

ABSTRACTS WITH PROGRAM OF
**SECOND TENNESSEE HYDROLOGY
SYMPOSIUM**

August 8-10, 1989



Sponsored by:

**U.S. Geological Survey
Water Resources Division
American Institute of Hydrology
Tennessee Valley Authority
Tennessee Department of Health and Environment
Tennessee Technological University
U.S. Army Corps of Engineers, Nashville District
U.S. Army Corps of Engineers, Memphis District
U.S. Department of Energy, ORNL**

In cooperation with:

American Water Resources Association

*Tributary to Bushman Creek near Murfreesboro, Tennessee,
Photograph by David Canaan, U.S. Geological Survey*

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Edited by
Ferdinand Quinones
and
Barbara H. Balthrop

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Nashville, Tennessee
1989

PREFACE

Water has become a critical commodity in Tennessee. In spite of a relative abundance of rainfall, with an annual average of about 46 inches, and two large river systems (Tennessee and Cumberland), the distribution in time and space of rainfall and runoff is not uniform. Significant areas of the State, particularly Middle Tennessee, are severely affected during drought periods. During the record drought of 1988, streamflows at many streams in Middle Tennessee declined to historical low levels. Surface- and ground-water supplies to many communities were severely reduced, resulting in the implementation of strict water-management controls.

Although the water-supply fluctuations induced by cyclical climate changes are a basic issue in Tennessee, perhaps the most important water-related problem the State faces pertains to the contamination of the water sources. Surface and ground water across the State are being affected by domestic, industrial, and agricultural wastes. Federal and State "superfund" sites that threaten to contaminate the most productive aquifers constitute one of the most important environmental problems Tennessee will face in the next decade. The issue of nonpoint sources of pollution and their impacts on the quality of water is critical in defining strategies for source control of contaminants. The quality of urban storm runoff and its impact on receiving water bodies is emerging as a major program to be implemented in the next few years by the U.S. Environmental Protection Agency and State regulatory organizations.

The scope of the water issues described above is well represented in the papers that were selected for presentation in this "Second Tennessee Hydrology Symposium". The issue of nonpoint sources of pollution is addressed extensively not only by one of the keynote speakers, but also through applied and theoretical research papers included in the first session. Although not designated as one of the four main sessions, the issue of wetlands and its importance in the natural environment is addressed by the second keynote speaker. The complexity of the water-related systems and problems in Tennessee makes it essential to pursue solutions that many times require simulations of these systems. The modeling section provides an insight into some of the initiatives and problems researchers face in simulating the problems on hand. The operation and management of our principal river systems, and the impact of extreme floods and droughts is extensively discussed in the third session. The concerns for contamination and water quality are presented in the papers of the fourth session.

The goals of these meetings, which we hope will continue during the next few years, are to provide a forum for the water-resources scientific community to exchange information and ideas. This forum also offers the opportunity to propose solutions to the increasing water problems Tennessee will face in the next decade. The participants and organizers of the Symposium are committed to this goal. We hope that our efforts in this activity will contribute to the solution of these problems.

Ferdinand Quinones
General Chairman,
Second Tennessee
Hydrology Symposium

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Michael C. Yurewicz (USGS), AWRA Representative

Proceedings compiler: Eva G. Baker

August 9

- 8:25 a.m. **Introduction: Ferdinand Quinones, General Chairman**
8:30 a.m. **Keynote speaker: U.S. Environmental Protection Agency Nonpoint Sources of Pollution Program: Mr. Robert F. McGhee, Chief, Water Quality Management Branch, U.S.EPA, Atlanta, Georgia**

SESSION 1A – NONPOINT POLLUTION

Moderator: *Dr. Andy Barrass, TDHE, DCGL*

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3	Effects of Storm-Water Runoff on Local Ground-Water Quality at Clarksville, Tennessee: A.B. Hoos (USGS)
5	Understanding Stormwater Management: A.J. Reese (Edge Group, Inc.)
9	Evaluation, Modeling and Mapping of Critical Bridge-Scour Conditions in West Tennessee: A. Simon, G. Outlaw, and R. Thomas (USGS)
11	Tradeoff between Nonpoint and Point-Source Controls in Water-Quality Management at Boone Reservoir: G. Hauser and M. Bender (TVA)
12	Reconnaissance of the Impact of Agricultural Chemicals on Ground-Water Quality in Haywood, Shelby, Lake, and Obion Counties, Tennessee: D. Hanchar (USGS)
13	Wetland Sedimentation in Relation to a Highway Crossing, Big Sandy River, West Tennessee: D.E. Bazemore and C.R. Hupp (USGS)
14	Evaluation of Embankment Erosion at TVA's Chickamauga Project: L. Buck (TVA)
17	Characteristics of Inflow of Pesticides and Nutrients from Storm Runoff into Reelfoot Lake, West Tennessee: J.W. Garrett and A.B. Hoos (USGS)
18	Metropolitan Nashville-Davidson County Stormwater Infrastructure Inventory-Pilot Study: W.B. Hinchey (Edge Group, Inc.)

SESSION 1B – MODELING

Moderator: *Dr. Dale Huff, ORNL-MMES*

Page/Time	
22	Hydrologic Simulation of Alternative Operation Scenarios for TVA's Reservoir Operation and Planning Review: W.G. Brock, H.M. Goranflo, B.A. Miller, and J.A. Parsly (TVA)
23	Use of a Forecasting Model to Estimate Travel Time and Dilution of Spills to White Oak Creek: D.M. Borders and D. Huff (ORNL)
27	Modeling Watershed Erosion on North Reelfoot Creek, Tennessee: R.H. Smith, L.W. Moore, and Chee Chew (MSU)
29	Results and Preliminary Interpretation of Hydrogeologic Packer Testing in Deep Core Holes at the ORNL Y12 Plant, Tennessee: H. King and S. Haase (C.E. Inc.)
30	Effects of the 1988 Drought on the Mississippi River near Memphis, Tennessee: J. Webb and D. Jones (Memphis COE)
34	Determination of the Dam Break Flood Zone Using GIS Technology: R. Smith and C. Traylor (MSU)
37	Application of Streamflow Synthesis and Reservoir Regulation (SSARR) Model to the Cumberland River Basin: J.S. Daughenbaugh, P.A. Kee, and E.L. King (Nashville COE)
42	An Evaluation of Help2 for Predicting Water Budgets of Landfills: M. Velasco and S.C. Young (TVA)
46	Application and Validation of a Groundwater Model at Oak Ridge, Tennessee: J.M. Bownds, R.H. Kettle, R.R. Lee (ORNL), and T.A. Rizk (N. Car. St. Univ.)

August 10

8:30 a.m. **Keynote speaker: Wetlands Hydrology:** *Mr. Donald Hay, Wetlands Research Corporation, Chicago, Illinois*

SESSION 2A—CLIMATE, FLOODS, DROUGHTS, AND RESERVOIR OPERATIONS

Moderator: Mr. Larry Richardson, TVA

Page/Time	
51	Climate Variations and Trends--What Are We to Expect? <i>N. Nielsen (TVA)</i>
54	Karst Hydrogeologic Investigation of the Proposed Middle Tennessee Site for the Superconducting Supercollider: <i>N.C. Crawford, R.L. Villa (Western Kentucky University), and P. Thompson (TDC/DG)</i>
58	Effects of Low-Flow Conditions on Cheatham Lake Water Quality: <i>H.A. Crouch (TTU)</i>
62	Review of Lake Level and Reservoir Release Alternatives of TVA's Reservoir Operation and Planning Review: <i>C. Ungate (TVA)</i>
63	Flood-Frequency Estimates Based on Botanical Data for Rock Creek, East Tennessee: <i>S. Kautz and B. Bryan (USGS)</i>
64	Operation of Cumberland Basin Reservoir System During Drought of 1988: <i>J. Upchurch and J. Farley (Nashville COE)</i>
69	Water-Quality Aspects of Minimum Flow and Pool Level Alternatives for the TVA Reservoir Operation and Planning Review: <i>G. Hauser (TVA)</i>
70	Analysis of the 1988 Drought in Tennessee: <i>J.D. Weaver (USGS)</i>
71	Ground-Water Use by Public Supply Systems in Tennessee: <i>S.S. Hutson (USGS)</i>

SESSION 2B—GROUND WATER AND WATER QUALITY

Moderator: Dr. William Miller, Saturn

Page/Time	
72	Hydrogeology above the Water Table: <i>G.K. Moore (UTK)</i>
73	A Water-Quality Survey of Nutrient Loadings to Center Hill Lake from Caney Fork River Basin: <i>S.J. Pucker and J.A. Gordon (TTU)</i>
77	Ground-Water Investigation of Cave Spring near Chattanooga, Tennessee: <i>A.D. Bradfield (USGS)</i>
79	Assessing Ground-Water Flowpaths from Pollution Sources in the Sinkhole Plain in Putnam County, Tennessee: <i>E.D. Hannah (DSF) and T.E. Pride and A.E. Ogden (TDHE, TTU)</i>
80	Rapid Determination of the Extent of Gasoline Contamination of a Shallow Aquifer near Jackson, Tennessee: <i>R.W. Lee (USGS)</i>
81	Oak Ridge Reservation Hydrologic-Geologic Study: Progress Report on Bedrock Geology and Potential Applications to Groundwater Investigations: <i>R.D. Hatcher and P.J. Lemiszki (UTK)</i>
82	An Assessment of Groundwater Contamination from Oil and Gas Wells in Overton County, Tennessee: <i>J.A. Gordon, A.E. Ogden, and F.H. Meriwether (TTU)</i>
86	Aquifer Characteristics and Geology at the Geohydrologic Survey Well, Humphreys County, Tennessee: <i>M.W. Bradley (USGS) and P. Craig (DuPont)</i>
87	Hydrology Components of Long-Term Ecological Research and Monitoring in the Great Smoky Mountains: <i>R. Brown (TTU)</i>

EFFECTS OF STORM-WATER RUNOFF ON LOCAL GROUND-WATER QUALITY
AT CLARKSVILLE, TENNESSEE

By Anne B. Hoos

U.S. Geological Survey, Nashville, Tennessee

Storm-water runoff from urban areas has been recognized as a source of contamination to receiving surface- and ground-water bodies. In many karst areas, drainage wells have been installed to accept storm-water runoff from urban areas in order to reduce surface flooding. This diversion can introduce contaminants into the ground-water system, and thus alter the quality of ground water downgradient from the drainage well. The U.S. Geological Survey, in cooperation with the Tennessee Department of Health and Environment, Division of Construction Grants and Loans, has been investigating the impacts to ground-water quality from diverting urban runoff to drainage wells. Storm-related data were collected from a drainage-well site and nearby Mobley Spring in Clarksville, Tennessee, to (1) characterize the quality of the receiving ground-water body during base flow as well as stormflow conditions, and (2) estimate the storm loading rates of selected constituents to the local ground water from runoff entering the drainage well.

Evaluation of the impact on local ground water caused by storm-water runoff is complicated by the presence of other sources of contaminants in the area. Concentrations and loads of most constituents in storm-water runoff at the drainage-well site were much smaller than concentrations and loads at Mobley Spring. This indicates that the principal quantities of these constituents are coming either from natural sources, or from some other source(s) of contamination in the ground-water basin. The exceptions to this are for constituents associated with roadway runoff: arsenic, copper, lead, organic carbon, and oil and grease, indicating that the drainage-well watershed may be contributing relatively large amounts of these constituents to local ground water during storms. The close correlation between concentrations of total organic carbon and most trace metals at the drainage-well site and Mobley Spring suggests that these constituents are transported together. Many trace metals were flushed early during each runoff event.

Storm-water quality at the drainage-well site and Mobley Spring was compared to background water quality of the local aquifer, as characterized by dry-weather samples from three springs and two observation wells in the Clarksville area. Concentrations of total recoverable cadmium, chromium, copper, lead, and nickel were higher in many storm-water samples from both the drainage-well site and Mobley Spring than in samples from any other site. In addition, concentrations of total organic carbon, methylene blue active substances, and total recoverable oil and grease were generally higher in storm-water samples from the drainage-well site than in any ground-water sample.

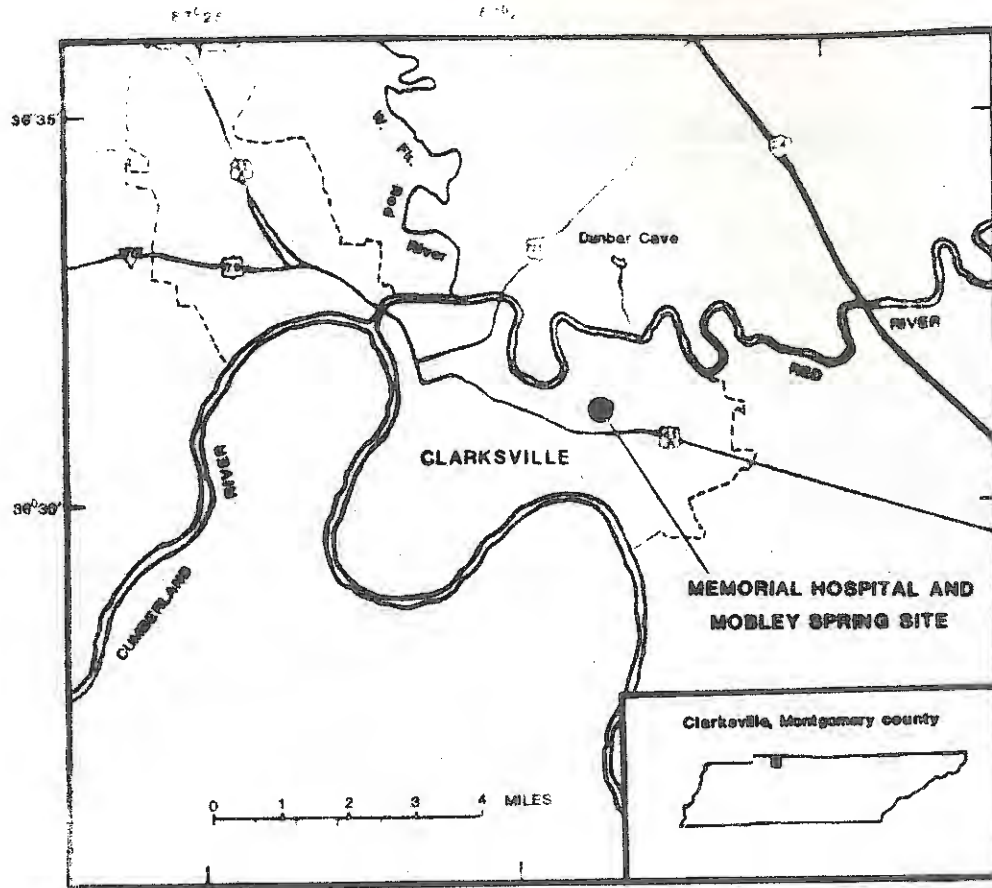


Figure 1.--Location of study area in Clarksville, Tennessee

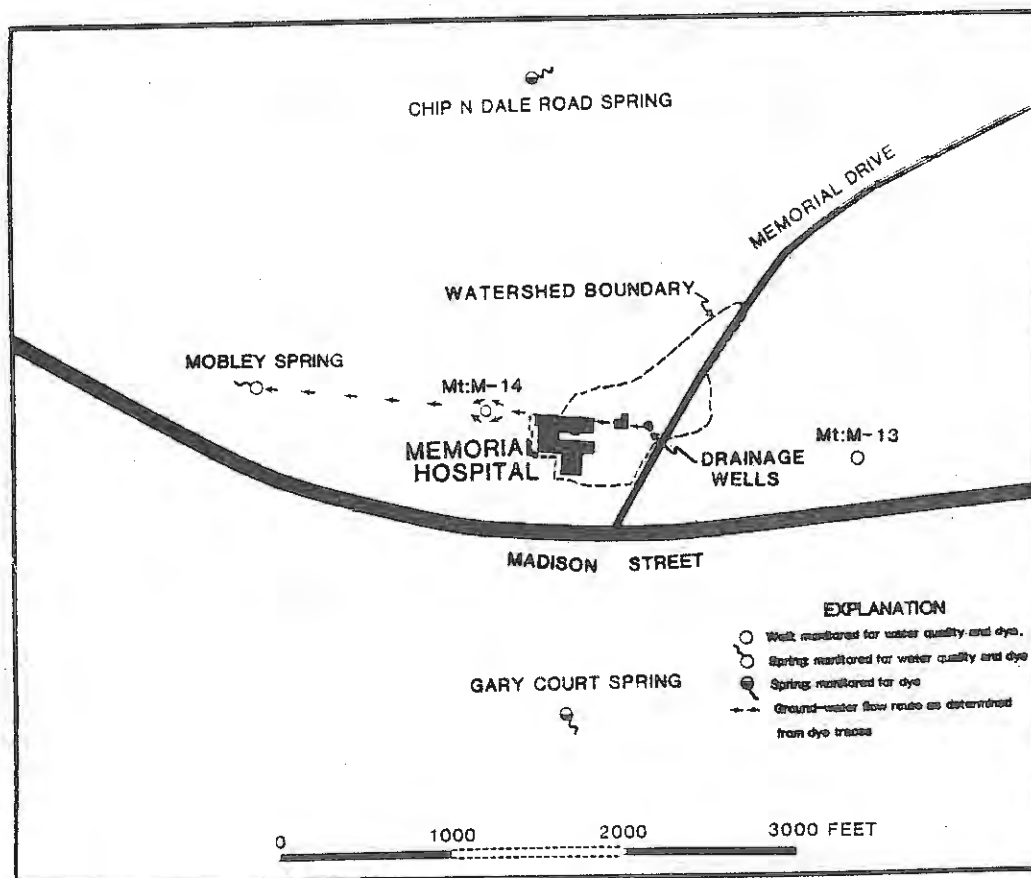


Figure 2.--Memorial Hospital and Mobley Spring area and location of drainage wells, observation wells, and springs

UNDERSTANDING STORMWATER MANAGEMENT

By Andrew J. Reese

INTRODUCTION

The term "stormwater management" means different things to different people. To the municipal administrator it often means a drainage study to "solve Mrs. Smiths backyard flooding". It might mean "floodplain management" to the community FEMA representative; or "water quality enhancement" to the environmentalist. Whatever its meaning or eventual activities, an ordered understanding of its various components is essential to proper control of stormwater.

A typical program begins when a particular problem becomes apparent. Usually it is flooding, erosion, water quality and/or drainage infrastructure problems. The solution normally is to fix the individual problem. However, a "quick fix" solution to the apparent problem is rarely a permanent solution because it rarely addresses the underlying issues and root causes.

The Nashville situation will be used to illustrate briefly an understanding of stormwater management. Based on a national study performed by the EDGE Group, the situation in Nashville is typical for cities in the southeast.

METHOD: UNDERLYING ISSUES ANALYSIS

Figure one below illustrates the underlying issue or root cause phenomenon. Level 5 is the apparent or presentation level of the problem. It is the type of problem most staff personnel encounter day-to-day. Some immediate causes and possible solutions are found at level 4. Many "stormwater management" programs end at this level. Therefore the problems, which really originate or are generated in lower levels, continue to surface when tested by storm events or time.

Nashville, Tenn., for example, experiences a number of level five stormwater management problems. Major flooding occurs or is expected to occur in many locations. One estimate puts average annual damages from flooding at about four to five million dollars. Major capital improvements could cost more than fifty million dollars. Minor drainage complaints outnumber all other complaints about eight to one. Though water quality sampling of urban runoff is not yet performed for first flush and event mean concentration, it can be expected that there exist a number of locations with degraded water quality due to stormwater pollution transport. Combined sewers and sewer seepage are also problems. Erosion is a problem in reaches where urbanization pressures on banks attack and widen the primarily bedrock channels.

Level four problems/causes are also apparent in Nashville. For example, urbanization impacts are expected to cause a flood peak frequency shift in reaches of McCrory Creek such that the ten-year peak event becomes roughly the two-year event, with corresponding shift in the existing 100-year event. The rural and urban USGS regression equations for Tennessee bear this out for the general situation as well. Some homes are simply located too close to the streams.

Some reasons for the large and growing number of complaints in the Nashville urban area are found at level three. Maintenance is normally driven by complaints rather than scheduled. Fifty percent of the conveyance structures in the Nashville system are clogged or damaged to some extent. It is estimated that about ten to thirteen million dollars are needed for one-time remedial maintenance of the drainage infrastructure in Nashville while about four to five million should be spent annually on routine maintenance. City staff have little way to assess the impacts of the use or non-use of detention on flood problems downstream from potential development; even when the frequency and magnitude of flooding downstream is known. Enforcement and detailed inspection is infrequent. Staffs are undermanned and some activities are not covered at all. Designs are sometimes inadequate and reviewers spend a perceived disproportionate amount of time in plans review.

The immediate reasons for stormwater management problems of this type almost always are insufficient authority and lack of adequate and stable funding (Level 2). Enforcement is difficult with inadequate ordinances, diffuse responsibility and small staffs. General fund dollars often must go to higher priority needs such as landfills and transportation.

Often the most effective means to finance a stormwater management program has been found to be the use of a stormwater utility, similar to a sewer or water utility. Charges are based on total land and percent imperviousness.

But the root causes (Level 1) are almost always lack of political consensus and poor public awareness and support. Where politicians have an understanding of and support stormwater initiatives and the public is aware of the problem, it has been amply demonstrated, effective stormwater management flourishes. The stormwater conveyance system must be thought of as a public utility just as necessary to plan, construct and maintain as water supply and sewer. Strong support is needed on a city or municipal staff, from key political leaders and from key citizen leaders or groups. Consensus building is of paramount importance.

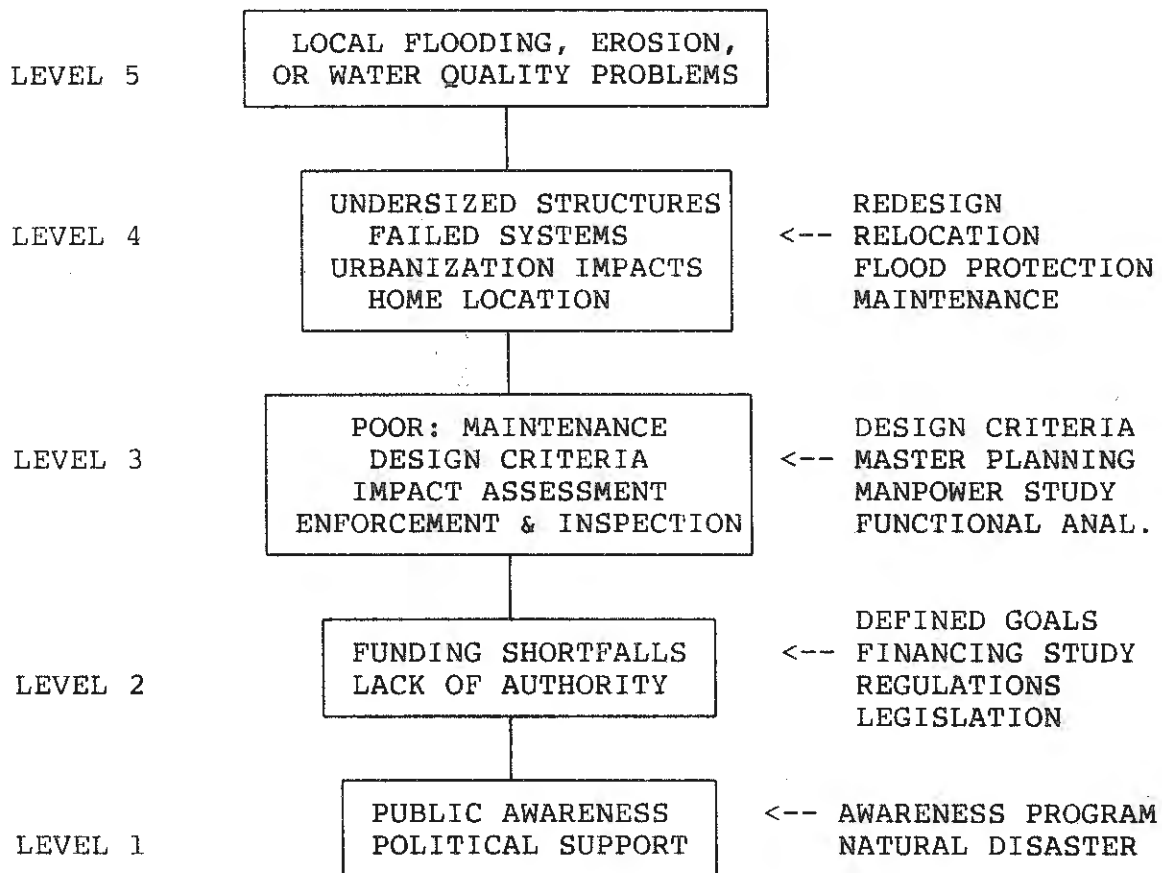


Figure 1.--Levels of stormwater management problems, causes and solutions

STORMWATER MANAGEMENT STRUCTURE

From the discussion of this figure an ordered approach to understanding and solving stormwater management problems can be developed. As shown in Figure 2, stormwater management consists of both technical and institutional aspects. The higher numbered more visible levels are primarily technical. The root causes are primarily institutional. When properly conceived, regulations and ordinances span the gap between the two by pairing institutional goals or concerns with technical solutions through the use of performance oriented criteria.

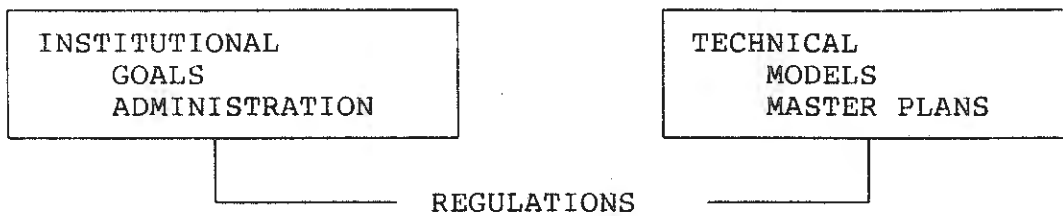


Figure 2.--Stormwater management structure

A stormwater management program must address problems and causes simultaneously at as many of the levels as possible to both solve physical problems and prevent the generation of similar problems due to more basic obstacles. Master planning is often the vehicle for stormwater management to achieve success.

MASTER PLANNING

Stormwater master planning plays a key role in identifying existing and future problems, opportunities for enhancement of stormwater use, cost estimates, impact assessment and assigning priorities. Even master planning does not address the core issues unless it explores, however summarily, other than strictly technical aspects. After the needs and problems have been thoroughly identified and root causes uncovered the master planning process moves, in turn, through identifying constraints to possible solutions and assessment of an appropriate technical approach to find useful solutions.

SUMMARY AND CONCLUSIONS

Stormwater problems have both a technical and institutional side. The technically based person is in the best position to cultivate and bring to maturity a stormwater management program because he or she can understand both the technical and institutional requirements of such a program better than his or her non-technical counterpart. Therefore, technical persons must become involved and adept in the institutional side of stormwater management for a program to be successful.

EVALUATION, MODELING, AND MAPPING OF CRITICAL BRIDGE-SCOUR CONDITIONS IN WEST TENNESSEE

By Andrew Simon, George S. Outlaw, U.S. Geological, Nashville, Tenn.
and Randy Thomas, U.S. Geological Survey, Memphis, Tenn.

Evaluation of channel conditions and bridge characteristics in West Tennessee are used in conjunction with flow and sediment modeling to estimate depths and volumes of scour. Field inspections of all State Route bridges between the Mississippi and Tennessee Rivers are used to identify combinations of geomorphic, vegetation, and bridge-related variables that result in a high potential for significant amounts of scour. Some of the diagnostic variables are obvious such as pier skew, longitudinal differences in channel width (contracted openings), and type of bed material. However, several variables that are related to high scour potential are more subtle and include stage of channel evolution, vegetation ages and percentage of cover, potential for debris production upstream, debris accumulation, and type of bank material.

The streams of West Tennessee have been periodically channelized since the turn of the century, and as a result are undergoing dramatic changes in plan and profile. The most dominant factor affecting the potential for critical scour appears to be related to these system-wide channel adjustments; particularly the full-scale channel widening that follows bed degradation. These processes result in an over-widened section upstream of the bridge compared to the protected bridge opening. During high flows, backwater conditions upstream from bridges cause lower velocities and reduced sediment transport into the bridge section. Erosion of the bed occurs just downstream of the bridge as a result of the increased velocities and bed shear derived from the hydraulic drop through the opening. The imbalance between reduced bed-material transport entering the bridge section and the heightened transport capacity exiting the section maintains the condition of general scour over a wide range of flow conditions. This condition is exacerbated if the bed material is silt (as opposed to sand) because of the absence of a fill sequence on the falling limb of storm hydrographs. Scour holes up to 30-feet deep have been observed along silt-bed channels; up to 17-feet deep along streams with sand beds. In either case, additional widening can occur along the scoured reach of channel because of excessive bank heights, resulting in the classic 'blowhole' form.

The second most important factor relating to scour and potential bridge failure in West Tennessee appears to be the accumulation of debris on the upstream side of piers. Failure of a large State Route bridge on the Obion River in 1974 occurred following 9 years of aggradation that decreased channel capacity by 39 percent. Channel capacity at the bridge was further reduced by the collection of a large rack of debris on the two main piers that caused large-scale eddies, additional bed scour, and bank failures during high flows. Failure of the bridge can be attributed in part to accumulation of debris and the resulting

increase in velocities through the contracted opening. Most of the debris that became lodged on the upstream side of the bridge was woody vegetation transported to the structure from failed banks upstream. The potential for debris accumulation on adjusting channelized streams is a function of the magnitude and extent of upstream states of channel widening. During flow modeling of similar scenarios, debris accumulation is accounted for by increasing Manning's 'n', and by reducing the size and configuration of the bridge opening.

For those bridge sections that rank high in terms of potential scour, modeling is accomplished using two techniques: (1) 1-D sediment modeling that distributed erosion equally across the section and is based on sediment-transport capacity, and (2) sediment modeling that used sediment-transport equations, and is based on a mass-balance approach between sections upstream, downstream, and at the bridge. Both methods provide realistic estimates of depths and volumes of general scour. For locations determined to be susceptible to localized critical scour (around piers), 1-D modeling will be applied over two dimensions using a stream-tube model.

Brief (1 hour) inspections of both bridge characteristics and channel conditions at roughly 1,100 sites in West Tennessee have been used to identify those bridges with high potential for critical bed scour. These data can be displayed on geographic information system-based (GIS) maps to provide diagnostic information on a county-wide basis. Data such as scour depth and elevation of the scoured bed relative to the elevation of caps and footings are also mapped with GIS; thereby providing a quick method to locate the most critical scour problems.

TRADEOFFS BETWEEN NONPOINT AND POINT SOURCE CONTROLS
IN WATER QUALITY MANAGEMENT OF BOONE RESERVOIR

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Merlynn D. Bender

TVA Engineering Laboratory
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In cooperation with EPA and TDHE, TVA investigated the cost-effectiveness of nonpoint and point source pollution abatement schemes for water quality improvement in downstream Boone Reservoir. Nonpoint pollution sources include runoff from livestock operations, cropland, urban areas, construction activities, and failing septic tanks. Point sources include five municipal and industrial treatment plant effluents. Costs and loading reductions into Boone Reservoir were determined for a range of control technologies, and effects of these reductions were simulated using a two-dimensional water quality model of the reservoir. Results were compared to a pretreatment case in terms of algal biomass, nutrient concentrations, and volume of reservoir with depleted dissolved oxygen.

Results indicated that:

- (1) A modest improvement in water quality could be achieved with nonpoint source controls at a cost about a third of that using point source controls;
- (2) Major improvements in water quality would require both nonpoint and tightened point source controls in the upstream watershed and would be expensive;
- (3) Algal biomass would decrease by 40% and low DO volume would decrease by 80% with all point and nonpoint source control technologies implemented simultaneously.
- (4) A surplus of nutrients now enters Boone Reservoir stimulating algae growth that is usually phosphorus-limited. Significant nutrient reduction would be required to achieve noticeable algal biomass reductions and oxygen improvements.
- (5) Direct oxygen demands of ammonia-N and BOD and seasonal hydrology also exert important influences on Boone Reservoir water quality.

RECONNAISSANCE OF THE IMPACT OF AGRICULTURAL CHEMICALS
ON GROUND-WATER QUALITY IN HAYWOOD, SHELBY, LAKE,
AND OBION COUNTIES, TENNESSEE

By Dorothea Withington Hanchar
U.S. Geological Survey

ABSTRACT

Data are sparse on the impact of agricultural chemicals on ground-water quality in Tennessee. Because of the importance of the surficial alluvial aquifer to domestic water supplies in West Tennessee, and because the shallow aquifer would be the first aquifer affected by any surficial contamination from agricultural chemicals, shallow wells in Haywood, Shelby, and Lake, and Obion Counties in West Tennessee were chosen for sampling ground water for nitrogen species and pesticides. This investigation was conducted by the U.S. Geological Survey in cooperation with the Tennessee Department of Health and Environment, Division of Construction Grants and Loans. Nineteen shallow wells drilled in areas of high density agricultural use were completed into the alluvial aquifer and were sampled during the winter and summer of 1988 to ascertain any possible impact of agricultural practices on ground-water quality. Although no triazine herbicides or organophosphorous insecticides were detected in any of the wells sampled, elevated nitrite plus nitrate (as nitrogen) concentrations indicate an adverse effect of agricultural practices on water quality. Results from the winter sampling period indicate a range of nitrite plus nitrate as nitrogen concentrations of less than 0.1 to 7.8 milligrams per liter with a median of 2.6 milligrams per liter. Results from the summer sampling period indicate a range of nitrite plus nitrate as nitrogen concentrations of less than 0.1 to 8.9 milligrams per liter, with a median of 2.5 milligrams per liter. The highest of these concentrations occurred in the shallowest wells, and, in one instance, in a shallow well located near a heavily irrigated field.

WETLAND SEDIMENTATION IN RELATION TO A HIGHWAY
CROSSING, BIG SANDY RIVER, WEST TENNESSEE

D.E. Bazemore and C.R. Hupp
U.S. Geological Survey, Nashville, Tenn.

Spatial and temporal variation of sediment deposition are documented to assess the effects of a highway crossing (causeway) on sedimentation in a forested bottomland along the Big Sandy River in West Tennessee. Dendrogeomorphic techniques are used to determine rates of deposition by sampling individual trees for age and for depth to their germination surface below the present ground surface. Two hundred sixty trees were sampled for age and depth to germination surface along upstream-downstream transects aligned perpendicular to the causeway. This sampling provides detailed information on the areal distribution of sediment deposition. Deposition rates determined for trees grouped by age display trends over time. Mean rates of fine-grained (clay and silt) deposition ranged from -0.1 to 0.7 centimeters per year. Localized areas with high rates of fine-grained deposition were identified both upstream and downstream of the causeway. Fine-grained deposition rates varied with elevation and transect location,; but no overall variation was observed upstream versus downstream of the causeway. Micro-patterns of flow (and ponding) due to floodplain topography appear to be more important than the causeway in fine-grained deposition. However, sand splays downstream of the bridge opening are fairly extensive and occur downstream at least 600 meters. This downstream sand deposition appears to be related to constricted flow through the bridge. Channel-bed aggradation because of backwater from a downstream lake may contribute to the magnitude of the sand deposition.

Analysis of trends of fine-grained deposition rate through time suggests that from 80 years ago (age of oldest trees) to around 40 years ago, annual-deposition rates were decreasing; then rates began increasing to the present. This temporal pattern is not likely a result of the causeway because the causeway was in place for about 30 years before the apparent trend reversal occurred. Timing of the trend reversal suggests it could be related to the creation of the Big Sandy Dewatering Lake in 1944 downstream from the study site. Filling of this lake has increased the base level of the Big Sandy River. This increased base level has contributed to more frequent and sustained inundations of the site since 1944. The causeway does not appear to have a widespread or significant effect on the deposition of fine-grained sediment; however, the constriction of flow does appear to effect deposition of sand downstream.

EVALUATION OF EMBANKMENT EROSION
AT TVA'S CHICKAMAUGA PROJECT

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Civil Engineer, Flood Hazard Analysis
Flood Protection
Tennessee Valley Authority
(615) 632-6118

INTRODUCTION

The Chickamauga project was constructed by TVA in the late 1930's and early 1940's. It is located on the Tennessee River at mile 471.0 in Hamilton County about 7 miles upstream of Chattanooga, Tennessee. The project consists of impervious rolled earthfill embankments and a concrete structure which includes an 18-bay spillway, 4-unit powerhouse, and navigation lock. The maximum height of the concrete structures is 129 feet, and the compacted earthfill embankments are 40 to 50 feet high. Chickamauga Dam impounds 628,000 acre-feet of storage at normal maximum pool.

TVA, like other State and Federal agencies, is currently evaluating the hydrologic safety of its existing dams for conformance to present-day criteria. The probably maximum flood (PMF) is being used for our evaluation at the Chickamauga project because of the magnitude of the social, economic, and environmental consequences that would result from dam failure. The project, as it is, can pass a flood equivalent to about 77 percent of the PMF without overtopping. It is estimated that the probability of such a flood being exceeded in any year is in the order of 1/200,000 or 1/2,000 in a 100-year period.

METHODS AND PROCEDURES

The extent of embankment erosion to be expected under PMF conditions was evaluated using the recently released EMBANK computer model. EMBANK is a state-of-the-art computer model developed by Simons, Li and Associates of Fort Collins, Colorado, under contract with the U.S. Department of Transportation and U.S. Department of Agriculture to determine hydraulics of overtopping flow and associated erosion damage. The EMBANK model is based on physical processes which consider the erosion potential of overtopping flow and the strength of the embankment to resist erosion. The model (1) computes the unit width discharge over an embankment section for a given headwater elevation; (2) corrects the unit width discharge for submergence and determines the water surface profile, including hydraulic jump conditions, for the corresponding tailwater elevation; (3) computes the velocity and corresponding flow shear stress; and (4) determines the extent of embankment erosion for a given duration of overtopping.

The headwater and tailwater elevation hydrographs used in the erosion study were determined by TVA's unsteady flow routing model. These represent the water surface elevations reached when routing the PMF through the existing Chickamauga project assuming no erosion or failure of the embankments when overtopped. The computed maximum headwater and tailwater elevations are 716.2 and 711.6, which are 10.2 and 5.6 feet above the top of the existing embankments (elevation 706.0) respectively.

From the standpoint of embankment erosion, the use of these elevation hydrographs is conservative because the differential between headwater and tailwater (HW/TW) levels is maximized. If the additional flow over the eroded embankments was considered, the HW/TW differential would be smaller and the resulting erosion would be less.

RESULTS

The rate of erosion is influenced by the flow velocity over the embankments. The velocity depends on the water-surface profile which is in turn influenced by headwater and tailwater conditions and the location and extent of hydraulic jumps. When overtopping begins, the HW/TW differential is at its maximum (about 11 feet) and locally high velocities resulting from hydraulic jumps on the downstream embankment slopes initiate erosion. The embankments are submerged by tailwater after about 1 day of overtopping and the hydraulic jumps subside. As the PMF progresses, the HW/TW differential has decreased to about 6 feet, and hydraulic jumps are again occurring on the downstream slopes. The computed maximum tailwater elevation (711.6) occurs about 18 hours later. After about 3 days of overtopping, the HW/TW differential has decreased to about 3 feet and the hydraulic jumps subside. The embankments have eroded to about their final levels after about 4 days of overtopping. At this point the HW/TW differential is less than 2 feet and velocities are nonerosive. Overtopping from start to finish would last about 4.5 days.

The embankment erosion is most sensitive to the HW/TW differential. The headwater elevations are based on discharge ratings which are in turn influenced by tailwater conditions due to submergence. The tailwater elevations depend primarily on (1) channel geometry and (2) energy losses. The influence of Nickajack Dam on tailwater levels is relatively minor because the constricted gorge section downstream of Chickamauga Dam acts as a hydraulic control. In order to simulate expected conditions, the existing cross sections downstream to Nickajack Dam at mile 424.7 have been enlarged to account for the postulated channel scour during the PMF. Two conditions were evaluated: (1) low tailwater conditions which assume minimum energy losses and (2) high tailwater conditions which assume energy losses based on doubled roughness values. The EMBANK predicted extent of embankment erosion for these tailwater conditions would extend to about elevation 679 which is 4 feet above the normal minimum pool at elevation 675.0.

SUMMARY AND CONCLUSIONS

The results of the EMBANK model study using best estimates for the various model parameters indicate that the embankments would erode to about elevation 686.0, which is 3.5 feet above the normal maximum pool at elevation 682.5. The results of the sensitivity analysis indicate that the embankment erosion would extend to about elevation 679 which is 4 feet above the normal minimum pool at elevation 675.0.

Based on the results of erosion and structural stability studies, it is concluded that a PMF would damage the dam by overtopping, but breaching would not occur. Therefore, leaving the dam as it is becomes a viable option. This option will be further evaluated to assure that is an economically, socially, environmentally, and politically acceptable solution and reviewed periodically as overtopping research and technology progresses.

CHARACTERISTICS OF INFLOW OF PESTICIDES AND NUTRIENTS FROM STORM
RUNOFF INTO REELFOOT LAKE, WEST TENNESSEE

By J.W. Garrett and A.B. Hoos
U.S. Geological Survey, Nashville, Tenn.

Storm runoff for tributaries to Reelfoot Lake is expected to contain considerable amounts of suspended sediment along with residues of fertilizers and pesticides, because of the high level of agricultural activity in the area surrounding the Lake. Previous sediment studies conducted by the U.S. Geological Survey indicate that between 150,000 and 200,000 tons of suspended sediment are delivered to Reelfoot Lake annually. The primary source of sediment is the bluff area to the east, which is drained by North and South Reelfoot Creek, and to a lesser extent the area north of the lake, which is drained by Running Slough. The annual budget of nutrients and pesticides entering the lake from these sources, and the extent contribution by storms, have not been adequately defined. The Geological Survey, in cooperation with the Tennessee Department of Health and Environment, is currently conducting a 2-year study of streamflow and water quality of the three tributaries flowing into Reelfoot Lake. Daily streamflow and storm and annual loads of suspended sediment, nutrients, and triazine herbicides, will be computed for each station. Storm loads of suspended sediment, total organic and ammonia nitrogen as N, and total phosphorus, as P, were computed for the North Reelfoot Creek station for the storm of November 18-22, 1988, as 13,300, 22, and 13 tons, respectively.

METROPOLITAN NASHVILLE-DAVIDSON COUNTY
STORMWATER INFRASTRUCTURE INVENTORY PILOT STUDY

By
W. Byron Hinchey

INTRODUCTION

A vast amount of Metro Nashville has open ditches with culverts and bridges instead of storm sewers for carrying stormwater runoff. Due to the rate of growth in Nashville throughout the eighties, the Metro Department of Public Works (MDPW) has been unable to track and service the overwhelming amount of culverts being installed. Therefore, a pilot study was conducted for MDPW to assess the general condition of the stormwater infrastructure in Metro Nashville. The study addressed questions about maintenance needs, location and density of structures, and conditions expected throughout the Metro area.

Davidson County covers an area of approximately 533 square miles of which 30.2 square miles or 5.6 percent were inventoried in this study. The study area included portions of the Whites Creek, Browns Creek, Richland Creek, East Fork Hamilton Creek, and Pages Branch watersheds. These watersheds were selected as a sampling base because they include a variety of known landuse conditions, and they coincide with areas currently being studied under a comprehensive stormwater management project.

Drainage structures inventoried for this study were limited to those with an equivalent diameter of 15 inches or greater that were located on, or passing through, the public right-of-way. Only surface drainage structures such as culverts and bridges were inventoried. Storm sewers were excluded from this study.

PROCEDURES

Topographic maps at a scale of 1"=400' were used to locate structures and to keep a record of areas being inventoried. Data were collected in two ways: approximate structure locations and lengths were drawn on the field maps, and various data about the structures were recorded on coding forms. The data collected were subjected to a number of quality control measures and then entered into an electronic spreadsheet. The spreadsheet provided an organized display of the data and allowed editing and retrieval to be performed easily and quickly.

Map numbers, approximate state plane coordinates, and descriptive locations were used to describe the location of structures.

Material, shape, size, and length were obtained to physically describe the structures themselves. Structures were evaluated based on several items which included structure condition, flow obstruction, and flooding potential. Using data collected on these three items, structures were placed into maintenance categories that describe the level of attention needed at the structures.

RESULTS

The study area was analyzed by landuse category to determine if landuse had any bearing on maintenance needs. For the purpose of this study, landuse was divided into four categories as follows:

1. Small-lot residential areas (lots <1/2 acre)
2. Large-lot residential areas (lots >1/2 acre)
3. Commercial and industrial areas
4. Open or undeveloped areas such as woods, pastures, and croplands

Results did not show any distinct correlation between landuse and maintenance needs.

A total of 2,879 structures were inventoried in the study area (30.2 square miles) resulting in an average structure density of 95.3 structures/square mile. The average structure density in the four landuse categories were 118.3, 218.9, 91.7, and 20.9 structures/square mile, respectively. A summary of results for structure condition, flow obstruction, and flooding potential is presented in Figures 1, 2, and 3, respectively.

Structures were grouped into maintenance categories based on the results of their structure condition, flow obstruction, and flooding potential. Approximately 48.2 percent of the structures inventoried were in good working order and require no maintenance. Routine maintenance and potential structure repair or replacement is recommended for approximately 26.0 percent of the structures inventoried to maintain system integrity. Routine maintenance and potential structure repair or replacement is recommended for approximately 25.8 percent of the structures inventoried to alleviate existing or potential flooding problems.

A 30.2 square mile study area was utilized for this inventory, and a variety of geographic and landuse conditions were sampled. Assuming the results of this study are representative of conditions throughout Metro Nashville, the following conclusions can be made. The condition of the drainage structures is relatively good with only 8.7 percent of the structures in Nashville needing repair or replacement. However, a large portion of the drainage structures (51.8 percent) have some degree of obstruction that will reduce the flow carrying capacity of the structures. These results suggest that an emphasis be placed on cleaning out drainage structures to improve the capacity of the storm drainage system.

DISTRIBUTION OF STRUCTURES
BY STRUCTURE CONDITION

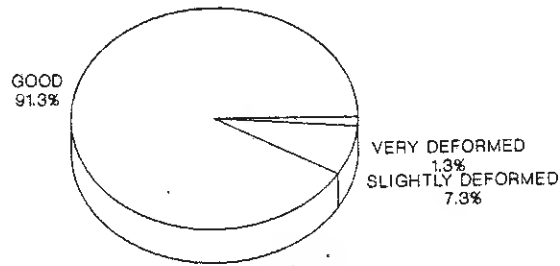


Figure 1

DISTRIBUTION OF STRUCTURES
BY FLOW OBSTRUCTION

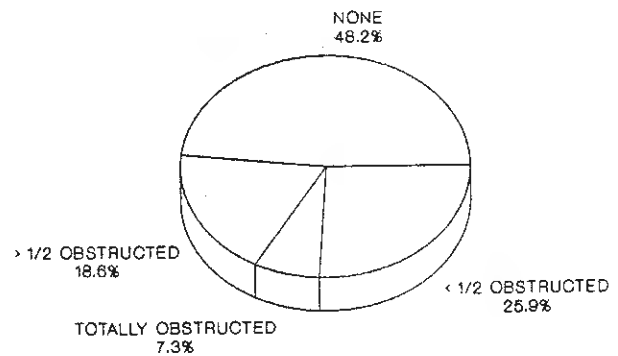


Figure 2

DISTRIBUTION OF STRUCTURES
BY FLOODING POTENTIAL

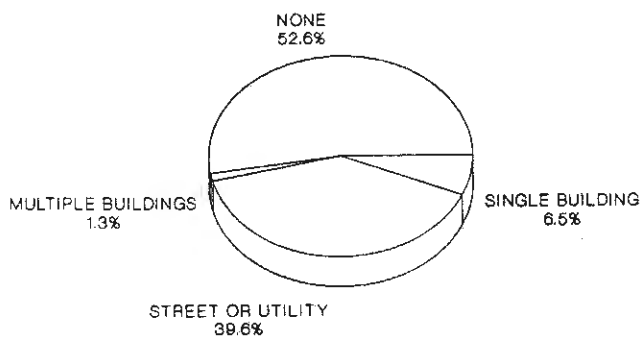


Figure 3

CONCLUSIONS

This pilot stormwater infrastructure inventory was used to estimate the overall condition of the stormwater infrastructure and define what problems exist. A complete inventory of the storm drainage system in Nashville is recommended as a planning tool that MDPW can use to better scrutinize drainage plans for proposed developments and identify deficient areas of the system to aid the direction of the stormwater maintenance program.

HYDROLOGIC SIMULATION OF ALTERNATIVE OPERATION SCENARIOS
FOR TVA'S RESERVOIR OPERATION AND PLANNING REVIEW

W. Gary Brock, H. Morgan Goranflo, Barbara A. Miller,
and James A. Parsly - TVA

In support of TVA's Operation and Planning Review, it was necessary to utilize mathematical modelling tools to accurately simulate operation of the TVA-operated reservoir system for various operation policies. Prior to the study, a mainframe computer model had been developed and implemented for planning and operation studies. However, this model required extensive computer resources, and specialized staff to codify the various policy changes and manage the data input and model output. Considering the number of alternative scenarios to be addressed as part of this planning review, it was decided to make extensive changes to the model to allow for less expensive simulations, faster turnaround time, and greatly reduced staff time.

The resulting product was a PC version of the Weekly Scheduling Model, capable of simulating operation of 42 reservoirs on a weekly time step for 86 years of available hydrologic data, requiring about 2 hours of computer time on a 386-type machine. The model allows the user to enter operation policies in the form of priority constraints on releases or elevations for each project. Higher priority constraints are satisfied first, and lower priority constraints are then satisfied to the extent they do not violate any constraints of higher priority. Results of the model include weekly releases, elevations, and generation at each project for the entire historical record. These results can then be analyzed by various interest groups to determine how their objectives or program interests would be impacted by the policy changes modelled.

The presentation includes an overview of the model, various constraints and constraint forms, and a discussion of some of the scenarios which were modelled.

USE OF A FORECASTING MODEL TO ESTIMATE TRAVEL TIME AND DILUTION OF SPILLS TO WHITE OAK CREEK

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Environmental Sciences Division
Oak Ridge National Laboratory

INTRODUCTION

As a consequence of the abnormal release of radionuclides from White Oak Creek (WOC) late in 1985, several notable problems became evident. It was recognized that no predetermined criteria existed for operation of White Oak Dam (WOD) under emergency response conditions. Contaminant transport and dispersion within the WOC drainage system and downstream in the Clinch River were not adequately characterized to support requests for modified reservoir releases to achieve safe dilutions. Furthermore, real-time data on streamflow, precipitation, and water quality within the watershed were not readily available in sufficient quantity and usable format. The modeling study was initiated to address these problems.

As part of a comprehensive task to develop improved capabilities for managing accidental releases of contaminants into streams, a model that forecasts streamflow, travel time, and downstream concentrations resulting from spills has been implemented at the Oak Ridge National Laboratory (ORNL). The Streamflow Synthesis and Reservoir Regulation (SSARR) model is being used to examine emergency response alternatives to accidental spills into the White Oak Creek watershed from ORNL facilities. The model simulates streamflow using hydrologic parameters and meteorologic data to reproduce runoff conditions at the time a spill occurs. A forecast of the expected flows and concentrations is made from a quantitative precipitation forecast and parameters describing the characteristics of the spill.

METHODS AND PROCEDURES

A procedure has been established for using ORNL's SSARR model results as input to the Tennessee Valley Authority (TVA) Clinch River dispersion model to predict the fate of contaminant releases discharged at WOD. The SSARR model has been used to simulate rainfall runoff and streamflows within the WOC watershed (Fig. 1), water levels and storage volumes in White Oak Lake (WOL), and the routing of contaminants released from ORNL facilities through stream reaches and WOL to subsequent release at WOD. SSARR model output includes discharge and contaminant mass flux from WOD. The Clinch River dispersion model has been employed to calculate the time of travel and concentrations of contaminants at downstream locations at the water intakes to the Oak Ridge Gaseous Diffusion Plant (K-25) and to the City of Kingston. The dispersion model utilizes SSARR model output as well as TVA reservoir elevations and

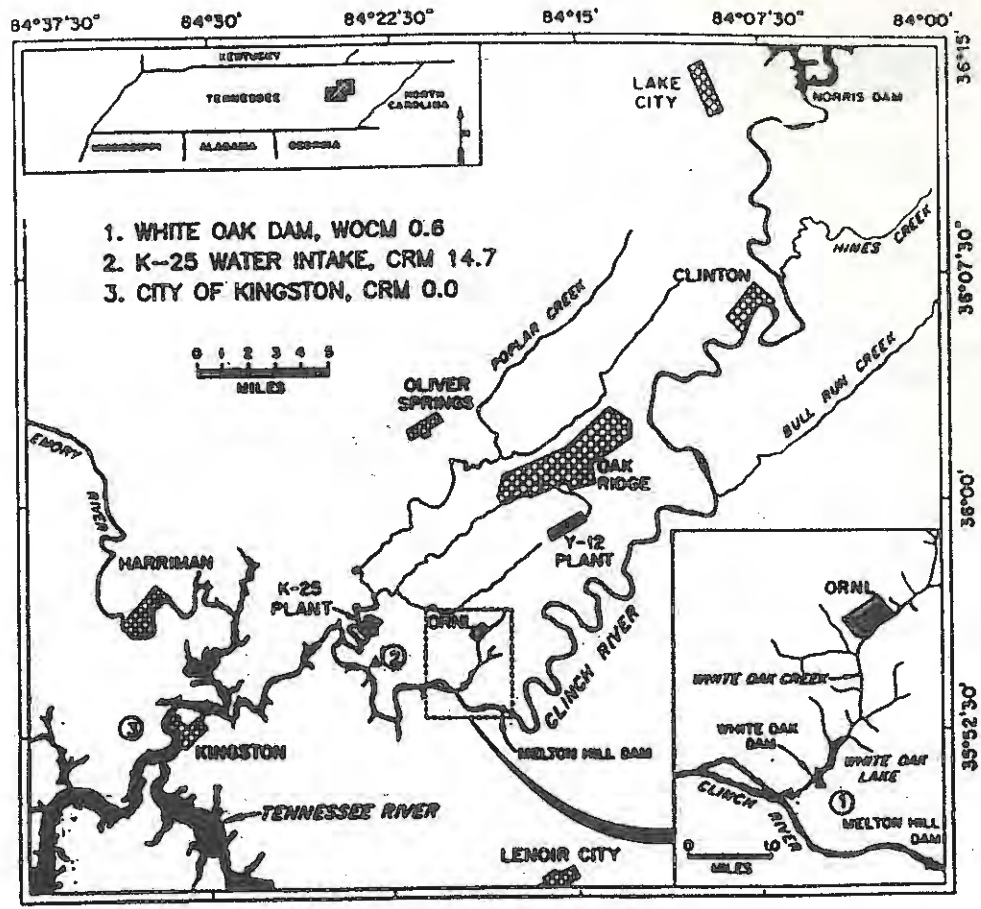


Fig. 1 White Oak Creek and Clinch River System.
 Simulated White Oak Lake and Clinch River Response
 to Contaminants Released from ORNL

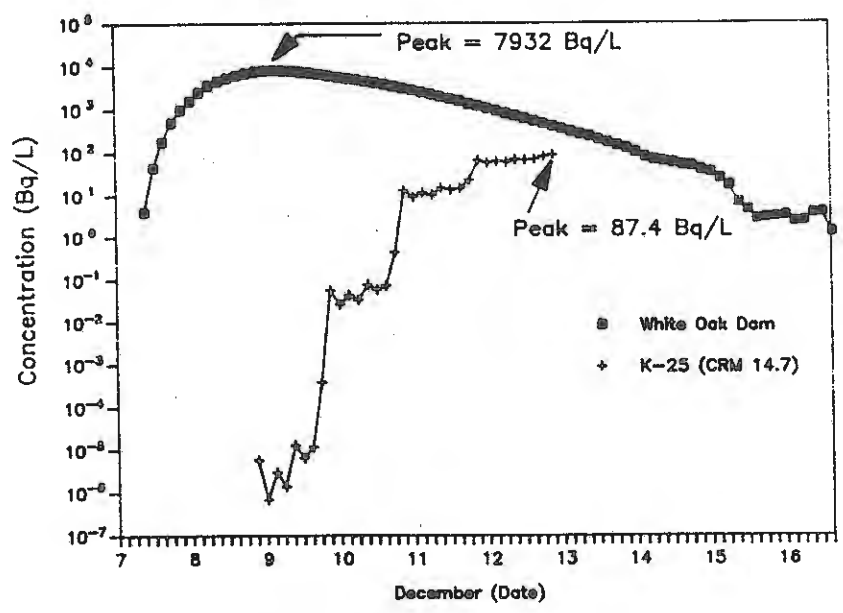


Fig. 2 Simulated response of the White Oak Lake/Clinch River system to a slug release of liquid containing 0.01 Curies (3.7 E+8 Becquerels) of Sr-90.

releases to calculate hourly concentrations resulting from contaminants released at WOD.

For emergency response applications, the model has been used to simulate releases for typical streamflow conditions. An emergency response casebook of spill scenarios has been developed to facilitate the rapid response and decision making required in the event of an accidental release of contaminants into the surface waters of the WOC watershed. The casebook contains a summary of expected travel times and dilution factors for spills originating from ORNL facilities. It can be used to evaluate possible courses of action, such as closing the gates at WOD or requesting modification of release schedules at Melton Hill Dam on the Clinch River. The intent of the guide is to provide a set of basic graphs and quantitative methods to serve as a basis for valid decision making. Under actual spill conditions, the models will be used to provide the flexibility needed to adapt to changing conditions and to supplement information in the casebook. The scope of the casebook will expand continuously as the models are upgraded and additional scenarios are modeled.

RESULTS

A "walkthrough" emergency response drill was performed in December 1988. ORNL discharge forecast modelers simulated the response to an accidental release of contaminated liquid into the headwaters of WOL. A time series data file of flows and concentrations leaving WOD was generated from the SSARR model simulation. This data file was then transferred to the ORNL STC VAX for access by TVA's Norris Engineering Laboratory for input to their Clinch River dispersion model. TVA generated time series information on contaminant flow and transport characteristics in the Clinch River. Fig. 4 illustrates the simulated response of the WOL/Clinch River system to a slug release of liquid containing 0.01 Curies ($3.7 \text{ E}+8$ Becquerels) of Strontium-90. The plot represents resulting concentrations at downstream locations at WOD and the water intake at the K-25 facility on the Clinch River, about 7 miles downstream from WOD. The prevailing conditions for this simulation consist of baseflow (low flow conditions) in WOC, no regulation of the gates on WOD (freeflow conditions), and seasonal high flow in the Clinch River. A peak concentration of 7932 Bq/L was observed at WOD approximately 5 hours after the initial release. The peak concentration at the K-25 water intake was observed to be 87.4 Bq/L approximately five and a half days after the initial release. This represents a dilution factor of approximately 90 from WOD to the K-25 intake.

SUMMARY AND CONCLUSIONS

Project goals include the improvement of the quality and quantity of data in order to better calibrate the streamflow forecasting model. Use of the model at ORNL has helped to identify limitations in data acquisition processes and provide a framework for organizing and using the data that are gathered. In addition, the high priorities remain of achieving a continuously operational

forecasting model and development of a true forecasting center with a high level of operational emergency response preparedness, to most effectively aid management decisions under emergency conditions. It is anticipated that the model will be used during emergency preparedness drills and will be available for ongoing studies of contaminant transport at watersheds on the Oak Ridge Reservation. With the improved performance of the forecasting model on the WOC system for ORNL facilities, future applications of similar forecasting systems to other facilities and installations on the Oak Ridge Reservation would be highly feasible. Subsequent forecast modeling systems, patterned after the ORNL system, would profit from previously gained experience in establishing forecasting operations.

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MODELING WATERSHED EROSION ON NORTH REELFOOT CREEK, TENNESSEE

Dr. Roger H. Smith, Associate Professor
Dr. Larry W. Moore, Associate Professor
Chee Chew, Graduate Assistant

ABSTRACT

In West Tennessee soil erosion due to agricultural practices has contributed to severe surface water quality problems. This problem is particularly evident in the Reelfoot Lake area in Obion County of Tennessee. Reelfoot Lake is the primary wintering ground of the American bald eagle, and it provides excellent fishing opportunities. This valuable natural lake has decreased in size from 20,000 ha to 5,000 ha because of soil erosion and sedimentation.

State and federal cost-sharing funds have been provided to encourage farmers in the Reelfoot Lake area to implement agriculture best management practices (BMP's) to reduce cropland erosion. The impact of these programs on water quality has not been adequately documented. The authors are currently utilizing Hydrological Simulation Program - FORTRAN (HSPF) to evaluate the effects of BMP implementation on water quality in the North Reelfoot Creek watershed.

The overall purpose of the project is to demonstrate the usefulness of HSPF as a watershed management tool for West Tennessee. The primary objectives of the project are as follows:

1. To demonstrate the ability and to define the limitations of HSPF to model the hydrologic, hydraulic, sediment erosion, and sediment transport behavior of the North Reelfoot Creek watershed.
2. To determine selected model parameters via calibration, and to confirm the parameters via verification.
3. To determine the impact of agricultural best management practices (BMP's) on surface water quality using HSPF.

Substantial meteorological, hydrological, water quality and land use data have been collected for the 56.3 square mile watershed. These data have come from field surveys, Corps of Engineers (Memphis District), U.S. Geological Survey, Soil Conservation Service, Tennessee Department of Health and Environment, U.S. Department of Agriculture, and the National Weather Service.

Based upon a thorough review of watershed characteristics (soils, topography, geology, land use, and climate), the study area was divided into two segment groups. Segment Group 1 is the western portion of the watershed, characterized by loess soils on steep uplands. Segment Group 2 is the eastern portion of the watershed, characterized by loess soils on level uplands.

To provide accurate land use information for the modeling effort, spatially complete data over the entire watershed were required. Aerial photographs and information from the Reelfoot Lake Rural Clean Water Project and Obion County Agricultural Stabilization and Conservation Service were used to prepare a land use inventory. Using this information, Segment Group 1 was divided into four segments representing land uses of cropland, grassland, gullies, and other. Segment Group 2 was divided into three segments representing land uses of cropland, grassland, and other.

Based upon field measurements, the channel system was segmented into ten reaches, with each reach demonstrating uniform hydraulic properties. The entire watershed was then represented by connecting the individual reaches and the area of each land segment that drains into each reach.

Hydrologic and sediment simulation with HSPF requires time series data: precipitation, potential evaporation, streamflow and sediment loadings (for comparison with simulated results), water temperature, and air temperature. These data for the period April, 1984, through December, 1988, are being used for calibration and verification of the model.

Initial parameter values were determined or estimated by the investigators. Using these initial values, hydrologic/hydraulic calibration runs have been conducted to compare simulated monthly and annual runoff volumes with observed data. Hydrologic/hydraulic calibration parameters were adjusted after each run to improve agreement between simulated and recorded values. Once satisfactory agreement is obtained on a monthly and annual basis, simulated and recorded hydrographs for selected storm events will be compared.

Following calibration of basin hydrology, soil erosion and sediment transport calibration can be performed. First, overland sediment transport is simulated to provide edge-of-stream loadings. Estimates have been made or obtained of gross erosion volumes by various techniques, and are being used as an overall guide to assess simulated values for each pervious land segment. Second, instream sediment transport calibration will be performed by adjustment of channel sediment parameters to improve agreement with observed instream sediment data. The calibration effort will be completed by August 1, 1989.

Following HSPF calibration, model verification will be conducted to assure that the model properly assesses the variables and conditions which can affect model results. Only a portion of the available record of observed values will be used for calibration. Once the final parameter values are developed through calibration, simulation will be performed for the remaining period of observed values and comparison of recorded and observed values will be reassessed.

The results of the hydrologic and sediment simulation efforts using HSPF on North Reelfoot Creek Watershed will be presented at this symposium.

RESULTS AND PRELIMINARY INTERPRETATION
OF HYDROGEOLOGIC PACKER TESTING IN DEEP CORE HOLES
AT THE OAK RIDGE Y-12 PLANT¹

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Straddle packer tests have been conducted in six core holes located in Bear Creek Valley at the Oak Ridge Y-12 Plant. A total of 52 intervals, ranging in depth from approximately 100 to 1,200 ft below ground surface were investigated. The width of the tested intervals ranged from 12 to 27 ft. Results of the packer testing indicate that hydraulic conductivities for the Conasauga and lowermost Knox groups range from approximately 1×10^{-4} to 1×10^{-8} cm/s. The distribution of hydraulic conductivities with depth is irregular and does not follow a simple pattern. With one exception, the greatest hydraulic conductivities ($>5.0 \times 10^{-5}$ cm/s) are noted from structurally disturbed zones and solutionally altered zones within the Maynardville Limestone and the Copper Ridge Dolomite. With the exception of a fractured massive sandstone in the uppermost Rome Formation, hydraulic conductivities for clastic-bearing units, structurally undisturbed intervals of carbonate units, and some structurally disturbed intervals in carbonate units are $\leq 5.0 \times 10^{-5}$ cm/s.

Hydraulic head distribution determined by packer testing permits a hydrologic cross section across geologic strike to be constructed, assuming stratigraphic dependence of hydrostatic heads in the subsurface. If this assumption is correct, the hydrologic cross section suggests that Bear Creek Valley is "floored" at a depth of between 500 and 700 ft by upward-moving groundwater. Additionally, the model implies that much of Bear Creek Valley is underlain by an area of groundwater discharge. The principal recharge areas for groundwater into the deeper portions (below approximately 100 ft) of Bear Creek Valley are the two prominent ridges that form the northern and southern boundaries of the valley.

¹ Research sponsored by the Remedial Action Program at the Oak Ridge Y-12 Plant, operated by Martin Marietta Energy Systems, Inc. under contract DE-ACO5-84OR21400 with the U.S. Department of Energy.

EFFECTS OF THE 1988 DROUGHT ON THE MISSISSIPPI RIVER NEAR MEMPHIS, TENN.

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INTRODUCTION

The effects of long-term precipitation deficits over most of the upstream regions of the Ohio, Missouri, and Upper Mississippi Basins during the spring and summer of 1988 combined to produce stages and flows of unprecedented low levels on the Lower Mississippi River Basin. These extreme low water conditions significantly impacted navigation and dredging requirements and produced hydrologic and hydraulic anomalies in the vicinity of Memphis, Tennessee that are not easily understood or explained. An effort is made, through the analysis of observed responses and available data, to provide insight on long term trends and inter-relationships among pertinent hydraulic parameters.

BASIN DESCRIPTION

The Mississippi River Basin has the third largest drainage basin in the world. The basin drains 1,245,000 square miles, which includes 31 states and 2 Canadian Provinces. The principal drainage basins contributing to the Lower Mississippi at Cairo, Illinois are the Upper Mississippi River basin, Missouri River basin and the Ohio River Basin. The Corps operates relatively large reservoirs on the main stem of the Missouri River that were Congressionally authorized for navigation and hydropower production and contain sufficient volumes of stored water to affect the flow rate and stages on the Lower Mississippi River. Corps reservoir projects in the Upper Mississippi River Basin do not contain sufficient storage volumes to affect the flow regime of the Lower Mississippi River. Flows from this basin are mostly uncontrolled and result from snow-melt and rainfall run-off, not from the release of stored water. The Ohio Basin is similar to the Upper Mississippi except for two large reservoirs located at the lower end of the basin (Kentucky Lake, which is operated by the TVA, and the Corps' Barkley Lake on the Cumberland River) which can be used during low flow periods to retain storm run-off and augment low flow conditions on the Lower Mississippi River.

OBSERVATIONS

The extreme low water levels in the vicinity of Memphis were preceded by six consecutive months of below normal rainfall in the upper basins. The June 1988 rainfall for the Mississippi River basin totaled 40 percent of the normal. The driest tributary basin was the Ohio with only one-fourth of the normal June rainfall. Stages in the study reach started downward during May and seasonal record lows were exceeded at all gaging stations, with, some gaging stations exceeding historical record low stages. The authorized navigation channel was maintained through extensive dredging activities by the Corps during the low water period, but nevertheless, blockages occurred and barge tow pilots were forced to use smaller,

lighter tows to navigate a river system that was unfamiliar and continuously changing.

COMPARISON WITH HISTORIC LOW RECORDS (PERIOD 1944-1987)

LOCATION	DATE	1988		PREVIOUS RECORD		
		STAGE (ft)	DISCHARGE (cfs)	DATE	STAGE (ft)	DISCHARGE (cfs)
STAGES:						
Cairo, IL	07/12/88	4.9	92,800	12/24/1871	-1.0	*
Memphis, TN	07/10/88	-10.7	110,300	01/20/1981	-7.3	142,000
Helena, AR	07/11/88	-4.2	112,800	11/08/1895	-3.0	*
DISCHARGES:						
Cairo, IL	07/12/88	4.9	92,800	08/22/1936	5.1	69,000
Memphis, TN	07/10/88	-10.7	110,300	08/25/1936	0.0	78,000
Helena, AR	07/11/88	-4.2	112,800	08/26/1936	-0.2	81,000

* Not available

Stage and discharge records at Memphis indicate that in 1936 the river reached a stage of 0.0 feet with a discharge of 78,000 cfs. At this time all the upstream flood control and navigation projects were not in place. In 1981 the Memphis gage recorded a stage of -7.3 feet, however, this stage occurred at a discharge of 142,000 cfs. It is noteworthy that double the flow was carried at a seven foot lower stage. In 1988 the Memphis gage reached an all time low of -10.7 feet at a discharge of 110,300 cfs. At this record low condition the Ohio Basin was contributing 35 percent of the flow with the Upper Mississippi (Upper Mississippi and Missouri River Basins) contributing 65 percent. Based on observations during this period it is felt that the base flow for the Mississippi River in the subject reach is approximately 85,000 to 100,000 cfs. The 1981 stage and associated shift in the rating curve at Memphis prompted an investigation by the District to determine the causal mechanism associated with the observed river response. Needless to say the 1988 stages at the Memphis gage prompted additional studies by the district and also by the Mississippi River Commission. The determination of the causes related to the river response and accurate prediction of future conditions is important with respect to national and area economics and the Corps responsibility of maintaining the authorized navigation channel. Also the accurate prediction of future low flow conditions is critical in establishing minimum tailwater conditions for the design of navigation structures such as the Norrell lock on the Arkansas Post Canal, which is part of the McClellan-Kerr Arkansas River Navigation System, and for raw water intakes for power plants along the Mississippi River.

METHODS AND PROCEDURES

The Mississippi River is a dynamic alluvial river which continually adjusts its hydraulic characteristics in accordance with the hydrologic cycle and natural or artificial changes imposed on the fluvial system. The complexity of this system challenges the engineer to apply the theories and concepts which form the basis of rigid boundary hydraulics to explain the anomalies experienced during the

low water events of 1981 and most recently 1988 and predict future responses of the system to similar circumstances. Several factors are considered in the analysis such as changes in alignment and geometry resulting from the overall master plan for stabilizing the lower Mississippi River, severity of the hydrologic cycle and inter-relationships among hydraulic parameters such as roughness, energy slope, bed forms, bed material composition and water temperature. Given limitations of data for extreme events, and present day technology, a specific explanation of the cause-effect relationship is not practical, but several hypothesis have been developed which explain components of the observed response.

RESULTS

The assumption that man's attempts to modify and control the river have induced this adjustment cycle certainly merits consideration. Major manmade components utilized on the lower Mississippi River include: flood protection levees, cutoffs, revetments, dikes and dredging to rectify localized trouble spots. These modifications have collectively and individually affected river behavior and its characteristics in varying degrees. The cutoff program has probably had the greatest effect of the manmade components on the in-bank capacity of the Lower Mississippi River. The program included the construction of 16 cutoffs between 1929 and 1942 which shortened the river below Memphis by about 152 miles. Immediate effects of the program were observed at Arkansas City and gages further downstream whereas gages such as Helena and Memphis, which are above the majority of the cutoffs, are continuing to experience a slow decline in stages. Isolating effects of individual manmade components is complicated by the regulation of discharges of major tributaries by the construction of flood control reservoirs. The magnitude and duration of high flows has been reduced and the duration of low to medium discharges has increased. These changes certainly affect the rate of channel adjustment which is certainly dependent on concepts of dominant discharge and geomorphic thresholds.

A review of hydraulic and sediment parameters necessary to assess water surface profiles and particularly channel roughness added to the complexity of the analysis. A high degree of variability (D50 ranged from 0.4mm to 0.9mm) was observed in bed material content across a given cross section and bedforms shifted from plane bed with sediment motion to well defined dunes. Using concepts of developing a composite or weighted Manning's roughness value for the channel during the extreme low flow periods an average value of 0.054 was computed with individual subsections varying from 0.03 to 0.165. This value compared favorably with studies of other gages on the Mississippi where an increase in roughness from 0.03 to 0.05 is not uncommon for relatively low discharges. However, this phenomena certainly does not explain the lowering of stages for various low discharges experienced at Memphis during the 1981 and 1988 low water events. There is also much documentation of an increase in energy slope for low discharges that would tend to compensate for the the corresponding increase in roughness. This increase in slope is attributed to an overall lowering of the crossings in the river which would tend to lower water surface profiles.

Other factors which impact stages include temperature and loop effects. The most significant effects of decreasing water temperatures for a given stage is the reduction in the height of the crossings and reduction in the amplitude of sand waves which results in less resistance to flow which in turn allows more water to pass a specific point at a given stage. During cold-water flow, the carrying capacity of the river is greater than the actual load, allowing the river to entrain additional material from crossings and bed forms which results in less resistance to flow. The water temperature during the January 1981 event was approximately 38 degrees Fahrenheit which could alter stages by as much as three feet. The dynamic loop effect in stage-discharge relationships indicates that a river will carry a certain discharge at a lower stage when it is rising than when it is falling. This principle results from the variation in energy slope due to changing discharge and is often applied to flood peaks but very little is known of effects during low water periods. Since energy slope has been shown to change dramatically as discharge decreases, it is reasonable to assume that similar looping type effects may occur during low water conditions. A study of the specific gage records at various stations and a graphic representation of the severity of the hydrologic cycle associated with the observed responses provides insight as to the possible driving force behind the slow decline in stages at the Memphis gage. The concept of episodic adjustment and exceedance of some stability threshold of the river system to floods of a certain recurrence interval and subsequent recovery or partial recovery is dramatically demonstrated by the continual oscillation between aggradational and degradational cycles observed on the river. The local oscillations in the specific gage record at Memphis appear to be a function of the severity of the flood cycle.

CONCLUSIONS

There is not a specific explanation of the cause-effect relationship to the observed response of the Lower Mississippi Basin to the drought of 1988 but several hypotheses are proposed that offer logical explanations. From the data presented, it is apparent that the observed complex response is a function of several long term trends that are dependent on man-made modifications, water temperature, and severity of the hydrologic cycle. The sequence of events resulting from these external stresses produce specific adjustments in rigid boundary hydraulic parameters that complicates the assessment and accurate prediction of low flow conditions such as those observed in 1988. A better understanding of the variability of low flow hydraulic parameters is essential in resolving future navigation problems. There is a noticeable lack of information in this study on the adjustments to velocity and energy slope that have prevailed with time for extreme low water conditions. The data collected during the 1981 and 1988 low water periods represent snapshots in time that will certainly go in the record books but may not represent a total picture of what the future holds for the Lower Mississippi Basin. This reach of the river will continue this adjustment phase until a state of quasi-equilibrium is reached.

DETERMINATION OF THE DAM BREAK FLOOD ZONE USING GIS TECHNOLOGY

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INTRODUCTION

An inventory of dams in Tennessee shows approximately 200 are Category I, or high hazard potential, 300 are Category II, or significant hazard potential, and 500 are Category III, or low hazard potential. Many dams are owned by municipalities and by various state agencies in addition to the large number of privately owned dams. These inventory data are representative of many other states. Dam safety is a serious issue in Tennessee and other states. The owner of a dam has a responsibility to prescribe minimum dam safety standards. Through regulations and enforcement policy the states are attempting to assure that unsafe dams are either upgraded and brought into compliance or drained and rendered incapable of impounding water. As land use patterns change and more development occurs in potential inundation zones below dams both the public risk and the need for an effective dam safety program increases. Therefore, a carefully defined system for classifying the downstream hazard potential is essential to a dam safety program. It is needed to apply dam safety standards, to set priorities for regulations, and as an essential fact in enforcement cases.

Quantitative measures are necessary for downstream hazard potential classification. This can be accomplished by a detailed dam break floodwave analysis; delineation of the resulting flood limits; enumeration of the number of occupants and number and type of structures located within the flood limits; and estimating the total damage of the dam break flood. Classification can then be made based upon the type and number of floodplain structures (i.e., total amount of property damage) and the number of floodplain occupants (i.e., loss of life potential) and the degree of damages greater than the spillway design flood. The dam breach wave analyses can be performed using data taken from USGS topographic maps, but often they do not reflect current conditions or are not of sufficient accuracy and valley cross-sections along with first floor elevations of the floodplain structures must be field surveyed. Depending upon the nature of the downstream hazard zone, the dam breach wave analysis can be quite computationally complex and an expensive part of the dam safety study. Consequently, there is a great need for developing a modeling technique that would be relatively inexpensive, quick, and sufficiently accurate for determining the downstream hazard potential category for dams.

METHODS, PROCEDURES, AND FACILITIES

A research project is currently underway to demonstrate the utility of using aerial photography in conjunction with a photogrammetric and geographic information system (GIS) for purposes of determining the necessary floodplain data used to conduct a dam breach analysis, define the downstream hazard zone, and identify the hazard potential.

This small pilot study project involving one selected dam was divided into three major tasks as discussed below:

1. Selection of Case Study Dam and Collection of Field Data.

The Tennessee Department of Health and Environment, Safe Dams Section was contacted for a recommendation regarding a case study dam. Several dams in Shelby County were considered but Casper Dam was selected. Casper Lake Dam is located approximately 2.5 miles north of the Millington Naval Air Base. Downstream of the dam, Casper Creek passes through the Air Base near the Naval Hospital and empties into the Big Creek Drainage Canal. Field data collected along this 3.75 mile stream reach included ten surveyed valley cross-sections and first floor elevations of pertinent floodplain structures.

2. Development of a New GIS Data Base and Analysis Procedure.

The Department of Civil Engineering at Memphis State University has obtained from ESRI, Inc. the ARC/INFO geographical information system software package for a Prime 750 minicomputer. A Calcomp 60" x 44" Digitizer Tablet (Model #91600) with a power drafting base and back lite, a Tectronix (Model #4111) color graphics work station, and a Calcomp Pen Plotter are interfaced with the Prime minicomputer to create a highly capable geographically referenced database mapping and analysis system.

A special software package called TIN (stands for Triangulated Irregular Network) is used to store, manage and perform analysis of three-dimensional surfaces for ARC/INFO. The TIN software is being used in conjunction with USGS 7.5 minute contour map data (i.e., Digital Elevation Model, DEM) for the Casper Creek floodplain to build a database for the National Weather Service (NWS) dam break computer model (DAMBRK). The TIN products include generation of a contour map of the floodplain, main channel profile, and valley cross-sections.

3. Comparison and Feasibility Analysis.

The NWS computer model DAMBRK was used to perform the dam break analysis for both data bases. The valley cross-sections using GIS Technology, computed water surface elevations,

velocities, and travel times from the DAMBRK computer run are being compared with the field survey data results. Interpretation of the results of the DAMBRK analysis using both data sources is currently underway.

SUMMARY

Defining the downstream hazard zone using GIS technology will be compared with conventional techniques and the results will be presented at this symposium. If the GIS method proves to be feasible, the responsible state agencies will be able to assign a uniform hazard classification to dams on a statewide basis. On the attractive side of such a technique will be the consistency involved with each dam evaluated and the fact that it can be easily updated periodically when operating certificates must be renewed. Consistency in evaluation of a dam's safety is vital from a regulatory standpoint. At the present time, many states possess neither the manpower nor the funds necessary to perform detailed determinations of downstream hazard zones below existing dams using conventional field survey methods.

APPLICATION OF STREAMFLOW SYNTHESIS AND RESERVOIR REGULATION
(SSARR) MODEL TO THE JAMESTOWN WATERSHED
IN THE CUMBERLAND RIVER BASIN

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ABSTRACT

The Reservoir Regulation Section is calibrating the SSARR model for operational use on the Cumberland River Basin. The experience gained during the early period of this project has provided valuable hydrologic training and a more comprehensive view of the hydrology of the region. Initial results of model runs indicate SSARR has great potential for use in reservoir operations of the future.

INTRODUCTION

Recently, the Nashville District evaluated its current water control management practices for the Cumberland River Basin. Koussis(1987) and Sverdrup Corporation(1988) also submitted independent evaluations and recommendations. The SSARR model was selected as a candidate to be the basic model for the Cumberland River forecasting and regulation. Although much scientific debate transpired to select an improved model, experience and results obtained thus far indicate that SSARR was a prudent choice. The Jamestown watershed located in the Dale Hollow Reservoir Basin in Tennessee was selected by the authors for the initial watershed calibration. This paper discusses this work.

BACKGROUND

The watershed portion of the SSARR model is well documented in several technical journals and enjoys a great reputation for its performance on the Columbia River Basin. Rockwood(1974) describes its ability to simulate the hydrologic extremes of flood and drought during 1972 and 1973 in the Pacific Northwest. The Cumberland River System has experienced similar extremes during the past several years. It is the District's objective to apply this model performance on the entire Cumberland River Basin. It is paramount that the District use a model that can forecast disparate hydrologic conditions with sufficient skill to manage basin water resources responsibly according to its authorized purposes; flood control, navigation, hydroelectric power, water supply, recreation, and water quality.

The SSARR model accounts for the basic processes of the hydrologic cycle (snowfall, snowmelt, interception, soil moisture, interflow, groundwater recharge, evapotranspiration, and the various time delay processes). It maintains continuity of the above processes and provides complete water accounting. To the extent that actual hydrometeorological conditions are discernable from observed data,

SSARR can assimilate this information according to pre-derived relationships and compute the hydrologic state of a river system.

Formal SSARR training to Corps personnel assigned to the model calibration was provided by SAR CONSULTANTS of Vancouver, Washington. They introduced the basic algorithms and data processing techniques in the model; which in addition to watershed hydrology, include channel routing and reservoir operations. During this year, the authors have concentrated their efforts on the optimization of the coefficients in the watershed simulation portion of the SSARR model. The channel routing phase is scheduled to commence in October 1989 and progress concurrently with the continuing watershed calibration.

METHODS AND PROCEDURES

The SSARR model was installed on the District's Zenith microcomputers in January 1988 and on the Harris 1000 computer system in May 1989. All model runs were executed on the Zenith. The Harris provides more computer power and longer simulations but the microcomputer is independent from operational commitments and offers more convenience and flexibility.

The Jamestown watershed (202 square miles, average elevation 1,800 feet, MSL) was selected for the early calibration work because of its workable size and representativeness of the hydrology of the region.

The hydrometeorological data were acquired from EarthInfo, Inc.[1], U.S. Geological Survey, Mid-South Agricultural Weather Service[2], and the National Climatic Data Center[2]. Initial data used were daily rainfall, daily maximum and minimum temperature, daily evaporation (used for corroboration of computed evapotranspiration), and daily average discharge.

Net basin rainfall was computed from rainfall stations at Monterey, Jamestown, and Livingston, Tenn., and Albany and Burkesville, Ky. Basin weighted average precipitation was used to compute initial gage weights from a ratio of normal station to normal watershed precipitation (computed from 21 years of complete records for these stations).

SSARR model evapotranspiration, which is an adaptation of Thornthwaite's computation, was computed based on Crossville's mean daily temperature. Mean daily streamflow was used for the water balance phase of the calibration.

The first phase of the calibration was to determine an accurate water balance of the Jamestown watershed. Rockwood(1982) describes the water balance as the accountability for water in a closed hydrologic system defined by inputs from rainfall and/or snowmelt, outflows from runoff as measured at stream gaging stations, losses by the processes of evapotranspiration and losses resulting from changes in soil moisture in the surface or sub-surface layer of the soil mantle. Losses to the deep ground water aquifers are not

subject to evapotranspiration but are eventually returned to outflow according to a specified outflow relationship.

Initial model runs were executed in a continuous mode in yearly sequences because of microcomputer memory limitations. Water balance calibrations were accomplished for water years 1966-1973. Simulation error (forecast minus observed) was computed by SSARR for measuring forecast skill. Final calibration of hydrograph timing is yet to be undertaken.

RESULTS

Figure 1 shows the forecast error by month. Figure 2 depicts annual observed net basin rainfall, SSARR simulated annual runoff, and observed annual runoff for Jamestown during water years 1966-1973. During the eight year period, the maximum of the continuously accumulated forecast error did not exceed three inches. These results are preliminary and represent the progress of the water balance calibration to date.

Throughout the calibration study many parameters were initially selected to represent specific hydrologic processes. These parameters were adjusted individually and collectively to match observed response as accurately as possible. Calibration of the first three years when applied to the remaining five years indicated additional refinement of coefficients were necessary.

CONCLUSIONS

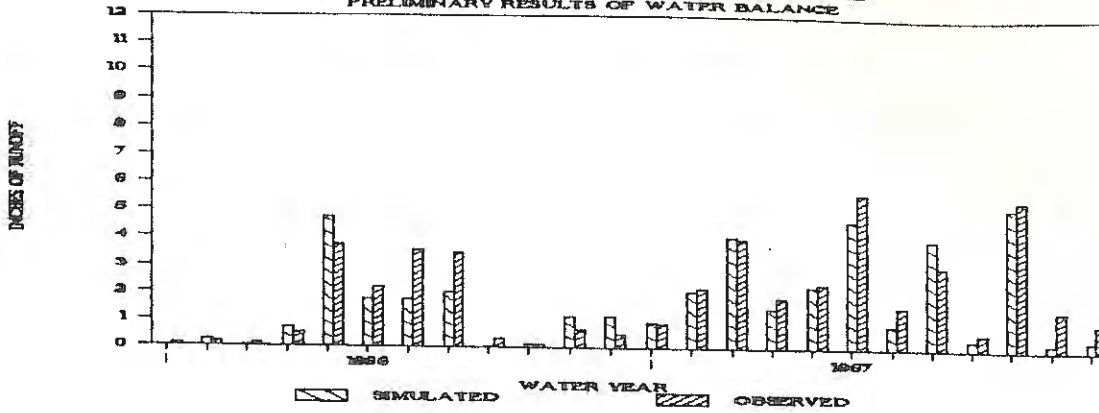
A great deal of calibration effort was expended in this Jamestown basin. Much of this time must be assigned to learning the SSARR methodology. The model offers a great deal of flexibility and versatility so that the full creativity of the user can be applied to the simulation process.

Hydrologic parameters and characteristics used in past models and procedures were restudied and modified to fit recent and past observed runoff. Calibration personnel developed their hydrologic skills and acquired knowledge of the basin via their creative use of SSARR methodology. As Corp's experience grows, additional personnel will receive training. Operational implementation will require more of the water management staff to be involved. From this work, Corps hydrologists and engineers will become more knowledgeable and experienced in the hydrologic behavior of the basin.

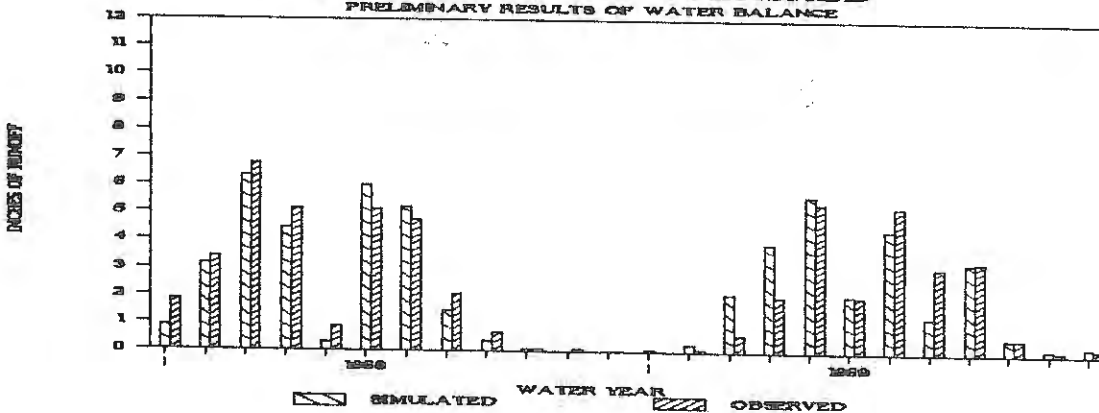
The next phase is to calibrate the model with hourly rainfall and six-hourly temperature data to permit refined adjustments to runoff variability as a function of rainfall intensity and evapotranspiration. Snow and snowmelt were not optimized in these studies but will be addressed later.

- [1] formerly U S West Optical Publishing
- [2] US Dept. of Commerce, NOAA

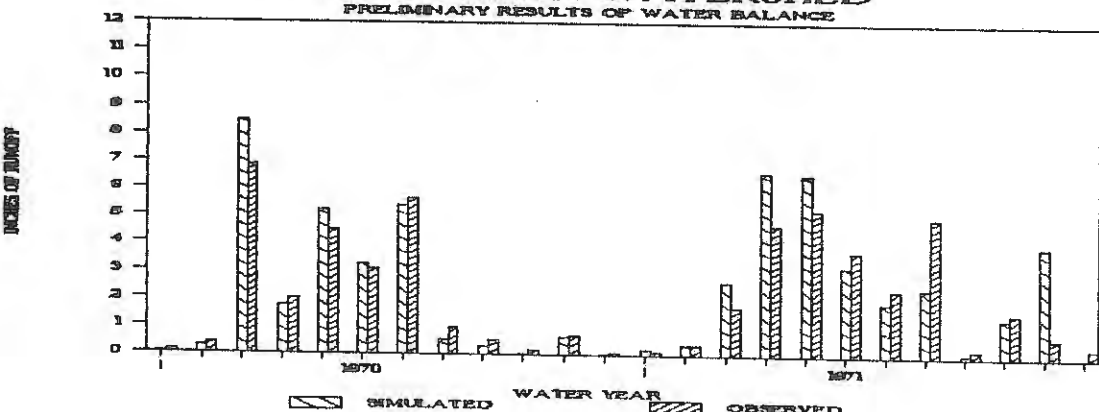
JAMESTOWN WATERSHED
PRELIMINARY RESULTS OF WATER BALANCE



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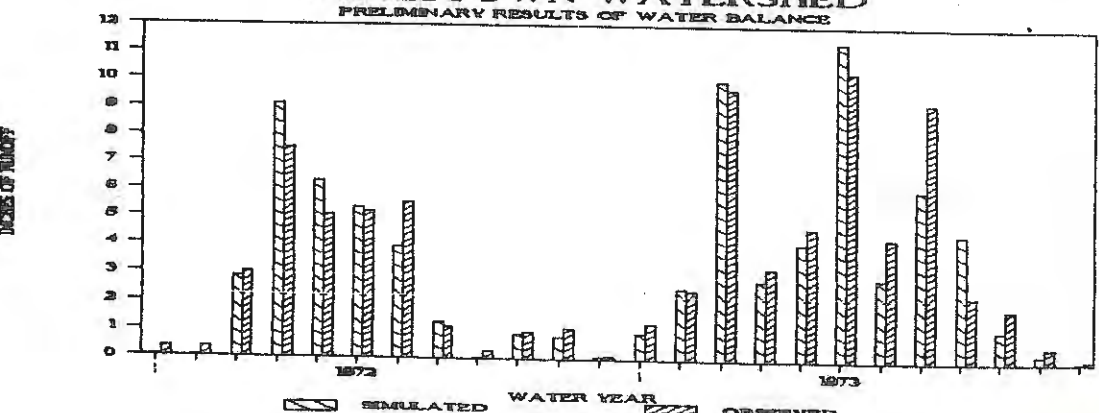


Fig. 1

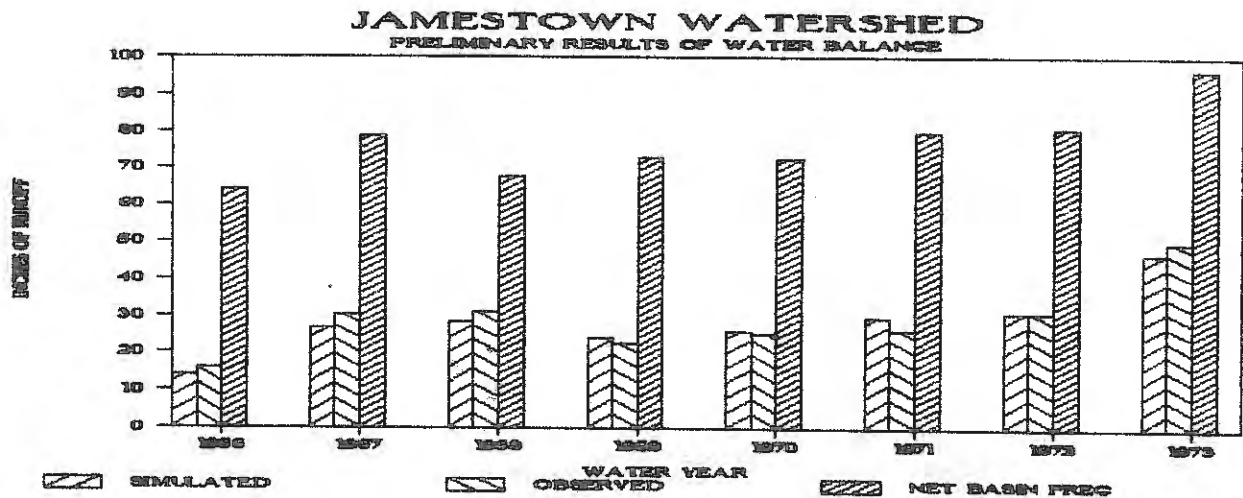


Fig. 2

Final calibration of Byrdstown and the local ungaged watersheds in the Dale Hollow Reservoir is scheduled during August 1989. It is anticipated that experience gained by the authors from the study of the Jamestown watershed will be readily transposed to adjacent basins throughout the Cumberland System.

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AN EVALUATION OF HELP2 FOR PREDICTING WATER BUDGET OF LANDFILLS

Marta L. Velasco and Steven C. Young

INTRODUCTION

In order to develop a database and a better understanding of how dry-stacked fly ash might impact groundwater resources, the TVA initiated several studies at the Bull Run Fossil Plant. The Bull Run Fossil Plant is located in Anderson Co., Tennessee, on Melton Hill Lake Reservoir (Clinch River mile 48.0). The plant began commercial operation in February 1966 and burns approximately 2.2 million tons of coal annually. In 1983, the plant changed the method of fly ash disposal from sluicing and ponding to dry stacking. As part of the project, the Hydrologic Evaluation of Landfill Performance (HELP2) Model for predicting the water budget for the stack was evaluated by comparing the results produced by the model with the results obtained from field measurements at Bull Run.

FIELD STUDIES AT BULL RUN

Field investigations included measurements of runoff from the fly ash stack, evaporation from 24 lysimeters installed at the stack, the vertical profile of moisture contents in the stack, and the hydraulic properties of the fly ash. Runoff from the stack was measured from August 1, 1987 to June 8, 1988. The amount of runoff was determined to be 4.4 percent of the rainfall and a Soil Conservation Service Curve Number of 75 was estimated for the Bull Run site and stacked material. The lysimeter field study, conducted from August 21 to November 3, 1987, produced an evaporation coefficient of $0.82 \text{ cm/day}^{1/2}$. This value is a measure of the ability of the soil to transmit water to the atmosphere in the form of evaporation.

Vertical moisture profiles were determined at Bull Run based on borehole drillings made in November 1987, March 1988, November 1988, and March 1989. No evidence of saturation in either the fly ash or the underlying clay layer was encountered. It appears that the steady flux of leachate is less than the saturated hydraulic conductivity of the clay. During the drilling events, a total of 15 Shelby tubes were collected from the clay material beneath the fly ash. The average saturated hydraulic conductivity of these samples was $2.2 \times 10^{-8} \text{ cm/s}$. The hydraulic properties of the fly ash were determined based on 25 undisturbed samples, in-situ and recompacted fly ash measurements collected at Bull Run. A saturated hydraulic conductivity value of $3.0 \times 10^{-5} \text{ cm/s}$ was calculated for fly ash. The results of the field experiments have provided information for an estimate of the water budget components of the fly ash stack at Bull Run Fossil Plant. Evaporation is estimated between 50 and 64%, storage between 25 and 35%, runoff between 5 and 10%, and leachate between 0 and 5%.

MODEL DESCRIPTION

The HELP2 Model (Schroeder, 1984) is a quasi-two-dimensional deterministic water budget model. The method of solution for the unsaturated hydraulic conductivity is based on a two-step process which applies a combination of the Brooks-Corey (Brooks and Corey, 1964) equation and the power function of Campbell (Campbell, 1974). Potential evaporation is computed with the modified Penman method. The rainfall-runoff process is modeled based on the empirical relationships established in the Soil Conservation Service Curve Number method. The evaporation coefficient values are calculated based on empirical equations that relate evaporativity to unsaturated hydraulic conductivity at 0.1 bars. These equations were developed based on experimental results conducted by Ritchie (Ritchie, 1972). Upper and lower limits of 0.33 and 0.51 cm/day**1/2 are placed on evaporation coefficient values applied by the model so as not to exceed the range of the experimental data. Lastly, HELP2 model uses a modified form of Darcy's equation to predict flow. This subroutine ignores matrix potentials associated with unsaturated flow and assumes the pressure to be constant within each vertical layer.

WATER BUDGET PREDICTIONS

The HELP2 model was used to predict the water budget for the fly ash dry stack at Bull Run Fossil Plant from November 1, 1983 to October 31, 1987. For this period, daily rainfall data from Bull Run and monthly temperature averages from the nearby National Oceanic and Atmospheric Association station were used for input to the HELP2 model. Because of the uncertainty associated with setting up the model, several different scenarios were modeled. A total of eight different simulations were made to predict the water budget. The eight simulations were created by the combinations produced by considering two approaches for handling the moisture retention characteristics of fly ash, the bottom boundary condition of the dry stack, and the history of the construction of the dry stack. For all eight scenarios, the experimentally determined SCS runoff number of 75 and evaporation coefficient of 0.82 cm/day**1/2 were used. The model did not offer guidance as to which moisture retention curve should be used, therefore, both curves, the initial drainage curve (IDC) and the main wetting curve (MWC) were used to create soil data for input to the model in order to try to capture the variability of results based on a drying or a wetting front moving through the soil. The bottom boundary conditions of the dry stack provided for a "clay liner" or "no clay liner" because a clay layer can significantly affect the migration of leachate. The two approaches used to model the construction of the fly ash dry stack was the "no build-up" and the "build-up" scenario, i.e., constant height or increasing stack height, respectively. These runs were made to evaluate the sensitivity of the model results to the rate at which waste is added to a fly ash stack.

SENSITIVITY ANALYSIS

A series of scenarios were simulated using the Bull Run site characteristics in an attempt to establish the sensitivity of the HELP2 model to different input parameters. Among the parameters tested are stack height, SCS Curve Number, evaporation coefficient, hydraulic conductivity of fly ash, and daily rainfall patterns. Stack height affect only the leachate and storage components of the water budget. As the stack depth is increased, the storage component increases and the leachate component decreases. The sensitivity of HELP2 to the Curve Number was determined by running simulations with the Curve Numbers ranging from 25 to 95. The model seems to be insensitive to values less than 90 for the type of ash modeled. The range of evaporation coefficients tested is between 0.3 and 2.0 cm/day**1/2. The model is sensitive to changes in evaporation coefficient values only in the range from 0.3 to 0.4 cm/day**1/2. Scenarios which reflect a hydraulic conductivity of fly ash one order of magnitude higher and one lower than that established by field measurements were simulated. The effect of this parameter on the water budget is readily seen and establishes the importance in the determination of the soil's hydraulic conductivity for accurate modeling. When incorporating the higher hydraulic conductivity value, a drastic redistribution of water takes place in the runoff, percolation, and storage components, with a slight decrease observed in the evaporation portion. However, when applying the lower conductivity value, the effect of this parameter is seen only in the runoff and percolation components.

CONCLUSIONS

Site specific characteristics and a strong meteorological database are important when estimating water budgets of landfills. Field studies conducted at the Bull Run Fossil Plant provided information on the hydraulic characteristics of fly ash, the vertical moisture profiles, and runoff and evaporation. An evaporation coefficient of 0.82 cm/day**1/2 was calculated from field data. The HELP2 model calculated an evaporation coefficient of 0.51 cm/day**1/2 for fly ash which is the highest value it can calculate based on Ritchie's experimental results (Ritchie, 1972). In addition, the project showed the effect of continual stacking on leachate production. As much as 100% difference was observed in the predicted leachate values for the "build-up" and the "no build-up" scenarios simulated.

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APPLICATION AND VALIDATION OF A GROUNDWATER MODEL
AT OAK RIDGE, TENNESSEE

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INTRODUCTION

Modelling groundwater flow in the Appalachian orogenic belt presents numerous challenges in site characterization, data collection and interpretation, and model application. Reliable performance assessment of sites proposed for land disposal of solid waste depends on the combination of a properly implemented site characterization program, development of an accurate conceptual model of site geohydrology, and use of a numerical model and grid combination which incorporate the site data and conceptual model.

A groundwater flow and contaminant transport model validation study was performed to determine the applicability of typical groundwater flow models for performance assessment of proposed waste disposal facilities at Oak Ridge, Tennessee. Previous experience with standard practice site characterization methods, data interpretation, and groundwater modelling resulted in inaccurate prediction of contaminant transport at a proposed waste disposal site. The site's complex and heterogeneous geology, the presence of flow dominated by fractured and weathered zones, and the strongly transient character of shallow aquifer recharge and discharge combined to render assumptions of a horizontally layered, homogeneous but anisotropic aquifer and steady-state groundwater flow invalid.

OVERVIEW

This study was designed to integrate geologic and geohydrologic concepts and data with setup and application of a numerical groundwater flow and contaminant transport model. Site characterization investigations were guided by hypothesis testing which sometimes incorporated model simulation of alternative hypotheses. The geohydrologic conceptual model evolved continually as site testing and modelling efforts progressed and hypotheses were proven, modified, or abandoned. In addition to the battery of field tests and routine data collection, a natural gradient groundwater tracer (Rhodamine-WT) migration test was performed and monitored for more than fifteen months. This test was performed in a quantitative mode with parts per billion resolution tracer analyses performed on groundwater samples from more than three dozen wells in and near the plume. Tracer migration behavior was

documented and used as a bench mark against which model results were compared.

SITE CHARACTERISTICS

The study site encompasses about an acre of hillside terrain underlain by weathered interbedded calcareous siltstones, limestones, and shales of the uppermost Maryville Limestone and lowermost Nolichucky Shale of the Upper Cambrian Conasauga Group. Individual bed thicknesses range from about 1 to 50 cm and lithologic units (limestones, shales, and siltstones) range from less than 1 m to several meters in thicknesses. Bedrock dips southeast at about 45 degrees and strikes northeast-southwest consistent with regional structure.

The goal of site characterization was to obtain quantitative measurements of subsurface conditions which control groundwater flow. Detailed site characterization is an intrusive process which may significantly alter subsurface conditions, consequently altering groundwater flow characteristics. All drilling was performed either by augering or using water as the drilling fluid to reduce the artificial dilation of fractures which often occurs when high pressure air is used as the drilling fluid. Geologic and geohydrologic characterization studies at the site included: rock core drilling, lithologic logging, and geophysical logging; core hole packer testing of hydraulic conductivity and static head; construction of individual and cluster wells; performance of two pump tests drawing water from different aquifer zones; single well hydraulic conductivity testing; continuous and periodic water level monitoring in site wells. Detailed characterization tests at the study site extended to a depth of about 30 meters below ground surface.

Initial working hypotheses of geologic and hydrologic factors which may control groundwater flow at the site were developed on the basis of early core drilling and packer testing results. These hypotheses are generalized in two categories: (1) geologic structures and differential weathering may control groundwater flow and are related to individual lithologies which vary at the meter scale, and (2) the variable tracer migration rate observed at the site was caused by a decrease in hydraulic gradient associated with seasonal water table decline.

Field tests performed to evaluate these hypotheses included: (1) falling head and straddle packer tests at the 0.6 to 1.1 m zone thickness scale in two nominal 20 m deep boreholes to test the relationship of hydraulic conductivity to lithology and structure, and 2) collection of tracer concentration (nominal monthly frequency) and water elevation data (biweekly frequency). Conductivity test intervals were selected by inspection of rock core to coincide with discrete lithologic and structured intervals. About 30 conductivity tests (15 each above and below the weathering interface) were performed in the two borings, one of which was

upgradient and along strike from the tracer flow zone and the other was down-dip near the center of the tracer plume.

Interpretation of the hydraulic conductivity test results revealed no consistent relationship between conductivity and lithology or with degree of rock weathering when stratigraphically correlative intervals were tested above and below the weathering interface. The apparent determinant of conductivity was degree of fracturing. Based on these 30 discrete zone tests the hydraulic conductivity was found to range from about 1 E-4 to 5 E-5 cm/s with the mean conductivity about 5.3 E-5 cm/s. This range of conductivity is generally consistent with results of the numerous other single well, pump test, and packer test results obtained at similar depths in the area. Aquifer conductivity anisotropy was determined on the basis of aquifer pump test behavior with maximum conductivity parallel to geologic strike.

Analysis of tracer migration and water table fluctuation data indicates that tracer migration rate and direction are strongly controlled by the local geologic structure. Tracer migrated parallel to strike, consistent with aquifer anisotropy, and the axis of migration was nearly tangential to hydraulic gradient indicative of the dominance of fractures and bedding interfaces in controlling local groundwater movement. Early time (the first month) tracer migration was quite rapid ($0.6\text{-}5$ m/d) with migration of a narrow ($2\text{-}3$ m), high concentration plume for about 15 m. Subsequent migration occurred at rates less than 0.5 m/d and measured migration velocity was observed to vary over one order of magnitude in relation to variations in precipitation. Analysis of water table data show that coincident with the rapid tracer migration zone there is a fracture related water table anomaly. This anomaly appears as a water table high under drought conditions and as a water table low under elevated water table conditions. In combination the tracer migration and water table configuration and fluctuation data indicate the presence of a fracture controlled "slot" through which initial flow occurred. Later time tracer migration data show fingering and lateral spreading of tracer within the aquifer. Other slots are inferred from tracer and water table data.

MODELLING METHOD

The site was modelled using standard concepts of groundwater flow through porous media. The underlying assumptions in this approach are that the velocity field is determined by Darcy's Law and contaminant transport is controlled by advection and dispersion processes. The numerical model used for site simulation was driven by shallow aquifer hydraulic data and tracer migration data collected from April 1988 through June 1989.

Modelling proceeded in the following steps.

1. A detailed two-dimensional grid was constructed based on the heterogeneous site geology. This grid incorporated elements

representing the 1 m variations in lithology. Grid elements were aligned parallel to geologic strike and flow was assumed to occur in a horizontal aquifer 3 m thick.

2. An initial boundary value problem was formulated and solved for this grid configuration to simulate a steady-state theoretical head distribution and time dependent concentration distribution. Grid boundary hydraulic head data (Dirichlet data) were developed using the fit of a quintic spline to measured water table elevations at wells within the test area.
3. The hydraulic conductivity field assigned to the grid was based on conductivity measurements previously discussed. Conductivity was randomly assigned for each grid node with the overall conductivity distribution in the model grid consistent with the measured conductivity distribution from field data. Flow and transport simulations using the purely randomized grid showed transport behavior similar to the tracer behavior but underestimated early time migration velocity. To enable the model to simulate the early rapid migration, a line of elevated conductivity (1 E-4) nodes, equivalent to the observed rapid flow slot, was superimposed on the grid.
4. Transport was assumed to be advection driven based on observed concentration/time tracer behavior, and consequently dispersivity parameters in the model were held at low values. It was assumed that the tracer was non-reacting and not subject to retardation.
5. Flow and transport computations were made using the USGS Method of Characteristics computer program. The problem was solved repeatedly with variation in input parameter values to optimize parameter input and arrive at a combination of parameters which allowed the code to most closely simulate the observed tracer migration behavior. The range within which input parameters were allowed to vary was constrained to that defined by field data.

Performance of the computer simulations established the following points:

1. When isotropic porous medium conditions with randomly distributed conductivity are assumed, the simulations show migration of tracer directly down hydraulic gradient at a rate of about 0.2 m/d.
2. When randomly distributed conductivity conditions with conductivity parallel to strike 10+ times that perpendicular to strike are assumed, the simulated tracer migration is essentially parallel to strike. The actual plume migration velocity is best simulated when an anisotropy of 30+ is used and a line of elevated conductivity nodes are superimposed on

the grid to simulate the rapid migration zone observed in the tracer test. Aquifer anisotropy values as high as 30 have been measured by pump testing in the Conasauga Group at Oak Ridge. Use of a permeable slot in simulation is indicated based on water table and tracer migration behavior measured at the site.

CONCLUSIONS

This study demonstrates the fundamental influence of geologic structure on groundwater flow at the site. By incorporating a systematic approach to site characterization and conceptual model formulation and testing with development of a groundwater flow simulation model, it was possible to numerically simulate a field tracer test using rational model input parameters derived from the interpretation of site data. While mathematical simulation of aquifer behavior using the concept of porous medium flow can provide an approximation of observed groundwater flow and contaminant transport, the field test results clearly demonstrate that much of the significant transport activity occurs through mechanisms of fracture flow. The methods used in model grid specification can and will be used in development of scaled up site groundwater models.

CLIMATE VARIATIONS AND TRENDS - WHAT ARE WE TO EXPECT?

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INTRODUCTION

Essentially, climate is the averages and extremes of the weather, which is constantly changing. The climate in the TVA region is the product of many influences, which vary in themselves and with respect to each other. Some change so slowly that people do not think of them as changing. Most geographical features are like that.

For comparable latitudinal and geographical areas on other continents, the TVA region has a unique distribution of the average annual precipitation. [1] Because of the relative position with respect to the Gulf of Mexico and the lack of barriers to cold air masses from the north and west, most of the region has an average peak of precipitation in the late winter and early spring.

The long-term precipitation record of about 100 years is examined for the patterns of variation and any trends. Concern about the multiple-year drought pattern of the 1980s and global warming predictions raises questions about future expectations. The focus is on precipitation, but other climate variables are also important. Factors that can influence climate in this region, and elsewhere, are briefly reviewed. Additional consideration is given to the Southern Oscillation in the Pacific Ocean, with emphasis on precipitation and temperature anomalies in North America.

METHODS AND PROCEDURES

Tennessee River Basin precipitation data for 1890-1979 and the severe drought years of 1985-1987 were compiled and plotted in 3-month moving averages centered on each month of the year to examine differences in seasonal and annual patterns. The data for 1988 were also examined, and the pattern in 1988 was essentially the same as in the December 1984-January 1988 period. Therefore, a 4-year drought pattern is represented by the 3-year numbers. The same procedure as for 1985-1987 was used for the wettest four years in the 1970s, 1972-1975 (December 1971-January 1976).

The full 99-year record of Tennessee River Basin precipitation (1890-1988) was used to plot annual values and 3-, 5-, and 10-year running averages. Best fit trend lines were determined by a simple linear regression approach for the running averages plots. Annual temperatures in the region since 1930 were also examined. Knowledge gathered from various sources of climatic information was utilized to lend some perspective on possible influences on climate in this region.

RESULTS

The drought period of the 1980s has a spring minimum and a fall maximum of precipitation. This is nearly opposite the long-term pattern and is the worst combination for TVA reservoir operation procedures, which are based on the long-term pattern and flood protection concerns. The extremely wet period in the 1970s has an exaggerated cool season maximum and a slight shift of the driest period from fall to late summer-early fall. The overall pattern still resembles the long-term intra-annual pattern.

For the full 99-year period, the plots show increasing multiple-year variations with time. The amplitudes of the variations are significantly greater in the last half than in the first half of the record. The wettest and driest decades are the 1970s and the 1980s, respectively. The trend line has an upward slope. Temperature "normals" for 1931-1960, 1941-1970, and 1951-1980 generally decreased in the TVA region, but the temperatures for the last few years have been above the warmest of these "normals" (1931-1960). [2] The global average annual temperature has changed little over the past 100 years, but it has become significantly more variable. [3]

The oceans experience changes in currents and surface temperatures that affect atmospheric circulation patterns. One of the most pronounced phenomena is the variation in the tropical Pacific Ocean that is called the Southern Oscillation. The extreme negative and positive phases of the variation are termed "El Nino" and "La Nina," respectively. Their occurrence is correlated with temperature and precipitation anomalies in other parts of the world. [4,5] These include distinct wet and dry anomalies in Gulf Coast states and the southeast corner of the United States. Somewhat cooler and warmer temperatures tend to accompany the respective wet and dry anomalies. There are other oscillations in the atmosphere or oceans which appear to affect weather patterns, but less evidence of possible influence on the TVA region climate exists.

Other climate change factors that are identified with global variations and long-term shifts in climate include volcanic activity, solar activity cycles, variations in the earth's orbital position from the sun and the other planets, and recently increasing levels of "greenhouse" gases that affect the earth's radiative energy balance.

SUMMARY AND CONCLUSIONS

The effects of the Southern Oscillation on short-term climate in the Gulf Coast-Southeast anomaly area has been observed. The cool season wet expectation with the 1986-1987 El Nino was met by observed above normal precipitation in that southern tier of states. [6] The southeast portion of the TVA region was included. December 1988 to March 1989 precipitation was well below normal along the Gulf Coast and in Atlantic Coast states, approximately

the area predicted for the cool season following the first La Nina event in 13 years during 1988. [7]

The trend toward greater climate variability can be expected to continue as changing climate factors, particularly the greenhouse gases, increasingly disturb the earth's climate system. The climate system is the dynamic response to the various forcing factors that can alter the energy balance. The existing oscillations are examples of the quasi-equilibrium in the system. Increased forcing can be expected to result in stronger oscillations and alterations in their character and frequency. The multiple-year extremes witnessed in the TVA region in the 1970s and 1980s are likely to be experienced more frequently in coming decades.

Change in the long-term climate is also likely. A cooling is possible because of the variety of factors and the unknown feedback from increased atmospheric water that would result from an initial warming. However, a warming over the next several decades is more likely. Long-term changes in patterns of precipitation and other climate variables would accompany this warming. The most critical aspect is that smooth changes are unlikely, and rapid shifts over a few years at a time may not afford adequate reaction time.

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KARST HYDROGEOLOGIC INVESTIGATION OF THE PROPOSED MIDDLE
TENNESSEE SITE FOR THE SUPERCONDUCTING SUPER COLLIDER

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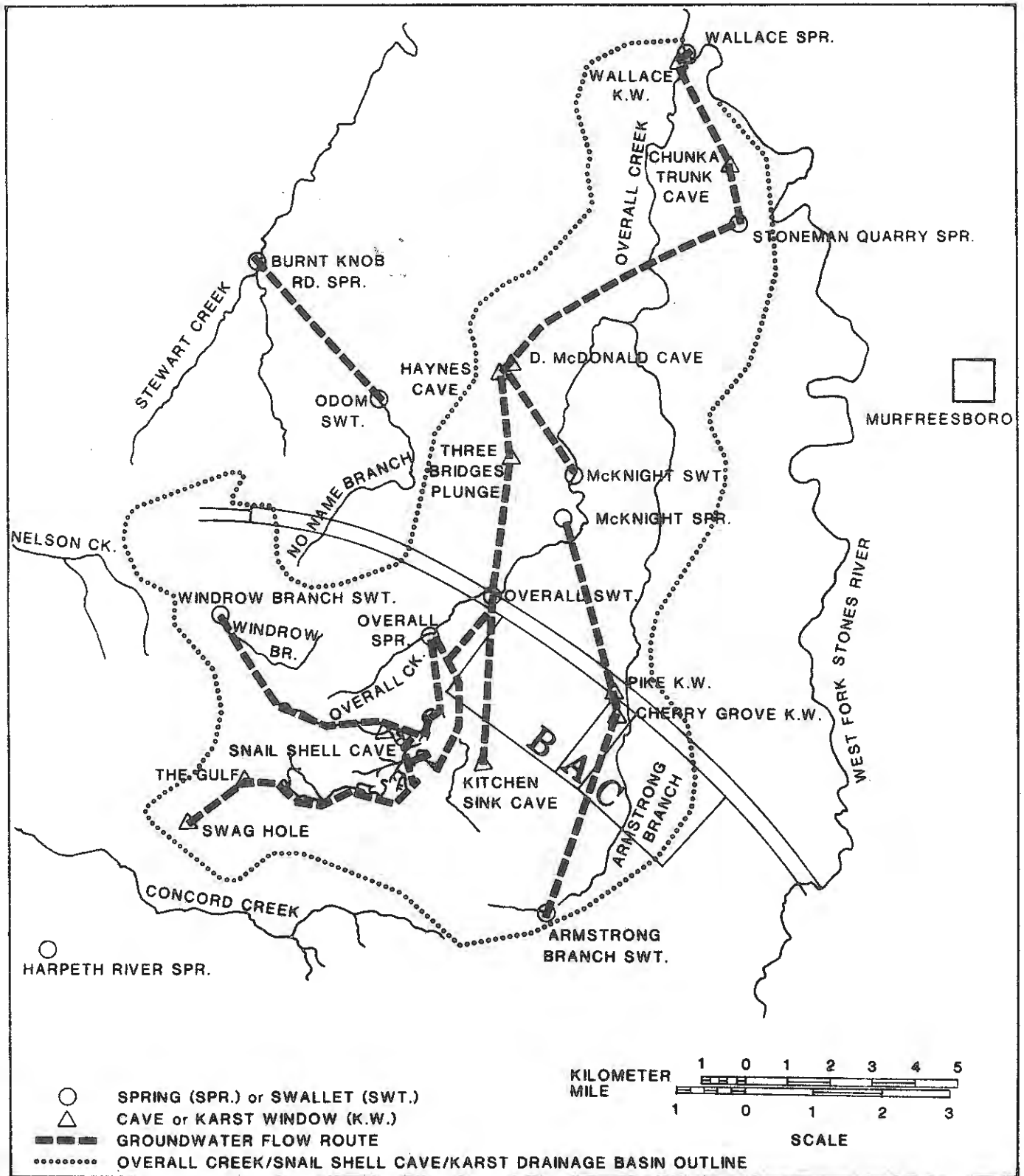
ABSTRACT

The Superconducting Super Collider, if funded by Congress, will be one of the largest and most expensive scientific instruments ever developed. It will be a basic research tool for scientists who seek to understand the fundamental forces and constituents of the universe. It will consist of a ring 86 kilometers (53 miles) around, through which superconducting magnets steer beams of protons, traveling at nearly the speed of light, in opposite directions. The two beams will be steered into head-on collisions. The resulting interactions and subatomic particles will be studied by physicists who hope to make new discoveries about the fundamental forces and basic constituents of matter.

Twenty-six states submitted proposals to the U.S. Department of Energy in an attempt to lure the 4.5 billion dollar Superconducting Super Collider project to their states. Tennessee was one of the seven finalists picked by the DOE. In December 1988, it was announced that Texas was the winner of this competition.

The proposed Middle Tennessee site, located south of Nashville near Murfreesboro, is in a karst landscape formed upon the Ordovician Limestones of the Central Basin. The Tennessee proposal called for placing the 87-kilometer (53 mile) ring, approximately 91 meters (300 feet) underground by using tunnel boring machines. Concerns about ground water contamination of the karst aquifer in the vicinity of the Campus-Injector Complex resulted in the funding of this investigation.

A karst hydrologic inventory was made to locate all significant karst features in the vicinity of the proposed SSC Campus-Injector Complex. These included: (a) sinking streams, (b) caves, (c) karst windows (sinkholes with a cave stream flowing across the bottom), (d) springs, and (e) significant sinkholes. A map of the potentiometric surface of the uppermost karst aquifer was prepared by measuring water level elevations in numerous area water wells. Seventeen dye traces, often using four different dyes simultaneously, were made in the Snail Shell Cave-Overall Creek Karst Groundwater basin in order to determine the groundwater flow routes through the system. The main surface and subsurface flow routes are shown on figure 1.



The drainage system begins where the surface flowing Windrow Branch has breached a confining layer (a thinly bedded limestone with numerous shale layers) in the Ridley Limestone, and invaded the subsurface. The chemically aggressive stream has slowly dissolved Snail Shell Cave in the lower Ridley Karst aquifer, a 10-meter (33 feet) thick, massively bedded limestone located between the Ridley Confining Layer and the Pierce Confining Layer (also a thinly bedded limestone with numerous shale layers). After flowing through Snail Shell Cave, the stream flows across the bottom of Blue Sink Karst Window and Horseshoe Cave Karst Window and then resurges at Overall Spring. It flows on the surface for 1.5 kilometers (1.0 mile) and sinks again at Overall Swallet. Originally, it was thought that it resurged again at McKnight Spring 2.5 kilometers (1.5 miles) farther down Overall Creek. However, the dye traces revealed that it flows to Three Bridges Plunges Karst Window and then joins the subsurface Overall Creek just upstream from Dennis McDonald Cave (fig. 1).

Dye traces also reprove that the cave stream in the Swag Hole Karst Window flows through the Gulf Karst Window, Nanna Cave, Echo Cave and into the Grand Canal passage of Snail Shell Cave. The stream then splits at The Link passage with part of it joining the Snail Shell stream and the rest flowing on down the Grand Canal passage. Two separate dye traces started at the end of the Grand Canal where the stream sumps (the cave passage becomes completely water-filled) prove that the stream then joins the Snail Shell stream and flows to Blue Sink Karst Window and on to a resurgence at Overall Spring. Dye was not detected at McKnight Spring on either occasion. Therefore, Overall Spring is the primary resurgence for all the drainage in the Snail Shell Cave System, although some of the water is flowing directly to Three Bridges Plunge Karst Window within first resurging at Overall Spring.

Dye injected into the Armstrong Branch Swallet was detected at the Cherry Grove Karst Window, the Pike Karst Window in Area A of the Campus-Injector Complex and then resurged at McKnight Spring. Therefore, it appears that the drainage from the Campus-Injector Complex flows to McKnight Spring without joining any of the streams in the Snail Shell Cave System. After resurging at McKnight Spring, the stream flows down Overall Creek for 1.0 kilometer (0.6 mile) before sinking at McKnight Swallet. The subsurface Overall Creek was then detected at the Jack Wright water well, the Dennis McDonald cave stream, the Donald McDonald water well, the MTSU Blue Hole Karst Window, the Asbury Pike Karst Window, the Stone Man Quarry Spring, the Chunka Trunk Cave stream, the West Fork Cave stream, the Wallace Karst Window, and at a final resurgence at Wallace Spring on the West Fork of the Stones River. The Snail Shell cave stream after flowing through Three Bridges Plunges Karst Window and Ida Haynes Cave joins the subsurface Overall Creek upstream from Dennis McDonald Cave (fig. 1).

Following heavy rains the subsurface Overall Creek cannot handle the increase in discharge and it rises to the surface at several overflow springs which flow into the usually dry Overall Creek.

Form the headwaters of Snail Shell Cave to Wallace Spring on the West Fork of the Stones River, the entire surface-subsurface karst drainage system is perched upon the Pierce confining Layer. The decision by the Tennessee Division of Geology to place the SSC tunnel deep underground at an elevation of 1076 meters (350 feet) MSL in the Murfreesboro Limestone was made to protect the karst and associated groundwater resources. It was also chosen to avoid the problems of tunneling in karstified carbonate rock. This investigation supports the conclusion that the karst is shallow and not hydrologically connected to the Murfreesboro Limestone at the level of the proposed tunnel. Therefore, the karst should not have an impact upon the tunnel and the tunnel should not have an impact on the karst.

All of the known and mapped passages of the Snail Shell Cave System lie to the west and upstream of the proposed site for the SSC Campus-Injector Complex. Since underground stream, like surface stream, cannot flow uphill (from lower potential to higher potential), it is hard to imagine any activities in the Campus-Injector Complex site which could in any way affect the explored and mapped passages of the Snail Shell Cave System

The Campus-Injector Complex is however drained by cave streams which could carry contaminants into the subsurface Overall Creek System and then all the way to Wallace Spring on the West Fork of the Stones River. The authors recommended that extra precautions be taken to protect these downstream caves and groundwater resources. In addition to secondary containment systems for underground tanks and other precautions which will be taken by DOE to prevent accidental spills and leaks, the authors recommended that a special groundwater monitoring and emergency recovery system be installed. This would consist of continuous monitoring instrumentation in the cave stream which flows under areas A And C. The Pike Karst Window is ideally located for continuous monitoring, being just inside the proposed eastern boundary for the Campus-Injector Complex. If a contaminant is detected, an alarm would be sounded and recovery pumps, already in place, would pump the flow of the entire cave stream into a lined surface impoundment. A small earth dam across the usually dry Armstrong Branch would make a good surface impoundment. With gates which could be electronically controlled, both groundwater from the cave stream and surface flow down Armstrong Branch could be contained in the lake for treatment if necessary in the event of a spill or leak of hazardous chemicals. Hopefully this system would never need to be used, but in view of the extreme vulnerability of karst aquifers to contamination, the authors believe that it is justified at this location. Development upon karst terrain need not result in groundwater contamination or damage to the underlying caves if special precautions are taken.

EFFECTS OF LOW FLOW CONDITIONS ON CHEATHAM LAKE WATER QUALITY

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INTRODUCTION

The BETTER two-dimensional water quality model was successfully applied to Cheatham Lake, Tennessee. It will be utilized by the US Corps of Engineers in a sequence of models for managing water quality in the navigable reaches of the Cumberland River Basin. The Corps of Engineers uses Old Hickory Dam as the control point for water quality downstream. The state of Tennessee regulates discharge permits and controls water use in Cheatham. Metropolitan Nashville uses the reservoir for its potable water supply and waste receiving stream. Metro conducts a weekly river survey which collects water quality data at 13 locations between Clees Ferry (CuRM 174) and Old Hickory Dam (CuRM 216). Daily effluent water quality records are also maintained by Metro Nashville.

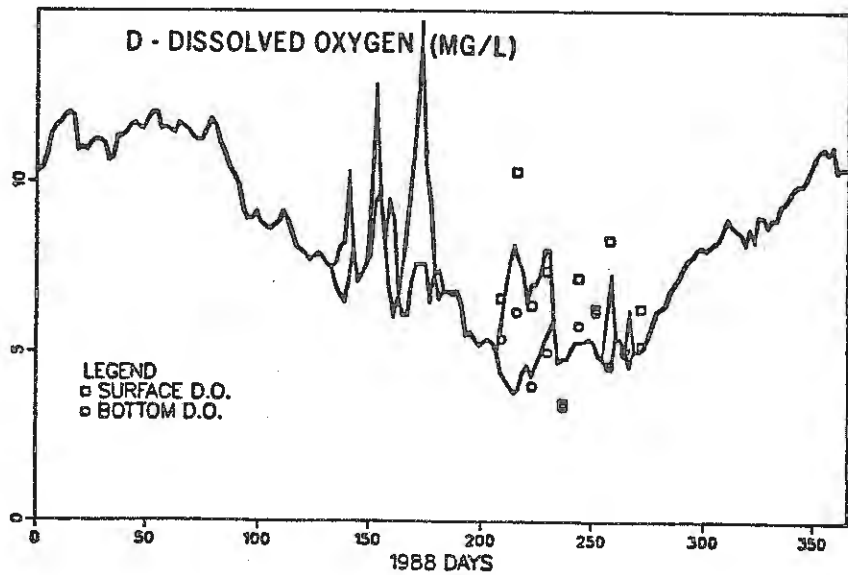
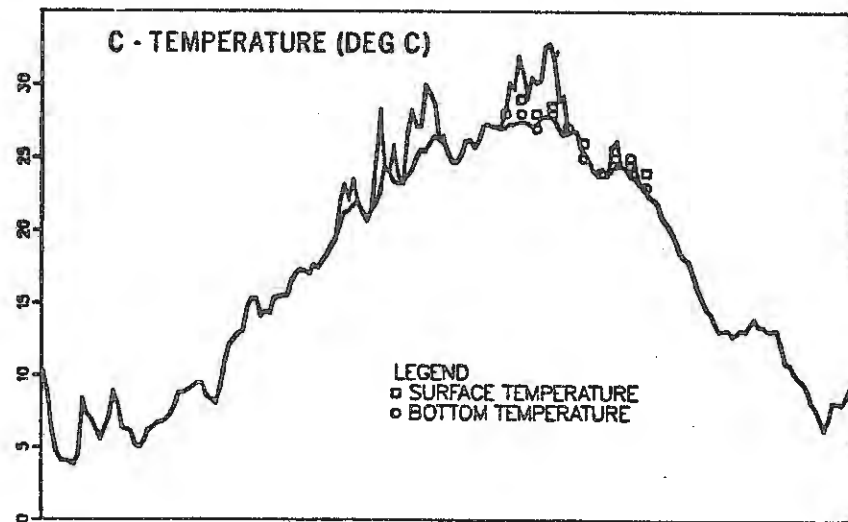
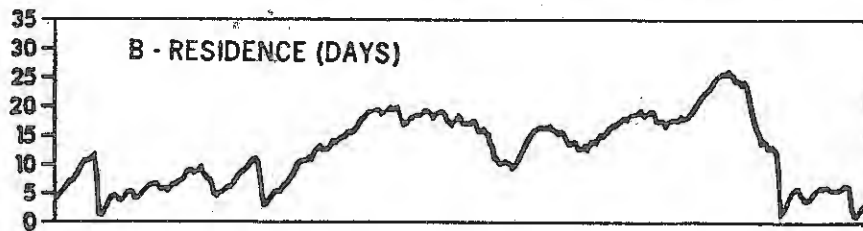
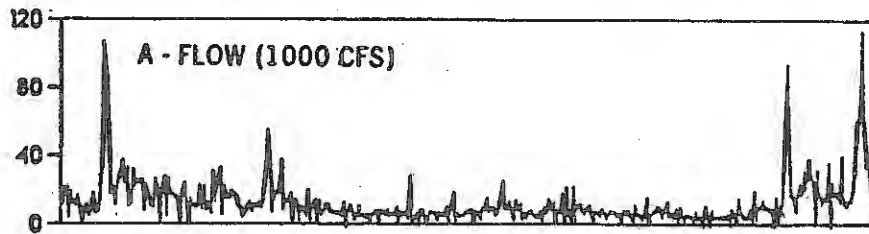
METHODS AND PROCEDURES

The Corps directed that the existing Old Hickory version of the BETTER model (Brown et al 1986) be used to simulate Cheatham water quality patterns. A simple riverine model such as QUAL-2E would not have provided a realistic picture of reservoir water quality patterns. BETTER is an acronym for Box Exchange Transport Temperature and Ecology of Reservoirs. The model is a useful tool for evaluating the hydrothermal and biochemical patterns in lakes and reservoirs that have longitudinal and vertical gradients in mixing regimes and water quality. BETTER is driven by reservoir hydraulics, meteorological conditions, and inflow concentrations.

The modeled geometry of the lake consists of 19 segments, divided into 5 foot vertical layers. The first 4 cells are each 6 miles long. The remaining downstream cells are 3 miles long. Inflows enter the reservoir at several locations. Old Hickory releases are the major inflow, with minor contributions from J. Percy Priest Reservoir, Mill Creek, the Harpeth River, and three Metro Nashville wastewater treatment plants.

The model required flow and water quality data from the USGS, Corps of Engineers, Metropolitan Nashville's wastewater, water, and weekly river survey, and NOAA. A residence time program was used to calculate retention time within the lake and to determine periods when low flow and high residence time would cause thermal stratification, changes in DO, algal growth, and low dilution of point source discharges to occur (Figures A-D).

CHEATHAM LAKE 1988



Calibration was accomplished using 1985 water quality data. Two coefficients were varied to adjust mixing due to wind shear and advection (WDFAC and DC, respectively). The densimetric Froude factor for density deflections was also adjusted.

The model was validated with water quality data from 1986 and 1987. Correlation through statistical comparison and graphical means provided equally good comparisons for both years without further adjusting the model coefficients. However, downstream data for temperature and DO profiles (below Clees Ferry), and nutrient data, including nitrate and chlorophyll a, were not available for the calibration and validation of these features of the model predictions.

It was recommended that Metro expand their weekly river survey with the addition of surface nitrate and chlorophyll a sampling at ten stations throughout the lake, and temperature and DO profiles at all stations including some new locations in the downstream portion of the lake. Metro accepted the proposal, and performed the extended survey from mid-July through the end of September in 1988. It was fortunate that Metro expanded their data collection program during this period of extreme low flow conditions.

Drought conditions in the Cumberland River Basin began in 1984. Daily average flows declined noticeably, with residence times in Cheatham increasing from a summer average of 5-8 days in 1985, to 18-20 days in 1988.

RESULTS

Recalibration was performed using the Metro extended river run temperature and dissolved oxygen profiles. The wind mixing coefficient was adjusted up slightly to provide a match between model predictions and field data. Other model coefficients were not altered. Model predictions were correlated with weekly field measurements for each modeled parameter using both SAS statistical analysis and timeseries plots. A series of sensitivity runs was carried out to analyze the effects of advective mixing, wind mixing, and sediment oxygen demand coefficients, algae growth rate and reaeration. It was determined that wind contributed 75 % of the reaeration in the lake, while advective mixing was responsible for 25 %. Effects of SOD were negligible, due to the riverine characteristics of the lake. Varying the mixing coefficients by an order of magnitude produced either completely mixed conditions, or strong thermal stratification throughout the summer months. Doubling the nutrient waste loads from the Nashville Central Wastewater Treatment Plant resulted in a 0.1 mg/l increase in BOD-5 in the lake, with no apparent effect on DO concentrations. Nitrate and total phosphorus concentrations in the reservoir were observed to double (to 0.4 and 0.2 mg/l, respectively) between Old Hickory and Clees Ferry under normal conditions, indicating significant nutrient loading due to Central's effluent discharges, although indirect effects on algae did not greatly impact oxygen concentrations.

SUMMARY AND CONCLUSIONS

Through evaluation of field data and simulation of water quality patterns in the lake using the BETTER model, it was determined that low flow conditions during 1988 did not have much of a negative effect on Cheatham Lake water quality. The Corps began controlling Old Hickory releases in July 1988 with the objective of maintaining a minimum of 4 mg/l DO in the releases. Operation in this mode continued through September 1988.

Cheatham Lake hydraulics are controlled by primarily by peaking releases from Old Hickory and J. Percy Priest reservoirs, with weak intermittent stratification and diurnal mixing occurring during summer low flow conditions. Therefore, the lake should be modeled on an hourly timescale rather than daily, to allow more accurate simulation of the peaking and diurnal effects.

The model provided reliable simulations of water quality patterns in Cheatham Lake for the years simulated. The model should be utilized on a continuing basis to support informed management decisions by the Corps, Metro, and State of Tennessee.

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REVIEW OF LAKE LEVEL AND RESERVOIR RELEASE ALTERNATIVES
FOR TVA'S RESERVOIR OPERATION AND PLANNING REVIEW

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TVA's dams and reservoirs are currently operated according to the priorities laid out more than 50 years ago in the TVA Act. Navigation, flood control, and power production have priority over all other water use purposes--such as recreation, water quality, or water supply.

The Reservoir Operation and Planning Review, authorized by the TVA Board in September 1987, is reassessing these priorities in light of the changes that have occurred in the Valley since the 1930's. Floods are not the threat they once were, and Tennessee River navigation is no longer plagued by shoals and rapids as it was before TVA. Moreover, public demand for abundant supplies of clean water and for high quality outdoor recreation on the Tennessee River system has increased, now rivaling the demand for low residential power rates afforded by hydropower.

This reassessment of reservoir system purposes is developing recommendations for a long-term operating strategy for the Tennessee River and reservoir system that matches the future needs of the Valley. The principal focus is how to include recreation and water quality as operating purposes along with the statutory purposes of navigation, flood control, and power production. Two sets of alternatives are being evaluated: lake level policy alternatives to improve summer recreational pool levels in tributary lakes; and reservoir release alternatives to improve the water quality of reservoir releases and help restore habitat for the living resources downstream of TVA dams.

The approach used to identify the issues, develop the alternatives, and evaluate their effects will be presented. The results of the evaluations of lake level policy and reservoir release policy alternatives will be discussed as necessary to illustrate the approach. Highlighted will be the tradeoffs made among operating purposes during this process, and how these tradeoffs were reviewed by technical staff, reservoir user groups, and decision-makers.

FLOOD-FREQUENCY ESTIMATES BASED ON BOTANICAL DATA
FOR ROCK CREEK, EAST TENNESSEE

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Botanically derived flood record and Maximum Likelihood Estimation statistical analyses were used to obtain flood-frequency estimations for Rock Creek. An indirect flood record was produced by dendrochronologically dating past flood events from riparian trees and assigning representative discharges estimated from a hydraulic-flow model. Techniques for estimating flood frequency at ungaged sites typically ignore flood data available from botanically derived flood records. Maximum Likelihood Estimation techniques categorize floods as discharge ranges, as lower bounds, or in terms of threshold exceedances. The data set for Rock Creek consisted of 14 botanically derived floods and 2 exceedance thresholds that supplied information for an 87-year period. Application of the log-Normal distribution generated a 2-year estimate for 500 (ft³/s) cubic feet per second with standard error of 70 ft³/s, and a 100-year flow estimate of 1,920 ft³/s with standard error of 570 ft³/s. Regional equations yielded a 2-year flow estimate discharge of 500 ft³/s with standard error of 220 ft³/s, and a 100-year flow estimate discharge of 1,900 ft³/s with standard error of 950 ft³/s. The log-Normal Maximum Likelihood techniques using botanically derived site-specific data resulted in reasonable return-period discharges and reduced standard error of the estimates when compared to regional-equation estimates.

OPERATION OF CUMBERLAND BASIN RESERVOIR SYSTEM DURING DROUGHT 1988

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ABSTRACT

The author presents an overview of the Cumberland Basin reservoir system, discusses the operation under normal conditions, and then outlines the deviations from normal that were necessary during the 199 drought. Rainfall and runoff data showing the severity of the drought is also presented.

INTRODUCTION

The Nashville District operated ten water control projects with the Cumberland Basin for the authorized purposes of flood control, navigation, hydropower, recreation, and water quality. These projects are also operated for various secondary purposes such as water supply, fish and wildlife, water quality and recreation.

Four of the projects Laurel, Wolf Creek, Dale Hollow, and Center Hill have extensive amounts of storage allocated for hydropower production. It is this storage that provides the capability to manage the surface water supply from the basin and enable the reservoir system to respond to various hydrologic conditions.

Another four projects Barkley, Cheatham, Old Hickory and Cordell Hull impound various reaches of the Cumberland River to provide a nine foot navigation channel from its mouth at the Ohio River to the City of Celina, Tenn. Water levels at these projects are maintained at specified elevations, regardless of hydrologic conditions, to provide adequate channel depths. Because of this feature, droughts have very little effect on navigation within the Cumberland Basin. This is in contrast to the Missouri and lower Mississippi Rivers where channel depths are dependent on the amount of flow.

Two remaining projects, J. Percy Priest and Martins Fork, are operated for recreation. All projects except Martins Fork are equipped with hydropower generating facilities.

NORMAL OPERATION

The Southeastern Power Administration is the agency responsible for marketing the hydropower generated at Cumberland Basin projects. Their contract stipulates that certain minimum amounts of energy be generated each week, depending on the month of the year. In meeting these minimum energy requirements, flows along the Cumberland River will range from a low of about 4,000 cfs in October and November to a high of about 9,000 cfs in March. The demand for energy, and the accompanying hydropower generation and flows, varies with the day of the week, hour of the day, and season of the year. Therefore to insure some flow during low power

demands periods, the following minimum desired flows have been established at certain points in the basin.

LAUREL - One unit generation for one hour within any 48 hour period.

DALE HOLLOW - During the summer and fall months one unit generation for one hour within any 48 hour period.

CENTER HILL - During the summer and fall months one unit generation for one hour within any 48 hour period.

NASHVILLE - Average daily flow of 1,000 cfs.

BARKLEY - Instantaneous flow of 6,000 cfs.

MARTINS FORK - Instantaneous flow of 5 cfs.

In addition to the above, consideration is also given to providing adequate cooling water for the Gallatin and Cumberland City steam plants and sufficient flow to maintain acceptable water quality conditions along the Cumberland River.

The reservoir systems' ability to respond to drought conditions is dependent on the amount of water available at the four major storage projects. It is desirable to have these projects full by late spring. Water can then be released from storage during the dry summer and fall months to augment low flows and to meet hydropower, navigation, recreation, water quality, and water supply needs. Every effort is then made to refill these lakes during the wet winter and spring months.

DROUGHT CONDITIONS

The Cumberland Basin experienced drought conditions between 1985 and 1989. Below is a summary of rainfall and runoff conditions for this period.

YEAR	OBSERVED RAINFALL	NORMAL RAINFALL	OBSERVED RUNOFF	NORMAL RUNOFF
1985	35.9	51.5	12.5	22.0
1986	39.2	51.5	16.1	22.0
1987	35.1	51.5	12.6	22.0
1988	38.6	51.5	13.1	22.0

DROUGHT OPERATIONS

As of May 1985 the reservoir system had 90% of normal water in storage. This was considered adequate and no special drought related reservoir operations were initiated during the summer and fall of 1985. For the first time since it was built, J. Percy Priest did not reach full summer pool.

During the winter and spring of 1986, runoff was less than half of normal and every effort was made to conserve water. For the first time since Barkley became operational in 1966, it was necessary to reduce discharges below the desired minimum of 6,000 cfs. In an effort to raise lake levels to summer pool, discharges were reduced to 3,500 cfs during the last ten days of April. This reduction was accomplished without seriously impacting downstream navigation or water quality. As of mid-May, water in storage was only 75% percent of normal seasonal amounts and there was the potential for water shortage problems during the coming summer and fall months. The normal wet season was about over and the chances of any additional runoff-producing storms was decreasing. With a view toward conserving water, the district entered into discussions with SEPA concerning the possibility of reducing hydropower generation to about 75% of the contract minimum. This would still provide sufficient flow to maintain acceptable water quality standards during the hot summer months. Plans were also made to increase water quality monitoring to better anticipate and respond to any problem and to provide data for future studies. However during late May and early June, the basin received almost six inches of rain which helped refill the storage projects and eliminated the need for any reduction in power generation. While not officially deviating from normal procedures, the reservoir system continued to be operated in a drought mode for the remainder of 1986. Water released of storage was the minimum necessary to meet hydropower, navigation, water quality and recreation needs. At the end of October 1986 water in storage was only 80% of normal.

During the four-month period November 1986 through February 1987 the Cumberland Basin received near normal rainfall and runoff amounts and therefore project power pools were full at the beginning of the summer. Although statistically the summer and fall of 1987 was dry there were no significant reservoir operating problems. Requirements for hydropower, navigation, and recreation were met and there were no significant water quality problems. At the end of October 1987, water in storage was about 80% of normal.

During the first half of 1988 drought conditions became more serious and more widespread. Between January and June the Cumberland Basin received only 15 inches of rain, 12.3 inches below normal, with runoff being only 7.8 inches, 9.2 inches below normal. At the end of May, water in storage was only 70% of normal. Except for a period when Lake Cumberland was maintained artificially low for foundation work, this was a record low amount of water in storage for May. Also drought conditions started impacting the Ohio, upper Mississippi, and Missouri River basins. This in turn resulted in low flows and inadequate navigation channel depth on the lower Mississippi River in early summer. The following is a summary of the deviations from normal reservoir operations within the Cumberland Basin due to the severity and widespread nature of the drought.

1. The priorities for utilizing available water resources within the Nashville District during this drought were established in

June as (1) water supply, (2) water quality to meet water supply requirements, (3) navigation, (4) hydropower, and (5) recreation.

2. To assist in keeping the navigation channel open on the lower Ohio and Mississippi Rivers, Barkley and Kentucky releases were maintained as steady as practical, as opposed to normal power peaking operations. It was determined that the Mississippi River was better able to maintain an adequate channel with a steady flow. This operation was started in June and continued through November 1988.

3. Barkley and Kentucky Lake levels were maintained from one to three feet above the normal guide curve elevation during the summer and fall. This ensured adequate releases could be maintained for downstream water quality and navigation and also increased channel depths in the Barkley/Kentucky pools. The extra channel depths were especially important due to the increased barge traffic on the Tennessee-Tombigbee Waterway.

4. Prior to July, releases from the storage projects were limited to that necessary to provide the minimum hydropower stipulated in the SEPA contract. Between July and September, releases were limited to that necessary to provide acceptable water quality conditions along the Cumberland. This required reducing the total hydropower generation below that necessary to meet the SEPA contract. SEPA purchased the difference in energy generated and that necessary to meet their contract requirements. Generation was reduced by about 25% in July and August and about 10% in September.

5. The demand for energy is usually greater on week days than on weekends. Generation at storage projects varies with the day of the week to meet energy demands. This release pattern results in downstream flows being lower on certain days of the week. During the latter part of the summer, cooling water problems were occurring at the Cumberland Steam Plant on these low flow days. Therefore between August and October generation at Cumberland Basin storage projects was distributed equally throughout the week in order to provide more uniform flows in the of the Steam Plant.

6. Between May and October, Nashville District personnel were involved in nine meetings with other Federal, State, and local government agencies to get their input and keep them advised of our operating plans. The resource manager at each project was kept advised of expected lake levels to be able to respond to inquiries from recreation interest and the public. The Public Affairs Office responded to 33 media inquiries (28 newspaper, 5 radio, 2 television) and sent out 5 news releases.

The reservoir system was operated in a drought mode until the latter part of November. In spite of the efforts to conserve, water in storage declined from 70% of normal in May to 64% in October. The basin received over six inches of rain in November allowing water in storage to increase to 135% of normal and reservoir operations were returned to normal.

During the winter and spring of 1989 the Cumberland Basin continued to recover from the drought. However, conditions in the upper Mississippi and Missouri Basin remained extremely dry. Therefore every effort has been made to store excess water in the Cumberland Basin to augment the expected low flows on the Mississippi River this coming summer and minimize potential navigation problems.

ASSESSMENT

Considering the length and severity of this drought, problems were relatively minor. The dissolved oxygen along the Cumberland River did not fall below 4.0 ppm. Under natural conditions, flows would have ranged from 1,000 cfs to 1,500 cfs during the summer of 1988. With the projects in place, flows were from 6,000 cfs to 8,000 cfs. Communities that withdraw water from Corps lakes did not experience any shortage. Also no taste and odor problems were reported. Full authorized navigation channel depths were maintained.

Throughout the drought, recreation facilities remained operable with only minimal impacts at a few beaches and boat ramps. Most of the affected ramps were low use. Total hydropower generated was only 55% of the average annual amount.

The Corps had all necessary authority to respond to this drought situation. No revision to the authorizing legislation or approved operating plans appear to be necessary.

WATER QUALITY ASPECTS OF
MINIMUM FLOW AND POOL LEVEL ALTERNATIVES
FOR THE
TVA RESERVOIR OPERATION AND PLANNING REVIEW

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In the TVA Reservoir Operation and Planning Review, TVA is exploring alternatives to historical operating policies for its reservoir system. As part of this policy investigation, options for providing sustained minimum flows below 16 tributary hydroprojects were explored, including continuous sluicing, turbine pulsing, and turbine pulsing with weirs. Where existing unsteady flow models were available, they were used for assessment of hydraulic variables in the downstream tailwaters with various minimum flow options. About a third of the hydroprojects were found to be likely candidates for turbine pulsing, a third were weir candidates, and the remaining third needed no instantaneous minimum release due to backwater from downstream impoundments. Alternative minimum flow and pool level alternatives were also explored for their effects on reservoir and release water quality using two-dimensional water quality models where calibrated models were available. Impacts on temperature, dissolved oxygen, and algal activity are examined in a comparison of the effects of operational changes on mainstem and tributary reservoirs.

ANALYSIS OF THE 1988 DROUGHT IN TENNESSEE

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A severe meteorological, hydrologic, and agricultural drought occurred throughout Tennessee during 1988. Many communities and utility districts experienced water supply problems and agricultural losses were extensive. The severity of the drought increased rapidly as rainfall decreased below the long term average of 46 inches across the State for much of the decade of the 1980's. A accumulative deficit of 41.5 inches from the long-term average was experienced from 1985 to 1988 across Tennessee.

The long-term rainfall deficit and the timing of the delivery in 1988 resulted in extremely low runoff and streamflow quantities. Streamflow discharges equaled or were less than the 3-day 20-year minimum flows at many streams throughout Middle and East Tennessee. The 1988 drought was compared to several historical droughts using plots of accumulated departures from long-term average monthly discharges. The comparison showed that in Middle Tennessee the drought was the most severe since the 1930's. In some areas of East Tennessee, the drought was the most severe since the 1920's. The Palmer Index, a gage of drought severity, varied from -1.2 (mild drought) in West Tennessee to -4.3 (extreme drought) in East Tennessee. Groundwater levels also reflected the severity of the drought. Record low levels were reached at four of five ground-water indicator wells across Tennessee.

GROUND-WATER USE BY PUBLIC SUPPLY SYSTEMS IN TENNESSEE

By Susan S. Hutson,
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Ground water is an important resource in Tennessee, supplying about 50 percent of the drinking-water needs of the State. In 1985, public-supply ground-water withdrawals in Tennessee totaled 243 million gallons per day or about 55 percent of the total ground-water used. These public-supply withdrawals represent a 22 percent increase from 1980 to 1985. Most of the withdrawals occurred from the Memphis Sand aquifer in Shelby County (Memphis) (141 million gallons per day). Of the 182 public-supply systems, 122 operated wells and 59 withdrew water from springs. Localized water-quality problems occur, but are generally related to natural geochemical process (relatively high concentrations of iron, manganese, chloride, or fluoride).

HYDROGEOLOGY ABOVE THE WATER TABLE

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Materials above the water table can be separated into a stormflow zone, which extends from land surface to a depth of 1-2 and an underlying vadose zone. Calculations based on Darcy's law can be used to determine permeability, effective porosity, flow rate, and average linear velocity of water in these zones; all parameter values have a large range. Discharge from the stormflow zone in the Oak Ridge area accounts of all of the 50%-duration streamflow, about 80% of the 10%-duration streamflow, and about 30% of the 1%-duration streamflow. The calculated drainage densities that correspond with these streamflows are 1.1, 4.6, and 8.2 km/km², and the average lengths of the subsurface flow paths are 450, 110, and 60 m. Only about 5-10% of the annual discharge from the stormflow zone is from fractured rocks below the water table. The rest of the water flows laterally through the stormflow zone below a perched water table. Water level hydrography for observation wells of the USGS show that the maximum daily rise in water level during a recharge event is 1-2000 cm, average linear velocity of vertical flow through the vadose zone is 0.02-50 m/d, and the time delay for the water table to rise to a peak during recharge is 0.5-45 d. The range in hydraulic conductivity that will produce these effects is 5.4E-5 to 0.27 m/d. The range is seasonal fluctuation of the water table is 0.2-7.6 m; most of this range is probably caused by local differences in effective porosity near the water table.

A WATER QUALITY SURVEY OF NUTRIENT LOADINGS TO CENTER HILL LAKE FROM THE CANEY FORK RIVER BASIN

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INTRODUCTION

In recent years, concerns have been raised by various state and federal agencies over water quality changes in Center Hill Lake. During the period of March, 1988 to January, 1989, sampling of Center Hill Lake and its inflows and outflows was conducted on a regular basis in order to determine the water quality of the lake, its embayments, and its trophic state. Major inflows and wastewater treatment plants were sampled at two week intervals for water quality in order to perform a meaningful nutrient analysis for the lake.

CONCLUSIONS

The results of the study are specific for the data collection period, but none-the-less are quite meaningful for lake managers and standards-setters. The study led to the following conclusions:

1. The main lake portion of Center Hill Lake is low in essential nutrients and is phosphorus limited. The mean orthophosphorus concentration was less than 10 micrograms per liter.

2. Embayments had more of the essential nutrients and phosphorus was more abundant in the metalimnion and hypolimnion.

3. Dissolved oxygen values are much lower in the embayments and are well below life sustaining concentrations below the epilimnion.

4. The main lake portion of Center Hill Lake has good dissolved oxygen concentrations except for a pronounced zone of low D.O. termed the metalimnetic minimum.

5. This new information supports the conclusions of Hunter (1987) who noted that Center Hill Lake is lower in nitrogen and phosphorus than it was in the early 1970s.

6. Based upon 1988 concentrations of total phosphorus and chlorophyll a and 1988 Secchi disk measurements, the main-channel of Center Hill Lake has been identified as mesotrophic through criteria set forth by three different methods. The lake's classification using 1973 data indicated that the lake was strongly eutrophic (Gordon, 1976). It is believed that land-use changes and more efficient domestic wastewater treatment within the basin are the cause of an improved trophic classification.

7. Identical analyses performed for two of Center Hill's embayments, Falling Water and Mine Lick, indicate that the embayments are eutrophic. Higher nutrient loads and low flushing rates are believed to be significant factors in the trophic state of Center Hill's embayments.

8. The Caney Fork River which leaves Great Falls Lake contributed 71 percent of flow, 59 percent of orthophosphorus, and 56 percent of the total nitrogen to Center Hill Lake. The McMinnville and Sparta wastewater treatment plants contributed 15 percent of this ortho-phosphate phosphorus but only 3 percent of the total nitrogen. (See Figures 1, 2, 3, and 4.)

9. The Falling Water River contributed 4.7 percent of flow, 23 percent of orthophosphorus, and 7.2 percent of total nitrogen to Center Hill Lake. The Cookeville wastewater treatment plant contributed most of the orthophosphorus and half of the nitrogen. (See Figures 1, 2, 3, and 4.)

10. Direct precipitation contributed 4.8 percent of total nitrogen to the lake. (See Table 1.)

11. Ungaged, unmeasured runoff contributed 15 percent of flow during the study period. (See Table 1.)

12. Center Hill Lake trapped 78 percent of incoming phosphorus and 52 percent of total nitrogen during this study period. (See Table 1.)

Table 1. Water Budget for Center Hill Lake from March 1988 through January 1989

Item	Drainage Area (acre)	Mean Flow (ac-ft/yr)	Runoff (ac-ft/yr)	Water Inflow (%)	Total Phosphorus (lbs)	Total Nitrogen (lbs)
Mine Lick	12,352	10,500	0.85	0.636	5,400	27,700
FWR	80,000	78,200	0.98	4.740	42,500	308,000
Pine	14,848	16,400	1.10	0.994	1,320	80,300
Sink	23,808	19,300	0.81	1.170	1,600	67,200
Fall	8,000	6,590	0.82	0.399	590	21,300
Taylor	21,760	13,000	0.60	0.788	3,100	49,800
Great Falls	1,073,280	1,174,000	1.20	71.200	128,000	2,390,000
Precipitation	18,220	79,000	4.40	4.790	4,530	312,000
Ungaged Direct						
Runoff	152,532	253,000	3.20	15.300	24,100	1,000,000
Runoff	152,532	253,000	3.20	15.300	24,100	1,000,000
Total Inflow		1,650,000	1.2	100.0	211,150	4,266,300
Evaporation		45,550	2.5	2.7	-	-
Total Outflow		1,333,000	-	80.8	50,800	2,610,360
Change in storage		317,000	-	-	15,500	560,000

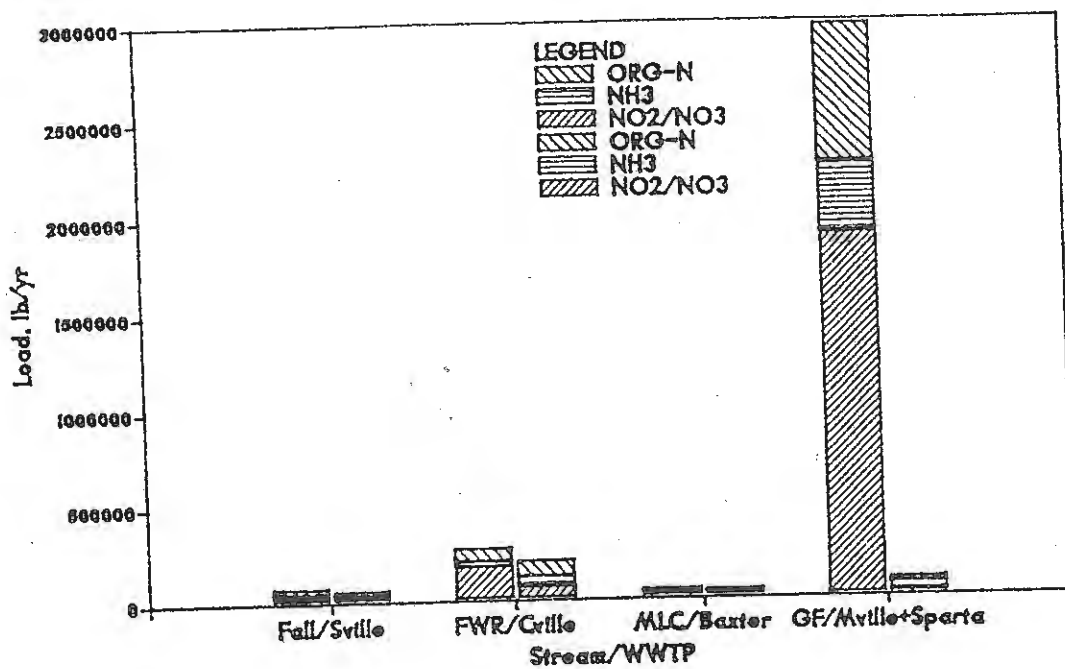


Figure 1: Nitrogen Loadings for WWTPs and their Receiving Streams

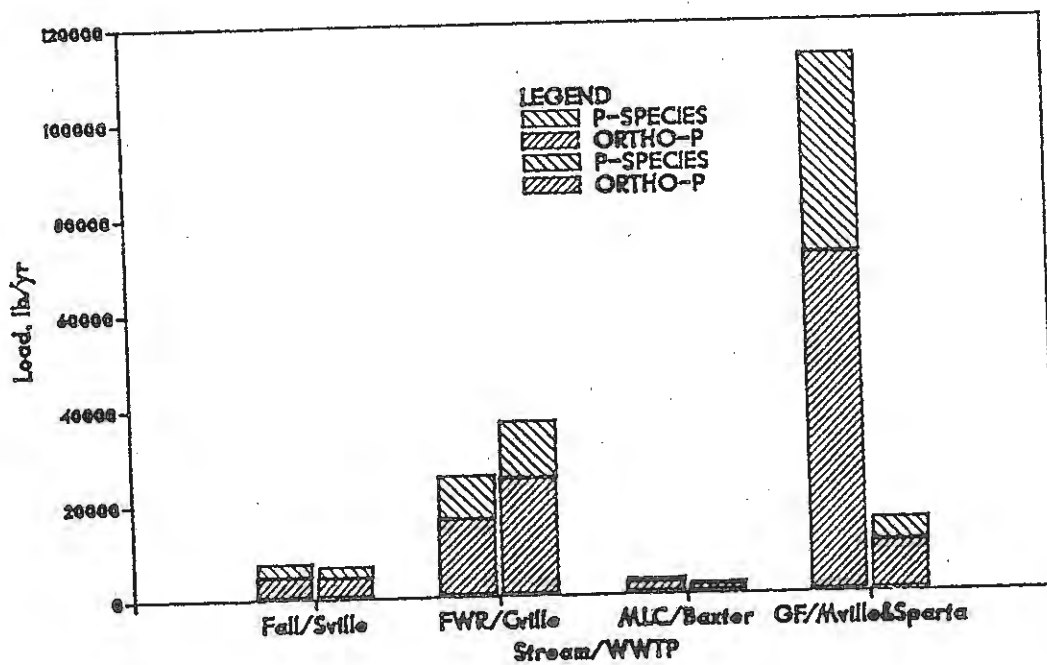


Figure 2: Phosphorus Loadings for WWTPs and their Receiving Streams

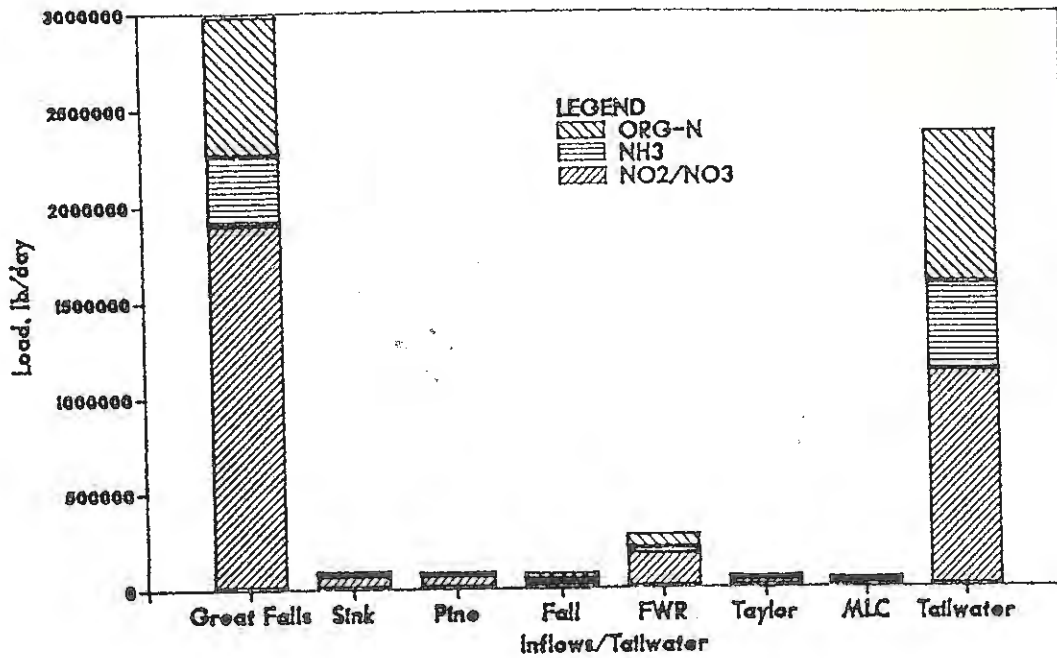


Figure 3 : Center Hill's Inflow Nitrogen Loadings

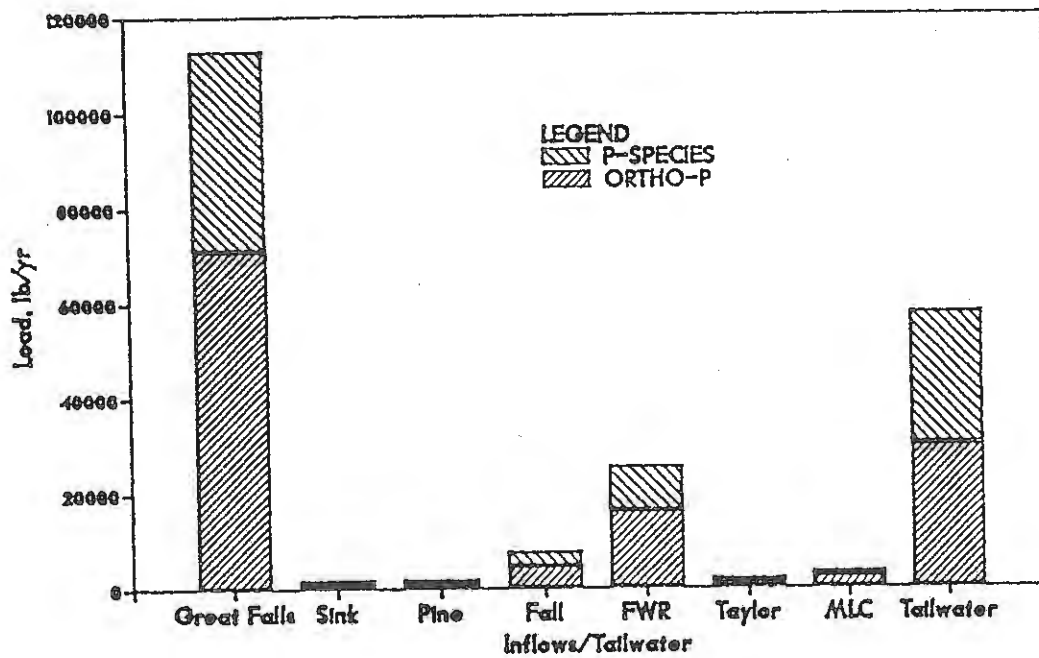


Figure 4 : Center Hill's Inflow Phosphorus Loadings

GROUND-WATER INVESTIGATION OF CAVE SPRING
NEAR CHATTANOOGA, TENNESSEE

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In cooperation with the Hixson Utility District of Chattanooga, Tennessee, the U.S. Geological Survey has been conducting an investigation of the ground-water resources of the utility district service area. This study was initiated to determine the feasibility of further development of ground-water resources because of increasing demands for water in the north Chattanooga area and a lack of information as to the potential yield of Cave Spring, before resorting to the Tennessee River to meet future water-supply needs. The objectives of this investigation were to determine the potential yield of the Cave Spring ground-water reservoir, to define the area recharging the spring, and to explore the utility district service area for additional ground-water supplies.

Cave Spring issues from the Newman Limestone below a thrust fault separating the Newman Limestone below from older Knox Group dolomites above. Southeast of Cave Springs Ridge, clay and chert regolith as thick as 350 feet overlie bedrock. The area is bounded on the north and east by the Tennessee River and on the south and west by North Chickamauga Creek and its tributaries.

In order to determine the potential yield of the Cave Spring system, continuous discharge of the spring was monitored for 2 years to obtain a mean annual flow. The discharge was combined with the water pumped by the utility district for an estimate of the total amount of water available. Specific conductance and water temperature at the spring were also monitored for 2 years. Extensive drilling in the area, water-quality data from surface and ground water, and aquifer tests were used to define the geometry and hydrogeologic characteristics of the study area.

The discharge of Cave Spring is estimated to be about 15 cubic feet per second. The fact that the spring is dry during part of the summer was a cause of concern to the utility district. However, as much as 9,000 gallons per minute were pumped during one aquifer test with only 2.5 feet of drawdown. A reduction in specific capacity with declining water levels was observed in tests conducted during the summer. Deep test wells at the spring indicate fractures as deep as 275 feet are in hydraulic connection with the flooded cave. Specific capacities of wells drilled in the service area were considerably less and varied significantly depending upon local geology.

In order to assess the potential water supplies in the service area and to determine the area recharging Cave Spring, a detailed seepage investigation was conducted. Discharge measured at 70 sites indicated numerous dry or losing stream reaches that provide recharge to the ground-water system. Based on this information, 19 wells were located and drilled to define the geology and hydrologic properties of the ground-water reservoir and to provide

a potentiometric map of the service area. Geophysical logs and aquifer tests from the test wells illustrate the variability in lithology and the amount of water available to individual wells.

The potentiometric map indicates an area of approximately 15 square miles is supplying water to Cave Spring. This is a reasonable area for a spring of this magnitude based on the average yield per square mile of surface streams in the area. The potentiometric surface is controlled by the major surface drains rather than being a subdued replica of the topography. Most of the recharge to Cave Spring comes from the Knox Group southeast of Cave Springs Ridge.

Continuous monitoring of specific conductance and water temperature monitored in wells at Cave Spring indicate that specific conductance increases as water levels rise. This fact, coupled with a lack of turbidity in the spring discharge, supports the theory that water in longer residence with limestone is driven out of the spring during recharge events. Water-quality data from wells and surface streams support this theory. Concentrations of major cations and anions also indicate that the Tennessee River and North Chickamauga Creek are unlikely sources of water to Cave Spring.

ASSESSING GROUND-WATER FLOWPATHS FROM POLLUTION SOURCES
IN THE SINKHOLE PLAIN PUTNAM COUNTY, TENNESSEE

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During the last two years, a systematic analysis was performed of groundwater flow paths between pollution sources and springs in Putnam County, Tennessee utilizing dye tracing techniques. Putnam County is located on a sinkhole plain underlain by nearly flat-lying Mississippian carbonates. Over 100 sinkholes have been delineated from topographic maps. An earlier study (Mills et al., 1982) showed that approximately 25% of the sinkholes contain solid waste, organic fill, or are receiving sewage. This alarming information prompted the present study aimed at delineating the recharge areas to the springs.

The area is suffering growing pains that have resulted in groundwater contamination from leaky underground storage tanks, untreated municipal sewage, an unpermitted landfill, municipal storm water runoff, and agricultural practices. At least three corporations having leaky underground storage tanks contribute petroleum products to a sinking stream. The contaminated water in the sinking stream moves a distance of 3000 ft. to a spring in less than eight hours and thus travels to the old Cookeville City Lake. The town of Algood injects its poorly treated wastewater into a sinkhole causing contamination of a spring and creek just 2000 ft. away. An unpermitted landfill outside Algood occurs in a deep sinkhole. Runoff from the landfill area is believed to travel approximately one mile to a spring that usually remains turbid, likely due to the dumping of limestone dust into a sinkhole next to quarrying operations.

Groundwater tracing has been conducted south of Interstate 40 from the industrialized portion of Cookeville. Petroleum products have been observed at the springs along Hudgens Creek, but the point sources of contamination have not yet been identified.

The end product of the research is a map delineating the drainage basins for the springs in the study area. This map can be utilized for planning purposes and for emergency response to spills along Interstate 40 and state highways within the county.

RAPID DETERMINATION OF THE EXTENT OF GASOLINE CONTAMINATION OF A
SHALLOW AQUIFER NEAR JACKSON, TENNESSEE

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Soil-gas analyses of the unsaturated zone provided a rapid and low cost approach to determining the extent of gasoline contamination of a shallow water-table aquifer. An underground storage tank in Jackson, Tennessee, leaked about 3,000 gallons of unleaded gasoline from 1980 to 1988. The gasoline leaked to the water table about 4 feet below land surface. A survey of soil gas using a gas chromatograph equipped with a photoionization detector showed concentrations of volatile organic compounds greater than 10,000 parts per million near the leak. The contaminant plume was about 240 feet long and 110 feet wide extending west from the point source. Two "fingerprints" of volatile organic compounds were observed in the chromatograms. Benzene, toluene, and xylenes were present from the unleaded fuel in addition to other volatile compounds in the area near the gasoline leak. Just north of the leak, volatile compounds containing no benzene, toluene, or xylene were observed in soil gas samples. Mapping of total concentrations of volatile organic compounds in the unsaturated zone indicated that a second plume about 200 feet long and 90 feet wide, also extending to the west, was present about 100 feet north of the gasoline leak. Previous activities on this site during the 1950's or earlier, such as handling of solvents used at the nearby railyard, or flushing of tanks containing tar onto a gravel parking area may have contributed volatile organic compounds to the second plume.

OAK RIDGE RESERVATION HYDROLOGIC-GEOLOGIC STUDY:
PROGRESS REPORT ON BEDROCK GEOLOGY AND POTENTIAL
APPLICATIONS TO GROUNDWATER INVESTIGATIONS

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Detailed geologic mapping of the Oak Ridge Reservation (ORR) at 1/12,000 and 1/24,000 scales has been in progress for the past three years. An initial goal is to produce a modern geologic map of all major stratigraphic subdivisions, contacts, and mesoscopic structures (bedding, small folds, joints). Relationships of joints to ground water flow in sedimentary rock and the need to understand how regional permeability is controlled by different joint sets is another major goal. Relationships of major (e.g., large thrust faults and folds) to small structures in ORR (e.g., joints and bedding), facies, and systematic fracture intensity and spacing to ground water occurrence and movement is the ultimate goal of this investigation.

The oldest unit exposed in ORR is the Rome Formation. Earlier mapping by McMaster recognized upper sandstone-dominant and lower shale-dominant units. Subdivision of the Conasauga Group is being carried out using criteria developed by ORNL and USGS geologists working in ORR. Our studies have resulted in subdivision of the Knox Group using criteria and markers originally developed in the Mascot-Jefferson City Zinc District, and in the Cleveland, Tennessee, area. Chickamauga Group rocks in Bethel Valley in ORR are being mapped using southwestern Virginia units correlated to ORR by E. Weiss, whereas the Middle Ordovician stratigraphy of Oak Ridge Valley may be divisible into C.W. Wilson's Middle Tennessee units. The Reedsville Shale, Rockwood-Sequatchie Formation, Chattanooga Shale, and Fort Payne Chert are mapped as previously by McMaster.

The most common mesoscopic structures at ORR are extensional, hybrid (?), and shear fractures. Joint studies from the Cumberland Plateau, Valley and Ridge, Blue Ridge, and Piedmont indicate some joints developed because of erosional unloading and the recent stress fields, while others formed during Triassic-Jurassic extension. Therefore all joints here are not a result of Paleozoic folding and thrust-Sheet emplacement.

AN ASSESSMENT OF GROUNDWATER CONTAMINATION FROM OIL
AND GAS WELLS IN OVERTON COUNTY, TENNESSEE

by

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The objective of this research was to determine the effects, if any, of active oil and gas exploration and production on the shallow groundwater quality in aquifers underlying some Tennessee well fields. The research, by necessity and design, had to be restricted to areas which had (1) active oil and/or gas production, (2) access points to the groundwater (since no money was available for monitoring well construction), and (3) a minimum number of citizens in designated areas who were willing to participate in a ten-month study of their groundwater supply. The research involved monthly sampling of over 60 water sources from August 1987 through May 1988. Dye traces were performed throughout most of the study to assess subsurface connections between potential contamination sources and spring outlets. Stream surveys in the study area were conducted during low flow periods to locate possible locations of contaminant inflow.

The study area selected was in Overton County which is the 5th most productive county in Tennessee as shown by Table 1. This county fit all of the previous criteria.

Table 1. Major Oil Producing Counties in Tennessee, 1987

County	Production (bbls)	No. of Wells	Production per Well-Day (bbls)
Morgan	151,530	260	1.6
Scott	141,671	258	1.5
Claiborne	107,897	40	7.4
Fentress	90,566	121	2.1
Overton	56,993	89	1.8

Water quality in control wells was variable as shown by Table 2. Chlorides in control wells ranged from 0 to 76.9 mg/l with conductivities from 141 to 431 mmho/cm.

Table 2. Selected Analyses of Water Quality Parameters in Control Points from August 1987 through May 1988 (N=56)

Parameter	Mean	Minimum	Maximum	Variance	C.V.
Chloride (mg/l)	10.4	0.0	79.6	394	191
Temperature (C)	14.6	9.0	20.0	4.6	14.6
Conductivity (mmhos/cm)	431	141	1190	104000	74.8

Chlorides in an oil production area known as Brown's Chapel ranged from 0 to 685 with a mean of 23.5. Only a fish pond and a dug well were likely contaminated. The fish pond was a known receiver of brine. Table 3 shows this information.

Table 3. Selected Analyses of Water Quality Parameters in the Brown's Chapel Area from August 1987 through May 1988 (N=308)

Parameter	Mean	Minimum	Maximum	Variance	C.V.
Chloride (mg/l)	23.5	0.0	685	6387	339
Temperature (C)	15.3	4.1	29.8	15.7	26.0
Conductivity (mmhos/cm)	390	117	2290	60743	63.2

Chlorides in the Hilham area which contained oil and gas wells ranged from 0 to 38 mg/l and did not show evidence of brine contamination. Table 4 shows this information.

Table 4. Selected Analyses of Water Quality Parameters in the Hilham Area from August 1987 through May 1988 (N=110)

Parameter	Mean	Minimum	Maximum	Variance	C.V.
Chloride (mg/l)	7.2	0.0	38.3	61.3	108
Temperature (C)	14.6	8.6	20.4	3.6	13.0
Conductivity (mmhos/cm)	539	110	1696	239000	90.7

Chlorides in the Eagle Creek area showed no contamination from gas production wells. Chlorides ranged from 0.5 to 25 mg/l as shown by Table 5.

Table 5. Selected Analyses of Water Quality Parameters in the Eagle Creek Area from August 1987 through May 1988 (N=60)

Parameter	Mean	Minimum	Maximum	Variance	C.V.
Chloride (mg/l)	6.9	0.5	24.7	32.8	83.6
Temperature (C)	13.9	6.0	18.9	5.6	17.0
Conductivity (mmhos/cm)	327	240	443	332	14.8

Chlorides in the Puncheon Camp Creek area which is an oil production field ranged from 0 to 300 mg/l. There was slight evidence of contamination of a single unused spring in this area and high chlorides in the stream itself. This information is shown by Table 6.

Table 6. Selected Analyses of Water Quality Parameters in the Puncheon Camp Creek Area from August 1987 through May 1988 (NJ60)

Parameter	Mean	Minimum	Maximum	Variance	C.V.
Chloride (mg/l)	23.8	0.0	300	2729	220
Temperature (C)	13.7	2.9	21.0	14.5	27.9
Conductivity (mmhos/cm)	344	188	3150	159000	116

A ranking of the five areas sampled by their mean chloride concentration is given by Table 7.

Table 7. Differences* in Mean Chloride Concentrations (mg/l) in Water Collected from Five Different Sites

Grouping	Mean	N	Site
A	23.8	61	PCC
B	12.1	298	BC
B	10.4	56	C
B	7.2	110	HH
B	6.9	60	EC

* Means with the same letter are significantly (alpha = 0.05) different by the Duncan's Mean Range Test.

Only the Puncheon Camp Creek area differed from the control group and this was due to high stream levels and a single spring.

Another analysis shown by Table 8 showed that dug wells had the highest mean chlorides while surface sources, springs, and bore wells were similar in chloride content.

Table 8. Differences* in Mean Chloride Concentrations (mg/l) in Water Collected from Four Different Water Sources

Grouping	Mean	N	Source
A	37.7	50	dug well
B	11.9	73	surface
B	9.0	248	spring
B	8.6	214	bore well

* Means with the same letter are not significantly different (alpha = 0.05) by the Duncan's Multiple Range Test.

Study results indicated two instances of minor local groundwater contamination by oil field brines in the Brown's Chapel area, and one instance of brine discharge in the Puncheon Camp Creek area to the ground surface by brine pit overflow during heavy rains. None of the contaminated groundwaters was known to be used as a direct source of potable water, the scale of contamination was relatively small in degree and area, and the associated springs were located in sparsely inhabited areas. Chloride levels in all groundwater sampled in the study were well within established secondary standards of 250 mg/l.

No significant (alpha = 0.05) difference in water chloride levels was detected between areas of active oil production, gas production, gas-and-oil production, or control areas. However, significantly greater chloride levels were found in shallow dug wells, than in deeper, more protected sources, such as springs or bore wells.

The lack of evidence for substantial groundwater contamination in the study areas in Overton County is not a recommendation to ease the environmental regulations on the oil and gas industry. Instances of contamination in Overton County, not to mention other oil-producing counties, may not have been detected due to lack of access to many groundwaters for sampling.

AQUIFER CHARACTERISTICS AND GEOLOGY AT THE GEOHYDROLOGIC SURVEY
WELL, HUMPHREYS COUNTY, TENNESSEE

Michael W. Bradley, U.S. Geological Survey
and Phillip Craig, E.I. duPont deNemours and Co.

The Geohydrologic Survey (GHS) well is currently being cored from land surface to a planned depth of 8,500 feet. The well is being drilled to provide information on aquifer characteristics, water quality, and confining bed properties of the hydrogeologic units encountered. The results of these tests, including vertical-head gradients and age dating of the ground water, will provide information on the regional confining layers and aquifers, and regional ground-water flow in Tennessee.

The only water-bearing zones encountered were in the Fort Payne Formation and at a fractured zone in the top of the Chattanooga Shale. The Chattanooga Shale acts as a regional confining layer separating the ground water in the Fort Payne Formation (10 to 15 tritium units) from ground water in the underlying Devonian limestones (less than 2 tritium units). Fractures in the Fort Payne Formation produced 0.3 gallons per minute with a drawdown of 126 feet. The specific capacity for this zone was about 0.002 gallons per minute per foot. Nearby domestic wells in the Fort Payne Formation are capable of producing 3 to 10 gallons per minute.

The Hermitage Formation in the Ordovician age Nashville Group, is apparently the next major confining layer. At the GHS well, the Hermitage Formation is a dense, shale and shaly limestone. This zone produced only small pockets of natural gas and no water. Although the limestones of the Stones River Group below the Hermitage Formation produced very little water, oil and gas test wells just south of Waverly, Tenn., encountered solution openings and salt water in the Stones River Group.

The aquifers occurring in the Mississippian through Ordovician age formations are dependent on the occurrence of local fractures and solutions openings. The regional confining layers are the Chattanooga Shale and the Hermitage Formation. Shales within the Silurian age formations also may act as confining layers in specific areas.

HYDROLOGY COMPONENTS OF LONG-TERM ECOLOGICAL RESEARCH AND MONITORING IN THE GREAT SMOKY MOUNTAINS

Russ T. Brown, Water Center, Tennessee Technological University

INTRODUCTION

Plans are being formulated for a long term ecological research and monitoring (LTERM) strategy in the Great Smoky Mountains National Park (GRSM). A review of available rainfall and streamflow station locations provided the basis for a suggested hydrologic component of the LTERM plan. A network of 10 streamflow gages around the perimeter of the Park will capture 80% of the runoff. These perimeter sites should be augmented by additional locations on tributary streams. Rainfall data from the higher locations is limited. Cooperation between TVA, NWS, NPS, and the Gatlinburg Flood Warning System will be required. The National Acidic Deposition Program site at Elkmont should be maintained to provide rainfall chemistry data.

The hydrology component of the LTERM plan should provide descriptive and diagnostic information concerning the hydrologic conditions of the GRSM watersheds through time. Although basic rainfall and streamflow information are important, many additional hydrologic variables will be of interest, such as canopy interception of rainfall and fog, near surface runoff following rainfall, soil moisture profiles, percolation to groundwater, spring and seepage baseflow, and evapotranspiration patterns. The integration and interpretation of these hydrologic data can be accomplished with a series of water budget models that include soil moisture and groundwater storage terms. These hydrologic models can provide useful links with stream chemistry, aquatic biology, and terrestrial ecology components of the LTERM plan.

METHODS AND PROCEDURES

Hydrologic data should include an adequate description of the watersheds themselves. The stream networks and topography identified on USGS 1:24000 scale maps have been digitized into the ARC/INFO Geographical Information System (GIS) for the GRSM. These GIS data can provide the necessary information for estimating spatial patterns of hydrologic processes within the GRSM.

Figure 1 shows the major watersheds in the vicinity of the GRSM and indicates the locations of historical streamflow gages. The watersheds can be grouped into four major river basins. Several streams on the Tennessee side of the GRSM drain into the Little Pigeon River. The streamflow gage at Sevierville with a drainage area of 353 mi² (114 mi² in GRSM) has provided a record of flow from these streams since 1967. However, a considerable portion of this drainage area is located in the Valley and Ridge limestone province located between the GRSM boundary and Sevierville. Several streamflow gages have been located along the West Prong of the Little Pigeon River as part of the flood warning system for Gatlinburg, but no daily records of streamflow are being

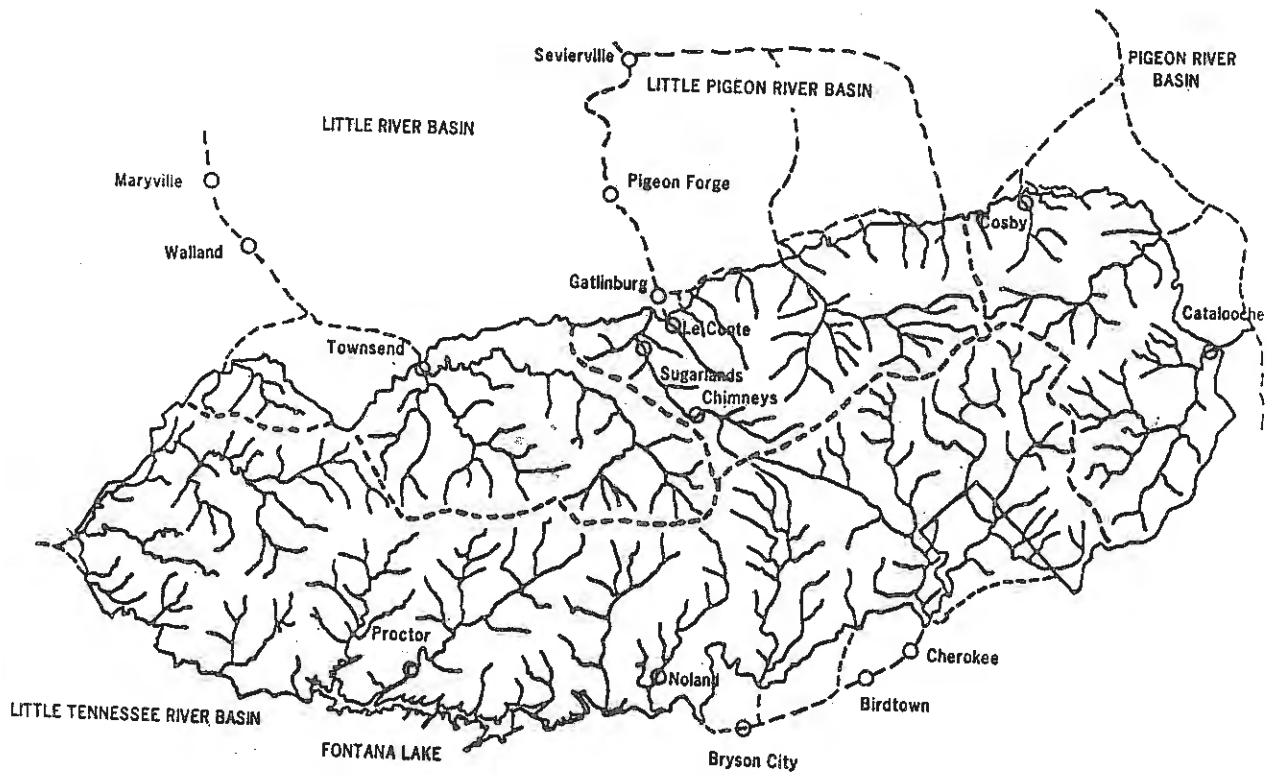
obtained. The Gatlinburg water intake could be used as a cooperative water quality sampling location. An additional gage should be installed on the Middle Prong of the Pigeon River, which drains 46 mi² of the GRSM above Greenbrier.

To the east are several watersheds which drain into the Pigeon River. A streamflow gage was located on Cosby Creek from 1966 to 1987. Big Creek, which is entirely within the GRSM with a drainage area of 33 mi², has never been gaged. A streamflow gage was operated on Cataloochee Creek between 1934 and 1952. This stream drains 49 mi² entirely within the GRSM. The USGS reactivated this gage as part of the Hydrologic Benchmark network for natural reference watersheds beginning in 1962. Daily streamflow and quarterly water quality samples have been collected at this site.

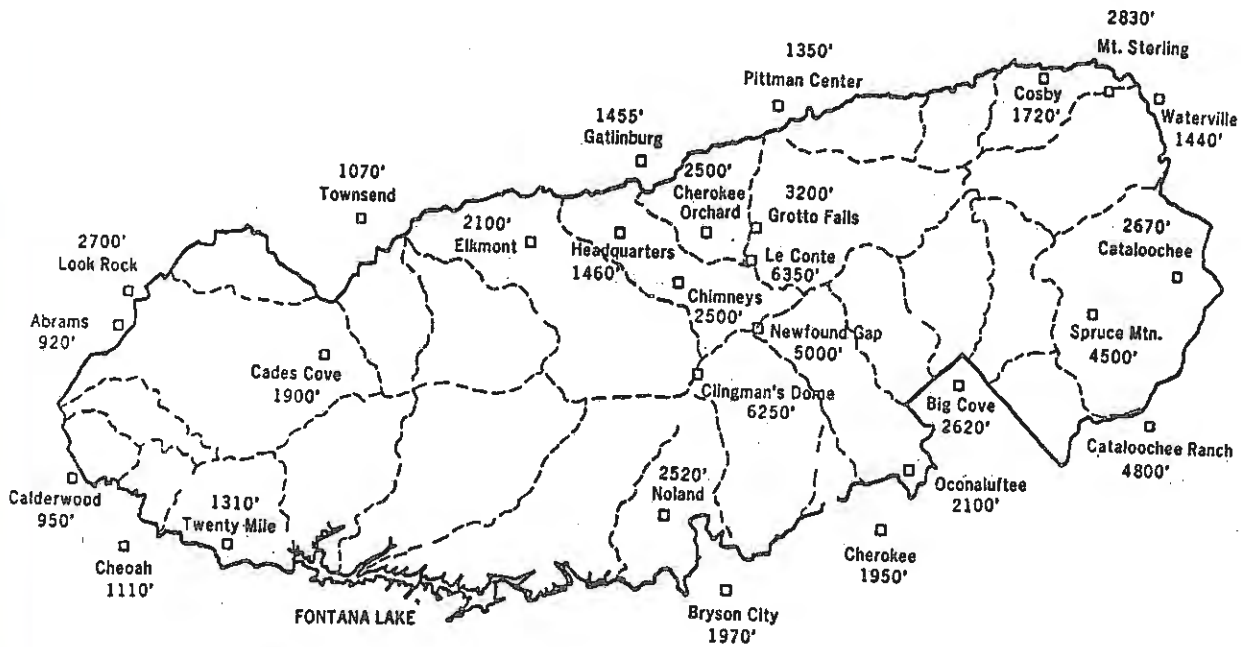
The majority of the streams on the North Carolina side of the GRSM drain into the Little Tennessee River basin. A streamgage was located on the Oconaluftee River near Cherokee from 1921 to 1949 with a drainage area of 131 mi², (106 mi² in GRSM). This gage was moved downstream to Birdtown (184 mi²) where it is presently operating. If the gage were located back at Cherokee it would coincide with the proposed water intake for the city of Cherokee where water quality measurements could be obtained cooperatively. The Oconaluftee River joins the Tuckasegee River upstream of Bryson City, where a streamflow gage has been operated continuously since 1898. This gage has a watershed of 655 mi² (149 mi² in GRSM). Several watersheds on the North Carolina side of the GRSM flow south into Fontana reservoir. A streamflow gage was operated on Noland Creek (14 mi²) from 1935 to 1971. Another gage was operated on Hazel Creek (42 mi²) from 1942 to 1952. One or both of these gages should be reactivated. Abrams Creek drains the western portion of the GRSM and contains calcareous geology in the Cades Cove area. There has never been a streamflow gage on Abrams Creek, but one should be installed.

The Little River is the fourth major stream draining the GRSM. The West Prong and Middle Prong join the Little River just upstream of the Park boundary near Townsend. A streamflow gage has been operated at the park boundary since 1963 with a drainage area of 106 mi². Remarkably, this was also established as a Hydrologic Benchmark station, so that quarterly water quality and several years of daily temperature and conductivity data are available.

Figure 2 indicates the location of historical raingages near the GRSM. Currently, several locations within the GRSM report daily rainfall: Park Headquarters, Cades Cove, Oconaluftee, Le Conte Lodge, and Newfound Gap. Several other rainfall gages are operated by TVA or the NWS including: Abrams Creek, Big Cove, Bryson City, Calderwood, Cataloochee, Cataloochee Ranch, Cheoah Dam, Cosby, Gatlinburg, Twenty Mile, and Waterville Powerhouse. The NPS is operating Elkmont as an acid deposition station, Look Rock as an ozone monitoring and air quality station, and Clingman's Dome as part of the Integrated Forest Study. The Gatlinburg Flood Warning system includes rainfall gages at Grotto Falls, Cherokee Orchard, and Chimneys. Several of the historical stations are no



Streamflow Gage Locations in the Vicinity of the
Great Smoky Mountains National Park



Rainfall Gage Locations in the Vicinity of the
Great Smoky Mountains National Park

longer active including: Pittman Center, Townsend, Mt. Sterling, Spruce Mountain, Noland Creek, and Cherokee.

There are relatively few high elevation sites in the interior of the park. Since much of the park is between elevation 2000 and 5000 feet, and since rainfall increases significantly with elevation, estimates of rainfall in the interior of the GRSM are actually quite poor. Studies by TVA in the GRSM and at Coweeta indicate that rainfall increases by 15% for each 1000 ft elevation increment. The rainfall gage network is not sufficient for detailed daily water budgets of the major basins. Possibilities for remote rainfall gage installations at developed backcountry sites or other suitable locations should be identified. Advanced NWS rainfall radar in combination with GIS digital terrain maps and the point rainfall gages may allow fairly sophisticated analyses of the spatial rainfall patterns within the GRSM in a few years.

Direct measurements of soil moisture depth profiles with neutron probes are recommended to help interpret the hydrology of the park watersheds for forestry and botanical purposes. Several transects of permanent access tubes, located at vegetation study plots, should be established to demonstrate valley to ridge gradients in soil moisture. This information would more directly indicate the effects of extreme wet and dry periods on soil moisture and evapotranspiration processes. Estimates of evapotranspiration (ET) potential should be obtained with pans or other suitable devices since this is such an important environmental condition for vegetation. The streams in the GRSM are well sustained through dry periods because of relatively high baseflow originating from the slow draining of soil and the discharge of springs. Some direct monitoring of ground water levels should be included as a component of the LTERM plan. These monitoring wells would be used to track the ground water levels seasonally, and could be used for groundwater quality sampling.

Streamflow gages are convenient locations to monitor several parameters which are natural tracers of meteorological and water quality processes. Three variables which should be monitored at several of the streamflow gages are temperature, conductivity, and turbidity. Water temperature indicates the cumulative exposure of stream water to meteorological conditions and canopy cover, but may also suggest the relative quantity of flow from ground water. Conductivity indicates the overall concentration of solutes from weathering processes, and may be used to track fluctuations in dominant water pathways during storm runoff and low flow conditions. Turbidity is a direct measure of upstream erosion and land surface washoff processes. Long term records of these indicator variables, integrated with the rainfall and streamflow records, would provide an excellent basis for interpreting hydrogeochemical conditions in the major watersheds of the GRSM. This information might be extremely useful for detecting global warming, increasing or decreasing acidic deposition, or other regional trends in environmental conditions.

CONCLUSIONS

Hydrologic components are extremely important for the LTERM plan at GRSM. Hydrology provides a natural framework for monitoring environmental conditions and processes. Several objectives can be accomplished: (1) document fluctuations in rainfall, runoff, soil moisture and ET over the landscape and through time, (2) demonstrate the influence of hydrologic conditions on vegetation, weathering and erosion, stream chemistry, and aquatic habitats, and (3) provide reference data for assessing regional or global trends in hydrology.

POSTER SESSION ABSTRACTS

RESERVOIR INTERPOOL PLANT HABITAT DYNAMICS I

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Drawdown zones, unstable wetlands between summer and winter pool levels, are often a large part of the area within nominal reservoir boundaries in the Upper Tennessee River Valley. When exposed, these interpool zones support various, depauperate plant associations on substrates now more related to full pool hydrologic energy gradients than to pre-reservoir landscape characteristics. Many seasonal and some perennial species discriminate dewatered sand, silt and clay sediments and, occasionally, truncated historic soil profiles. Existing pool-shore substrate interfaces exhibit thermal and chemical hiatuses and exposure impacts which change with wave action and short-term and seasonal water levels. Preliminary delineations of plant associations have been made. Microenvironmental dynamics and sediment modifications have been inferred. There is little pedogenetic horizonation, even in low energy sediments. Investigations of successful "mudflat" plant establishment effects on temporally saturated to very dry strands and superior summer pool shores continue.

HYDROLOGIC INTERPRETATION OF WATER QUALITY DATA FROM TENNESSEE RIVER TRIBUTARIES

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Julie L. Young, Tennessee Division of Water Management

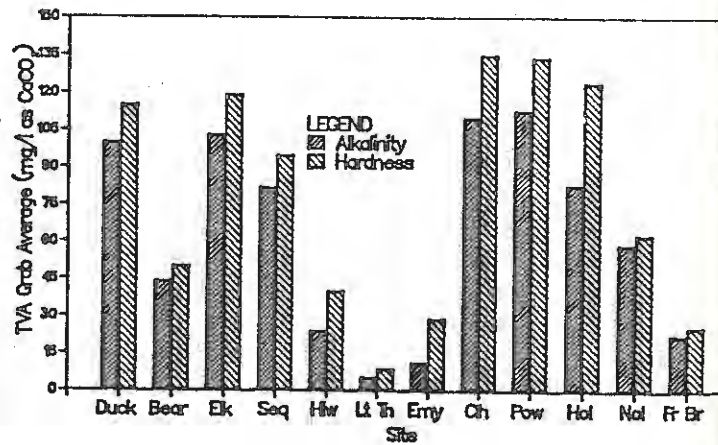
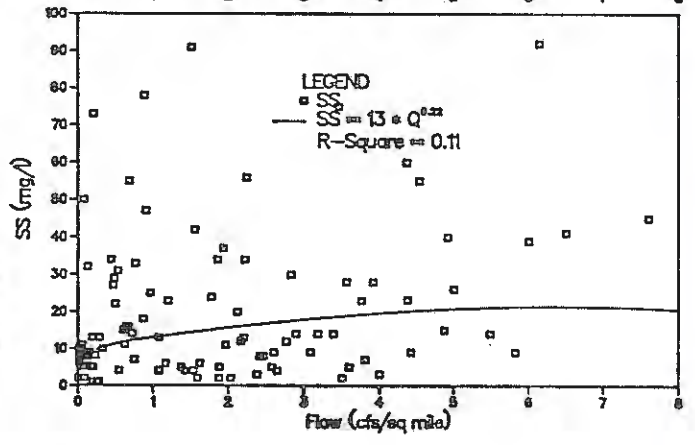
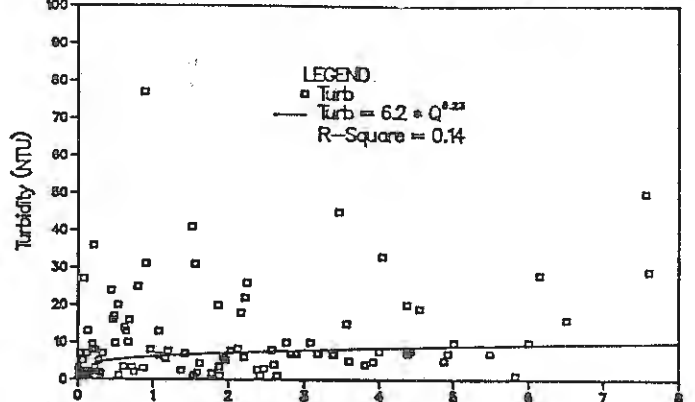
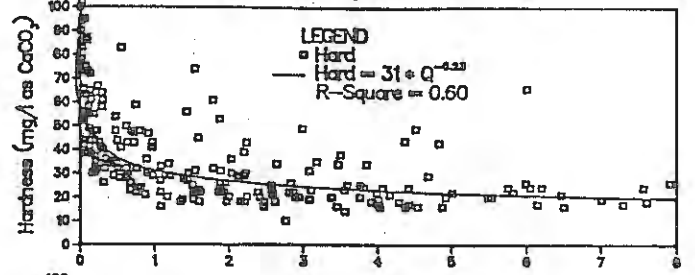
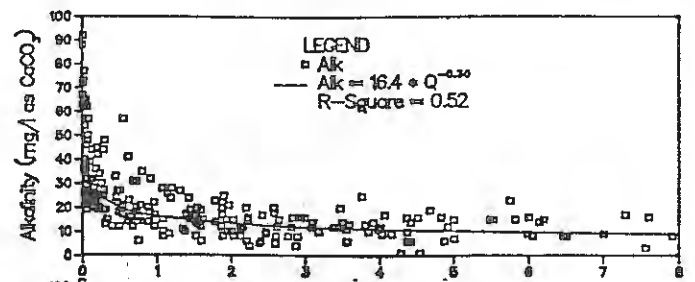
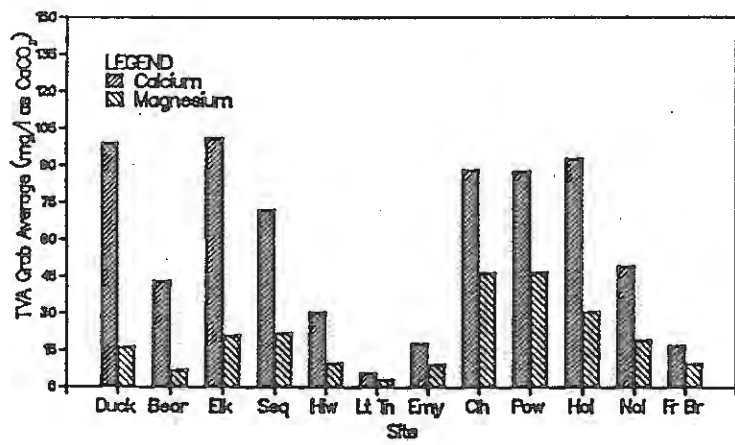
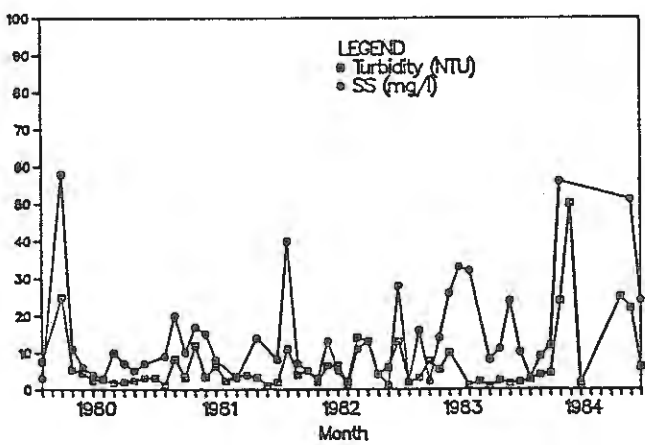
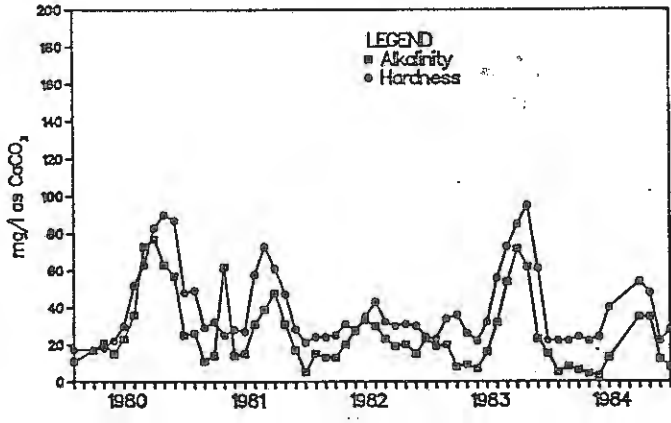
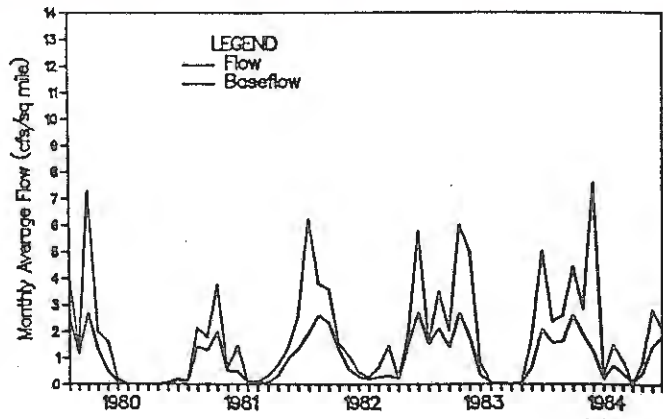
INTRODUCTION

Several sampling stations provide a general description of water quality from major tributaries of the Tennessee River basin. Accounting for hydrologic variability improves the information obtained from these samples. Variations of solutes and particulates with hydrologic conditions were identified for 12 stations in the TVA Surface Water Monitoring System (SWMS). Historical and recent TVA data were compared with monthly composite and daily measurements obtained from nearby water treatment plants. These data were integrated and interpreted with available streamflow records. Initial data checks confirmed the general validity of the data. Basic statistics, correlations, and regressions with flow, conductivity, and turbidity were used to characterize the water quality data.

Fixed station monitoring can provide valid information to characterize water quality, identify flow relationships, and detect long term trends if designed and operated properly. Each tributary basin of greater than 1000 km² should be sampled separately. Fifty samples are sufficient to characterize water quality patterns if collected to represent the full range of flow conditions. All sampling strategies will provide similar mean values for solutes. Daily sampling is required if storm event quality is desired. Composites may be attractive for particulates and for detecting trace chemicals that are transported episodically. The possibility of monitoring conductivity and turbidity at streamgages and water intakes should be considered along with grab or composite sampling for laboratory analyses.

METHODS AND PROCEDURES

The Tennessee River basin covers 106,000 km². The long term average flow is approximately 1840 m³sec⁻¹, representing an average runoff of 55 cm from an average rainfall of 130 cm (42% runoff). The geology is predominately limestone, although sandstone and siliceous rocks are found in portions of the basin. The basin has been extensively developed by the Tennessee Valley Authority (TVA) and private power companies, so that a significant portion of the basin flow is regulated. Ambient water quality monitoring stations have been operated by government agencies within the basin. The USGS has operated three Hydrologic Benchmark stations on relatively small natural watersheds and seven NASQAN stations with monthly to quarterly samples for 10 to 25 years. The State of Tennessee Department of Health and Environment (TDHE) operates 45 quarterly stations and other states have stations in their portions of the basin. TVA established a comprehensive monitoring network at approximately 100 sites below dams and along major streams in 1974. TVA grab samples have been collected at monthly,



bi-monthly and quarterly intervals, with some missing data over a period of 5 to 15 years. This intermittent and irregular sampling frequency precludes most time series and trend analyses. TVA now collects bi-monthly samples from 12 tributary streamflow gage locations. Surface water treatment plant (WTP) intakes located on major streams collect daily measurements of temperature, pH, alkalinity, and hardness. TDHE collected monthly composite samples from about 25 of these water treatment plants with two to twenty years of record.

Each of the data sets were analyzed using comparable laboratory procedures. Transient parameters such as temperature, DO, BOD, pH, and coliforms were not considered. Metals and organic chemicals were not considered because of the shifting analytical methods and detection limits. Only the major solutes, particulates, and nutrients have been analyzed in this study. Initial data analyses were performed to evaluate the accuracy of the historical data. The accuracy of the chemical analyses for solutes can be checked by comparing anions with cations or calculated and measured conductivity values. Time series or scatterplots of related variables were used to determine the consistency of their ratios. Monthly composites and monthly averages of the daily WTP measurements were compared as a data check.

Statistics and graphics were used to compare the water quality characteristics of the twelve tributaries. Quartile distribution values were used to summarize the range of the data. Each of the data types provided similar average concentrations for the solutes. Particulates were not well represented in the periodic grab data. Composite sampling captured some of the high particulate concentrations during storm events, but daily measurements were necessary to accurately sample the particulate patterns. Correlations were computed among all the variables and the strongest relationships were further delineated with regression equations. Daily streamflow data were used to estimate the baseflow and direct runoff using a simple recession curve method for those basins without extensive upstream impoundment. Several of the tributaries are highly regulated so flow regressions were not attempted. Monthly average flows were used for regressions with the monthly composite data.

A simple flow regression of the form $C = a Q^b$ was used, where C is the concentration, Q is the specific discharge (flow/area), a is the coefficient representing the concentration at a specific discharge of 1.0, and b is the flow exponent. For solutes, the flow exponent was quite consistent among variables at each site, but varied between -0.1 and -0.4 among the several sites. Many of the particulates were directly related to flow with an exponent of between 0.3 and 1.0 at several of the sites. Regressions with baseflow and direct runoff did not significantly improve the results. These simple flow regressions were able to account for 10% to 50% of the fluctuations in the data at some sites. Watershed runoff and water quality models may be required to adequately describe observed water quality patterns. Basin size

must be limited to provide reasonably uniform hydrologic and water quality responses.

Significant and consistent linear relationships between solutes and conductivity were observed for each data type at all sites. More variation in the relationships between turbidity and particulates were observed between sites and data types. Conductivity and turbidity are easily measured and provide a direct indication of solute and particulate response during hydrologic episodes. Utilizing conductivity and turbidity monitors at streamgages or cooperative sampling at water intakes should be seriously considered.

CONCLUSIONS

Fixed station monitoring systems can provide valid information to characterize water quality, identify flow relationships, and detect long term trends if designed and operated properly. Sampling stations should be located to allow hydrologic interpretation of the water quality. This involves choosing relatively uniform watersheds and providing streamflow measurements for determining flow relationships. Each tributary basin of greater than 1000 km² should be sampled separately. This would require approximately 50 to 100 stations within the Tennessee River basin. The results of this study suggest that the basic characterization of water quality patterns from each tributary basin could be accomplished with approximately 50 samples if they are collected to represent the full range of flow conditions

The comparison of daily, monthly composite, and grab data suggests that each sampling strategy will result in similar averages for most water quality variables. The daily data includes the greatest range of flows and concentrations. Daily samples are required if accurate measurements of water quality during runoff events are required. Monthly composites offer an interesting compromise between expensive laboratory analyses of frequent samples and periodic grab data which are likely to miss significant hydrologic events. Composites may be especially attractive for detecting trace chemicals that are transported episodically from the watershed. Grab samples can provide an adequate characterization of basin water quality if the samples cover the full range of flow conditions.

Techniques for verification of data should be incorporated into the monitoring system so that the measurements can be checked immediately after laboratory analyses. Solutes should be checked with an anion/cation balance and a measured/calculated conductivity ratio. Other variables should be compared with related parameters and historical data to detect outliers. Correlations and regressions should be routinely utilized to describe relationships between variables and with hydrologic conditions in the watershed. Changes in the relationships should be investigated. Easily measured parameters can be used to provide more detailed time series of solute and articulate responses to hydrologic events. Watershed runoff and water quality models will be required to adequately

describe the complex sequences of water quality responses to hydrologic conditions. The development and use of these models will require accurate daily streamflow and daily measurements of representative water quality variables.

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