ABSTRACTS of the FIRST TENNESSEE HYDROLOGY SYMPOSIUM

June 21-23, 1988
MAXWELL HOUSE HOTEL
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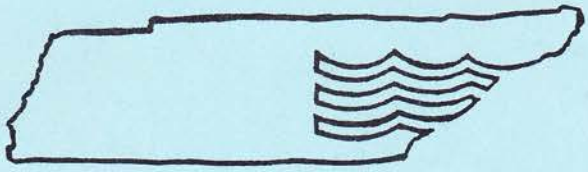

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HYDROGEOLOGIC MODELING OF A LOW-LEVEL RADIOACTIVE WASTE BURIAL GROUND, OAK RIDGE, TENNESSEE

Paul M. Craig
ECE

Oak Ridge National Laboratory's (ORNL) Solid Waste Storage Area #6 (SWSA 6) has been classified as a mixed waste facility by EPA. Early site characterization efforts by ORNL resulted in a preliminary groundwater flow and mass transport modeling study being conducted. Continuing RI/FS work is currently ongoing at SWSA 6 and other ORNL sites. The preliminary modeling results of SWSA 6 will be presented.

The USGS 3-D modular model (MODFLOW) by McDonald & Harbaugh was used to model the groundwater flow. The Kansas State version (KONIMOD) of the USGS MOC model by Konikow and Bredehoeft was used for the preliminary contaminant transport modeling. Data input and site descretization will be presented. The use of data input preprocessors to the models will be discussed.

This preliminary modeling study was useful in providing general ground-water flow paths and to highlight future data needs, including groundwater stream interactions, anisotropy, and aquifer thickness in a weathered bedrock zone. Contaminant transport modeling results present a unit discharge scenario of tritium due to lack of definition of the source terms.

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AGRICULTURAL RUNOFF MODELING IN A SMALL WEST TENNESSEE WATERSHED

Larry Moore, Harvey Matheny, Ted Tyree,
David Sabatini, Stephen Klaine
MEMPHIS STATE

The application of Hydrological Simulation Program FORTRAN (HSPF) to agriculture runoff data was examined. An 18 hectare watershed planted in corn was secured along its perimeter and all runoff from the conventionally tilled field was directed to a single discharge structure equipped with an H-flume, continuous flow recorder, and automatic sampling equipment. Data on runoff, suspended solids, nitrogen forms, and atrazine over a 19-month period were used to develop a preliminary calibration of the model.

In general, hydrology and sediment simulations were good on a monthly and long-term basis. The greatest discrepancies occurred during summer, when intense thunderstorms occurred. Simulation of atrazine content in the runoff was reasonably good; the long-term simulation of runoff atrazine was about twice the actual atrazine runoff. Simulation of total nitrogen was quite good for monthly and long-term values. Monthly ammonia and nitrate nitrogen simulations were fair, while the long-term simulations were generally good.

Simulation of hydrology, sediment, and water quality for individual storm events was mixed with good to poor results. Simulation of soluble pollutants was difficult because they occur primarily in the interflow (water that moves through

the soil layer above the groundwater table), some of which was not captured by the gage.

With due consideration of errors in data collection and analysis as well as limitations of the HSPF algorithms, the model performed reasonably well.

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A 2-D WATER QUALITY MODEL OF WATTS BAR RESERVOIR FOR SIMULATING THE TRANSPORT AND FATE OF CONTAMINANTS

Russ T. Brown
TN TECH - CIVIL ENGR

A branched two-dimensional (longitudinal/vertical) water quality model (WB-BETTER) has been developed and tested for the Watts Bar Reservoir, including the Clinch River and Emory River embayments. The general stratified flow, mixing, and mass-balance scheme follows the previously successful BETTER models developed by the TVA Engineering Lab for Ft. Loudoun, Pickwick, and Chickamauga reservoirs. The Watts Bar version is more complex because of the branching flows, including the effects of contaminant transport and organism exposure within the waterbody. The reservoir has been segmented into 52 columns with 10 vertical layers. The model simulates seasonal patterns of physical and chemical limnological variables for the entire reservoir using daily inflows. Hourly peaking flows for Melton Hill Dam and release patterns from White Oak Creek (WOC) Dam are simulated using an hourly timestep for the Clinch River embayment. Daily inflow and inflow concentrations are specified at ten locations; a great deal of data is required. The initial calibration is based on 1961-1962 data collected by TVA during the Clinch River Study.

The model is being modified to include the adsorption of radionuclides onto suspended sediment, and the settling and resuspension of these particulates. The model demonstrates the importance of hydrologic conditions for the inflow, residence time, mixing, and inflow water quality patterns. The model will allow various historical sequences of flows and contaminant releases to be simulated, as well as allow the effects of future management alternatives to be compared. In the short term, the model has provided a significant integration of available data and has assisted in the design of additional data collection activities.

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A METHODOLOGY TO CREATE METEOROLOGICAL DATABASES FOR NUMERICAL COMPUTER PROGRAMS THAT PREDICT WATER BUDGETS

Steven Young, Joanne Logan, Marta Velasco, and Henry Fribourg
TVA & UT

By determining the statistical properties of a 20-year database of daily rainfall and calculated potential evaporation values, a program was developed to create meteorological databases for use in numerical computer codes that predict water budgets for landfills. The 20-year

database was created by calculating the daily rainfall and potential evaporation from hourly values of temperature, solar radiation, relative humidity, windspeed, and rainfall. The meteorological data was collected near Knoxville, Tennessee. The program can be used to generate possible, extreme, or average scenarios of daily rainfall and potential evaporation patterns over specified time periods. By using a Monte Carlo approach and the capability of this program, a modeler can predict the expected mean and standard deviation of leachate from a landfill over a specified time span.

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FLASH FLOOD WARNING SYSTEM – GATLINBURG, TENNESSEE

Donald W. Newton and Janet C. Herrin
TVA

The resort town of Gatlinburg, Tennessee, lies next to the West Prong Little Pigeon River on the western slopes of the Smokey Mountains. The steep, mountainous headwaters of the river can produce swiftly rising floods shortly after an intense rainfall event. In order to alert city officials as early as possible of an impending flood, the Gatlinburg flood warning system was developed. This is one element of the city's local flood warning and response plan.

The flood warning system consists of five rain gages and two stream gages located in the 41.6-square-mile watershed above the city. The gages transmit information by radio telemetry through an antenna repeater to a computer-based central site located in the fire station. The central site equipment includes a microcomputer, color monitor, and printer. A computer program estimates flood discharges and elevations in the city using standard hydrologic computational procedures with daily input from a National Weather Service soil moisture accounting model. When predictions indicate a flood is threatening, audio and visual warnings are issued.

The system displays rain and stream information and primary forecasts, as well as supplemental "what if" scenarios which provide additional information about the flood potential. This system increases warning time to 1 to 2 hours as compared to about 30 minutes with the previous stage sensor located upstream of the city.

The system was installed in June 1986 and is currently operated by city personnel. System performance is being monitored in real-time and by analyzing the archived data. Model calibration will be refined as specific flood events occur. The response plan is being drafted.

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OVERVIEW AND DIRECTIONS FOR WATER QUALITY MODELING IN TENNESSEE VALLEY RESERVOIRS AND TAILWATERS

Gary E. Hauser and Merlynn D. Bender
TVA

In an evolutionary process of model development over the past decade, TVA has formulated, calibrated, and applied dynamic water quality models of reservoirs and tailwaters to enhance its exploration of management alternatives for these systems. These models have proven useful in providing focus

for development of water quality monitoring strategies; interpreting sketchy, conflicting, or counterintuitive data; improving understanding of important physical and biochemical processes driving these systems; and assessing a variety of improvement schemes under environmental conditions too costly to test in prototype.

For reservoirs, the models have been used to explore the effects of point and nonpoint pollution sources, thermal discharges, reservoir operations, wet/dry hydrology, and others. For tailwaters, models have been used to explore downstream effects of reservoir release improvement schemes and the variability of temperature and dissolved oxygen under a range of release patterns. This effort has resulted in detailed calibration of models for eight TVA reservoirs and six tailwater reaches in the Tennessee Valley. This paper will be an overview of these developments that will include a description of the scope of activities as well as results of some selected case studies for specific reservoir and tailwater applications.

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DAILY SUSPENDED SEDIMENT MODEL FOR WATER RESOURCES MANAGEMENT

Russ T. Brown and Kimberly D. Choate
TN TECH-CIVIL ENGR & TVA

A daily model of streamflow suspended sediment (SS) concentrations (RAINRUNMUD) has been developed to analyze daily suspended sediment records from tributary basins. The model has been tested on the Clinch and Powell watersheds in SW Virginia and NE Tennessee, using SS data collected by TVA during the years 1936-1940. The model utilizes a daily water budget model (RAINRUN) to keep track of baseflow and the soil moisture conditions in the basin. Two basic approaches are used to simulate the observed patterns of SS concentrations: (1) a streamflow regression which depends on soil moisture conditions and the baseflow, and (2) a "mud" budget that accounts for the source of SS during rainfall, with the subsequent runoff of water and SS which depends on the soil moisture conditions.

Both methods have produced reasonable approximations of the observed patterns of daily SS concentrations during very different hydrologic conditions. The model demonstrates the importance of hydrologic conditions for streamflow SS concentrations and the corresponding transported loads. The model provides a way to "normalize" SS data from different years and separate basins, so that comparisons can be made without the large hydrological variability that exists in the raw datasets. The model can be extended to other water quality variables, and applications made to various non-point source pollution analyses. The methods should be tested and further developed with daily streamflow and SS datasets from other basins.

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CONTROLS ON SHALLOW GROUNDWATER COMPOSITION IN A GEOLOGICALLY COMPLEX TERRAIN NEAR OAK RIDGE, TENNESSEE

C. Stephen Haase and Helen L. King
ORNL

Major element variations in shallow (< or = 100m) groundwater have been studied from eight sites within an area underlain by carbonate (Knox Group) and interbedded clastic-rich and carbonate sediments (Chickamauga and Conasauga groups). Groundwaters associated with the Knox Group have neutral to slightly basic pH values and have total dissolved solids (TDS) values < micrograms/mL. The groundwaters have $(Na+K)/[(Na+K)+Ca+Mg]$ milliequivalent ratios of 0.4 to 0.7. The dominant anion is bicarbonate. Groundwaters from the Chickamauga and Conasauga groups also have neutral to slightly basic pH values, TDS values < 1000 micrograms/mL, and bicarbonate as the dominant anion, with subordinate sulfate and chloride as additional anions, $(Na+K)/[(Na+K)+Ca+Mg]$ milliequivalent ratios of < 0.1 to 0.7 and $Ca/Ca+Mg$ milliequivalent ratios of 0.1 to 0.9.

There is generally good agreement between compositional and mineral saturation trends and bedrock type, suggesting that water/rock reactions strongly influence shallow groundwater composition. Speciation and saturation calculations using the computer code EQ3NR indicate that shallow groundwaters are typically saturated or supersaturated with respect to calcite, dolomite, illite, kaolinite, k-feldspar, and quartz. The $(Na+K)/[(Na+K)+Ca+Mg]$ ratios of Chickamauga and Conasauga group groundwaters suggest that reaction with illite and feldspars control the alkali contents of groundwaters. Calcium and magnesium concentrations in groundwaters from all stratigraphic units are influenced by reactions with calcite and dolomite. The increased sulfate content of Chickamauga and Conasauga group groundwaters is consistent with oxidation of disseminated pyrite that is locally common in these clastic-bearing sediments; these groundwaters are also saturated with barite, whereas Knox Group groundwaters are not.

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FLUID MOVEMENT IN SEDIMENTARY ROCK SYSTEMS

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UT & ORNL

Movement of groundwater in consolidated sedimentary rocks occurs by a combination of interconnected intergranular pore spaces and fracture systems. In most lithified sedimentary rocks, predominantly carbonates and fine-grained clastics, matrix permeability is very low, and transport is dominated by a fracture permeability. Most of Central and East Tennessee groundwater systems are located in consolidated sedimentary rocks. Hence it is essential to understand the nature and variability of fracture systems in sedimentary rocks in order to understand fluid transport mechanisms in different geologic settings.

Fracture parameters that strongly influence the character of a hydrologic system include fracture density, length, orientation, aperture and the amount of fracture mineralization. In turn, these parameters vary as a function of lithology, bedding characteristics, tectonic setting, previous fluid/rock interactions, and the recent weathering cycle. The magnitude and orientation of hydraulic conductivities in Central and East Tennessee are influenced by regional fracture systems. For example, on the Oak Ridge Reservation (ORR), hydraulic conductivity for the shallow groundwater system (< 30 m) is strongly anisotropic with conductivity values on the order of 10 times greater parallel to the strike of bedrock. We speculate that flow may occur along the intersection lineation formed by a strike parallel fracture set and bedding. Groundwater flow also occurs normal to strike on the ORR and probably occurs by flow through a NW fracture set. Possible conjugate shear fractures related to this set may also provide additional interconnecting porosity. Hydraulic conductivity and porosity data for different structural settings and lithologies are needed to quantify the relationships between these mechanical parameters and groundwater flow.

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OAK RIDGE NATIONAL LABORATORY PROCESS WASTE SYSTEM

J.B. Berry and R.H. Ketelle
ORNL

Oak Ridge National Laboratory (ORNL) has conducted basic and applied research and development activities related to the nuclear field since 1943. Liquid wastes have been generated as a result of these activities and treated, disposed of, or stored as part of routine Laboratory operations. Underground storage tanks and waste treatment facilities have been installed within the ORNL plant area to manage liquid wastes. Routine waste management operations have resulted in spills and leaks that contaminated soil and groundwater with radionuclides.

The process waste system is used to collect potentially radioactive waste and ground and rain water that becomes waste due to contact with radioactively contaminated spill sites and underground tanks and sumps. Process waste is treated for removal of ^{90}Sr and ^{137}Cs prior to discharge to an on-site stream. The treatment process is complicated by the high dissolved mineral content of the waste water due to the groundwater component. (Approximately 30 volume percent of process waste is groundwater).

The process waste piping system consists of approximately 27,000 linear feet of underground piping. This piping is being repaired to reduce the hydraulic loading on the treatment plant. Water-table maps have been used to anticipate the effect of lining underground clay pipe on the movement of groundwater.

This paper describes the ORNL process waste collection system, the treatment process, and pipe-repair planning and process.

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LATERAL TRANSPORT OF CONTAMINANTS ABOVE THE WATER TABLE DURING STORM EVENTS

S.M. Gregory and D.K. Solomon
ORNL

At Oak Ridge National Laboratory (ORNL) a variety of contaminants have been disposed of by shallow burial in unlined

trenches. Although the majority of these trenches are in the unsaturated zone, the principal pathway for the transport of contaminants to surface water systems has traditionally been thought to be the saturated groundwater system. This concept stems from the classic notation that the water flux is principally vertical in the unsaturated zone and predominantly horizontal below the water table. However, our measurements of contaminant fluxes in first order streams suggest that significant lateral transport occurs above the water table during storm events. Presumably this movement occurs along fractures and macropores that become locally saturated during storms.

A time series of stream samples, along with continuous stream flow measurements, were used to compute the instantaneous flux of ^{3}H throughout a variety of storm events from three separate streams located in a waste disposal area at ORNL. For example, during an event which produced 21 mm of rain in a 4 h period, the ^{3}H flux at monitoring station 3 increased by more than 25 times above the base flow value. If the saturated groundwater system were the only source of ^{3}H to the stream, groundwater discharge would also have to increase by more than 25 times, which is unlikely.

A three component mixing model using concentrations of Si and ^{3}H in rain, baseflow and stormflow along with stream flow measurements, was used to estimate the fraction of the total contaminant flux which occurs above the water table. The model suggests that during the peak of the stream hydrograph approximately 95% of the ^{3}H flux results from water moving above the water table. During 1986 streams at this site were in flood approximately 27% of the time, which accounted for about 65% of the total ^{3}H release. Thus, contaminant transport above the water table during storm events may represent a significant portion of the total contaminant release at ORNL.

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USES OF PROBABILITY GRAPHS IN THE HYDROLOGIC CHARACTERIZATION OF FRACTURED ROCKS NEAR OAK RIDGE, TENNESSEE (1)

Gerald K. Moore (2)
ORNL

More than 1,500 observation wells have been drilled near Oak Ridge National Laboratory since 1949. In this area, as in other fractured-rock aquifers, hydrologic parameters have a large numeric range, little correlation with other parameters, local spatial relationshps among wells, and abrupt changes in these spatial relationships. Under these conditions, tools such as contour maps, regression analyses, and statistical comparisons of means and standard deviations have limited utility and can produce misleading results. The best approach to this problem may be parameter characterization by a graphical method of statistical analysis.

Cumulative probability graphs are not widely used in hydrology and require a fairly large number of data values. However, these graphs may show deviations in a distribution (by curvature of the plotted points or by a change in slope of a fitted line) that otherwise would have been obscure. Most individual hydrologic parameters (including such diverse measures as well depth, regolith thickness, and concentrations of major constituents in the water) plot as a single,

log-normally distributed population. However, multiple populations have been determined for hydraulic conductivity, October depth to water, and amount of seasonal fluctuation in water level. These deviations in the distributions mainly represent changes in the conditions of groundwater occurrence at deeper levels in the aquifers. In addition, abnormal seasonal fluctuations of the water table have been identified in one area.

(1) Research sponsored by Office of Defense Waste and Transportation Management, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

(2) Research Associate, University of Tennessee, Knoxville. Registered Professional Hydrologist, American Institute of Hydrology, Certificate No. 105.

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POLLUTION SUSCEPTIBILITY EVALUATION WITH RADAR DATA IN EASTERN TENNESSEE

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USGS

The classification and mapping of landforms that appear in side-looking airborne radar (SLAR) images was used in conjunction with the Environmental Protection Agency's DRASTIC system for evaluating ground-water pollution potential in eastern Tennessee. The Oak Ridge Scene radar image was used to test the procedure, and results were transferred to the Chattanooga 2 quadrangle. Four major landform classes were recognized, with further breakdown within these classes making a total of nine individual landform classes. These were then grouped according to boundary correlations to coincide with the three hydrogeologic settings developed for the DRASTIC analysis. A DRASTIC index was computed for each hydrogeologic setting, Ridges, 109; Rolling Uplands, 111; Valleys, 146. Larger numbers denote relative increase in pollution potential. The successful correlation of hydrogeologic settings and landform classes in the Oak Ridge Scene enabled transfer of the classes and associated indexes to the Chattanooga 2 quadrangle. A separate DRASTIC index was computed for a landfill site on the Chattanooga quadrangle and was used for comparison to the transferred index. The difference between the DRASTIC index for the landfill, 89, and the index for the Rolling Uplands hydrogeologic setting in which it was located, 111, can be accounted for in the difference between site specific depth to water measurements and averaging the depth to water on a regional scale.

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DEMONSTRATION OF CONFINEMENT IN CAMBRIAN AND LOWER ORDOVICIAN STRATA IN WEST-CENTRAL TENNESSEE

J.E. Clark
DUPONT

The carbone section represented by the Lower Ordovician Knox Group and the Cambrian Copper Ridge Dolomite, Conasauga Dolomite, and the Rome Formation has an aggregate thickness of approximately 5600 feet in Humphreys County. This sequence is dominantly finely crystalline, dense dolostone with variable amounts of chert and silica. Limestone is a minor constituent of the Lower Ordovician and Cambrian strata. Sandy horizons and thin shale beds are present

throughout the sequence. Porosity and permeability of these strata are low.

With few exceptions, high-angle fractures observed in cores are healed with the mineral dolomite. Analyses of the cores confirm the low porosities indicated by geophysical logs. Drill stem test data corroborate very low permeabilities for the formations, yielding confining values on the order of 10^{-7} cm/sec. Values in this range are equivalent to RCRA clay in terms of hydraulic conductivity and its confining ability.

Artesian head data also indicate that the upper Mascot Dolomite is hydrologically separated from both overlying and underlying units. Confinement can also be demonstrated by means of pressure-pulse testing. These tests involve injection of fluid under conditions of variable flow rate and wellhead pressure, while, at the same time, pressure responses (if any) of zones different from that being injected are monitored.

In summary, methods for determining the adequacy of confining layers include: (1) Pressure-Pulse and Drill Stem Tests of various zones, (2) Hydraulic Head Data, (3) Geochemical Analysis of Formation Water, (4)Downhole Geophysical Logs, (5) Physical Core Analyses, and (6) Age Dating of Formation Water.

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INVESTIGATION OF A HAZARDOUS-WASTE DISPOSAL SITE NEAR BRENTWOOD, TENNESSEE

Patrick Tucci
USGS

A numerical ground-water flow model was constructed and calibrated as a part of a study of the overall hydrogeology of a hazardous-waste disposal site near Brentwood, Tennessee. The model was used to test conceptual models of the ground-water flow system, and to provide a tool for the evaluation of remedial-action alternatives.

The model simulates ground-water conditions for April 1987, which are assumed to be representative of steady-state conditions. Two model layers represent the upper and lower aquifers, which are separated by the Hermitage confining unit. The top of the Lebanon confining unit is assumed to be the impermeable base of the model. Transmissivity values are varied areally to correspond to variable geologic conditions. The lower aquifer transmisslivity is simulated as five times greater in a northwest-southeast direction than a northeast-southwest direction, as indicated by analysis of the aquifer test for this aquifer. Model calibration indicates that recharge is also variable across the model area, and is greater on the hills than the valleys. The average areal recharge rate over the model area for the calibration period is about 15 inches per year.

Model results support the concept of two aquifers separated by an effective confining unit. Simulated ground-water levels are similar to measured levels in both the upper and lower aquifers, and model-calculated ground-water seepage to streams is similar to the total seepage measured in the model area. Model results indicated that most of the ground-water flow is in the upper aquifer. Nearly all recharge to the upper aquifer discharges to streams and less than 1 percent of this recharge flows down to the lower aquifer.

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QUANTITATIVE HYDROLOGICAL ANALYSIS OF THE REELFOOT LAKE BASIN IN NORTHWESTERN TENNESSEE

Michael E. Lewis
USGS

Reelfoot Lake, located in northwestern Tennessee, is the state's largest natural lake, with approximately 15,500 acres at a normal pool of 282.2 feet above sea level. The quantitative analysis of the surface-water and ground-water hydrology of the Reelfoot Lake basin was conducted for application to the development of a long-term lake management strategy.

A precise water budget for the lake was determined for the period December 1986–March 1988. This investigation was supported by an extensive data collection network covering the basin's 240 square miles. The network included streamflow gaging stations on 2 of 3 major tributaries to the lake, 8 continuous recording and 29 observation ground-water wells, 2 meteorological data stations, and 3 rainfall gages. The meteorological data stations provided data for the precise quantitative evaluation of lake surface evaporation via the energy budget method.

Surface-water modeling with the distributed parameter streamflow-synthesis model PRMS was conducted on ungaged areas of the basin to determine ungaged surface runoff contributions to the lake. Ground-water modeling was conducted with a calibrated, finite-difference ground-water model. The model was employed to evaluate the effects of lake-level manipulations, pumpage from the alluvial aquifer for agricultural irrigation, and the drainage system in the area adjacent to Lake No. 9 on ground-water levels and water supply to Reelfoot Lake.

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A STUDY ON SOIL EROSION IN WESTERN TENNESSEE

K. Madhaven
CHRISTIAN BROS. COLLEGE-CIVIL ENGINEERING

The state of Tennessee has abundant supply of surface and ground water resources. The availability, development and preservation of these sources is very important for the social and economic development of this state. Soil erosion, resulting in sedimentation in streams, rivers and lakes poses a threat to the water quality of surface sources. Sediments from erosion of natural ground has been a serious problem in Western Tennessee. A sediment loading rate as high as 200 tons/acre/yr has been reported for some soils. The construction activity in such soils only adds to or contributes to the erosion problem. A study has been undertaken to determine the quantity of sediment load from a construction site in Western Tennessee and the effect of construction activity on soil erosion is examined.

Soil erosion is influenced by many factors like soil type, soil cover, previous erosion history of the area, season, intensity and duration of rainfall and land modification. A comprehensive study is needed to account for all these variables. This study was done at a construction site in Shelby County. Rainfall on the site was monitored for three seasons to determine the amount of rainfall, quantity of runoff and the amount of suspended solids in the runoff volume. Field

measurements were taken for runoff and water samples were collected during and after the storm and analyzed for sediment content. Using these data, the soil erosion for the project area is assessed and compared to determine the degree of influence the construction activity has on the quantity of erosion.

The season seems to play an important role on soil erosion. It is severe in Spring and milder in Summer for about the same quantity and duration of rainfall. The increase in sediment loading rate due to construction activity is determined to be about 15%. The results of this study and qualitative conclusions are reported.

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DRY STREAM REACHES IN CARBONATE TERRANES: SURFACE INDICATORS OF GROUND-WATER RESERVOIRS

J.V. Brahana and E.F. Hollyday
USGS

The method of identifying dry stream reaches in carbonate terrane as surface indicators of potential ground-water reservoirs offers a valuable exploration technique that is more rapid and less expensive than traditional exploration methods involving random test drilling. In areas where dry stream reaches occur, subsurface drainage successfully competes with surface drainage, and sheet-like dissolution openings have developed parallel to bedding creating the ground-water reservoir. The occurrence and hydraulic characteristics of such reservoirs is highly variable, as attested to by the wide range of well yields.

Union Hollow in south-central Tennessee is the setting for a case study that illustrates the application of the dry stream reach technique. In this technique, dry stream reach identification is based on two types of readily acquired information: (1) remotely sensed black and white infrared aerial photography; and (2) surface reconnaissance of stream channel characteristics. Test drilling in Union Hollow subsequent to identification of the dry reach proved that a localized ground-water reservoir was present.

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SURFACE IMPOUNDMENT INVENTORY/ ASSESSMENT FOR THE STATE OF TENNESSEE

Wade W. Munday, Yvette Robinet-Clark, V. Dean Adams, John A. Gordon, Hugh H. Mills III, and Paul J. Whalen
TN TECH

An inventory and assessment of all surface impoundments (pits, ponds, and lagoons) located in the State of Tennessee was conducted. The surface impoundment assessment (SIA) provided a first round approximation of the number, location, operational features, and relative ground water contamination potential of these impoundments. Approximately 1532 active and abandoned sites containing in excess of 2437 surface impoundments have been located in Tennessee.

The assessment consisted of two phases: (1) rating of the ground water contamination potential and (2) rating the potential endangerment to current or future users of ground water supplies. The ground water contamination potential was obtained by evaluating the hydrogeologic characteristics

of the site and the relative hazard of the waste. The potential endangerment to water supplies was obtained by determining both the distance from the impoundment to the water supply and the direction of flow that any contaminant plume would take.

Surface impoundments used for the storage, treatment, or disposal of liquid wastes show significant potential for ground water contamination. Approximately thirty percent of the assessed sites had high ground water contamination potential ratings. Forty percent of the sites were located in areas characterized as karst. Eighty percent of the impoundments were located within 400 meters of drinking water supplies that had the potential to be adversely effected if seepage from the impoundment were to occur. Only thirteen percent of the impoundments had liners to prevent seepage of contaminants from the impoundment. Less than two percent of the impoundments had installed ground water monitoring wells.

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TENNESSEE VEGETATION STUDIES IN RELATION TO HYDROLOGIC PROCESSES: FLOOD FREQUENCY, CHANNEL-BANK STABILITY, AND SEDIMENTATION AND EROSION IN BOTTOMLANDS

Cliff R. Hupp and Bradley A. Bryan
USGS

Vegetation studies, including tree-ring and plant-ecological analyses, have had wide use in hydrologic investigations, particularly in Tennessee. The development of maximum likelihood estimators in statistical hydrology has allowed for an efficient use of historic information in flood-frequency analysis. Botanical evidence of floods (a form of historic information) may now be used with more accuracy and efficiency than previous approaches to extend flood records and improve flood-frequency estimation for streams with short or problematic gage records. This interdisciplinary approach may offer the best method for estimating flood frequency on ungaged streams. Standard errors of the 100-year flood have been reduced, in many cases, by an order of magnitude.

Riparian or bank vegetation has been analyzed dendrochronologically and plant ecologically to determine channel-widening rates, bank accretion rates, and degree of geomorphic and ecologic recovery following disturbance. These analyses have been used successfully to provide valuable hydrogeomorphic information along streams subjected to channelization and nearby strip-mining, where other methods of monitoring would have failed or would have been time consuming and expensive. Important inferences may be made concerning sediment transport and storage (suspended and tractive load), shifts in channel pattern and rates of channel migration.

Vegetation studies may provide current and historic information on sedimentation and hydroperiod in wetland areas. Rates of sediment deposition in wooded wetlands have been determined through tree-ring analysis of affected woody plants and related to channel modification, bridge construction, and upland erosion. The effects of these activities on wetlands may likewise be inferred through plant-ecological

analysis. Vegetation analyses in wetlands will have important bearing in investigations of nonpoint source areas of pollution.

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A RECORD TENNESSEE RIVER FLOOD—DECEMBER 1987 MISSED BY ONLY 300 MILES

William D. Felts (1), Arland W. Whitlock (2), and Randall Z. Kerr (2)
TVA

The legislation which created the Tennessee Valley Authority in 1933 directs the agency to regulate the storage and release of water from its system of dams and reservoirs primarily for promoting navigation and controlling floods. The priority that was established for flood control operations early in the life of TVA has not been diminshed in the intervening years, and the wisdom and foresight of that decision is reflected in the fact that the system can conservatively be credited with averting flood damages of about $3.0 billion since its inception.

During the last 3-1/2 years, however, a severe drought throughout much of the Valley has diverted attention away from the potential for flood damages. Around the end of December 1987, even though rainfall amounts over the Valley were more nearly normal, the problems associated with a prolonged period of insufficient rainfall continued. In contrast, just to the west of the Tennessee Valley significant heavy rainfall amounts fell with some locations recording around 14 inches for a 3-day period. To evaluate the impact of the storm had the center occurred over the Tennessee Valley region in the midst of this prolonged dry spell, the storm was transposed to be centered near Knoxville.

Using actual antecedent conditions that existed over the Tennessee Valley on December 22, various computer models were used to convert rainfall to runoff, calculate inflows, and route the subsequent inflows thru the TVA reservoir system. The results indicated just how close the Tennessee Valley came to having a major flood occur in the middle of a multi-year drought. Had the storm occurred in its transposed position, it would have provided the highest unregulated flows of recorded history at Chattanooga, Tennessee.

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STATISTICAL AND SIMULATION ANALYSIS OF HYDRAULIC-CONDUCTIVITY DATA FOR BEAR CREEK AND MELTON VALLEYS, OAK RIDGE RESERVATION, TENNESSEE

Joseph F. Connell and Zelda Chapman Bailey
USGS

A total of 338 single-well aquifer tests from Bear Creek and Melton Valleys were statistically grouped to estimate hydraulic conductivities for the geologic formations in the valleys. A cross-sectional simulation model linked to a regression model was used to further refine the statistical estimates for each of the formations and to better understand ground-water flow in Bear Creek Valley. Median hydraulic-conductivity values were used as initial values in the model.

Model-calculated estimates of hydraulic conductivity were generally lower than the statistical estimates.

Simulations indicate that (1) the Pumpkin Valley Shale controls ground-water flow between Pine Ridge and Bear Creek; (2) the formations having smaller hydraulic gradients may have a greater tendency for flow along strike; (3) localized aquifer conditions in the Maynardville Limestone cause poor model-calculated estimates of hydraulic conductivity; and (4) the conductivity of deep bedrock neither affects the results of the model nor does it add information on the flow systems.

Improved model performance would require: (1) more water-level data for the Copper Ridge Dolomoite and (2) better estimates of hydraulic conductivity in the Copper Ridge Dolomite and Maynardville Limestone.

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AN EVALUATION OF HYDROLOGIC TECHNIQUES CURRENTLY USED FOR URBAN DRAINAGE DESIGN IN MEMPHIS

Roger H. Smith, Ph.D., P.E. and Ross B. Jennings
MEMPHIS STATE-CIVIL ENGR

The current accepted practice for predicting the rates and amounts of runoff that may be expected from urban watersheds at given recurrence intervals is to relate runoff to rainfall. The new Drainage Design Manual for the City of Memphis contains the following general guidelines for using three accepted methods for drainage design: (1) Rational equation for minor drainage (watershed areas less than 100 acres); (2) USGS regionalized flood frequency equations for major drainage (100 acres < watershed areas < 250 acres); (3) SCS dimensionless unit hydrograph analysis (watershed area > 250 acres). The manual also states the following: "If a time distribution of the runoff is required, i.e., design of a detention basin, then a 24-hour runoff hydrograph developed by the SCS unit hydrograph will be acceptable. If conflicts arise as to the peak discharges determined by various methods, then the peak discharges as determined by the unit hydrograph method will govern."

The city of Memphis is currently experiencing controversial decisions arising due to conflicts between the various methods for determining peak discharges especially when detention basins are designed for drainage areas in the range of 25 to 100 acres. When the required SCS method is used for the design of a detention basin for watersheds within this size range, it produces outflow peaks greater than the existing downstream storm drainage system can handle as designed from the rational method.

A research project is currently underway at Memphis State University to make a comparison study of the three hydrologic techniques using data from approximately four to six selected gaged watersheds in the Memphis metropolitan area. The principal objectives of this study is to provide additional information and more specific guidelines in the use of the various methods for purposes of consistency in the city's drainage design standards.

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CALCULATION OF HYDRAULIC CONDUCTIVITY FROM SLOW WATER LEVEL RECOVERY

Laura Toran
ORNL

The deep groundwater flow system provides a potential path for contaminants to move away from waste disposal areas on the Oak Ridge Reservation. To examine this possibility, several clusters of wells were drilled at depths of approximately 30, 60, and 120 m at six locations in Melton Valley. The water levels in the well clusters were then monitored for a year to a year and a half.

The head in the deeper wells has not yet recovered from dewatering during drilling because of the low hydraulic conductivity of the surrounding formation. I used this slow recovery to estimate hydraulic conductivity in the deep layers by assuming that the Hvorslev equation applies. The assumptions this equation requires include instantaneous removal of water, no drawdown in the surrounding rock, no casing leakage, and an isotropic medium. Since the wells have not yet recovered, I also assumed the final head would be within approximately 2 m of the head in shallow wells. With the time frame and drilling methods, the Hvorslev equation and its assumptions provide order-of-magnitude estimates that may be appropriate.

The hydraulic conductivity estimates are about 10^{-8} cm/s in the 120-m-deep wells drilled in the Rogersville Shale and 10^{-9} cm/s in the wells drilled in Maryville and Nolichucky formations. The conductivities are slightly lower than previously measured in bedrock in Melton Valley and are typical of tight shales. Further study of the geology and water chemistry is needed to delineate flow systems.

*Research sponsored by the U.S. Dept. of Energy under contract DE-AC05- OR-21400 with Martin Marietta Energy Systems, Inc.

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FLOOD INFORMATION MANAGEMENT SYSTEM: A COMPUTERIZED DATA BASE

Janet C. Herrin
TVA

TVA annually responds to over 1,000 requests for flood information from the Federal, state, and local agencies and private firms. The information that is provided is used in siting, planning, and designing structures and evaluating land use. Many of the requests can be answered using previously developed information. To facilitate these efforts, the Flood Information Management system (FIMS) was developed.

FIMS is a computerized data base that provides an efficient means of storing, retrieving, monitoring, and otherwise managing flood and related information. It is designed to:

1. Provide, upon request, the most accurate flood data available for the specified location and to identify any regulations affecting land use.
2. Reduce the manpower and time required to respond to requests and prevent duplication of effort.
3. Identify information previously provided and to ensure consistency at the same or nearby locations.
4. Provide a means to monitor information to ensure that only valid information is released.

FIMS currently resides on an HP-3000 minicomputer in an IMAGE data base. It is organized into 15 submenus containing reports that are used to access and display all FIMS information. These reports are written in COBOL and FORTRAN and can be grouped as:

1. Reports providing actual flow, elevation, floodway, and/or regulatory information.
2. Reports providing file references where data and/or reports can be found.
3. Reports facilitating data retrieval and display.

Actual data available on FIMS include computed profiles throughout the frequency range up to the probable maximum flood and dam failure flood, computed floodways, and historic flood profiles. File references available on FIMS include stream gages, community regulatory information, flood and storm reports, and previous responses to requests for data. Offline reports which release large amounts of information to the system printer, graphics which display computed and historic profiles, and stream-community cross reference listings facilitate FIMS data retrieval and display.

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SESSION 2A--June 23

CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT - AN OVERVIEW OF APPLICATIONS AND POTENTIALS FOR SURFACE AND GROUND-WATER PROTECTION

G.R. Brodie, D.A. Hammer, G.R. Steiner, D.A. Tomljanovich and J.T. Watson
TVA

Suitably designed and operated wetlands have demonstrated capability to remove nutrients, organic compounds, and metals and increase oxygen and pH levels in waste waters from domestic, municipal, mining, industrial, and agricultural sources. Capital and operating costs of wetlands waste treatment (WWT) systems are 1/10 to 1/2 as costly as conventional systems and require minimal operator training. We have successfully established WWT systems that turn acid drainage into clean water at strip-mined areas, a coal preparation facility, and coal-ash storage ponds. Four types of WWT for municipal waste are operating at communities of 500 to 5,000 residents in Kentucky and a housing development in Tennessee. Studies at the Acid Drainage Wetlands Research Facility will evaluate efficiencies of substrate types, macrophyte types, and microbial populations. Livestock operations and other non-point sources will benefit from demonstrations of practical applications to hard-pressed livestock producers, small industries, and for urban stormwater runoff. Our monitoring results at each site will produce the requisite database for development of design guidelines and improved recommendations. WWT provides an efficient, self-maintaining method to protect surface and groundwater resources without crippling the economic base of small communities, industries, and farms.

***

MODELING OF WATERBORNE SPILLS IN TENNESSEE

Lisa Beard and William Waldrop (1)
TVA

The Tennessee Valley Authority (TVA) is developing operational emergency procedures with computer modeling for monitoring the release of waterborne spills in specific river reaches of Tennessee. Currently, TVA is developing and/or providing modeling and other support for several operational plans including Watts Bar and Sequoyah Nuclear Plants on the Tennessee River, Department of Energy - Oak Ridge National Laboratory Facility on the Clinch River, the Ocoee River System, and the Holston River Basin. Each Stream requires inputs to be developed on a site-specific basis. This includes the identification of source and on-line computer capability to predict the transport and dispersion of a spilled substance; evaluation of potential control strategies; and development of emergency response procedures. TVA coordinates site-specific emergency plans with appropriate Federal, State, and local agencies and maintains liaisons with these agencies. Each agency's responsibility is outlined and standards for determining emergency situations are developed.

Real-time spill forecasting can be used to:

* Estimate travel time and downstream relative concentrations of a spilled substance given spill

characteristics for early warning to downstream water users.
* Guidance to field crews to locate and monitor a contaminant.
* Aid authorities to predict known or anticipate health risks associated with the release.
* Where appropriate, optimize reservoir operations to mitigate potential impacts to downstream water users.

The mechanisms considered in the current models for mixing and transport of contaminants are advection and dispersion. The solution of the models depends on the characteristics of the spill (time, location, concentration, rate, and duration), flow conditions (spatial and temporal variations), and the geometry of the stream. The advection component is provided by a river flow routing model. The dispersion component is superimposed upon velocities predicted by the flow model.

The Engineering Laboratory spill team is responsible for developing, calibrating, verifying, maintaining, and periodically updating the models. Spill team members have been trained in the basic assumptions, capabilities, limitations, and application of the operational models. Periodic training and drills are conducted to ensure the members remain efficient during emergency situations.

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ESTIMATING FLOOD FREQUENCIES AT UNGAGED LOCATIONS

Donald Newton and Janet C. Herrin
TVA

A study was made to determine what methods are likely to be most accurate and consistent for determining flood frequencies at ungaged locations in the Tennessee Valley region. This study was largely based on information developed during the 1981 pilot test of commonly used procedures conducted by the Interagency Work Group, Hydrology Committee, Water Resources Council. Pilot test results showed that there were significant differences in procedure performance with respect to accuracy, reproducibility, and practicality. These differences result from differences in procedures formulation which can be expected to occur outside the pilot test regions.

The most accurate and reproducible procedures were those in which prediction equations were calibrated to flood-frequency determinations at gaged locations using statistical estimation techniques. It is concluded that new procedure formulations should (1) use parameters which are well-defined and can be consistently determined; (2) be formulated so that flood-frequency estimates are not sensitive to parameter variations: and (3) be calibrated to a large number of gage records in a small, well-defined hydrologic region.

***

INVESTIGATION OF FAILING SEPTIC TANK SYSTEMS IN THE BOONE RESERVOIR DRAINAGE AREAS

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TVA & TTU

Problems with localized bacterial contamination of embayments associated with residential development along some of TVA's reservoirs have been noted. Due to the remoteness of many of these locations, septic tanks are the primary means of waste disposal and are often cited as a possible contributor of nonpoint source pollution to reservoirs. TVA uses color infrared (CIR) photography to identify and locate failed/failing septic tank systems. The purpose of this study was to assess and document the significance of septic tank system failures as a contributor of bacteria and nutrients to Boone Reservoir. In addition, current site selection and installation procedures of these systems, as well as maintenance schedules, were studied in order to assess their role in the overall problem.

A septic tank system evaluation questionaire was developed and distributed to homeowners in neighborhoods selected on the CIR photographs for a high rate of suspected failing systems. The criteria for using soil for sewage disposal systems in Tennessee were reviewed. Septic tank-disposal field performance factors were analyzed. Suspected contaminated springs were selected and tested for bacterial and chemical water quality parameters. Springs were also monitored for the presence of optical brighteners, man-made chemicals added to laundry detergents to make whites whiter.

Most of the springs were contaminated with fecal coliform and fecal streptococci. None of the springs exceeded the health limits for any of the chemical parameters and the measurements were somewhat normal for ground water in karst terranes. All of the springs monitored were contaminated with optical brighteners.

***

UTILIZING SWMM-GIS FOR A SINKHOLE-STORMWATER ASSESSMENT

Nick Taylor and Dennis George
TN TECH-CIVIL ENGR

Stormwater runoff for 50% of the City of Cookeville, Tennessee, is directed to sinkholes. With few exceptions, the karst drainage system adequately absorbs all runoff.

City officials became concerned that development was going to degrade the hydraulic conductivity of the sinkholes. An ordinance was created to regulate the use of those lands considered vital to the natural drainage systems of the city.

To assess the effects of development, the City needed predictive scenarios for the sinkholes drainage basins. These scenarios were developed using EPA's Storm Water Management Model coupled with a Geographic Information System.

The SWMM utilized numerous land surface features in its data sets. Combining the number of features needed with 160 sites selected made automation a necessity. GIS offered the link to automation for sinkhole volumes, drainage basin areas, average slopes, and average impervious surface areas. Slopes for overland-flow areas in the drainage basins were developed by assigning ranges of slopes, creating a slope map, which were areally weighted for each drainage basin. The

percentage of impervious areas were found similarly. The different zones of the City zoning map were assigned percentages of imperviousness found for selected representative zones, then areally weighed.

After calibrated basin results were verified, output volumes predicted by the SWMM for selected frequency storm events were entered into the GIS for the display of potentially enundated areas. The SWMM-GIS techniques gave excellent results and a timely screening.

***

ASSIMILATIVE CAPACITY STUDY OF THE OBED RIVER AT CROSSVILLE, TENNESSEE

Barry W. Sulkin
TDWR

During the Summer of 1987, the Tennessee Division of Water Pollution Control conducted a study to assess the ability of the Obed River to assimilate effluent from the Crossville sewage treatment plant. The EPA had funded the construction of this plant, but withheld the portion related to the tertiary treatment units in use until a study proved the need for such. This survey used dissolved oxygen as the indicator parameter, and involved time-of-travel measurements using a fluorescent dye. The U.S. Geological Survey cooperated in this project by measuring the river's reaeration rate, K-2, in one upstream and two downstream reaches during the dye study, using a newly developed propane method.

Results were used to re-evaluate Crossville's discharge permit limits and thus the need for the tertiary units. Also, data collected was used to calibrate the QUL2E computer model and compare the results to the state's simplified model used for determining permit limits. With the plant discharging well within tertiary limits, the river was found to be rather stressed, with dissolved oxygen levels of less than the standard of 5.0 mg/L below the plant. Follow-up work will include sediment oxygen demand measurements to assess the river's heavy sediment deposits' contribution to the total oxygen demand in the system, and further calibrate the computer model.

***

THE EFFECT OF URBAN DEVELOPMENT ON SPRING WATER QUALITY IN COOKEVILLE, TENNESSEE

Thomas E. Pride, Albert E. Ogden, Michael J. Harvey and Dennis B. George
TN TECH

Four sinking streams and four springs around Cookeville were sampled every two weeks for one year to determine the effects of urban runoff and sewage discharges into sinkholes on spring water quality and cave species diversity. Frequent sampling during a major storm event was also performed. Dye tracing was utilized to document subterranean flow paths. Insignificant levels of cadmium, chromium, zinc, lead, and nickel were found; but high fecal coliform and fecal streptococcus counts, high pH, and low dissolved oxygen were found in many streams. Blue dyes and other effluents from two large denim pre-wash factories commonly occurred due to the nearly consistent disposal of raw sewage into sinking streams. Cookeville's antiquated sewer lines are unable to

handle the recent load increases from these industries at this time. Comparison of historic data to the present study shows that relocation of the waste treatment plant has significantly improved the water quality at two sites. New sewer lines improved the water quality at two sites. New sewer lines currently under construction should further rectify Cookeville's water quality problems.

A preliminary survey of benthic species diversity in selected caves indicates an assemblage dominated by oligochaetes and chironomids. These organisms are commonly associated with degraded streams. A less polluted control cave exhibits greater macroinvertebrate diversity iin addition to blindfish (Typhlicthyes subterraneus).

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EROSION AND SEDIMENT CONTROL MEASURES AT THE SATURN CORPORATION SITE, MAURY COUNTY, TENNESSEE – A SEASONAL EVALUATION OF WATER QUALITY, BIOLOGICAL AND SEDIMENT CHARACTERISTICS

William R. Miller III, Ph.D.
ROY F. WESTON, INC.

The Saturn Corporation is building a large, integrated automobile manufacturing plant 30 miles south of Nashville in Maury County. Over the course of the four-year construction phase nearly 30 percent of the total acreage (2,450 acres) will have been disturbed. Reducing erosion and sediment transport to the local creeks was therefore an important consideration.

A series of seven erosion and sediment control dams were built along the western border of the site. Four of these dams were designed as temporary structures and served to impound storm runoff long enough to promote settling. The three permanent dams were designed for a 100 year-24-hour storm event with eventual conveyance to Titan Creek, a small (mean flow < 1 cfs) tributary to Carters Creek.

The effectiveness of the erosion and sediment control measures was evaluated using data from three seasonal surveys (Fall 1985, Spring 1986, and Spring 1987) of Titan and Carters Creek. Sieve analyses of sediment from these creeks revealed temporal changes in the silt and clay fractions. However, diversity indices for macroinvertebrates and fish populations revealed no significant change over time. Results from these surveys were used to modify other temporary on-site erosion and sediment control practices with a commensurate decrease in sediment transport to the creeks.

***

HYDROLOGIC IMPACTS TO UPPER ROCKY RIVER WATERSHED AS A RESULT OF LARGE SCALE AREA COAL MINING ON THE SOUTHERN CUMBERLAND PLATEAU OF TENNESSEE

Dave Turner
TDWPC

During October 1987, the Tennessee Division of Water Pollution Control initiated a water quality monitoring program within the upper Rocky River Watershed. Sample stations

were established to identify water quality problems directly related to coal mining activities as opposed to areas with no mining activities. The objective was to collect background water quality data from stream reaches during low and high flow periods. These data would be used to implement enforcement action to improve upper stream reach water quality.

All stream reaches, which had coal mining activities, were flowing and had degraded water quality, i.e., "acid-mine drainage" conditions. Sample points on streams which had no coal mining activity were found to be dry in this survey. The acid-mine drainage conditions were persistent in mine areas which had excellent surface reclamation, and mine areas which had not been reclaimed to SMCRA P.L. 95-87 standards. The discussion will focus on mine areas reclaimed to SMCRA standards and their related hydrologic balance water quality problems. During the investigation, two high volume springs were located on the edge of the reclaimed mine areas. A link of degraded water chemistry from the springs and of the receiving stream above the spring inflow was established, and we suspect a non-point subsurface contribution to the hydrologic stream charge. The Division suspects that the conduit for this water is related to the coal seam which incidentally dips toward the receiving stream.

The Division is presently working with the mining company to ameliorate these water quality problems. The complexity of this hydrologic balance scenario is beyond the "treat your pond technology" of typical acid-mine drainage problems. We are presenting this hydrologic pollution problem in this forum in hopes of stimulating thought and discussion.

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EFFECTS OF DREDGING ACTIVITIES ON SUSPENDED SOLIDS CONTENTS

Jerry Webb
COE

The objective of this paper is to describe the effects of dredging activities associated with channel enlargement projects on suspended solids. Concern is often expressed that localized dredging of rivers will entrain sediments and pollutants that will result in long term impacts on aquatic habitat. A thorough water quality sampling program has been performed by the Corps of Engineers on the Obion and Forked Deer Rivers over several years. Included in the sampled reaches are areas which have not been affected by channel improvement, along with areas in the immediate upstream and downstream vicintiy of dredging activities. The sampling program encompasses pre- and post-project conditions along with measurements taken a few hundred yards downstream of active dragline construction activities. Suspended solid samples indicate that there is an increase during and shortly after construction, with return to preproject suspended solid content values shortly after construction. Sample analyses indicate that levels of suspended solids and turbidity immediately downstream of an operating dragline are no greater than observed values of these same parameters during normal hydrologic/environmental conditions associated with periods of rainfall or high stream flows. Generally speaking, localized dredging activities will have a slight, short-term impact on suspended solid content.

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