of surface and groundwater, have been summarized. Available WOC surface water data include discharge and runoff, surface water quality, radiological and chemical contamination of sediments, and descriptions of outfalls to the WOC flow system. Climatological data available include precipitation, temperature, humidity, wind speed, and wind direction. Hydrologic data collection is an important component of several ongoing ORNL environmental studies and monitoring programs. Collection of these data aid in (1) characterizing the quantity and quality of the water in the flow system, (2) planning and assessment of environmental restoration activities, and (3) providing long-term data availability and quality assurance.

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HYDROLOGY OF THE CARSON SPRING SYSTEM, HAMILTON COUNTY, TENNESSEE

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The hydrology of Carson Spring and the surrounding area in the lower Wolftever Creek basin northeast of Chattanooga was investigated by the U.S. Geological Survey in cooperation with the Eastside Utility District from 1986 through 1989. Carson Spring is one of the larger springs of Tennessee, having a mean natural discharge of about 6 cubic feet per second. It discharges from the Chepultepec Dolomite of the Knox Group into a man-made spring pool close to Wolftever Creek. Near the spring, the creek channel is inundated by backwater from Chickamauga Lake.

Lithologic and geophysical logs of test wells drilled within 2 miles of the spring show that numerous solution cavities have developed in the Chepultepec Dolomite, which underlies about two-thirds of the lower Wolftever Creek basin. Many of the solution cavities are either partly or completely filled with cherty gravels and mud. Many cavities also contain and transmit water. Where cavities are small, of limited continuity, or only partly open, the formation can provide yields of 100 to perhaps 600 gallons per minute to bedrock wells; where cavities are large, or have become integrated into a conduit system, much larger yields are possible. A test well at Carson Spring intercepted a major conduit system, and was determined by pumping to be capable of yielding more than 2,000 gallons of water per minute.

The recharge area of the spring probably includes less than 9 square miles, based on a map of the potentiometric surface as measured in about 60 wells throughout the lower basin. The primary recharge area is thought to be south and southwest of the spring where stream channels underlain by cherty regolith and dolomitic bedrock are gravel-strewn and normally dry, indicating loss of stream flow to the ground-water system. The largest seasonal changes in water levels in wells in the lower basin also occur in this area. Most ground water in the recharge area, not intercepted by conduits, discharges to Wolftever Creek and the lowermost reaches of its tributaries. In May 1987, discharge to the creek in the lower basin upstream of the embayed reach averaged 0.50 cubic foot per second per square mile of drainage area, about twice that of other nearby drainage basins.

Public-supply wells drilled into the Chepultepec Dolomite within a few hundred feet of the spring orifice withdraw water that otherwise would be discharged at the spring. During a 16-month drought in 1987-88, combined pumpage at these wells exceeded the natural spring discharge, resulting in a cessation of flow. This indicates that, for at least a limited period of time, the aquifer at this location is capable of yielding more water than the spring would discharge under natural conditions. The additional increment of water initially comes from aquifer storage. If the overdraft is sustained, some of the increment might later come from induced recharge to the aquifer from Wolftever Creek.

Intensive pumping of wells at Carson Spring has potential to cause water in the embayed reach of Wolftever Creek to recharge the aquifer if the hydraulic-head relation

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between the aquifer and creek is reversed. Seasonal adjustments in Chickamauga Lake stage add a complicating factor. During the period of study, which included an extended drought period and several seasonal adjustments in lake stage, head in the aquifer at the spring was greater than that of the lake at all times except for a period of less than 1 day, indicating that the aquifer received little or no recharge from the lake. However, the water-table gradient in the area of Wolftever Creek upstream from the spring is small. Conceivably, intensive pumping of wells at Carson Spring could cause Wolftever Creek to become a direct source of recharge to these wells if the creek channel, at some point upstream from the spring, is hydraulically connected to the conduit system supplying the spring by a highly permeable zone through the bedrock. Samples of stream water were not collected for chemical analyses to further examine this possibility.

Water from wells in the Chepultepec Dolomite and other formations of the Knox Group generally is less mineralized than water from the impure limestone and mudstone formations that underlie the remainder of the basin. Although water chemistry is influenced by many factors, less mineralization may indicate that recharge flows through the open, continuous cavities of the dolomite more rapidly than it does through fractures, bedding planes, and other secondary-permeability features of the argillaceous carbonate and silicate rocks.

DEMONSTRATION OF THE ELECTROMAGNETIC BOREHOLE FLOWMETER FOR GEOHYDROLOGICAL ASSESSMENTS

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The electromagnetic (EM) borehole flowmeter provides geohydrologists and engineers with a sensitive and durable device for measuring vertical variations of horizontal inflow into a groundwater well. The EM flowmeter was designed and constructed by TVA in 1987 because of the limitations of conventional impeller borehole flowmeters. The sensitivity of the EM flowmeter is not dependent on parts that move, corrode, or wear down. The EM flowmeter can measure within a few percent at flowrates as low as 10 ml/min. The capabilities of the EM flowmeter make it very attractive in situations where low injection and/or pumping rates are required. The EM flowmeter provides a quick and inexpensive method for evaluating the integrity of wells used for deep injection of wastes, selecting the screened interval of monitoring wells, characterizing the hydraulic conductivity field of unconsolidated sediments, and determining the hydraulic properties of water-bearing fractures in bedrock. TVA is currently applying the flowmeter to projects funded by numerous agencies including the Environmental Protection Agency (EPA), United States Air Force (USAF), the Electric Power Research Institute (EPRI), and the Oak Ridge National Laboratory (ORNL). In conjunction with Auburn University, TVA is currently working with EPA to make EM flowmeter technology available to the public.

Introduction

In an aquifer, the three-dimensional structure of the hydraulic conductivity field (or fracture network) controls the groundwater flow patterns. To adequately perform site characterization requires an effective method for measuring the spatial variability in the hydraulic conductivity field. Recently, Boggs, et al. (1990), Rehfeldt, et al. (1989), and Molz, et al. (1989) evaluated different methods for measuring the vertical variation of hydraulic conductivity. Among the different methods are small-scale tracer tests, multilevel slug tests, laboratory permeameter tests, equations based on grain-size distributions, and borehole flowmeter tests. All three groups conclude that the borehole flowmeter test is the most promising method for measuring the spatial variability in the hydraulic conductivity field.

Borehole Flowmeter Technology

The borehole flowmeter method relies on the capability to accurately measure the drawdown rate (via pressure transducer) and the vertical flow distribution (via flowmeter) in a fully-screened pumped well. The method is summarized by the following five steps. First, the borehole flowmeter is lowered close to the bottom of the well. Second, a pressure

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transducer is lowered below the water table. Third, a constant and known flow rate is withdrawn from or injected into the groundwater well. Fourth, after the rate of drawdown in the well has stabilized, the flowmeter is used to take flow measurements at selected depths. Fifth, the pressure transducer is downloaded after the well has recovered.

Although borehole flowmeters have been commonly used in the petroleum industry for decades, borehole flowmeter tests have been relatively uncommon in the groundwater industry because of a shortage of borehole flowmeters with small outer diameters (< 10 cm) and accuracy in the range of 1.0 to 0.00001 m/s. Because of the relative scarcity of flowmeters suitable for groundwater applications, borehole flowmeter tests have been primarily restricted to research facilities such as the United States Geological Survey's site at Cape Cod, Massachusetts (Hess, 1989), Auburn University's site at Mobile, Alabama (Molz, et al., 1989), the Tennessee Valley Authority's site at Columbus, Mississippi (Rehfeldt, et al., 1989; Boggs, et al., 1990; Young, 1990a,b), and the Oak Ridge National Laboratory (Young, et al., 1991).

The Electromagnetic Flowmeter

The electromagnetic (EM) flowmeter was developed at the TVA Engineering Laboratory, Norris, Tennessee, in 1987. The flowmeter consists of an electromagnet and two electrodes (placed 180 degrees apart) that are casted in a durable epoxy. The epoxy is molded to a cylindrical shape to fit snugly with a 5-cm PVC pipe. The flowmeter has no parts that are moveable, adjustable, and/or corrodible. The flowmeter operates according to Faraday's Law of Induction, which states that the voltage induced by a conductor moving at right angles through a magnetic field is directly proportional to the velocity of the conductor through the field. The flowing water is the conductor, the electromagnet generates the magnetic field, and the electrodes measure the induced voltage. The electronics attached to the electrodes will transmit a voltage that is directly proportional to the velocity of the water.

Young (1990a,b) provides a thorough overview of the EM borehole flowmeter technique and calibration data. Currently, the EM flowmeter can measure within a few percent at flowrates as low as 10 ml/min. The flowmeter can be adapted with a mechanical collar or an inflatable packer assembly to direct water through the flowmeter in wells with diameters greater than 5 cm. Thus far, the flowmeter has been successfully operated at a maximum depth of 170 meters.

Application of the Electromagnetic Flowmeter

TVA has applied the technology to numerous groundwater projects. The first application was for a United States Air Force (USAF) funded project to develop and document a methodology for characterizing an aquifer's three-dimensional hydraulic conductivity field in the detail required to design an optimum network of wells and/or infiltration galleries for pump-and-treat remediation systems. Another project is an Electric Power Research Institute (EPRI) funded project to characterize the statistical properties of the hydraulic conductivity field in sufficient detail for the prediction of macrodispersion coefficients. Both the USAF and the EPRI projects occur in fluvial unconsolidated sediments. A third project is a Martin Marietta Energy Systems (MMES) funded project to develop a conceptual model of the hydrology for the network of fractures in the bedrock underlying the Oak Ridge Reservation. A fourth project is an Environmental Protection Agency (EPA) project to apply the EM flowmeter technology at three Superfund sites.

During the last several years, TVA has used the EM flowmeter as part of a generic groundwater assessment at several of its fossil plants including Colbert, Bull Run, and Johnsonville Fossil Plants. In addition, the EM flowmeter has been used to support the design of a closure plan for a CERCLA site at TVA's National Fertilizer Environment and Research Center at Muscle Shoals, Alabama.

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