1987
Virginia Water Resources Research Forum

Briefing Papers

Virginia Water Resources Research Center
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

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A publication of the Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University. William R. Walker, director; Edward Born, assistant director for publications.

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Foreword

One of the most important roles of the Water Center is to facilitate the exchange of information among researchers and potential users of research. To help accomplish this end, the Center is pleased to have organized the 1987 Virginia Water Resources Research Forum.

As you will learn from reading the research summaries, papers being presented this year touch on many aspects of water-resource related research. Equally impressive is the fact that seven different organizations are represented by the 24 presenters — the Virginia Water Control Board; University of Virginia; Camp, Dresser, and McKee; Virginia Institute of Marine Science; Virginia Tech; the city of Newport News; and Virginia Military Institute.

If you have suggestions to improve future water research forums, I hope you will share them with me or some other member of the staff, as we are constantly on the look-out for ways to improve the effectiveness of our programs.

— William R. Walker, *Director*
Virginia Water Resources Research Center

The West County Instream Flow Requirement: A Case Study

Joseph P. Hassell

Problem Statement

Beginning in the spring of 1980 and continuing through the fall of 1981, a serious drought occurred in Virginia. The Roanoke metropolitan area faced a serious water supply shortage with the principal source, Carvins Cove Reservoir, falling to record low levels. Officials from Roanoke County, Vinton, Salem, and Roanoke formed the Roanoke Valley Water Committee to search for additional supplies. After a review of past studies, the committee developed a list of six alternatives, including two reservoir options, two pumped-storage options, and intakes on either the New River or Smith Mountain Lake. In October 1983, the localities unanimously approved resolutions endorsing the West County Pumped-Storage Reservoir as the region's next major water supply.

The proposed project consists of an intake on the Roanoke River and a large reservoir near the western edge of Roanoke County. During periods of moderate to high flows, water would be pumped to the reservoir and stored for later release during periods of drought.

Roanoke County, faced with the region's fastest growing population and without a major supply of its own, took the initiative in developing the project. A joint permit application to obtain a 401 Certificate from the state and a 404 Permit from the Corps of Engineers was filed in April 1984. The major issue in the issuance of the 401 Certificate and the 404 Permit has been the setting of a minimum instream flow requirement. The Virginia Water Control Board (VWCB) issued 401 certification in January 1985. The Corps of Engineers has yet to issue the companion permit. This paper describes how the VWCB developed the flow-by requirement for the West County Project 401 Certificate.

Methodology

Until Roanoke County applied for a 401 Certificate, the VWCB had used only the 7Q10 flow in flow-by requirements. This flow is the seven-day low flow that occurs, on an average, once every ten years. Wastewater treatment facilities are designed so that water quality standards are maintained even when these low flows occur.

VWCB staff at the West Central Regional Office alerted headquarters of their desire to maintain a flow-by greater than the customary 7Q10, especially since two species of fish, the orangefin madtom and the Roanoke log perch, inhabited the river and were being considered for inclusion on the threatened species list. An ad hoc task force was created to make a recommendation to the board on an appropriate flow-by. The task force included an engineer, a biologist, a permits specialist and the director of the West Central Regional Office and was intended to bring representation to all sides of the controversy.

Results

The task force began work by examining the economic and hydrologic consequences of various combinations of water supply yield and flow-by requirements. A computer model was created to simulate the project's performance and to determine the volume of storage necessary to support the various proposals. Cost estimates were developed from reservoir size determinations. Initially, the task force was considering yields from 20 to 30 million gallons per day (mgd) and flow-by between 7Q10 and 30% of the mean annual flow (17.2 to 51.7 mgd). Depending on the combination, cost estimates ranged between 13 and 50 million dollars. The importance of this flow-by decision was fully understood by the task force.

After careful consideration of the environmental, hydrologic, and economic consequences of the flow-by decision, the task force settled on four final proposals. One proposal was the 7Q10 flow-by which had been standard agency practice up until this time. Although this proposal resulted in the highest yield at 32 mgd, the proposal was rejected because it provided the lowest degree of environmental protection. A second proposal was a flow-by of 30% of mean annual flow. Although this proposal provided the best environmental protection, it was rejected because of the low-water supply benefit of 17 mgd. In fact, it was feared that if this proposal were selected then Roanoke County would not build any reservoir but would instead, put a run-of-the-river intake in the river. According to Virginia Department of Health regulations, any existing intake can be permitted to withdraw a flow equal to the 1-d low flow that occurs once every 30. There is an intake at Glenvar, owned by Salem, that could, conceivably legally, withdraw 11 mgd without any additional permits.

The last two proposals were compromises. One required a flow-by that was greater than the 7Q10 by 5 mgd (22.2 mgd). The water supply benefit of this proposal was 27 mgd.

The proposal that was selected by the task force required a flow-by of 30% of mean annual flow at times and 7Q10 at other times and provided a trigger mechanism to determine when the lower flow-by would be allowed to take effect. The logic behind the proposal was that a high degree of protection to the environment should be provided for as long as possible but that this objective would become subordinate during a severe water shortage. The point at which a switch in flow-by rules would be allowed would be when the reservoir dropped to only a 100-d reserve supply.

The setting of the trigger mechanism in terms of reserve days provided extremely good near-term environmental benefits but held out some long-term consequences. In the near-term, when demands are low, a 100-d reserve is a small amount of storage and the county would have to use up the largest part of the reservoir at a very slow rate before it would ever be allowed to switch to the lower flow-by. Inevitably, though demands will grow and a 100-d reserve will become a larger portion of the total storage, the likelihood of storage dropping into this range increases along with the allowed switch to 7Q10 flow-by.

State and local planners did not agree on the projected increase in water supply demands. Local officials felt they needed an additional 30 mgd whereas state planners felt that no more than 20 mgd would be required over basically the same time frame. This discrepancy encouraged the task force because it felt that overdesigning the reservoir would build extra environmental benefit into the project. State water use projections show that the reservoir project would be operating at only 22 mgd by the year 2030 and not reach its maximum yield of 29 mgd until the year 2053, some 66 years hence. These projections are conservative because they include virtually no increase in groundwater use.

Implications

The flow-by proposal for the West County 401 Certificate represented a radical departure from past practices at the VWCB. For the first time, a flow-by greater than 7Q10 was endorsed; and also for the first time, trigger mechanisms were employed. However, debate over this project is far from over.

Fate and Transport of Nutrients in the James River Estuary

Wu-Seng Lung

Introduction

Results from a recent modeling study of point source phosphorus control in the James River basin indicate that while the present nutrient levels in the *upper* James River Estuary are adequate to support algal growth, reduction of nutrient inputs by removing phosphorus at publicly owned treatment works (POTWs) would lead to a phosphorus-limiting condition and thereby lower the phytoplankton biomass levels (Lung 1986a). The study results also indicate that inorganic nitrogen (NH_4, NO_2, and NO_3) not utilized by the algae due to possible phosphorus removal at POTWs can be transported into the *lower* estuary and possibly into the Chesapeake Bay. Additional modeling effort is underway to expand the analysis into the lower estuary to address a question: how much phosphorus originating from the upper estuary will enter the lower estuary under various phosphorus-control scenarios? Finally, the amount of nutrients from the James River basin contributing to the bay eutrophication will be quantified.

Phosphorus Loads from the James River Basin

The James River Basin contributes a significant amount of phosphorus loads to the bay, ranging from 24 to 36% depending on the hydrologic conditions (Lung 1986b). Such a high phosphorus input is because none of the POTWs in the basin currently practice phosphorus removal. In addition, no other form of nutrient control exists in the James River Basin. As a result, approximately 15 to 30% of the total phosphorus loads to the bay, again depending on the hydrologic condition, are from the POTWs in the James River Basin. More importantly, POTWs account for about 55 to 75% of the total phosphorus loads from the James River Basin with the majority coming from sources below the fall line (Lung 1986b).

Phytoplankton-Nutrient Dynamics in the Upper James River Estuary

To understand the fate and transport in the James River Estuary, one needs first to quantify the phytoplankton-nutrient dynamics and its cause-and-effect relationship in the *upper* estuary. A modeling study was conducted for the upper estuary using recent water quality data (Lung 1986a). Model calculation results from that study are shown in Figure 1 for two separate data sets in 1983. In general, the increase in ammonia nitrogen below Richmond was due to ammonia discharge from point sources such as the Richmond wastewater treatment plant and other POTWs and industrial facilities. However, the increase did not sustain beyond river mile 90 because of phytoplankton uptake and nitrification. Note that the phytoplankton chlorophyll *a* concentration increased starting at this river reach. The orthophosphate profile in Figure 1 closely resembles the ammonia profile. Again, the sharp increase in orthophosphate concentration was because of wastewater discharges from point sources. Subsequent decrease in concentration was the result of algal uptake. The lowest level of orthophosphate is about 0.01 mg/l of P, which is much higher than the Michaelis-Menton constant (0.001 mg/l) limiting the algal growth in the model.

Effect of Point-Source Phosphorus Control

Given the above quantitative phytoplankton-nutrient dynamics, the calibrated model was used to assess the effect of point-source phosphorus control. A number of phosphorus control alternatives for the POTWs in the basin were evaluated. They ranged from phosphate detergent bans to phosphorus removal at POTWs. Although phosphate detergent bans would provide small reductions in phytoplankton (chlorophyll *a*) biomass, phosphorus removal at POTWs would offer more promising results in reducing chlorophyll *a* levels. That is, phosphorus limitation starts to show under the phosphorus removal scenarios (Lung 1986a).

Under the phosphorus removal scenarios, inorganic nitrogen (NH_4, NO_2, and NO_3) would increase in the downstream direction because they would not be utilized by the reduced algal biomass (Figure

2). This result raises an interesting question: would phosphorus removal cause nitrogen increase and associated algal growth in the lower estuary and the Chesapeake Bay?

Fate and Transport of Nutrients in the Lower Estuary

Additional modeling effort is underway to expand the analysis into the *lower* estuary to address the above question. The objective of the ongoing work is to determine how much nutrients originating from the upper estuary will enter the lower estuary? It is known that nutrient releases from the sediments in the James Estuary would contribute a significant amount of nutrients into the water column under favorable conditions. Recent data on nutrient release and sediment oxygen demand rates are available (Cerco 1985) and being incorporated into the expanded model.

The above analyses were performed by assuming that 100% of the phosphorus loads from the James River enters the Chesapeake Bay. However, it is known that once leaving the James River, the bulk of the loads does not move in an upstream direction along the bay. Rather, it flows into the Atlantic Ocean. Would the nutrients (phosphorus and nitrogen) from the James River enter the Bay and affect the algal growth in the bay? If not, exactly how much nutrient from the James River is contributing to the bay eutrophication? To provide answers to these questions, a water quality model is being developed to quantify the interactions between the James River and the bay. The study results will be used to determine the fate and transport of nutrients from the James River Basin into the Chesapeake Bay.

Citations

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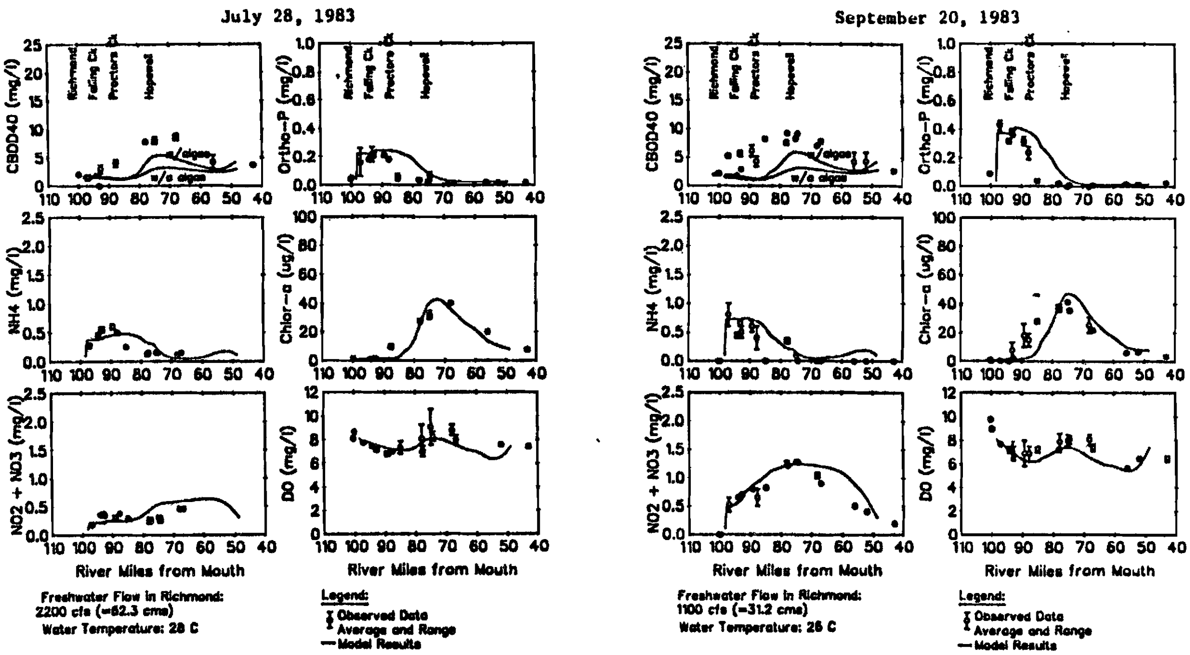

Fig. 1. Fate and transport of nutrients in Upper James River Estuary.

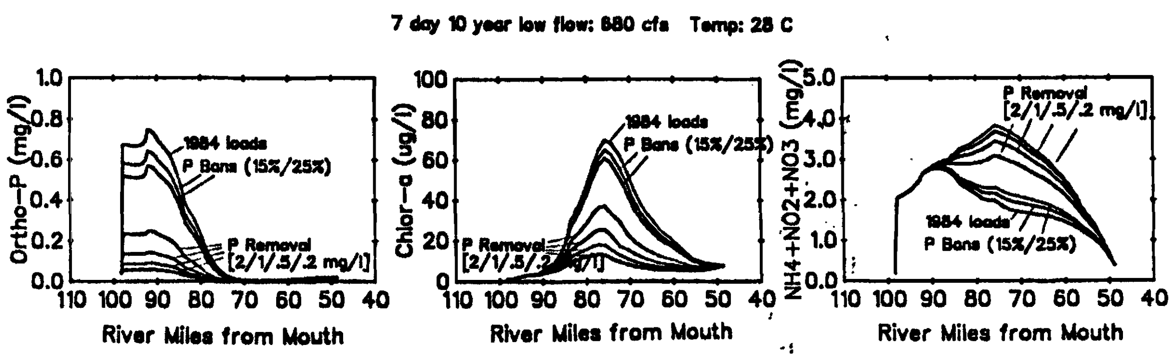

Fig. 2. Effect of phosphorus control on water quality.

Watershed Management for Reservoir Protection: A Case Study of the Occoquan Reservoir Program

John P. Hartigan and Thomas F. Quasebarth
(Presented by John P. Hartigan)

Problem Statement

The federal Safe Drinking Water Act Amendments which took effect June 1986 are likely to result in much more stringent water treatment standards for water utilities in Virginia and other states. For surface water reservoirs, which are a major water supply source in Virginia, the establishment of effective watershed management programs not only prevents contaminants from being discharged into water supply reservoirs but they can also minimize the risk of forming harmful by-products during water treatment. For example, management plans that reduce phosphorus discharges into a water supply reservoir will usually reduce algae concentrations in the reservoir, with reductions in the levels of trihalomethanes (a suspected carcinogen) in treated water a possible result.

Nonpoint pollution control is particularly critical for watershed management programs designed to protect reservoir water quality. This is because impoundments exhibit hydraulic residence times which may be several days or weeks in duration, thereby serving as efficient traps for nonpoint pollution discharges from upstream areas. The relatively long residence times can result in algal growth and dissolved oxygen impacts following the return to quiescent conditions after a rainstorm, as well as the undesirable buildup of nutrients and toxicants in the bottom sediments of the reservoir.

Regional Nonpoint Pollution Management Program

Following a two-year 208 planning study, the Northern Virginia Planning District Commission (NVPDC) coordinated the development of a continuing regional program for nonpoint pollution management activities in the Occoquan Reservoir watershed in 1978. The goals of the regional program, which is still in operation today, are as follows: (a) implementation of the most cost-effective nonpoint pollution mitigation techniques during the early stages of urbanization, so as to minimize the risk of irreversible water quality degradation and/or the need for costly remedial control measures at some later date; and (b) the management of nonpoint pollution loadings from agricultural lands within the basin. The management program is strictly advisory in nature, and as such, it is primarily a vehicle for fostering interjurisdictional cooperation, for providing continuing technical assistance to local staffs, and for monitoring local progress in the area of nonpoint pollution management.

The regional program is administered by a policy board which is composed of city and county managers and is advised by a special technical committee. The program is staffed by NVPDC which provides technical assistance with the evaluation of local nonpoint pollution control plans and periodically evaluates cumulative impacts with a water quality model of the reservoir and its watershed. Since 1978, the regional program has resulted in: The implementation of major land use controls within three of the counties; the requirement of structural best management practices (BMP's) for new development in all jurisdictions; and a switch-over to conservation tillage practices on the majority of cropland in the watershed.

Local Nonpoint Pollution Controls: Fairfax County Case Study

In 1982, Fairfax County adopted stringent land use controls (5-acre lot residential zoning for 27,000 acres) for its 100 square mile portion of the Occoquan Reservoir watershed. The intent of this nonstructural control program was to supplement the nonpoint pollution management benefits of the County's existing BMP requirements for new urban development. The County's selection of land use controls as the major element in its watershed management program was based upon water quality modeling studies of different nonpoint pollution control strategies. A 5-acre minimum lot size was selected for the management plan because: (a) it will result in the maintenance of "undeveloped" land cover on the majority of residential development site; (b) in comparison with the original 1-acre lot zoning throughout the watershed, a 5-acre minimum lot size would achieve a 50%-60% reduction in annual total phosphorus loadings which is a slightly higher efficiency than structural BMP's and about 5 to 6 times greater than the efficiency projected for smaller minimum lot sizes (e.g., 2-acre lots); and (c) from a real estate economics standpoint, there is a market for 5-acre lot residential development throughout the downzoned area. Several lawsuits challenging the Fairfax County downzoning were filed in 1982. The County's arguments in defense of the downzoning cited the following advantages of land use controls in comparison with structural BMP's:

1. Unlike higher density development relying upon structural BMP's, land use controls do not generate higher nonpoint pollution loadings for treatment;
2. More data is available on the long-term efficiency of land use controls (i.e., long-term reductions in nonpoint pollution loads) than is available on structural BMP's;
3. There are no maintenance requirements associated with land use controls, unlike structural BMP's;
4. Less risk of toxic loadings due to the lower levels of imperviousness;
5. Higher factor of safety; and
6. Since long-term nonpoint pollution impacts cannot be quantified precisely, it is advisable to select a sufficiently cautious and conservative approach to watershed management in order to ensure adequate water supply protection.

In a precedent-setting decision in January 1985, the Circuit Court upheld Fairfax County's use of land use controls for reservoir watershed management.

Useful Insights for Other Reservoir Watershed Management Programs

Included among the useful insights for other reservoir protection programs are the following:

1. Advanced wastewater treatment facilities are usually an important element in a reservoir protection program, but they should not be viewed as a panacea;
2. In developing a watershed management program for reservoir protection, controls for wastewater discharges and nonpoint sources should be evaluated at the same time;
3. Unless the watershed has a significant amount of cropland, nonpoint pollution loadings from uncontrolled future urban development will probably cause water quality degradation;
4. Areas located upstream of the reservoir can contribute significant nonpoint pollution loadings, meaning that the establishment of reservoir buffer zones should not be viewed as a panacea for reservoir protection;
5. The least desirable urban land uses for a water supply watershed are those producing significant amounts of pavement runoff;
6. The most cost-effective watershed management program is likely to be a combination of land use controls and structural BMP's; and
7. For structural BMP's, a master plan approach is likely to be more cost-effective than a piecemeal approach (i.e., onsite BMP's provided for individual development projects).

Effects of River Discharge Modifications on Tidal Wetlands

Carl Hershner

Problem Statement

Increasing development of Virginia's coastal zone has placed a premium on expansion of potable water supplies. Many of the current proposals focus on full development of potential surface water supplies in the region. Impoundments of drainage basins and direct instream withdraws both have potential impacts on the tidal freshwater and oligohaline reaches of Virginia's estuaries. Given a management objective of preserving the structure and/or function of tidal wetlands, resource managers are currently confronted with uncertainty regarding possible impacts of river discharge modifications resulting from water supply development. Substantial freshwater withdraws and/or modification of natural discharge patterns may affect salinity regimes, tide ranges, and sedimentation processes. The consequences of these effects may include alteration of both wetlands community composition and function.

Objective

The objective of ongoing work of the Virginia Institute of Marine Science is to develop an understanding of the potential incremental and cumulative impacts of modification of river discharge on tidal wetlands. For resource managers, we hope to produce a methodology for quantitative assessment of impacts.

Methodology

The approach in this project is to construct a theoretical model of a tidal river drainage basin and then use both the development and performance of the model to direct the supporting research efforts. The initial focus of the model development is simulation of salinity distributions on an hourly time scale. The model is designed to represent the river and drainage basin as a series of interacting cells. Flux between cells is modeled as volumes of water or mass of other parameters of interest. Long-term records of river discharge, tidal amplitude and precipitation are used in forcing functions. The design of the model allows for modification of surface water input at any point along the river's course.

The model is specifically designed to produce predictions of salinity distribution at short intervals over very long time spans. This design is intended to support the parallel research in this program which is attempting to relate long-term salinity exposure to plant species distributions. From autecological studies the average salinity tolerances of some wetland plants are known. In natural systems however, we believe species range limits may be controlled by the periodicity and amplitude of fluctuations in salinity. This would imply that the structure of wetland communities is, at least in part, a response to the high- and/or low-flow conditions of rivers rather than average conditions. When the model has been completed, it will be used to help reconstruct historical salinity exposures to further test this hypothesis.

The analysis/correlation of plant distributions with salinity exposure is presently proceeding using available long-term data sets. We are using the Pamunkey River basin as a test area because of the available historical records and the concurrent studies of wetland systems in the area.

Results to Date

The conceptual design of the model has been completed. Programming is currently underway. Initial compilation of the historical data sets is nearing completion. The first simulations of salinity distributions are anticipated in late March or early April.

Research Implications

Successful completion of this project will permit researchers and managers to assess potential impacts of both development plans and management protocols. We hypothesize that tidal wetlands, as they respond to altered salinity regimes, may be affected by either general reductions in freshwater input or altered patterns of freshwater inputs. Preliminary work on hypothetical river basins suggests that as the proportion of total input which is "managed" increases, the potential for altering stability/sensitivity in the system also increases. This effect can be either positive or negative. For example, if impoundments only bypass freshwater during extreme rainfall events the downstream effect can be an increase in the relative significance of those events due to the damping of salinity fluctuations in response to lesser events. Conversely, if management protocols for impoundments establish minimum discharge requirements the effect can be creation of an unnatural stability in salinity regimes by reducing the impact of very low-flow conditions.

While the hypothetical effects noted above can be readily demonstrated in theoretical calculations, assessment of their significance in natural systems is the objective of our current work. If the project is successful, resource managers will be able to assess some of the potential impacts of water supply development. Perhaps the most important implication of this research is that, if successful, it will place additional emphasis on the need for development of long range plans. If managers are provided tools to facilitate prediction of environmental consequences, it is clearly incumbent on those same managers to have clearly articulated, comprehensive objectives for development of natural resources.

Seasonal Variation in Responses of Aquatic Insect Communities to Copper in Laboratory Streams

William H. Clements, Donald S. Cherry, and John Cairns, Jr.
(Presented by William H. Clements)

Problem Statement

Aquatic toxicologists employ a variety of techniques, ranging from single species laboratory bioassays to experimental introduction of toxicants into natural systems, to examine the responses of freshwater organisms to pollutants. Presently, there is considerable controversy over which approach is most useful (Cairns 1983), particularly since there is often an inverse relationship between the simplicity or repeatability of these approaches and the degree of environmental realism. Single species toxicity tests are routinely employed to establish water quality criteria and to predict the environmental impact of hazardous materials on aquatic communities. Owing to their inherent simplicity, these tests are relatively inexpensive and have a high degree of replicability and statistical precision. Recently, however, some researchers have questioned the adequacy of single species tests for predicting the effects of toxicants on natural communities in the field. Although some studies have demonstrated good agreement between single species tests and field data, others have shown effects of toxicants in field experiments at considerably lower concentrations than indicated by single species bioassays. Kimball and Levins (1985) present several examples that illustrate the limitations of single species bioassays, but note the historical preference for these simpler tests. For several reasons, toxicologists have been reluctant to incorporate more environmentally realistic testing procedures into their repertoire of experimental techniques. Arguments against the use of multispecies bioassays and field experimentation include the greater costs, loss of replicability, and potential for environmental damage associated with experimental introduction of toxicants into natural systems. However, since the objective of hazard assessment is to predict effects of pollutants beyond the level of single species, it follows that community or ecosystem level tests must also be considered.

Objective

The purpose of this research was to examine the effects of copper on abundance, number of taxa, and species composition of aquatic insect communities established on artificial substrates over three seasons. Copper was chosen because it is a ubiquitous pollutant in freshwater systems and because of the availability of field and laboratory data in the literature on the responses of aquatic organisms to this toxicant.

Methodology

Artificial substrates were colonized in Adair Run, a second-order tributary to the New River located in Giles County, Virginia. The substrates consisted of 10 x 10 x 6-cm plastic trays filled with pebble and small cobble. Forty trays were recovered from Adair Run on three occasions: 22 January 1986 (winter), 28 April 1986 (spring), and 24 July 1986 (summer) after 30 d of colonization. Trays were collected by placing a 100-μ mesh net directly downstream to prevent loss of organisms and then gently removing each tray from the stream. Contents of 10 trays were washed through a 500-μ sieve, and the organisms retained were preserved in 10% formalin in the field. These samples (field controls) were used to estimate initial macroinvertebrate abundance and community composition. The remaining 30 trays were placed into 7-L coolers (two trays per cooler) filled with stream water. Each of the 15 coolers was supplied with an airstone attached to a 12-volt air pump. Trays were then transferred to the Virginia Tech Ecosystem Simulation Laboratory and the two trays from each cooler were placed into an artificial stream. After a 48-h acclimation period, each stream was randomly assigned to one of three treatments: laboratory controls (0 $\mu g\ L^{-1}$ copper), low dose (25 $\mu g\ L^{-1}$ copper), and high dose (150 $\mu g\ L^{-1}$ copper). Streams were dosed for 96 h, after which the trays were removed and the contents gently washed through a 500-μ net. All living organisms retained were removed and preserved in 10% formalin.

Results

The total number of taxa and number of individuals per tray did not differ significantly between field and laboratory controls during any season. After 6 d in laboratory control streams, the number of individuals was reduced by only 10 to 12%, and the number of taxa was 0 to 3% lower than in field controls. These results show that colonized substrates can be maintained in laboratory streams for short periods of time with no evidence of control mortality.

Exposure of aquatic insect communities to copper in laboratory streams significantly reduced both the number of taxa and number of individuals in all three seasons. With one exception (the number of taxa in winter experiments), both parameters were significantly reduced in high dose streams compared to low-dose streams, indicating a dose-dependent response to increasing copper concentration. The greatest percent reduction in the number of taxa and number of individuals was observed in summer experiments. Species diversity was also reduced in treated streams, but this parameter was less sensitive to copper exposure than the number of taxa and number of individuals. Species diversity did not differ significantly between treatments during the winter and was significantly reduced in the spring only in high dose streams.

The effects of copper exposure on the three dominant orders of aquatic insects varied between seasons and groups. Ephemeroptera were highly sensitive to copper exposure in laboratory streams. These organisms were significantly reduced in both low- and high-dose streams during each season, with the greatest effects observed in summer experiments. Owing to differences in sensitivity to copper, the percent composition of Ephemeroptera, Diptera, Plecoptera, and other aquatic insects varied among treatments. The relative abundance of mayflies decreased in dosed streams during each season, whereas dipterans increased in winter and spring experiments. Similarly, the percent composition of plecopterans increased in treated streams during winter and summer experiments.

The relative abundance of dominant taxa within these groups also varied between treatments and seasons. *Baetis* sp., the dominant mayfly collected, was reduced by 85 to 98% in low-dose streams compared to laboratory controls. The response of other common mayflies was variable, but these organisms were generally less sensitive to copper than *Baetis* sp. The relative abundance of Orthocladini, the dominant chironomid collected, increased in treated streams relative to controls in winter and spring experiments.

Research Implications

Results of this study demonstrate that simple community level parameters, such as number of taxa and number of individuals, are highly sensitive to copper exposure. Within 96 h in low-dose streams (15-32.0 $\mu g\ L^{-1}$), the number of taxa per tray was reduced by 24 to 36% and the number of individuals was reduced by 35 to 52% relative to laboratory controls.

The use of changes in macroinvertebrate community structure and distribution in the field to assess the impact of heavy metals is an important supplement for single species bioassays. Owing to complex interactions between aquatic organisms and various habitat features, particularly current and substrate, reduced abundance and/or species richness observed downstream of a particular effluent does not actually demonstrate that the effluent is responsible. LaPoint (1984) argues that experimental studies are necessary to show direct cause and effect relationships. Although experimental introduction of toxicants into natural streams can provide the strongest evidence for cause and effect relationships between the presence of toxicants and macroinvertebrate community structure, there are a number of serious problems associated with this approach that will limit its usefulness. In addition, Hurlbert (1984) discusses the statistical problems of field experimentation that require replication of both control and treated streams. The approach that we have outlined here, using colonized artificial substrates for toxicity testing, may represent an alternative to field experimentation and an important supplement to single species tests. This approach provides a unique opportunity to examine community level responses to toxicants under both replicable and environmentally realistic conditions and may be particularly useful during initial screening of an effluent, prior to its release into the environment. For example, substrates could be colonized in the proposed receiving system, transferred to outdoor experimental streams, and dosed with the proposed effluent. Changes in macroinvertebrate community structure, number of taxa, and number of individuals observed in treated streams could then be employed to predict the impact of these effluents in the field.

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Water and Sewer Service in Virginia

John Randolph

Summary

This paper provides an overview of water and sewer service in Virginia, including data on institutional arrangements, user charges, status of public systems, capital needs, and financing those needs. Current water and sewer issues facing the Commonwealth are also discussed.

Provision of Community Water and Sewer Service in Virginia

According to the 1980 Census of Housing (U.S. Bureau of Census 1983). Nearly 3/4 of statewide households have community water and 2/3 have community sewer service. In urban areas, more than 19 in 20 households receive community water and 9 in 10 community sewer, while in rural areas these figures are only 1 in 4 and 1 in 6 respectively. Nearly 3/4 of rural residences depend on septic systems. In 16 counties, more than 1 in 10 households have no plumbing, and in 14 counties more than 1 in 5 households still rely on privies for human waste disposal.

Since 1969 the Virginia Water Project (VWP) has funded projects to improve access of rural households to safe drinking water and sanitary wastewater disposal, generally through community systems. VWP has helped provide water and/or wastewater services to about 9,000 low-income families. Supported by foundation grants through 1977, VWP has received General Assembly appropriations since 1978. The original fund of $100,000 a year was increased to $150,000 in 1984 and to $250,000 a year for the 1986-88 biennium. VWP has proposed, and the Joint Subcommittee on Water Supply and Wastewater Treatment has recommended, increasing the fund to $750,000 a year (JS, WS&WT 1987).

Institutional Arrangements for Community Water and Sewer Service

Those households fortunate to have water and sewer service receive it from different types of utilities. Nearly all service is provided by public utilities, although about 3% of the state's population is served by 65 certified private water companies (dominated by Virginia American Water Company which supplies Alexandria, Dale City, and Hopewell); a much smaller percentage is served by 9 certified private sewer firms. Nearly all cities and most (72%) incorporated towns own and operate at least part of a water and/or sewer system. Only 14% of the counties own and operate systems under a utility or public works department. In most counties, systems are operated by one or more of the state's 51 public service, water, or sanitation *authorities*[1] or one or more of the 14 *sanitary districts*[2]. In addition, four special *sanitation commissions*[3] operate in the state, the most prominent being the Hampton Roads Sanitation District Commission which was created in 1946 and manages sewage disposal for more than 1 million residents of the Tidewater area (VDH 1985a).

While many of the city, town, and smaller county service authority systems provide "complete" service (i.e., from water source to sewage treatment) most systems are interdependent with one or more others. There is a statewide trend for more regional systems, particularly for water and wastewater treatment. For example, Richmond has a "complete" system, but it also provides treated water and

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[1] *Authority*: established for any of: water supply, wastewater collection treatment disposal, refuse disposal. Created by local governing bodies (e.g., board of supervisors) of one or more jurisdictions. May be controlled by local governing bodies or as separate entity by an authority board. Authorities cannot tax and are dependent on revenues or revenue bonds for financing.

[2] *Sanitary District*: established within a county to construct, maintain, operate any of: water supply, sewerage, garbage disposal, heat, light, fire fighting, power and gas, sidewalks. Controlled by local governing body. Can levy taxes within district and issue bonds which may not exceed 18% of district's assessed real estate value

[3] *Sanitation Commission and District Commission*: established by General Assembly or petition to circuit court for relief of tidal (district commission) or nontidal (commission) waters from pollution. Controlled by appointed members.

sewage treatment to neighboring Henrico County. Newport News operates a regional water system serving Hampton and Poquoson; Norfolk supplies water to Virginia Beach; and the entire region is served by Hampton Roads Sanitation District Commission. In Montgomery County, Blacksburg and Virginia Tech have their own water distribution and sewage collection systems, but are provided treated water by the Blacksburg-VPI-Christiansburg Water Authority and sewage treatment by the Blacksburg-VPI Sanitation Authority. Christiansburg also purchases water from the water authority, but operates its own sewage treatment facility. The Montgomery County Public Service Authority operates several independent water systems and three sewage collection and treatment systems outside of the towns.

Overall, the institutional arrangements chosen by specific localities have worked well. One issue that surfaced in 1985 was the independence and accountability of those county public service authorities which are controlled by an authority board rather than the county board of supervisors. The Bedford County Public Service Authority operates a number of small systems. Faced with high costs of eliminating a radiological quality problem in one subdivision system, the authority decided to abandon the system. While a subsequent settlement reversed this decision, the vulnerability of the hundreds of similar systems throughout the state was made apparent. A Joint Subcommittee of the General Assembly studying water and sewer treatment recommended that a subsequent joint subcommittee be established to study this issue further (JS, WS&ST 1987).

While management of water and sewer systems is primarily a local activity, the state has certain regulatory and planning responsibilities. The Virginia Department of Health (VDH) regulates all public water supplies for quality, imposing certain monitoring requirements on water treatment facilities, distribution systems, as well as independent systems serving more than 25 people (thus many restaurants are regulated). The Virginia Water Control Board (VWCB) regulates all sewage treatment facilities as part of its discharge permit program. In addition, the VWCB provides water supply and wastewater treatment planning through its office of water resource planning and construction grants program (see for example, VWCB 1976, 1983, 1986b). The State Corporation Commission regulates the rates of service of private water and sewer companies.

Still, most management and planning functions of municipally owned systems, including setting of rates, are performed locally. A survey of all water and sewer systems in the state revealed that these rates vary considerably; however, there was no clear correlation between rates and system size or regional location. For example, for a typical residential usage (9000 gal/month), the 1986 month charge by 20 systems of varying sizes throughout the state ranged from less than $5 to more than $30 (with an average of $13.40) for water, and ranged from $6 to $23 (with an average of $12.40) for sewer service. Most systems reassess their rates every year. Rate structures also vary: over 90% of 120 water systems responding to the survey have a service charge plus a volume rate; less than 3%, mostly unmetered systems, charge a flat rate for any use. For sewer rates, 30% of 107 systems responding simply charge a percentage of the water bill; nearly half have a service charge plus volume rate; and 10% charge a flat rate.

Status of Public Water and Sewer Systems

Four million people in Virginia receive public water supply from 300 systems;[4] 87% of that population is served by 54 major demand systems. Of the 520 million gallons per day (mgd) of water supplied by these public systems, 83% comes from surface sources, and 17% from groundwater. Of the state's population, 59% is served by community surface sources, 13% by community groundwater sources, and 28% by rural groundwater (i.e. individual wells and springs) (USGS 1984, 1985).

At least 30% of the water systems expect a supply deficit by the year 2030. The total expected supply deficit volume equals 1/4 of current demand. Nearly all the projected deficits are due to source constraints (62%) or limits on water treatment capacity (37%). Most of the deficit volumes occur in the growing Tidewater and Northern Virginia areas, while the most systems with anticipated deficits occur in the Valley and Southwest regions (VWCB, Regional Offices 1986).

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[4] The VWCB figure of 300 includes only water *supply* systems, and not systems which only distribute water (e.g., Town of Blacksburg). The VDH reports 494 separate public community systems owned by 270 local governments, authorities or districts; these include all supply and distribution systems.

There are well over 200 publicly owned wastewater treatment facilities in the state. About 1/4 of these plants are experiencing flow rates exceeding 95% of design flow; about 1 in 6 has had the "95% policy" applied, indicating serious capacity limitations. About 45% of the facilities are listed under the "National Municipal Policy," resulting from the EPA mandate that public owned treatment plants achieve permit-required level of treatment by 1988. Sixteen of Virginia's "Municipal Policy" facilities have been ruled "hardship" cases and have received extensions beyond 1988 for treatment upgrades. The largest number of facilities having capacity and treatment problems occur in the Southwest region, while the fewest occur in the Tidewater and West Central regions (VWCB, Regional Offices 1986).

Capital Needs of Water and Sewer Systems

The VWCB and VDH have respectively estimated the Commonwealth's capital costs for water and sewer improvement needs through the year 2000. The sewer needs are based on construction grant priorities and include only the need for interceptors and treatment facilities, not local collection. The water needs are based on a survey of all municipal systems by VDH and include all source, treatment and distribution works. The sewage treatment needs of over $2 billion include about $900 million in upgrades and new construction for 82 communities that are currently on the construction grants program priority list, $1.1 billion for new construction or upgrades in 250 communities not on the list, and $200 million for phosphorus removal in 36 communities (JS, WS&WT 1987).

The estimated $1.9 billion needed for water system expansion and improvements include $624 million for existing needs and an additional $1,277 million by the year 2000. Not surprisingly, the needs are concentrated in the most populated planning districts (PDs). These include the Hampton Roads area (PDs 20 and 21: $285 million now, $350 million more by 2000); the Richmond area (PD 15: $64 million now, $350 million more by 2000); and northern Virginia (PD 8: $80 million now, $160 million more by 2000). On a per capital basis, existing needs are greatest in Fairfax City ($950 per capita), Gloucester County ($750), and Bedford City ($700), while year 2000 needs are greatest in Salem ($1850 per capita), James City County ($1600), and Chesterfield County ($1600) (VDH 1985b).

Financing Capital Needs

To finance water and sewer capital needs, local governments and authorities have historically relied on federal and state grant and loan programs and on their own resources, namely, revenue and general obligation bonds, and reserve, capital improvement, and general funds. Federal and state programs have been particularly helpful in relieving the financial burden on localities. From fiscal years 1982 through 1986, a total of $427 million was provided from a range of programs. Of that total, 84 percent came from federal sources (nearly half from EPA) and 79% went to sewer works. The expected FY 1987 level of funding from these programs totals $153 million ($30 million for water and $123 million for sewer) (JS, WS&WT, 1987).

State support increased substantially in the past two years with the creation of the Virginia Resources Authority (VRA) (formed in 1984 to offer loans to local water and wastewater projects with a $300 million state bond fund) and the Virginia Water Facilities Revolving Loan Fund (created in 1986 with an annual appropriation of $10 million to provide loans for wastewater treatment facilities). Of the $153 million FY 1987 assistance funds expected from federal and state sources, nearly $60 million is from the Virginia Resources Authority and $10 million is from the VWCB revolving loan fund for wastewater facilities. The criteria for allocating the sewage treatment revolving loans gives highest priority to "Municipal Policy" facilities, moderate priority to meeting receiving water quality standards and toxic and nutrient discharges, and lowest priority to correcting infiltration, inflow and combined sewer problems, and providing basic treatment (VWCB 1986a).

Still, compared with the water and sewer needs described in the previous section ($1.9 billion for water and $2.1 billion for sewer systems through the year 2000), the current level of federal and state support will not cover the costs. These water and sewer financial needs annualized over 15 years equal about $227 million ($127 for water and $140 for sewer). If the available $153 million in assistance funds for FY 1987 continued in subsequent years (perhaps wishful thinking), there would still be a shortfall of $113 million a year ($96 million for water and $17 million for sewer). While the shortfall for sewer facilities is only 12%, the shortfall for water systems is 76% (JS, WS&WT 1987).

Based on these figures, the Joint Subcommittee Studying Water Supply and Wastewater Treatment recommended and the 1987 General Assembly passed SB 585 establishing a $10-million-a-year Virginia Water Supply Revolving Loan Fund to provide loans to local governments for improvement or construction of any part of a water supply system. Like the Water Facilities (Sewer) Revolving Loan Fund, the Water Supply Fund will be administered and managed by the Virginia Resources Authority (VRA), but while the sewer fund loans are allocated to localities by the Water Control Board, the water supply fund loans will be allocated by the Board of Health.

Still, $10 million a year does not come close to meeting expected water supply needs, and localities will have to continue to rely on local sources of funding. Based on a September 1986 survey of all water and sewer systems in the state, localities expect to continue to rely on a range of financing sources to meet capital needs. The majority of larger sewer systems expect to depend on EPA funds and revenue and general obligation bonds for financing, while small sewer systems see VRA loans as the most expected source. Most large water systems look to local revenue bonds and capital improvement funds (CIF) to cover capital needs. Most medium-sized water systems look to the Farmers Home Administration (FmHA), VRA, and local CIF, while most small systems see the Community Development Block Grant Program, FmHA, and CIF as principal sources.

In addition, it should be noted that while many of the federal and state sources have historically been grants (not to be repaid), the sign of the future is *loans*. The largest source of support, EPA grants, will increasingly go into the Sewer Revolving Loan Fund. By 1989, at least half and as much as 92% of the EPA funds will go to the loan program. EPA sewage treatment grants to states are scheduled to terminate after FY 1994. While the VRA and sewer and water revolving loan programs can certainly help localities obtain financing for projects and can reduce their debt service based on lower interest rates, the funds must be repaid. This means local water and sewer systems must recover more of system capital costs from user charges, and this will mean higher water and sewer rates. Based on the concept of "the user should pay," perhaps this is how it should be, but localities will need to better analyze system operating and capital costs as well as financing options to understand their effects on user charges.

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Wastewater Reuse and Recycling as Part of Water-Supply Management in Industrial Areas and as an Economical Means for Water Pollution Control

Menahem Rebhun

Problem Statement

Wastewater reuse is an essential factor in water resources management in many arid, semi-arid and other water-short regions. Also in water-rich regions, like the Commonwealth of Virginia, there might be local areas where as a result of dense population, intensive industrial activity and developments, the high water consumption and demand may exceed the safe yield of local resources, resulting in a local or subregional deficit, such as in the Hampton Roads area. The industrial consumption in this area constitutes a significant part of the total, therefore, reuse for industry and internal recycle in industrial plants should be seriously considered when planning water supply and resources management.

Reclamation for industrial use has several distinct advantages: due to the proximity of most industries to large population centers, and thus, to the source of wastewater, the transportation costs of renovated water are minimal; most industrial consumptions are constant in flow, permanent throughout the year, therefore, seasonal storage is not required; reclaimed wastewater is a reliable source of water and the industrial consumer is a reliable recipient; the product value per unit of water used in industry is often high, enabling economically justifiable advanced treatment processes, contributing to improved water and environmental quality control; and, the advanced purification processes, usually required in reuse schemes, are often similar in nature and equipment to processes used in industrial water conditioning.

Reuse for Cooling Systems

Cooling systems are major water consumers in many industries and in power stations and excellent candidates for utilization of renovated wastewater. In water short regions, recirculating cooling water systems with cooling towers are used, rather than once-through systems. As a result of expansion and development in the large Haifa refinery and petrochemical complex, the cooling water circulation rate reached 30,000 $m^3\ h^{-1}$ (195 mgd) (in a once-through cooling system this would be the amount required and impossible to supply) with a make-up consumption of 600 $m^3\ h^{-1}$ (4 mgd). While supplying the 4 mgd from fresh water sources posed serious problems in this water short area, a nearby municipal treatment plant produced 20 mgd of secondary effluent. The reuse of this effluent has been selected as a source for make-up water to the cooling system. Water quality factors were related to three major problems encountered in circulating water cooling systems: scaling, corrosion, and biofouling.

Scaling: Calcium carbonate scale formers are present both in fresh water and in wastewater, but in the latter, in higher concentrations. Calcium phosphate scale formers are specific for reclaimed wastewater and are not commonly found in fresh water supplies. Equilibria calculations show that the phosphate concentrations could be a strong scale-forming factor on heat exchanger surfaces.

Corrosion: Total dissolved solids including chlorides are a general corrosion factor present in freshwater and in wastewater, in the latter at higher concentrations. Their concentration in CCW is controlled by concentration cycles, e.g., by blowdown. A corrosion factor specific to wastewater effluents is ammonia which is corrosive to copper alloys frequently used in heat exchange systems.

Biofouling: Biofouling is encountered in most recirculating cooling systems, but when reclaimed wastewater serves as make up, biogrowth may be enhanced due to residual organic substrate and high nutrient content N and P.

To meet quality requirements, and following lab and pilot studies, high lime precipitation has been selected as tertiary treatment and implemented in a "solid contact" precipitator, giving complete phosphate removal and high reductions in BOD, alkalinity and calcium. It has been discovered that complete ammonia elimination takes place in the circulating cooling system by biooxidation-nitrification, eliminating the ammonia corrosion problem. A recirculating cooling water system was found to be an efficient nitrification reactor. The bioactivity is also beneficial in degrading residual organics originating in the effluent. The bioactivity is, however, the cause of biogrowth which has to be controlled not to exceed objectionable levels.

For each recirculating system, a maximum limiting concentration of components is set and controlled by blow-down, its rate depending on concentrations in make-up water. Concentrations in renovated waters are higher than in fresh water, requiring higher blow-downs and consequently, more make-up water consumption. The ratio of renovated water consumption to fresh water consumption is defined as "replacement ratio." Mathematical expressions have been developed to calculate replacement ratios. Replacement ratios should be evaluated in all reuse schemes and taken into account in cost evaluations of reuse projects. The reuse of wastewater for the cooling system has been in operation for 18 years, saving millions of cubic meter of fresh water. The effluent from the cooling systems is of generally better quality than the original secondary effluent, thanks to the additional tertiary treatment and to the biooxidation in the cooling system.

Internal Reuse in a Paper Mill

The paper mill reduced its specific water consumption from 110 m^3 per ton to 25 m^3 per ton within a period of a few years through loop closing and recycle. Further production expansion required water in quantities that could not be supplied from existing sources. Treatment-reuse units were installed in each paper machine, reducing the freshwater consumption to less than 10 m^3 per ton at steady state operation. Further reduction in specific consumption by recycle is limited by organic and heat buildup (temperature increase). Water serves as a heat disposal medium from the production machines. Cooling of the wastewater and biological treatment are necessary for increased recycle. Cost evaluation shows that reuse competes economically with the cost of fresh water supply plus the cost of wastewater treatment for disposal.

Summary

Wastewater reuse for and in industry and other purposes can and should be an integral part of water resources management in water short areas. In both the cases described, the cost of treatment and recycle could compete with real cost of fresh water, its treatment, plus the cost of waste treatment and disposal. The need of the reclaimed water and its value for the industry prompted installation of advanced treatment processes, thus providing better water pollution control. The reuse projects, though cost effective, needed the initiative and strong support of local and national government in their development stages. Also, many legal, political and institutional aspects have to be considered in all reuse-reclamation schemes, such as: water rights vs. effluent reuse, wastewater ownerships and rights, and cost sharing in case of municipal effluent reuse.

Entry of Nonrectified Data into a Geographic Information System

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(Presented by R.K. Byler)

Problem Statement

A geographic information system (GIS) requires that map data be entered from some source data, usually paper maps, referenced to some coordinate system which can be used in the GIS. However, other data sources, such as aerial photographs and similar imagery, offer the potential for important additional data but contain considerable distortion. Currently county soil survey maps are produced manually from soil scientist's field notes which show soil boundaries drawn on unrectified aerial photographs. The soil boundaries are transferred by hand to photo based maps georeferenced to the State Plane Coordinate System. Computer assisted techniques were needed to assist with this process and to provide soil maps in computer readable format.

Objective

The objective was to digitize unrectified field notes of soil mapping units, transform the data base, and create publishable quality maps meeting the requirements of the Soil Conservation Service (SCS).

This paper describes the personal computer (PC) assisted technique which has been successfully used to digitize the unrectified soil survey notes in vector form and rectify them for entry into the GIS. The data will then be compiled to SCS specifications to produce a county soil survey map.

Methodology

The data for this project were obtained from two sources, the field mapping units of the soil scientists drawn on aerial photographs, and the USGS 7-1/2 minute topographic map of the same area, located in Wythe County Va. (Crockett Quad). The aerial photographs were the source for the soil polygons and the USGS map was used as the source for all other data such as stream location and name, highway location, political boundary location and the reference

The original aerial photographs with soil mapping units represented considerable work and therefore could not be used directly. Enlarged copies were made for the working maps. Later difficulties were traced to the copying process. The firm which made the copies attempted to retain as much detail as possible in the background aerial photograph at the expense of retaining detail in the field notes. The opposite strategy would have made later processing easier. The quad was given to us on four photographs. These were combined to give two maps, a northern half and a southern half.

The polygons and nodes on the soils map were then numbered. Each polygon and each node had a unique number so that each part of the data could be identified, and the data could therefore be checked for consistency. The lines were then digitized with the beginning node, ending node, left polygon number, and right polygon number recorded with the short straight line segments making up the chain. The data was rectified and plotted for error checking and to provide the base map which was used for label entry.

At least 19 reference points for each half-quad were used in the rectification process. All of these points had to be identifiable on both the aerial photographs and on the USGS map. Usually there were enough road intersections to use, several buildings were used when roads were not well located. The State Plane coordinates of all of these reference points were obtained from the USGS map with the help of the digitizer.

Rectification was achieved by transforming the apparent coordinate from the aerial photograph to the estimated true coordinate using the Affine transformation. The coefficients for the equation were determined by regression. The regression attempted to minimize the difference between the true coordinates from the USGS map and the estimated coordinates, from the aerial photographs after the transformation. The results of the regression indicated that combining two maps to form the top and bottom halves of the quad sheet did not reduce the accuracy of the transformation, and that the points could be rectified to better than 100 ft.

The final soil map had nearly 2000 polygons and nearly 5000 nodes. The ASCII form of the data filled nearly 5 megabytes of storage on the PC. A relatively small percentage of the nodes or polygons were in error, but the number of errors was still large.

Several different programs were run to check the data for internal consistency. First, all nodes of the same number were checked to be certain that all occurrences were within 100 ft. This revealed many nodes which were mislabeled, and some data which had been poorly entered. Next, all of the chains which the data base indicated should make up a polygon were compared. This check revealed many mislabeled chains, some missing chains, and some chains which had been digitized more than once. Software, which ran on a PC, graphically displayed either all chains with a common node or all chains with a common polygon. These two programs, run concurrently on separate PCs, would often provide all the information needed to decide what was necessary to correct errors.

The stream, highway, and political boundary data were digitized directly from the USGS map, a simple task compared to entering the soil data. The guidelines for preparation of the final maps required that intermittent streams be represented differently than perennial streams, and that highways be represented in several categories. Each of these sets of lines were entered into the data base with an attribute which allowed proper representation later.

The final maps require labels for soil types, stream and highway names, and names of other things such as towns. The locations of the labels were digitized either directly from the USGS map or from a plot of the rectified soil polygons. Our PC software is not able to create these labels to the required specifications at this time. We expect to be able to add this feature later.

Finally, each of these separate data sets was entered into AutoCAD for editing. The specifications for the final map have many requirements about where stream lines can begin and where highway marks can be. In addition, the north and south halves of the map joined well, but not imperceptibly. All editing of this kind is being done using AutoCAD. The final maps will also be drawn from AutoCAD.

Results to Date

The data has been entered into PCs from all data sources and the soil polygon data has been rectified. The rectified data fits the USGS maps to within than 100 ft (0.05 inches on the final map at 1:24,000 scale). The soil polygons and nodes have been checked for correct topology. The final two steps, combining all layers of the map in AutoCAD and plotting the final map, have not yet been completed. Fairly sizable portions of the data has been transferred to AutoCAD, and no major problems are expected. However, the data base is large, and could present some additional problems.

Research Implications

These techniques allow data from sources of nonrectified data to be "rubber sheeted" by computer techniques and the creation of a rectified map. All of the computational work was done on PCs.

The vast quantities of data generated in computerizing these maps require extensive storage capacity, at least for a PC, and efficient routines for data manipulation.

The major problems encountered have been: insufficient quality of the map copies and the massive quantities of data in the data base. Map copies can be obtained of sufficient quality, the time to insist on quality is before any other work has been done. The mere quantity of data has required considerable software development, beyond what we first planned.

The Potential for Expert Systems Applications in Water Resources

Conrad D. Heatwole

Problem Statement

Rapid advances in the development of expert systems technology in the past six years have resulted in a computer-based tool that has many potential applications in addressing water resource problems. Expert systems are categorized as knowledge-based systems and have developed out of artificial intelligence (AI) research. There are many misconceptions about expert systems, in part a result of the association with AI. This brief paper will attempt to reduce this mystery by describing what expert systems are and do and by discussing why and when their use may be appropriate. Waterman (1986) provides an excellent introduction to the subject of expert systems, as do other sources (Hayes-Roth et al. 1983; Myers 1986; Sell 1985).

An expert system is a computer program that contains the knowledge and models the decision-making process of an expert in a narrow, well-defined subject area (domain). The purpose of an expert system is to represent the rules-of-thumb and judgmental knowledge (heuristics) an expert uses (often subconsciously) to solve problems. The associated knowledge and decision process cannot be readily represented using the algorithmic context of most programming languages. AI and expert systems rely primarily on symbolic processing which focuses on manipulating and matching symbols (words, phrases) in contrast to numerical computation. The most important part of an expert system is its knowledge-base, which includes facts, relationships between facts, and problem solving methods that relate to the domain of interest. Other important characteristics of expert systems are that they are able to explain the line of reasoning used in reaching a conclusion, are structured so that new knowledge can be added easily, and have the capability of dealing with uncertain and missing information.

Using an expert system has several advantages over relying on a human expert. Expertise in an expert system is permanent, easy to transfer, easy to document, consistent, and less expensive. Disadvantages are that coded expertise is not creative, is not adaptive, is limited to a narrow focus, and has little or no common sense.

Identifying a Suitable Problem

Expert systems are applicable in any discipline. Types of activities which can be addressed include planning, design, diagnosis and treatment, control, interpretation, and instruction. The nature of the problem determines whether or not the use of an expert system is appropriate. To be appropriate for an expert system, a problem must first require an expert. This implies that a heuristic (rule-of-thumb, judgmental) rather than an algorithmic approach is used in solving the problem. Also, the problem must not be too simple (not a trivial problem, but one that requires expertise) or too complex (the domain must be clearly identifiable). If the task takes more than several hours to complete, or if the expert cannot teach the job to a novice because on-the-job experience is required to develop expertise, then the problem is likely too difficult to be captured in an expert system. The task should require cognitive rather than physical skills and should not rely on significant amounts of common sense. Experts must be available and must be able to articulate their knowledge and problem solving methods.

Developing an expert system can be justified when it has a high payoff, when human expertise is being lost, or when human expertise is scarce. An expert system can be used to make expertise available in many locations at the same time. Expert systems can also serve in hostile environments where it would be costly or impossible for human experts to function.

Tools and Techniques

Two types of tools are available for building expert systems: languages and shells. While any computer language could theoretically be used to develop an expert system, languages oriented to processing symbols rather than numbers are desirable. There are two primary languages used in expert systems and artificial intelligence work, LISP and Prolog, although many "dialects" of these two exist.

An expert system shell is, in essence, a higher level language. It provides a predefined structure for the knowledge base and contains many of the components of an expert system (inference engine, explanation facilities) that would have to be developed if using a language. Other features such as a knowledge-base editor, links to external databases, and a structured user interface are generally provided. Because of these features, a shell makes the development process much faster and easier and is recommended for the beginner. The disadvantage of shells is that the structure and knowledge representation schemes are built-in, thus offering less flexibility to the expert-system developer. Commercial interest in developing expert system shells is very high, and shells are available for the range of computers, from micros to mainframes. Brief descriptions of some of the available shells have been compiled (Whittaker et al. 1986; Waterman 1986). Selecting the proper tool is very important and guidance for this task is available (Hayes-Roth et al. 1983; Waterman 1986).

The process of developing an expert system has also been addressed by numerous writers. The similarities between the project stages of expert systems development and traditional data processing projects are noted by Keller (1987), who describes in detail a project cycle for developing an expert system. Aspects of the development process frequently identified are: characterizing the problem, selecting the proper tool(s), eliciting the help of a domain expert, extracting and encoding the knowledge, and testing the expert system. Two areas that have eluded precise categorization by AI researchers are knowledge acquisition and knowledge representation techniques. Accomplishing these tasks appears to be as much art as science, but again, helpful direction is available (Hayes-Roth et al. 1983; Sell 1985).

Applications in Water Resources

No attempt will be made to itemize the potential areas where expert systems technology could be used to address water-resource problems. The identification criteria discussed above should help anyone with an association with water resource issues identify potential applications within their areas of interest.

Two major areas where expert systems applications are being made in the Agricultural Engineering Department at Virginia Tech are in integrating expert system techniques with simulation models and using expert systems with geographic information systems (GISs). Detailed simulation models are used extensively in addressing water resource problems. Artificial intelligence techniques are expected to have a significant impact on the next generation of simulation tools (Jones 1985; Kerckhoffs and Vansteenkiste 1986). O'Keefe (1986) identifies three potentially fruitful applications of expert systems in simulation: (1) new simulation tools developed by combining simulation and knowledge-based methods, (2) advice-giving systems for inexperienced simulators, and (3) intelligent front ends for existing simulation packages. Some research is proceeding in this area but primarily with models from other disciplines. One example of a system in water resources exists, an aid for estimating hydrology parameters for the HSPF model (Reboh et al. 1982). One advantage of integrating expert systems with models is that wider use of the models may be possible (by providing a simpler user interface) while maintaining the integrity of the model (by incorporating the knowledge of model experts).

It is expected that expert systems will be widely used in the water resources area in the future. As pressures on water resources rise, well-guided management and policy decisions become even more important. Expert systems (and knowledge-based systems in general) have the potential of making expertise available on a much wider basis.

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A Water Quality Model for an Urbanized Drainage Basin

C.Y. Kuo, G.V. Loganathan, S.P. Shrestha, and K.J. Ying
(Presented by C.Y. Kuo)

Problem Statement

The total amount of pollutants contributed to receiving waters by storm-sewer systems has been estimated to be of the same order of magnitude as that released by secondary sewage treatment facilities (Field, 1972). This is a major urban-runoff problem faced by many urbanized areas.

Impact of urbanization on the quantity and quality of runoff from a given area is a complex problem. Quantity impacts arise from changes in impervious areas and improvements in drainage system designed for rapid removal of stormwater to avoid its interference with various land use activities. Quality impacts are due to the increased runoff rate, which enhances the potential of contaminant delivery to receiving water bodies. In addition, a wide range of pollutants, being washed off from lawns, streets, and other paved areas, is a major source of pollutant contribution. The nonpoint pollution problem from urban runoff can affect streams, freshwater impoundments, and coastal waters. This concern has brought in efforts to develop best management practices (BMPs) as pollution control mechanisms. But the implementation of BMPs for stormwater management is complex in developed areas because of space and location limitations. Planning and design tools are required to assist planners and engineers.

Objective

The principal objective of this paper is to present a methodology to compute the hydrographs and pollutographs at pipe junctions of the existing storm-sewer network and at the drainage basin outlet as a whole in an urbanized area. This in turn will aid in sizing and locating various BMP alternatives to minimize adverse impacts of flooding and water quality degradation.

Methodology

The model uses the rainfall data and basin topographic information as inputs to generate the paved and grassed area hydrographs. The watershed is divided into a number of sub-basins based on the topography of the basin and the existing storm-sewer network. For each sub-basin, contributing areas — paved area, grassed area, and indirectly connected paved areas — are supplied as input data along with the soil type and soil antecedent moisture condition (AMC). Pipeline length and slope are also provided for each reach to facilitate the routing of hydrographs through each reach.

The Illinois Urban Drainage Area Simulator (ILLUDAS) (Terstriep and Stall 1974) which is a single storm event model has been modified for this study. Modifications have been made to add the features of sequential storm events simulation and water quality modeling. Hydrographs and pollutographs are computed at all storm-sewer pipe junctions and routed downstream until the watershed outlet is reached. The second-degree B-Spline technique is used to interpolate the ordinates of the routed hydrographs and the pollutographs. The basinwide composite hydrographs and pollutographs are calculated at the basin outlet and their maximum values can be compared with the design requirements.

Results to Date

The model has been applied to the Upper Holmes Run Watershed to obtain hydrographs and pollutographs for a sequence of storms composed of three rainfall events lasting 6, 16 and 18 h with inter-event times of 45 and 187 h respectively. Hyetographs, hydrographs and pollutographs at the basin outlet are shown in Figures 1-5.

Research Implications

The model can be used as a tool in planning and design of urban BMPs, which include detention basins, porous pavements and infiltration facilities. Sub-basin and basinwide hydrographs and pollutographs calculated by the model reflect the presence of BMPs. Any surcharge at junction due to inadequate drainage system or excessive runoff due to new developments in the basin can be handled through the design of BMPs in terms of type, location, and size. Thus, the urban stormwater management requirements of water quality and peak discharge can be satisfied.

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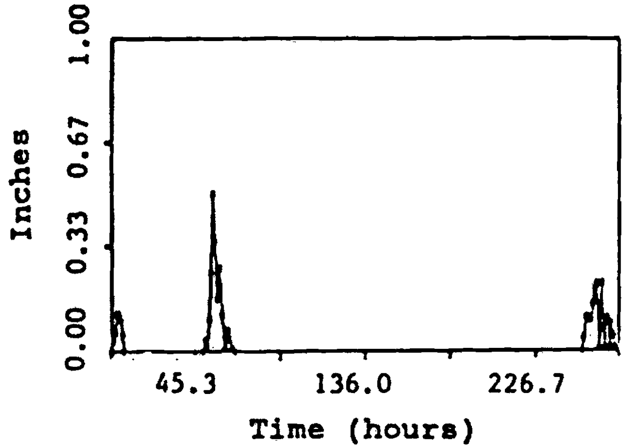

Fig. 1. Hyetograph

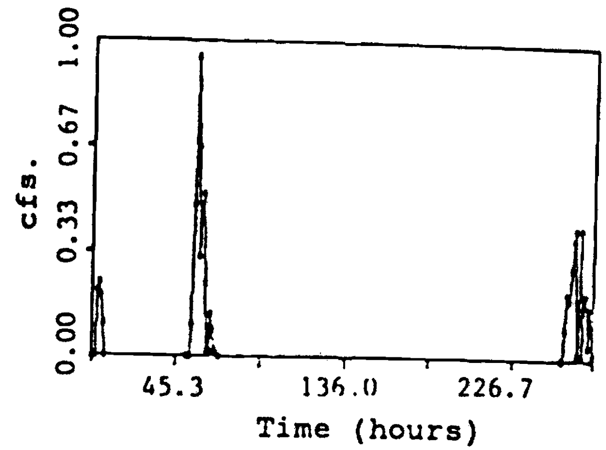

Fig. 2. Hydrograph

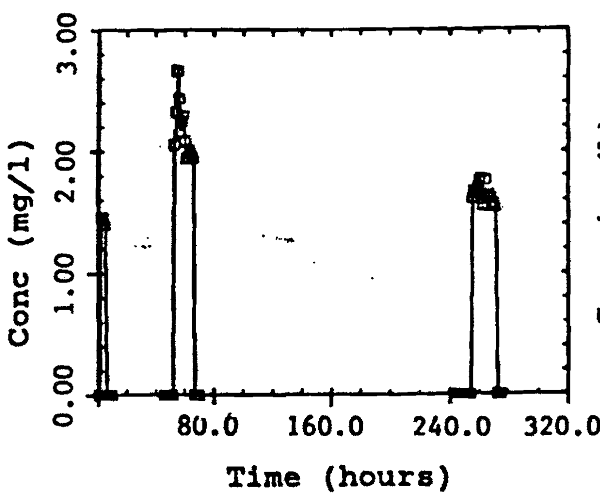

Fig. 3. Pollutograph
(Suspended Solids)

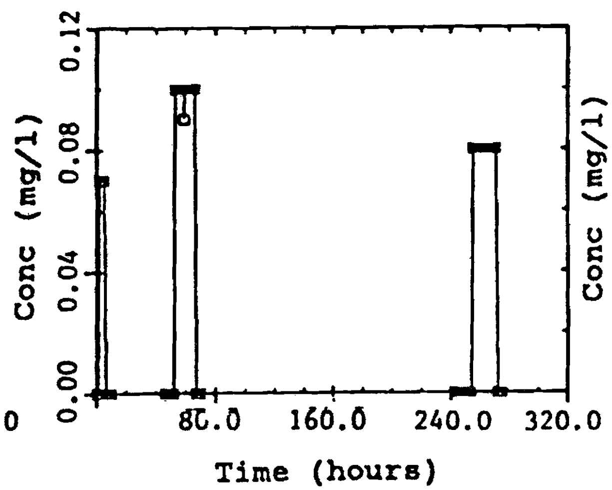

Fig. 4. Pollutograph
(Settleable Soilds)

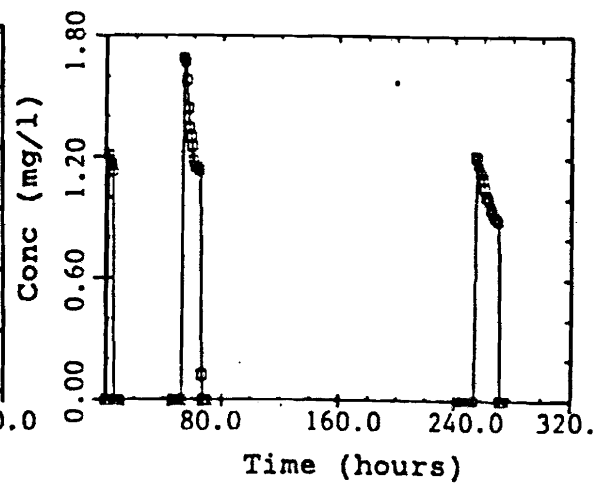

Fig. 5. Pollutograph
(BOD)

Virginia Acid Precipitation Network

Arthur L. Buikema, Jr. and Boris I. Chevone
(Presented by Arthur L. Buikema, Jr.)

Problem Statement

Virginia is in a region of the United States that has acidic precipitation. Much of this precipitation is believed to originate beyond the borders of Virginia. Concern exists that acid precipitation will affect the biological, geological, and material resources of the Commonwealth.

Objective

To evaluate the acid precipitation problem in Virginia, the Virginia Acid Precipitation Network (VAPN) was begun in 1982. The objectives of VAPN are three-fold: (1) to establish a valid data base for precipitation chemistry within the Commonwealth; (2) to fill a void in the Commonwealth not covered by other precipitation networks; and (3) to obtain data in a timely fashion. VAPN is a cooperative effort among state agencies, industries and academic institutions.

Methodology

The network comprises eight sites; in addition, a mobile unit can be co-located at a site for quality assurance or moved to other regions of the state.

Precipitation samples are collected over a seven-day period. At the collection site, samples are analyzed for pH and conductivity. Samples are then sent to the analytical laboratory, currently at Virginia Tech, for measurements of pH, conductivity, primary cations and anions, and trace metals. Chemical analyses are conducted according to established methodologies. Quality assurance protocols include the use of internal standards, standards from the National Bureau of Standards, quarterly VAPN standards prepared by an analytical chemist, and analysis of USEPA audit solutions.

Results to Date

Rain in Virginia is acidic. The mean volume-weighted pH for the VAPN during the period from 1982 to 1984 was 4.28 units. The dominant anions contributing to this acidity were sulfates and nitrates; the ratio of sulfates to nitrates was approximately 2:1. The dominant cations were hydrogen and ammonium. Sulfate, nitrate, and ammonium concentrations were positively correlated with hydrogen-ion concentration.

The average annual pH of precipitation in Virginia was generally consistent within 0.15 pH units throughout the Virginia Acid Precipitation Network over the three years of study and with data reported by other monitoring networks in this area of the country. Further, the pH of precipitation at Hampton, Virginia, determined in an independent study, was consistent over a seven-year period from 1977 to 1984 when compared to VAPN data.

The pH of precipitation varied seasonally and was lowest during the summer months. This decrease in pH was attributed to increased sulfate and nitrates during the summer coupled with poorer dispersion conditions. Ammonium increased as pH decreased.

The lowest volume-weighted pH values were recorded for Fairfax; this is probably attributed to a combination of urban influences, e.g., transportation, and proximity to regions of the Northeastern United States which exhibit low pH values. Nitrate values were consistently higher at Fairfax and these increased concentrations probably contributed to the lower pH values.

A maritime influence was noted at the coastal sites of Hampton, and to a lesser extent, West Point. Sodium and chloride concentrations were higher at these sites.

Aluminum and nickel were the most predominate of nine trace metals detected in precipitation samples. No unusually high concentrations of trace metals were noted.

VAPN continues to fill a void in Virginia that the other national networks do not cover. VAPN is unique because the greater density of the network allows a comparison of precipitation chemistry within the Commonwealth and the potential to distinguish local effects on precipitation chemistry. Lastly, VAPN provides data in a more timely fashion than do the national networks.

Research Implications

This study indicates that precipitation in Virginia is acidic and the potential exists for an impact on the Commonwealth's resources. Current research is being conducted to identify those resources at risk.

Evaluating Potential Expansion of Large-Scale Riparian Irrigation with Weather and Price Uncertainty

Darrell J. Bosch, Daniel B. Taylor, and B. Blake Ross
(Presented by Darrell J. Bosch)

Problem Statement

Irrigation has increased steadily in Virginia. As of 1982, irrigation equipment on farms was capable of irrigating an estimated 80,000 acres (Ross et al. 1982). Significant growth in irrigation from riparian sources has occurred in the Pamunkey River basin and certain other areas. Potential growth in irrigation from streams and rivers is important because these water bodies also support other biological, esthetic, and economic needs.

Taylor et al. (1985) and Vellidis (1985) developed a framework for evaluating the potential for irrigation expansion in a river basin when prices and the yield response to irrigation are known. However, output prices and yield responses to irrigation may vary greatly over the lifetime of the irrigation investment. In addition, an irrigation investment may have tax benefits not included in such a static approach. Also, the static approach does not consider the effects of water restrictions on investment feasibility. What is needed is a method to determine feasibility that compares the known investment costs with the uncertain returns. The method should be capable of evaluating a large number of systems efficiently in order to quantify potential irrigation expansion over a large area.

Objectives

The objectives of this research are:

1. To develop a framework for evaluating irrigation investments when output prices and yield responses are uncertain.

2. To apply the methods to the Pamunkey River basin in order to determine the potential for irrigation expansion.

Methodology

Irrigation feasibility is determined by physical, legal, and economic considerations. Physically, the land must be capable of being adequately drained, not be too steeply sloped, not be in use for permanent development, and must have access to adequate water supplies. Vellidis (1985) categorized individual land cells in the study area according to: (1) physical suitability for irrigation, (2) need for drainage, (3) vertical and horizontal distance from the water source, and (4) the soil's plant-available water-holding capacity (AWC). In this analysis, an additional category for weather patterns is added to the database. Cells are categorized according to which of two weather stations in the basin (Ashland and Walkerton) they are closer to. Historical records for 1973-1984 from these weather stations are used to provide data on random weather variability.

Only land that is part of a continuous legal tract bordering the water source has riparian water rights in Virginia (Cox et al. 1981). The legal riparian status of land cells is not considered here, but should be part of a more refined analysis.

A Map Analysis Package (MAP) (Tomlin 1980) is used to aggregate physically suitable cells that are adjacent to one another into large fields or clumps. The aggregation provides for possible economies of size in constructing irrigation systems and reduces the number of land tracts needing consideration. Further details on the clumping procedure are found in Vellidis (1985).

An irrigation investment is economically feasible if it has a positive net present value (NPV). Equations developed by Robertson et al. (1982) and Boggess and Amerling (1983) are used to calculate the NPV of the investment. The equations state that the NPV of the investment is equal to the present value of the after-tax net income produced by the investment over its life plus the present value of any tax benefits associated with owning a system, plus the present value of the system's salvage value, minus the initial investment cost. All costs and returns are inflated to the year in which they occur and discounted back to the present.

The system's NPV is uncertain because output prices, yield response to irrigation, and other variables are random (Boggess and Amerling 1983). A distribution of output prices is used that reflects anticipated corn price variability (Bosch et al.1987). The mean, minimum, and maximum prices of the distribution are $2.30, $1.91, and $2.90, respectively.

Variable yield response to irrigation is included through use of a crop model, CRPSM, (Hill et al. 1982) and random weather data. The model uses soil AWC, daily temperatures, rainfall, and irrigation data to determine the growth and yield of corn. The model is calibrated for Virginia growing conditions by statistically estimating parameters of the yield prediction equation using data from three Virginia experiment stations (Bosch et al. 1987). The model is used with 1973-1984 weather data and each soil AWC to generate a set of yield responses to irrigation and annual irrigation amounts.

Traveling gun and fixed and towable center pivot systems are considered for each potential site, and the system with the cheapest per acre purchase price is selected. Design models developed by Taylor et al. (1985) are used to estimate physical capacity and total investment and operating costs of each system as a function of field size, vertical distance, and horizontal distance from the stream.

The economic feasibility of each field is evaluated with a FORTRAN program, ECONFEAS. The physical characteristics of a given field are read and the irrigation system with the lowest investment cost is selected for that field. The present value of the system's cost equals the purchase cost plus the present value of annual ownership costs minus the present value of tax benefits of ownership minus the present value of salvage. An 11% discount rate is used. Input and output prices are assumed to inflate at 4% and 3% per year, respectively. The irrigator is assumed to be in a 15% tax bracket.

The after-tax benefits for each year in the system's life are calculated as follows: A yield response from irrigation and irrigation application amount are randomly selected from the 12 responses and application amounts generated by CRPSM over the 1973-1984 period for the AWC and weather station characterizing that field. An output price is selected randomly from the uniform distribution of output prices, inflated to the year of the system's life in which it occurs, and multiplied by the yield increase to get a gross return from irrigation. This return is reduced by the additional production costs of irrigation (primarily for added fertilizer and seed) as well as variable pumping costs associated with the selected irrigation application amount. Finally, taxes are subtracted from net income and the after-tax net income for the year is discounted to the present.

As the benefits of irrigation are uncertain, each system is simulated for 50 lifetimes, a present value of after-tax benefits is calculated for each lifetime, and the expected present value of after-tax benefits is determined. If the expected present value of benefits exceeds the present value of the system's cost, the expected NPV is positive and the field is economically feasible for irrigation. The procedure is repeated for each field and the total economically feasible acreage computed.

Results to Date

A total of 17,348 acres is projected to be economically feasible for irrigation using the methods described. Of this total, an estimated 3,329 acres are currently being irrigated (Vellidis 1985). About 7% of the acreage is on two-inch AWC soil and 93% is on four-inch AWC soil. Only one feasible system is more than one mile from the water source (5600 feet). The yield response to irrigation and the present value of benefits appear to be larger in the Ashland weather station area as it has more extended dry periods over the years 1973-1984. However, sites in the Ashland area tend to be further from the stream and have higher investment costs, which in many cases more than offset the higher benefits. Approximately 41% of the total potentially feasible acres is in the area covered by the Ashland weather station and 59% is in the Walkerton station area.

Further research is needed to compare the potential water demand from this expansion with variable streamflow supplies. It appears likely that streamflows will not be adequate to meet this expansion in all years.

Research Implications

The framework developed here efficiently incorporates the important variables of the irrigation investment decision. The methods can be used to project, under variable weather conditions, daily and seasonal demand for irrigation water, which can be compared with variable streamflow supplies. The effects of water shortages on irrigation feasibility can also be determined.

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Vegetative Filter Strip Effectiveness

T.A. Dillaha III, J.H. Sherrard, and D. Lee
(Presented by T.A. Dillaha III)

Problem Statement

Sediments and nutrients associated with runoff from agricultural areas were identified as primary causes of eutrophication and declining water quality in the Chesapeake Bay Program Study (USEPA, 1983). According to the EPA study, croplands were estimated to contribute between 27 and 53% of the phosphorus load and 60 to 70% of the nitrogen load in average and wet years, respectively. Cropland was also identified as the primary source of sediments. While much progress has been made towards the control of agricultural nonpoint source pollution through the use of best management practices, much work remains to reduce sediment and nutrient loadings to the Bay system. The Commonwealth of Virginia has long been a leader in the development and implementation of BMPs with a higher percentage of cropland in conservation tillage than any other state. In spite of this, however, water quality in the Chesapeake Bay and Virginia's streams, lakes and estuaries continues to decline and it is apparent that without further efforts, this trend will continue.

One BMP for removing sediment and nutrients from the surface runoff of cropland and areas of livestock activity which is receiving considerable interest in Virginia, is vegetative filter strips, VFS. Although VFS have not traditionally been part of state and federal agricultural cost-sharing programs, they are now being promoted with funds from Virginia's Chesapeake Bay Agricultural BMP Cost-Sharing Program.

Vegetative filter strips are bands of planted or indigenous vegetation used to remove sediment and nutrients from surface runoff. They reduce sediments and nutrients in runoff by filtering large solid particles from the runoff (hence the name filter strips) and by reducing the velocity of surface runoff which decreases sediment transport capacity and induces sediment deposition.

Objective

The major goal of this research was to evaluate the circumstances under which VFS are effective in reducing sediment and nutrient losses from cropland and areas of confined livestock activity in Virginia. To achieve the above goal, the following specific objectives were undertaken:

1. To conduct field plot experiments designed to investigate sediment, N, and P transport as influenced by type of runoff (cropland or feedlot), runoff rates, and filter strip length, slope, and hydraulic properties. Of special interest was the effect of concentrated flow on VFS performance as opposed to shallow uniform flow.

2. To conduct a survey of existing VSF located in the Commonwealth of Virginia and to qualitatively evaluate VFS performance in field situations.

Methodology

Simulated rainfall was applied to a series of 5.5 by 18.3 m bare soil plots with 4.6 and 9.1 m VFS located at the lower end of the plots as shown in Figure 1. The plots were used to evaluate the effectiveness of VFS for controlling sediment and nutrient losses from both feedlots and cropland. For the feedlot simulations, fresh dairy manure was applied to the bare portions of the plots at rates of 7500 and 15,000 kg/ha and compacted with rollers to simulate feedlot conditions. For the cropland simulations, commercial fertilizer, 112 kg/ha of granular P_2O_5 and K_2O and 222 kg-N/ha of nonpressurized N solution were applied to bare tilled plots. Water samples were collected from H-flumes at the base of each plot to evaluate the effectiveness of the VFS in removing sediment, N, and P from the simulated feedlot or cropland runoff. One set of plots was constructed with a cross slope so that flow through the filters would be deeper or concentrated rather than shallow and uniform.

Vegetative filter strips on 33 farms located in the Commonwealth of Virginia were visited and observed over a 13-month period to evaluate their long-term effectiveness for water quality improvement. Operational problems observed during the site visits were documented and design or maintenance procedures to alleviate the problems were evaluated.

Results

The 9.1 and 4.6 m VFS with shallow uniform flow removed 87 and 75% of the incoming suspended solids, 69 and 57% of the incoming P, and 72 and 61% of the incoming N, respectively. Soluble nutrients in the filter effluent were sometimes greater than the incoming soluble nutrient load, presumably due to lower removal efficiencies for soluble nutrients and the release of nutrients previously trapped in the filters. Vegetative filters with concentrated flow were much less effective than the shallow uniform flow plots, with percent reductions in sediment and nutrient loadings averaging 23 to 37% less for sediment, 46 to 53% less for N, and 43 to 46% less for P. The cropland filters were much more effective than the feedlot filters, but this increased effectiveness was due to reduced inflow of sediment, nutrients, and runoff into the filters because of higher infiltration rates in the cropland source areas.

Thirty-six percent of the in field VFS observed were judged to be totally ineffective, no longer in existence or simply extensions of pastures, although all were or had been part of the state cost-share program. Most of the sites visited had topographic limitations which severely limited VFS performance. Accumulation of surface runoff in natural drainageways within fields before it reached the VFS was the most common and critical problem. Runoff from the drainageways crossed the VFS in a few narrow areas, totally inundating the filters and rendering them ineffective for sediment and nutrient reduction. This situation is difficult to control and VFS are probably not appropriate for fields with extensive internal drainageways unless the VFS extend up into the fields and parallel the drainageways forming wide grassed waterways.

Vegetative filter strips were judged to be beneficial even when they could not filter sediment and nutrients from runoff because they provided localized erosion protection in critical areas along streambanks. They did not act as filters, however, and should be referred to as vegetative buffer strips or critical area plantings under these circumstances.

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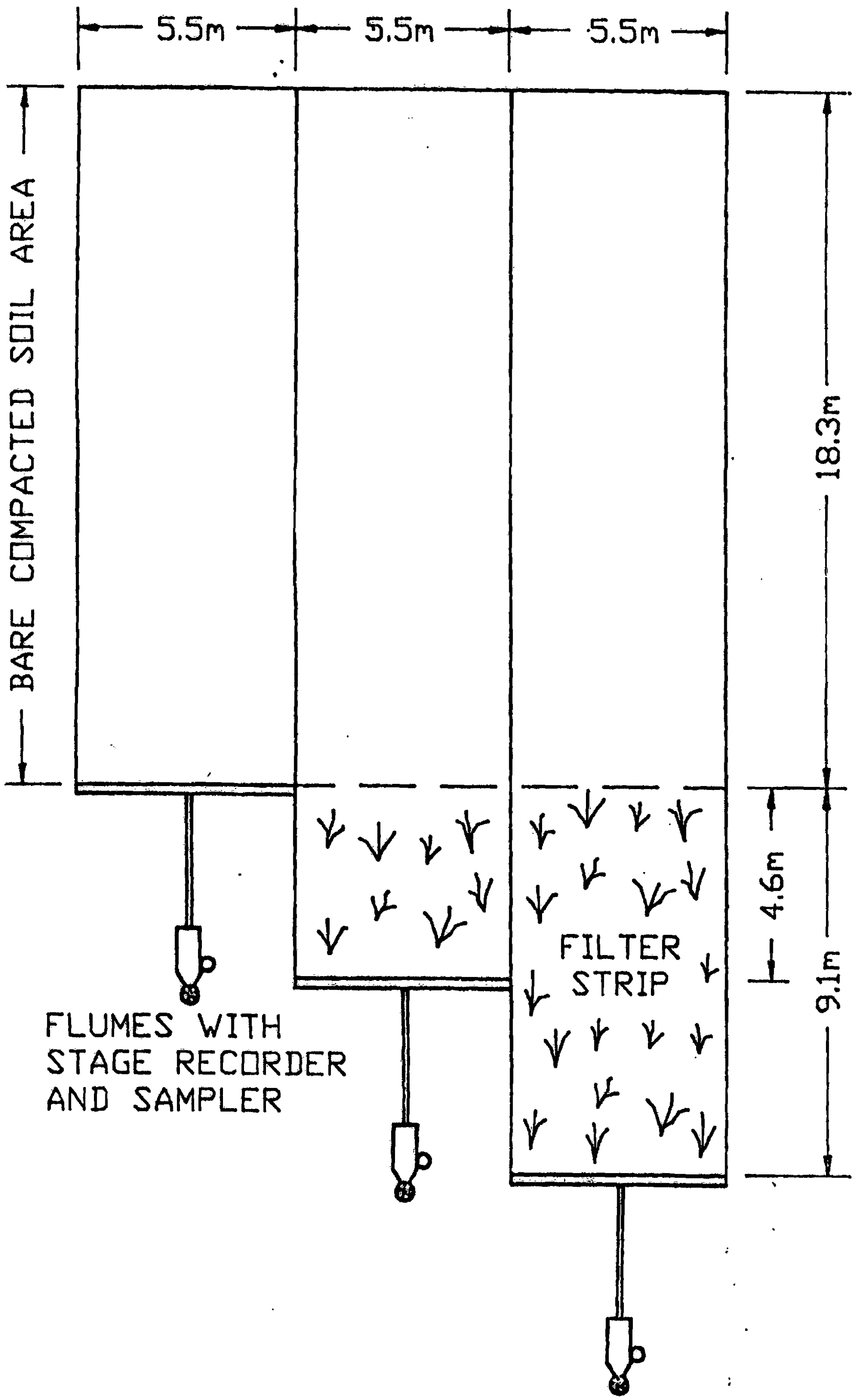

Fig. 1. Schematic diagram of experimental field plots.

Nitrogen Leaching Losses for Corn Produced in the Chesapeake Bay Area as Influenced by Selected BMPs

G. Menelik, R.B. Reneau, Jr., D.C. Martens,
T.W. Simpson, and G.W. Hawkins
(Presented by G. Menelik)

Critical State Water Problem

The pronounced effect of nitrogen (N) on crop yield has led to recommendations for increased application rates. Both organic and inorganic N sources, including sewage sludge, are used to satisfy this demand. An immediate concern is, however, the potential for degradation of surface and subsurface water quality (Gast et al. 1978; Broadbent and Carlton 1978) and the subsequent health hazards to both humans and animals (Lindemann and Cardenas 1984). Nitrate (NO_3^-) is the most abundant inorganic N form in typical crop systems. It is highly mobile and subject to leaching with percolating water through the root zone (McMahon and Thomas 1976; Cooper et al. 1984; Haghiri et al. 1978).

The Chesapeake Bay studies indicate that nonpoint sources of pollution contribute 67% of the N that enter the bay each year. Crop land is the largest nonpoint contributor. Currently, Virginia farmers apply approximately 90,000 Mg (100,000 tons) of N annually as inorganic fertilizer and 4,500 Mg (4900 tons) of N from sewage sludge valued, respectively, at approximately $50 and $2.5 million for crop production. These facts clearly indicate the need for better mechanisms to accurately predict loss of applied N from soil-crop systems, facilitate efficient N utilization by the crop, and reduce N contamination of ground and surface waters. The impact of N application to crop land with respect to crop yield and quality and ground- and surface-water degradation needs to be considered in conjunction with best management practices (BMP).

Objectives

This research will entail the development of procedures for predicting the potential N leaching losses under both no-till and conventional tillage systems for corn (*Zea mays* L.) production in two major crop rotations, i.e., continuous corn and corn-wheat (*Triticum aestivum* L.)-soybean [*Glycine max* (L.) Merr.] rotations. In addition, the influence of rate (four N levels), source (inorganic versus sewage sludge), and timing (preplanting versus split) of N application on N leaching are being studied on two representative agricultural soils.

The specific objectives of this research are to determine comparative N leaching losses from the two crop rotations where corn is grown by conventional and no-till management systems, to compare N leaching losses — as influenced by rate of inorganic N applications, and to evaluate N leaching losses for preplant N application, split N application, and N application in the form of sewage sludge.

Methodology

To accomplish the above objectives, two field sites were located for a three-year study on agronomically important and representative soils that are used for corn production in either the corn-wheat-soybean or the continuous corn rotations in the Chesapeake Bay drainage basin. The corn-wheat-soybean rotation is being conducted on a Suffolk sandy loam (coarse-loamy, siliceous, thermic Typic Hapludult) with a 0 to 2% slope located in the Coastal Plain region in the Nomini Creek drainage basin of Westmoreland County, Virginia. The soil is deep, well drained (water table at 12 m), and situated on a broad ridge top at an elevation of about 30 m. The continuous corn rotation is being conducted on a Groseclose silt loam soil (clayey, mixed, mesic Typic Hapludult) with a 2 to 7% slope located in the Ridge and Valley region on the Agricultural Engineering farm at Blacksburg, Virginia. The soil is well drained, gently sloping, and occurs on ridge tops. The depth of the bedrock is greater than 2 m.

The experimental treatments were arranged in a randomized complete block design with tillage management (no-till and conventional-till) striped across treatments. Conventional tillage consisted of plowing and disking to establish a seed-bed. The treatments consist of the following: a check (0 N), three rates of inorganic N fertilizer (75, 150, and 225 kg N ha^{-1} applied at planting as a 30% N [Urea-ammonium-nitrate (UAN)] solution, one split application of inorganic N (UAN solution) with 60 kg N ha^{-1} applied at planting and 90 kg N ha^{-1} applied six weeks later, and two rates of anaerobically digested sewage sludge (one polymer and another lime conditioned) designed to supply 150 kg of plant available N ha^{-1} The lime conditioned sewage sludge treatment was used on the Suffolk soil, but not on the Groseclose soil. The lime conditioned sludge came from the Atlantic Treatment Plant in Virginia Beach and the polymer conditioned sludge from the James River Plant in Hampton Roads. All treatments were replicated four times. "Pioneer 3192" was overplanted by 10% and thinned to 61,700 plants per ha.

Suction lysimeters, tensiometers, and neutron moisture meter access tubes were installed for the purpose of collecting soil solution samples and monitoring the energy status of soil water and water content. These are necessary to the process of assessing soil water dynamics.

Results to Date

Corn grain and stover yields were determined for all plots for the two field experiments at plant maturity in the fall of 1986. No-till cultivation increased grain yield for both the Suffolk and Groseclose soils. There was approximately a 1000 kg ha^{-1} increase in grain yield where no-till cultivation was employed. This was an increase in grain yield of 31 and 17%, respectively, for the Suffolk and Groseclose soils. Similar results also were obtained by Anderson (1986). Stover yields were increased by conventional tillage on the Suffolk sandy loam and by no-till on the Groseclose silt loam. Stover yield increases were 13.9 and 19.8%, respectively, for the Suffolk and Groseclose soils.

Application of N in either the inorganic or organic form had much less effect on grain and stover yields than did the tillage variable in 1986. Nitrogen treatment had no effect on grain yields from the Groseclose soil for either conventional or no-till systems or from the Suffolk soil for conventional tillage. Grain yields, however, were increased where no-till management and split application of N was employed compared with the 0 and 75 kg N ha^{-1} treatments. Stover yields were increased when either polymer or lime conditioned sewage sludge was applied to the Suffolk soil and to the Groseclose soil where conventional tillage was employed. There were no differences in stover yields with no-till for the Groseclose soil. However, the highest yields were measured for the no-till treatment on the Groseclose soil.

Grain and stover yield responses were as expected under conditions of extreme moisture stress (Triplett et al. 1968; Legg et al. 1979). Grain yields were influenced more by moisture conserving tillage practices than by N treatments. Stover yields increased with no-till cultivation for the Groseclose soil but was reversed for the Suffolk soil. The increased stover yield with conventional tillage for the Suffolk soil apparently is a compensatory response to reduced grain yields with more carbohydrates being used for stover production. With respect to N, treatments that tended to maintain a higher N solution concentration in the upper part of the soil for longer periods of time tended to increase grain and stover yields. However, response to N was minimal under the severe moisture stress conditions encountered during the 1986 corn growing season.

Nitrogen leaching losses will be evaluated by collecting soil samples at 10 to 15 cm intervals up to 2 m depth, both prior to planting and immediately following corn harvest. Nitrogen leaching will be studied using a similar techniques during wheat and soybean production in the corn-wheat-soybean rotation.

Research Implications

Studies by Gast et al. (1978), Cooper et al. (1984), King and Morris (1974), and McMahon and Thomas (1976) show that NO_3^- may be leached well below the rooting zone of corn. This NO_3^- is most probably unrecoverable and may result in ground water pollution. Proper combination of BMP, N source, and N application rate should maximize crop yield and minimize surface and subsurface water quality degradation. Though it is difficult to assess the exact economic benefits from the improved ground and surface water quality, this research could result in a saving of $5.7 million for only a 10% reduction in the utilization of N from inorganic fertilizers and sewage sludge in Virginia, including the Chesapeake Bay area.

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City of Newport News Reservoir Protection

Cynthia S. Taylor and David L. Morris II
(Presented by Cynthia S. Taylor)

Problem Statement

Since 1980, the City of Newport News has seen its urban population grow from 144,903 to 157,591 (1985 est.). As the primary provider of drinking water to the Virginia Peninsula, protection of the watershed area within Newport News's boundaries has become a primary concern as the population growth expands into areas that were once pristine environments. A concurrent study was undertaken by the Newport News Planning Department and Department of Public Utilities to identify the watershed areas within the city and to develop a strategy for protecting those areas which were vital for proper water quality management. The result of this 2-year study was a reservoir protection ordinance which would be incorporated into the Newport News City Code.

Objective

Newport News is in the unique position of owning some 7,830 acres surrounding its Lee Hall and Harwood's Mill terminal reservoirs. Of this acreage, 2,464 acres lie within the city limits of Newport News. Protection of the city-owned lands from development pressures was insured on March 25, 1986, when the Newport News City Council adopted an ordinance prohibiting development on all city-owned watershed property. Unfortunately, this protection covered about 50% of the total watershed of Lee Hall Reservoir, 45% of the Harwood's Mill watershed and less than 10% of the Skiff's Creek watershed. Complicating matters further, 50% of each of these reservoir watersheds lie in adjacent subdivisions. It was realized early on that if there was any hope of protecting the watersheds lying in other jurisdictions, protective measures must first be implemented in Newport News. Furthermore, even the Lee Hall reservoir has critical outfall sites which are not under city control. It became apparent that there was a need to protect these sites from nonpoint source pollution while still allowing development under certain criteria. What the city lacked was a process to review proposed development and require provisions for management of stormwater runoff.

While it was known that unwanted nonpoint source pollution is a side effect of urbanization, there was little staff expertise in dealing with the problem. In 1985, the city hired the consulting firm of Camp, Dresser and McKee (CDM) to help identify watershed characteristics for each of the reservoir sites and to compare existing nonpoint pollution problems with those that could be anticipated with future development. Based on their research, CDM evaluated annual nonpoint pollution loadings for each of the reservoir sites. Since the Lee Hall and Harwood's Mill reservoirs are terminal water supply reservoirs, any contamination at these locations is cause for concern. Phosphorus, nitrogen, lead and zinc were monitored to establish trend data and isolate existing water quality problems. Projections were made about future water quality assuming no best management practices (BMP's) were in place and the land developed according to uses identified in the land use plan.

In CDM's Phase 2 report, development was expected to increase from 13 to 34% in the Lee Hall watershed. Harwood's Mill watershed would see urban development increase from 16 to about 47%. This meant that the city could anticipate impervious surface coverage increasing from 10 to 20% for the former area and from 13 to 31% for the latter. With this new information, the city had to determine the best means available for dealing with the increasing runoff.

Methodology

The results of the CDM study alerted the city that protective measures would have to be initiated quickly. The Planning Department and the Department of Public Utilities along with input from the city's Engineering staff began to develop an ordinance that would address stormwater runoff control. A review of existing ordinances adopted by other localities (i.e. Fairfax County, Albermarle County/ Charlottesville) was helpful in giving us a framework for our standards. However, our own locality with its unique characteristics required us to prepare an ordinance which could be effective with our topography and could also be administered by city staff without undue delay to the developer. Newport News currently has a site plan review process so that body could naturally assume the primary responsibility for determining when runoff control permits should be required. Although structural BMP's are the preferred method for controlling surface water runoff, it is recognized that other types of BMP's would also have to be be considered especially for smaller sites. Therefore, all standards for acceptable BMP's would be placed in the city's *Design Criteria Manual* which is currently produced by the Department of Engineering for such things as street construction, sewer design, etc.

Certain uses were of a particular concern in the watershed areas, i.e. septic tank failures and activities involving petroleum, chemical or asphalt products. It was decided that the existence of these activities should not be encouraged beyond what presently existed and such activities are prohibited under the terms of the ordinance.

A vegetative buffer zone was also considered to be a integral part of any watershed protection legislation. Reservoir edges as well as perennial streams were a primary area for protection as well as intermittent streams but protection was needed in varying degrees. The Reservoir Protection Ordinance requires 200-foot horizontal buffer from the center of any perennial stream or from the edge of any reservoir. A 100-foot horizontal buffer is required from the center of any intermittent stream. Exceptions can be made to this buffer requirement but only after a hardship is demonstrated to the runoff control official.

Waiver options are placed in two categories:

1. Any buffer could be reduced down to a minimum of 50 ft provided acceptable BMP's are in place. This waiver applies to all land uses.

2. For detached single family development on 1 acre minimum lots, the buffer can be further reduced to 25 ft. The reason for allowing these waivers is to recognize the uniqueness of each parcel. When the terrain is fairly flat and runoff control requirements are minimal, a degree of flexibility is necessary in these situations. Conversely, where critical slops are evident, no reduction should be permitted when the velocity of runoff would not allow natural filtration.

Approximately 600 parcels are affected by this ordinance. Parcel size ranges from less than a half acre to several hundred acres. A portion of the Lee Hall watershed is so heavily developed that the city along with a developer are planning to construct a diversion drainage line around the Lee Hall reservoir thereby eliminating 200: acres from the overlay district. Diversion projects are not a panacea for all quality control problems. Therefore, the Reservoir Protection Ordinance provides an acceptable means of reviewing the impact of various development proposals while accommodating growth.

Results to Date

In August 1985, Newport News City Council approved a rezoning application for 272.7 acres for land that drained into the Lee Hall reservoir and had been zoned for agricultural use. The rezoning created new residential and commercial zoning districts with the net residential density of 11 units per acre. From the time this application was proposed and until it was approved, over one year of study and evaluation of the impact on the reservoir system was done. This rezoning resulted in a proffer from the developer that wetponds designed to city specifications would be constructed to prevent degradation of the existing water quality. The year-long process taught us that a faster more effective method was necessary.

By November 1986, a 95-acre planned residential development was proposed for property adjoining Skiff's Creek Reservoir. Without the Reservoir Protection Ordinance being in place, there was little the city staff could do to enforce watershed protection devices. This particular parcel had slopes in excess of 20% with the city only owning 50 horizontal feet from the 15-ft contour along the reservoir edge. In this situation, retention of a vegetative buffer area was critical and one in which we had limited control.

Research Implications

The technology of watershed management is constantly changing. We expect our standards and guidelines to change as newer techniques prove reliable.

The impact of such an ordinance on the property owner is currently unknown since most of the land is undeveloped. There have been comments that such an ordinance is a "taking" and, therefore, compensation is required. The question of compensation is a complex on requiring an examination of a number of factors: does the property owner have reasonable use of the property; what relief is available to property owners who are significantly affected by the buffer; and is the City in favor of purchasing selected sites? In the reservoir protection area, approximately 15% of the total parcels are affected by the buffer requirement. Of this percentage approximately one third have 50% of more of their property within the buffer area. It is our opinion that property owners who feel that a "taking" has been affected must seek all legislation relief mechanisms before they have cause for legal redress. The Reservoir Protection Ordinance provides the best means acceptable for managing the watershed areas of the city.

Citations

Camp, Dresser, and McKee, "Reservoir Water Quality Protection Study: Phase 2 Report," prepared for Department of Public Utilities, City of Newport News, November 1985.

Three New Trends in Stormwater Management

John A. Aldrich and Larry A. Roesner
(Presented by John A. Aldrich)

Executive Summary

Three new trends in stormwater management are discussed: (1) master plans, (2) level-of-service approach, and (3) stormwater utilities. Implications for local and state programs in Virginia are discussed, and case studies are presented.

Master Planning

Under the master plan approach, a local government develops a comprehensive scheme for stormwater management on a watershedwide basis. The master plan strategically locates regional stormwater management facilities (e.g., detention basins, channels, park lands) to maximize flood control benefits and minimize the risk of adverse synergistic impacts. This approach has significant advantages over traditional piecemeal approaches to stormwater management, which require individual land developments to provide on-site stormwater management facilities. Among the advantages are:

1. *Lower capital and operation and maintenance (O&M) costs.* Typically, master plans call for fewer and larger stormwater management facilities. Economies of scale are achieved in construction and especially in O&M. Strategic placement of facilities permits concentrating funds in areas where benefits are greatest. Cost-sharing arrangements reduce the cost of stormwater management to the community as a whole.

2. *Increased effectiveness throughout the watershed.* Different portions of watersheds often require different types of stormwater controls. Master planning permits the placement of facilities in locations where the greatest benefits are achieved.

3. *Greater use of nonstructural measures.* The most practical stormwater management alternatives frequently involve nonstructural measures such as land acquisition, floodplain zoning, subdivision drainage ordinances, and land use controls. The implementation and effectiveness of these measures can only be achieved by planning and enforcement throughout the the watershed.

4. *Less risk of negative spillover effects.* The piecemeal approach may adequately solve local drainage problems but seldom addresses potential downstream flooding caused by dynnamic interactions between runoff hydrographs within the watershed. A master plan accounts for these upstream effects and achieves solutions to both local and regional stormwater management concerns.

One of the Virginia jurisdictions to adopt a watershedwide approach to stormwater management is Virginia Beach. The primary drainage system for the rapidly growing 250-sq-mi city consists of several major canals stretching from the Chesapeake Bay in the north to Currituck Sound, North Carolina, in the south. The stormwater management master plan currently being developed will recommend structural and nonstructural control measures for peak-flow control and nonpoint pollution management for ultimate development conditions. A microcomputer version of EPA's Stormwater Management Model (SWMM) is being used to prepare the master plan for the city's 25 major drainage basins.

The Virginia Beach master plan study relies upon two different levels of stormwater modeling: a citywide model of the primary system and individual basin models of the secondary system. The citywide model of the primary channel system (40 mi) is used to evaluate watershed drainage patterns and control measures in response to varying tidal boundary conditions, rainfall events, and land use scenarios. The citywide model is also used to set the downstream boundary conditions for the 25 separate basin models that cover the more detailed secondary drainage system. A major product of the modeling study is the delineation of three zones for stormwater management in each basin: the zone subject to fluvial flooding, which can be controlled completely by stormwater management techniques; the zone subject to typical tidal storm surges, where stormwater management is relatively ineffective; and the transitional zone, where both fluvial and storm surge flooding may have significant impacts and stormwater management may be partially effective.

The Virginia Beach master plan will also evaluate the water quality management impacts of recommended drainage improvements.

Level-of-Service Approach

The level-of-service approach to stormwater management parallels procedures that have been used in water, wastewater, solid waste, and highway engineering for many years. It involves reliance upon streets and yards to provide a portion of required detention storage. Service levels can range from no street flooding for a specified design storm (level A) to significant street/yard flooding without structure flooding (level C).

The Ybor City area of Tampa, Florida, is nearly 100 years old and is largely a Historic Preservation Area. Its historical significance and its location near the central business district of Tampa ensure that revitalization of the area will continue. Stormwater infrastructure rehabilitation and expansion is limited by both historical concerns and urban density. Elimination of all flooding under a reasonable design scenario was both financially and politically infeasible. Thus, a service-level approach was used to provide stormwater controls where the greatest benefits could be achieved. The proposed improvement plan was designed to keep major highways open to all traffic, secondary highways open to emergency vehicles, and all structures free of flooding. Minor side streets, lawns, parks, and natural depressions serve as detention storage areas and are allowed to flood until peak runoff is passed downstream. The final recommendation resulted in a mix of service levels, averaging near a level B at a cost of about $2 million, or only 25% of the cost to achieve level A.

Stormwater Utility

The stormwater utility concept represents one of the most exciting recent developments in urban stormwater management. Under the utility approach, property owners within a jurisdiction are assessed a monthly user's fee (e.g., $3.00 per dwelling unit) to cover local stormwater management costs for *existing* development. Also, land development fees can be assessed to help manage the stormwater impacts of *new* construction. Thus, the stormwater utility provides funds to meet both capital and operating costs without impacting a local government's general fund. The result is that local public works departments have an adequate revenue source to construct additional regional facilities and to carry out maintenance activities.

The stormwater utility recently established by Tallahassee, Florida, is the first in the state and one of the first in eastern United States. Its stormwater user-charge is based upon the estimated runoff from an equivalent single family unit (SFU). Each SFU was estimated to contain about 2,700 sq ft of impervious area. Eighty-three percent of the developed parcels in Tallahassee are single family homes, and each is billed for 1 SFU of runoff. Equivalent SFUs are determined for other land uses based upon the impervious area in each. Land uses other than single family residential, which account for only 17% of the land area, generate 82% of the runoff and are billed accordingly. At a monthly fee of $1.00 per SFU, Tallahassee will generate $1.4 million in the first year.

Research Drilling Project in the Coastal Plain Physiographic Province of Virginia

Taylor Scott Bruce

Problem Statement

Increased dependence on groundwater supplies in the Virginia Coastal Plain has prompted the need to evaluate the groundwater resource. The first step in evaluating Virginia's groundwater resources is to collect hydrogeologic information from observation wells, especially in areas with little or no hydrogeologic data. Information from observation wells is crucial in developing a hydrogeologic framework and ultimately a computer model.

Objectives

The objectives of this work are to:

1. Collect hydrogeologic information including geophysical logs, cores, water-quality samples and water-level measurements.
2. Analyze the data to define the hydrogeologic framework.
3. Disseminate this data to the public and federal, state, and local officials.

Methodology

Objectives will be accomplished by (1) selecting sites in areas with little or no hydrogeologic data or in an area that requires additional data to define the hydrogeologic framework; (2) drilling a pilot hole to bedrock and collecting cuttings samples at 10-ft intervals; (3) logging the pilot hole to obtain a suite of geophysical logs including single and multipoint electric, gamma, and caliper logs; (4) analyzing geophysical logs, cuttings samples and other information to determine aquifer tops and bottoms; (5) drilling observation wells to obtain water quality samples; (7) measuring groundwater levels over time; (8) collecting selected core samples; and (9) adding research station data to the existing USGS hydrogeologic framework.

Results to Date

Since 1975, the Virginia Water Control Board has drilled 35 research stations in the Virginia Coastal Plain and Eastern Shore. Data from the drilling project has been incorporated into three USGS modeling efforts. They are the RASA, York-James Peninsula and Southeast Virginia digital models. A portion of the research stations provide saltwater intrusion data. Basement core samples have also been collected for the Virginia Division of Mineral Resources.

Underground Storage Tanks: Disposal Options and Financial Responsibility Provisions

W. David Conn, L. Leon Geyer, William R. Knocke, Janet E. Robinson, Denise W. Scott, and Paul S. Thompson
(Presented by W. David Conn)

Introduction

The number of reported incidents of groundwater contamination in Virginia and other states due to leaks from underground storage tanks (USTs) has risen dramatically in recent years. Under Subtitle I of the Resource Conservation and Recovery Act (RCRA), as amended in 1984 and 1986, a federal program is being established to address the problems posed by underground tanks used for the storage of petroleum products and other hazardous substances (not including hazardous wastes, whose storage is regulated under Subtitle C of RCRA). In response to the federal requirements, states are being encouraged to develop their own UST programs.

The project reported in this paper addresses two important issues facing the Commonwealth of Virginia as it seeks to formulate appropriate UST legislation and regulations. These issues relate to (1) the disposal of underground tanks, and (2) provisions for establishing the financial responsibility of tank owners and for financing the cleanup of abandoned tanks.

TANK DISPOSAL

Problem Statement

The number of unusable and/or unused underground storage tanks is growing rapidly as tanks installed during the growth decades of the 1950s and 1960s reach the end of their working lives and require replacement; furthermore, many companies are replacing newer but inadequately protected tanks in order to minimize the risk of leakage and the associated liabilities.

Tank disposal, which may be *in-situ* or following removal from the ground, itself poses risks to human health and the environment. Methods used in the past may no longer be considered acceptable by present-day standards; consequently, the identification of disposal methods that are effective, safe, and economically feasible is of major importance.

Objectives

The objectives of the research, which is still in progress, are (1) to identify and describe alternative disposal methods that are currently available or under development, (2) to estimate the economic costs associated with these methods, and (3) to examine the environmental implications of their use.

Methodology

The methodology to date has consisted largely of a review of the pertinent literature, consultations with representatives of the major trade associations involved in petroleum storage and tank disposal, individual companies, and government agencies, and an analysis of the information thereby obtained.

Results to Date

The study has confirmed that many of the disposal methods used in the past, such as the landfilling of untreated tanks, are now considered unacceptable because of the potential hazards presented to both workers and the environment by fumes and product residues. Petroleum fumes, for example, can be explosive, and residues of lead (from leaded gasoline) are potentially toxic. The two technologies currently recommended by industry trade associations are (1) abandonment in place, and (2) removal and recycling.

Abandonment in place, which avoids the expense of tank excavation and transport, generally involves the total removal of product, including sludge and fumes, puncturing of the tank walls, and refilling with a solid, noncompacting, and chemically inert substance. Sand is commonly used for this purpose, but other substances such as "flowable fill" (a cement-like aggregate) or polyurethane foam may also be used. Environmental effects result primarily from the gradual release of metal from the rusting tank, particularly residues of lead.

Removal and recycle requires tank excavation, cleaning, and transport to a scrap metal dealer. While this technique eliminates the tank itself as a lingering source of contamination, the recycling operation itself produces its own array of potentially polluting wastes.

The major concerns associated with both methods of tank disposal relate to the handling of tank residues and cleaning water, which often fall under the definition of *hazardous waste* under RCRA Subtitle C. Without cleaning, particularly of lead, old tanks may be essentially worthless as scrap; many scrap dealers, for instance, are refusing to take old tanks unless they are *certifiably* free from any regulated substance because of the liability risks associated with the handling of hazardous materials. However, the quantities of waste produced during cleaning are such that the tank owner may qualify as a "small quantity generator" of hazardous waste, and so may be required to dispose of the waste according to complex and usually expensive procedures. The additional costs that result may be a significant factor in discouraging proper tank disposal.

Research Implications

The results to date suggest that a need exists for the identification or development of ways in which residues could be either rendered nonhazardous before disposal or otherwise treated so as to reduce liability and expense. Both technological and institutional options may be applicable.

FINANCIAL RESPONSIBILITY

Problem Statement

The 1986 amendments to Subtitle I of RCRA provide for owners and operators of USTs to be required to maintain evidence of financial responsibility for taking corrective action and compensating third parties for property damage and bodily injury that might result from a leak. Several options are available for meeting this requirement, and there is a need to understand their relative advantages and disadvantages in the Virginia context.

Objectives

The objectives of the research, which is still in progress, are (1) to identify the areas of potential costs associated with underground storage tanks (e.g., damages, remediation, etc.), (2) to explore the potential liabilities (including situations where ownership cannot be established or the owners cannot be traced), (3) to identify alternative means of establishing financial responsibility (e.g., insurance, bonds, etc.) as well as of financing the cleanup of abandoned tanks, and (4) to examine the legal, economic, environmental, and other implications associated with these options.

Methodology

The methodology initially involved the development of case studies, an approach which was subsequently suspended because of problems in obtaining information about particular cases that would be pertinent to the aims of the project. Instead, greater emphasis has been placed on the literature review and on interviews with knowledgeable persons in the public and private sectors, including members of a specially identified *resource group* of experts on legal, financial, and other aspects relating to financial responsibility for USTs.

Results to Date

The costs associated with leaks from USTs include those for (1) corrective action, and (2) damages. Experience with insurance claims suggests that most incidents involve costs that are less than $100,000, with very few exceeding $1 million. These costs may be expected to grow with the demand for greater stringency in cleanup and, possibly, an increase in payments for damages. Under present legislation, if a responsible party can be identified *and* has the means, that party is expected to pay for corrective action. On the other hand, damages must be sought through civil remedy in the courts by individuals alleging injury. In both cases, however, it may be difficult or impossible to identify the responsible party; furthermore, even if identified, the latter may not be in a position to pay. Some tank owners currently have insurance; the only other potential source of relief in Virginia at the time of writing is the Oil Spill Contingency Fund which is too small to pay for corrective action in more than a small number of instances. A federal trust fund has been established, but payments from this fund are likely to be made only under a restricted set of circumstances and certainly cannot be taken for granted.

The options for establishing financial responsibility for tank owners, to ensure the availability of funds to pay the costs associated with future leaks, include one or more of the following: (1) insurance; (2) guarantee; (3) letter of credit; (4) surety bond; (5) self-insurance; and (6) trust fund. Considerations thought to be important in assessing these options include: (a) availability; (b) level and distribution of cost; (c) degree of incentive given to tank owners to adopt *prevention* measures; (d) administrative simplicity, including rapidity with which funds can be made available in the event of a leak; (e) conformity to federal requirements.

Where available and feasible, insurance generally appears to be the preferred option. Two firms in the U.S. currently offer UST insurance to petroleum tank owners or operators who belong to a group marketing association or a jobbers' association. It is likely that insurance will be offered soon to independent gas retailers *but not to nonmarketers* such as truck and rental car fleets, airports, etc. Minimum annual coverage is normally $1 million per incident, $2 million aggregate, with a deductible ranging from $5,000 to $100,000. Premiums are substantial (and appear to be growing) but are not thought to be financially prohibitive except, perhaps, for marginal independent retailers.

For those who cannot obtain insurance, or to supplement available coverage, other options are being examined. The very firms who have the least chance of obtaining insurance may be ineligible for some of the alternatives. This problem might be resolved by the setting up of a common trust fund in addition to, or in lieu, of the establishment of financial responsibility on an individual basis. This fund might also be used to pay costs in situations where no responsible, financially solvent party can be identified. However, critical issues then arise in relation to the method of financing the fund, such as (1) its fairness (in light of the generally accepted *Polluter-Pays-Principle*); (2) provisions for cost recovery from responsible parties; and (3) any incentive (or disincentive) effect it might have on tank owners' willingness to adopt leak prevention measures.

At the time of writing, a bill (HB 1022) establishing an Underground Petroleum Storage Tank Fund in Virginia, to be financed by an increase in the tax on motor fuels, has been passed by both houses of the Legislature and sent to the Governor for his signature. If enacted, the bill would reduce the level of financial responsibility that individual tank owners will have to demonstrate. A number of problems with the bill have already been identified.

Research Implications

Enactment of HB 1022 would create a need for further research that is directed, at least in part, at anticipating problems associated with the bill's implementation and at developing possible remedies. If the bill is not enacted, there will be a need for continued investigation of alternative ways of meeting the federal financial responsibility requirements in Virginia.

Residents' Appraisal of Water Supply and Quality In the Coal Mining Region of Southwest Virginia

B. Blake Ross, Sara A. Rosenberry, and Theo A. Dillaha III
(Presented by B. Blake Ross)

Problem Statement

The coal mining region of Virginia has historically experienced poor water supply, distribution, and quality conditions. As the quantity and quality of these supplies may continue to be affected by mining activities, more legal and social demands will be made upon municipalities, local governments, and mining companies to provide adequate and safe water supplies for domestic needs of residents, agriculture, and industry. The hydrologic consequences of mining activities may make it necessary to design alternatives for adequate water supplies.

Objectives

The objective of this study was to survey residents so that future educational and research efforts would address the hydrologic problems and needs of the region. In addition to examining local citizen attitudes, the response of those agencies, local political bodies, and private firms involved in water supply, water quality, land use planning, and coal mining activities was also sought to gain insights into public attitudes regarding the region's water supply and other environmental and hydrologic issues. Because such information would be useful in developing a long-term research agenda, the Powell River Project, a nonprofit agency that funds projects on land reclamation and mining-related issues, contacted researchers in the Agricultural Engineering Department and the Urban Affairs Program at Virginia Tech to conduct such a study.

Methods

A survey sample and survey instruments were developed by the researchers, and the surveys were administered during the months of May and June 1985. The survey was designed to provide a profile of residents' perceptions of water quality and environmental conditions in the region. It did not attempt to learn about actual water quality or physical conditions in the area. In addition, the results do not provide an explanation of why residents have certain attitudes, but instead simply provide profiles of the attitudes and perceptions of groups represented in the survey sample.

Given the relative intensity of surface mining activities in Wise County and deep mining activities in Dickenson County, the survey sample of residents was selected from these two counties. A random systematic sampling technique was developed to select a total of 407 households for surveying by telephone. In addition, 269 surveys were mailed to the contact person identified for each of the institutional water users and agencies involved in water-related activities. Ultimately, only 51 (37 institutions and 14 agencies) surveys were returned, a 19% return rate.

Results

Of the 407 residential surveys completed, 250 (61%) of the households relied on a public water system for their domestic water needs, and 154 (38%) relied on a private system. The most common source of water to private systems is a well.

Respondents were asked to specify the severity of each problem in their own water system, as well as the one problem that they would like most to see solved. The potential problems fell into three categories: reliability (water shortages and loss of water pressure); quality (bad taste, presence of sediment, bad smell, lack of clarity, presence of bacteria, rust stains, or chalky deposits); and cost. To the second question, the response "none" was given more frequently than any other (by 36%, or by 136 of 376 respondents who answered the question). About 20% of the respondents reported severe problems in each of the three problem areas. Thus, while 80% of the sample did not report having severe problems with water reliability, quality, or cost, 20%, or one out of five households, did.

Respondents were also asked a number of questions concerning regional water quality. From their responses, residents of the two counties apparently believe that the quality of water in the region has not deteriorated over the past five or ten years.

When asked to state what they thought was "the main cause of water-related problems in their county," more residents gave the answer "coal mining activities" than any other response. One hundred fifty-three of the 334 (46%) respondents who answered the question said the main cause was coal mining, while 19% said "natural causes," and 10% said "too much residential development."

Because of the small number of agencies and institutional water users who responded, making statistically significant comparisons among the groups is impossible. However, it is possible to draw a profile of the agencies and institutional water users that did return the survey. Based on the data collected, residential respondents and spokespersons for agencies are more critical of the adequacy of the region's water supply than institutional spokespersons. Fourteen percent of residential respondents and 16% of agency spokespersons said that they would rate their own or their constituency's water supply as unsatisfactory or very unsatisfactory, while all spokespersons for institutional water users said they would rate their water as satisfactory or very satisfactory. Institutional water users were also more likely than either agency spokespersons or residential respondents to say that they thought that the quality of the region's water supply was somewhat better or much better today than it was 10 years ago. Eighty-six percent of the institutional water users. said it was better compared to 67% of agency spokespersons and 54% of residents. Fifteen percent of agency spokespersons rated today's water quality as much worse or somewhat worse than five years ago, while only 11% of residential respondents and 3% of institutional respondents agreed with that assessment.

Agency spokespersons appear much more likely than residential respondents or institutional spokespersons to say that there are serious problems with the quality, reliability, and cost of the region's domestic water systems. This relatively critical view of the region's water supply was reflected in responses to individual questions relating to characteristics of the water supply. Agency spokespersons were more likely than residential respondents or spokespersons for institutional users to say that every problem listed in the questionnaire was somewhat or very serious rather than minor or nonexistent for their constituency. Spokespersons for institutional water users were less likely than residential users or agency spokespersons to identify coal mining activities as the main cause of water-related problems in the region (18%, 46%, and 54%, respectively). This difference may reflect the fact that a significant number of institutional users are coal mining firms.

Spokespersons for agencies and institutional water users were also asked to recommend priorities for data collection and research "relating to water quality and/or other hydrologic issues in Wise and Dickenson Counties." They were asked to make and rank three recommendations for increased research support and three recommendations for data collection needs. There is a clear consensus among those who responded that the highest priority ought to be given to data collection and research on the adequacy of the region's future water supply. Other major data recommendations in order of priority involve the collection of information on the impact of development, future water supply needs, and the effectiveness of current technology in controlling environmental hazards. Additional research needs in order of importance are the effects of mining on the region's water supply, a better understanding of environmental hazards, and evaluation of the impact of development on the environment and region's water supply.

Research Implications

While the population in general seems relatively satisfied with its current water supply, a significant minority experience one or more serious problems. While it has not been possible to identify specific factors that distinguish this group, the presence of serious water supply problems is not simply a function of absolute distance from a potential hazard. Clearly, more research designed to identify those groups with the most serious water supply problems is called for. As a whole, residential and institutional water users appear less likely than agency spokespersons to be critical of the region's water supply. One possible explanation for agency spokespersons' relatively critical view is that, since they focus on water-related issues and problems in their work, they are keenly aware of and concerned about general and long-term water-related issues. The residential population seems more likely than either agency or institutional spokespersons to focus its attention on short-term issues such as the cost of water per month rather than long-term problems such as the adequacy of the region's water supply. The disparity between the responses of agency spokespersons and those of the general population probably exists because agency spokespersons recognize and advocate for the needs of the minority of residents who experience serious water supply problems. If the public's general satisfaction with its own water system and its relatively positive assessment of its region's water supply is reflected in a lack of support for activities to address the needs of particular groups or the region's long-term water supply and hydrologic problems, then a research and public education program focusing on water and hydrologic issues may be useful.

The Use of Spontaneous Potential in the Detection of Subterranean Flow Patterns in and around Sinkholes

Ronald A. Erchul and Dwain K. Butler
(Presented by Ronald A. Erchul)

Purpose

The purpose of this research was to test and evaluate an indirect geophysical measuring technique called Spontaneous Potential (SP) on a newly developed sinkhole to determine whether this method would be able to detect the direction of groundwater flow.

The SP method measures natural electrical potential field differences at the earth's surface. Anomalies in the electric field can be produced by ore bodies, heat flow, or subsurface fluid flow. SP has been used widely in oil well logging to detect permeable zones and has also been used to delineate conductive ore deposit. The SP method has been used for many years in the USSR for geotechnical applications such as seepage analysis and study of landslide processes. Publication of papers by Soviet researchers (Ogilvy et al. 1969, Bogoslovsky and Ogilvy 1972) led to a number of geotechnical applications in the United States.

Recently, the U.S. Army Waterways Experiment Station (WES) has used SP measuring techniques at Gathright Dam in Virginia (Cooper et al. 1982), Clearwater Dam in Missouri (Koester et al. 1982), and Mill Creek Dam in Walla Walla, Washington (Butler et al. 1984), to determine the abnormalities created in the ambient electric field in cases where water was known to be flowing through porous zones of subsurface material but the location of these zones was not well defined. WES has greatly simplified the SP measuring technique by using copper-clad steel grounding rods as electrodes rather than the nonpolarizing electrodes that many investigators have used in the past.

Methodology

The study area is 6 mi south of Lexington, Virginia, in the southern Shenandoah Valley. This is an area of karst topography and contains many sinkholes, which range in diameter from 8 to 300 ft and in depth from 3 to 50 ft. Within the study area of 2 by 0.5 mi occur 25 sinkholes. Two of these were instrumented for this study.

These two sinkholes occur at an elevation of approximately 1200 feet and are developed in the upper portion of the Ordovician-aged Beekmantown Formation. The two sinkholes which were studied were selected because of their location at the low end of a large uvala (they therefore receive maximum runoff from the surface watershed), their convenient access, their representation of both collapse and subsidence forms, and their proximity to each other (600 ft).

The SP electrode configuration consisted of a double ring of electrodes circumferentially located around each sinkhole. Two reference electrodes were used in taking SP measurements. One reference electrode was located outside the rings of electrodes and the other was located in the center of one of the sinkholes. Once a major drainage path around the sinkhole was detected an array of electrodes was used to track the drainage path.

Results to Date

SP data was taken over a six-month period for the two sinkholes and tracking arrays. SP was effectively used in the detection of surface and subsurface drainage around the sinkholes. The same SP technique was also able to track a subsurface drainage path for over 600 ft from one sinkhole into another sinkhole. Confirmation of the SP data was obtained by visual observation, electrical resistivity measurements and geological studies. The SP data for a given electrode varied greatly over time by variation between electrodes remained relatively constant. Changes in ground water flow or surface ground temperature or a combination of these and other factors are probably responsible for fluctuating SP values.

In general, it seems that SP values decrease with a decrease in temperature or an increase in precipitation. This is consistent with work presented by other investigators (Ogilvy et al. 1969, Bogoslovsky and Ogilvy 1972, Cooper et al. 1982, Koester et al. 1982, Butler et al. 1984, Cooper 1983) in that an increase in water flow resulted in a lowering of SP values. The effects of temperature fluctuation on SP values have been studied by Corwin and Hoover (1978). They have noted a coupling effect and describe a decrease in SP values over geothermal areas (where temperature extremes are high). In this study area, as surface temperatures decrease in winter months a thermal couple develops between the cool surface and warmer ground at depth. This thermal difference may approximate the effects of geothermal areas and thus SP values decrease as surface temperature decreases. In summer months the temperature differences between surface and subsurface are reversed. A similar correspondence between temperature and SP is noted, although the response is not as marked, this could probably be due to a greater lag time in ground warming for these months.

Research Implications

The major implications from this research are the following:

1. The SP technique used in this study was effective in detecting surface and subsurface drainage around a sinkhole. In addition, the SP technique was able to track one drainage path for over 600 ft into another sinkhole.

2. Confirmation of SP data was obtained by visual observation of surface runoff into the instrumented sinkhole, by

3. Although SP values varied significantly during the six-month (July to December 1985) testing period for individual electrodes, the ranking values between electrodes were consistent. This was also true if the position of the reference electrode was changed. It appeared that changes in precipitation and surface ground temperature had the greatest affect on the variation of SP data over the testing period.

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A Rapid Technique for Isolating Fecal Coliforms from Soil

Charles Hagedorn

Problem Statement

The U.S. Environmental Protection Agency (EPA) is revising drinking water regulations in response to requirements of the Safe Drinking Water Act. This involves a comprehensive reassessment of the Interim Drinking Water Regulations established in 1976, and a review of new information on health risk and engineering process controls. *These revisions will affect monitoring procedures at the site and in the laboratory.* As previously, routine measurements of microbial contamination (total coliform bacteria and turbidity) will be part of the revised regulations. Proposed new criteria include limiting heterotrophic plate counts (HPCs) and providing protection from virus and *Giardia* occurrences. In addition, new regulations will require more frequent sampling for small water systems as well as identification of coliforms if the presence-absence coliform concept is chosen for compliance purposes (Geldreich, 1986).

Objective

The purpose of this investigation was:

1. To develop a rapid microtitration most-probable-number (MPN) technique that will provide rapid, accurate, and reliable recovery of fecal coliforms from soil and water.
2. To test the efficacy of such a technique in enumerating heterotrophic bacterial populations as part of proposed EPA regulations.

Methodology

Microwell plates (each 8 x 12.5 x 1.3 cm, 12 rows of eight microwells, 0.225-m^3 maximum cubic volume per microwell) were drilled from polycarbonate blocks and designed to fit inside a 15-cm glass petri dish for autoclaving. Used plates were washed and then rinsed with distilled water for reuse. Repeated autoclaving had little effect on the polycarbonate. Results from polycarbonate plates were compared with results from prepackaged sterile polystyrene plates (Linbro Scientific, Hamden, Conn.). The soil samples (containing sludge amendments) were diluted by placing 10 grams of soil in 90 ml of 0.1% peptone water. Plates were placed on a damp paper towel to eliminate static charge accumulation (Conrath, 1972) and loaded with lactose broth (Difco Laboratories, Detroit, Mich.) with an 8-channel micropipette (Flow Laboratories, Inc., McLean, Va.). The micropipette also delivered 100 microliters of single-strength lactose per microwell.

Diluted soil samples were shaken vigorously for 1 minute and allowed to settle for 40 seconds. Approximately 30 ml of the sample was poured into a sterile 10-cm petri plate for pickup with the micropipette, and the rest of the sample was used for 10-fold dilutions in the standard elevated-temperature fecal coliform MPN procedure. Microwell plates were oriented with the initial dilutions furthest from the airflow to minimize aerosol contamination. The micropipette discharged 100 µ/l of the sample per microwell into the first row of eight microwells. The wells were mixed 10 times by drawing up and discharging the micropipette gently to minimize splashing. In this manner, 11 rows were serially diluted; row 12 was left uninoculated as a control. The completed microwell plates were incubated for 9 h at 35° C. A multipoint inoculator (Fung and Miller, 1970) was sterilized by ethanol flaming and used to transfer a sample of each incubated microwell to a surface-dried, 15-cm m-FC (Difco) plate. Surface-drying the plates minimized spreading-type colonies. The m-FC agar plates were placed in a plastic bag and incubated underwater in a coliform incubator bath (Precision Scientific, Chicago, Ill.) for 15 h at 44.5 ± 0.2° C. Characteristic blue colonies were counted and converted to MPN values by using the three-column MPN code of Rowe et al. (1977). Soil moisture corrections, determined as a percentage of the dry to wet soil weight after overnight incubation in a 110° C drying oven, were used to establish final corrected MPN values. The m-FC medium was used. Differences between m-FC and -EC media were determined by inoculating a sample from each microwell of incubated lactose broth into a test tube (15 x 150 mm) containing a Durham tube and 10 ml of EC broth. Test tubes were incubated for 48 h at 44.5 ± 0.2° C in the coliform incubator bath, and were checked for the presence or absence of gas. Results were correlated with previous results from the m-FC agar plates.

Results to Date

MPNs from polycarbonate plates were not significantly different from MPNs on prepackaged, sterile polystyrene plates. Incubation of lactose broth for less than 9 h resulted in a significantly fewer of counts on the m-FC agar, whereas incubation for longer than 9 h had no effect on m-FC agar count.

A correlation coefficient (*r*) of 0.86 (95% CI of $0.76 < r < 0.92$) was obtained when the micro-MPN technique was compared with the standard elevated-temperature EC tube technique. The line of best fit is expressed as: $\log y = 0.69 \log X : 0.95$. Of 3,872 microwells, 96.4% (3,733) were m-FC^+/EC^+ or m-FC^-/EC^-, 3.6% (139) were m-FC^+/EC^-, and none was m-FC^-/EC^+ Assessments of m-FC^+/EC^- variation demonstrated no discernible variation of m-FC^+/EC^- microwells either over time or among the four sampling sites. All control microwells were negative.

The *r* between the standard fecal coliform MPN technique and the micro-MPN technique indicates they are closely related. MPN values from the two techniques are statistically significant ($P < 0.01$, paired *t*-test). Reasons for this difference are the increased end-point accuracy of 2-fold over 10-fold serial dilutions and the use of a three-column MPN code instead of a code of four or more columns. The three-column code was used for simplicity. The use of the slightly less restrictive EC agar would increase MPNs.

Research Implications

The major disadvantage of this microtechnique is the initial cost of materials. Costs can be reduced by using reusable polycarbonate plates, a simple glove box instead of a laminar flow hood (D. Y. C. Fung, personal communication), and reusing polypropylene tips of the eight-channel micropipette.

Advantages of this microtechnique are substantial savings in both time and media. The technique is especially appropriate for nonfilterable environmental samples. Fecal coliform populations could be accurately determined in only 24 h using 8 replicates of two-fold dilutions.

This procedure may be useful to local officials who may have to sample water supplies more frequently under proposed EPA regulations. The applicability of this technique in determining total heterotrophic bacteria and fecal coliforms in less contaminated water supplies should be examined.

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Assessing Subsurface Biodegradation of Organic Chemicals by the Microcosm Approach

Gary T. Hickman and John T. Novak
(Presented by Gary T. Hickman)

Problem Statement

Contamination of subsurface systems by organic chemicals, even at low levels, can render groundwater unacceptable for drinking or for other uses — constituting a health hazard if not detected. Cleanup of contaminated groundwater may require costly pumping and treatment techniques. *In-situ* biotransformation by naturally-occurring microorganisms has been found to be an important removal process for some organic chemicals in subsurface systems. Thus, it is important to be able to estimate biodegradation rates for use in solute transport models and to assess the need for remedial action.

Objective

The objectives of this microcosm study are to evaluate biodegradation rates of selected organic chemicals in soils and to take a broader look at the kinetics of subsurface biodegradation.

Methodology

The microcosm approach is a direct, as opposed to theoretical, technique for assessing biodegradation rates in soil systems. Authentic subsurface material containing native bacteria is added to test tube microcosms which are then dosed with a deoxygenated organic chemical solution, precluding headspace (producing saturated, anoxic conditions), and incubated at the ambient temperature of the system. Chemical disappearance is monitored over time via gas chromatography.

Subsurface soils have been collected at several sites in the eastern United States — including three in Virginia — representing a wide range of soil types, particle size, moisture content, redox conditions, and chemical characteristics. This paper concentrates on data obtained using Blacksburg, Virginia, soils which were sampled at several depths and locations within a localized area. Methanol, tertiary butyl alcohol (TBA), and phenol were used as organic substrates to represent an easily degradable solvent, a refractory gasoline additive, and a common industrial compound, respectively.

Soil bacteria are being enumerated by spread plate viable counts, incubated both aerobically and anaerobically, by acridine orange epifluoresence direct counts, and by most probable number tests (MPNs) in which the chemical of interest is added as the sole carbon source.

Results to Date

Methanol and phenol are degraded relatively rapidly in Blacksburg soils, with most average degradation rates (initial concentration = 100 mgL^{-1} incubation temperature = 10° C) falling within the ranges of 0.5-2.0 $mgL^{-1}d^{-1}$ and 0.25-1.75 $mgL^{-1}d^{-1}$, respectively. These rates concur with the ranges observed in similar experiments using soils from other sites in Virginia, Pennsylvania, and New York (Goldsmith 1985; White 1986; Smith and Novak 1987). Disappearance curves (concentration-time plots) are concave downward, approximating first (or mixed) order kinetics for these two chemicals. Average first-order reaction rate constants vary from 0.002-0.012 d^{-1} and 0.002-0.009 d^{-1} per dry gram of soil for methanol and phenol, respectively. The heterogeneity of the soil profile, with respect to biodegradation potential, is evidenced by the fact that at a given site the reaction rate constant varies by as much as a factor of five over a 10-ft change in depth.

TBA is relatively refractory in Blacksburg soils. Concentration-time plots exhibit a long, linear lag phase of slow but constant degradation followed, in at least some cases, by a defined increase in disappearance rate. Average zero order, 10° C reaction rate constants during the lag phase for an initial TBA concentration of 100 mgL^{-1} are on the order of 0.01-0.1 mgL^{-1} Novak et al. (1985) have observed that although the rate of TBA degradation is constant, it is first order with respect to the initial substrate concentration.

Biodegradation of organic chemicals at 10° C often is slow, requiring considerable periods of time to evaluate degradation rates. In evaluating biological wastewater treatment processes, temperature corrections are commonly made using the modified Arrhenius equation:

$$K_2 = K_1\theta^{(T_1 - T_2)}$$

Where K_i = reaction rate constant at temperature i (T_i) and Θ is called a temperature coefficient. For the Blacksburg soils, over the temperature range 10-30° C, Θ has an average value of 1.04 for the biodegradation of both methanol and phenol. Using this correction, the rate constant can be more quickly evaluated at a higher incubation temperature and then adjusted back to the ambient-temperature rate.

Microbiological studies are being conducted in an attempt to identify and quantify the group(s) of bacteria responsible for degrading the introduced substrates; this would facilitate biokinetic analyses. Viable counts range from 10^4-10^6 CFU per gram of soil in the Blacksburg samples. A direct relationship occurs between aerobically incubated viable count and degradation rate for the chemicals studied, while the substrate-specific MPNs did not yield a good correlation. Anaerobic studies are ongoing.

Research Implications

Methanol and phenol are readily biodegraded in subsurface soils from Blacksburg as well as other sites studied in Virginia, Pennsylvania, and New York. TBA is persistent in previously uncontaminated soils yet is biodegraded at a slow rate. Bacterial viable counts are a decent indicator of biodegradation potential and also may be instrumental in biokinetic analyses that ultimately provide information for unstudied sites.

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Potential of Groundwater Bacterial Populations to Adapt To Perturbations of Pentachlorophenol and Tertiary Butyl Alcohol

Steven A. Baranow, James B. Chadduck, and Robert E. Benoit
(Presented by Steven A. Baranow)

The biology of subsurface soils received very little study until recently because of the long-standing assumption that groundwater contained few, if any, microorganisms. Furthermore, standard drilling procedures made it impossible to obtain uncontaminated deep soil samples for microbiological examination. The stimulus to examine the microbiology of groundwater was the increased use of groundwater as a potable water supply and a general concern about the capacity of subsurface microorganisms to respond to chemical perturbations.

This study was part of a cooperative project with John T. Novak of the Civil Engineering Department of Virginia Tech. We have attempted to address the question, Do groundwater systems have the capacity to degrade or detoxify biochemical compounds which enter subsurface systems? We have used biologically recalcitrant model compounds such as tertiary butyl alcohol (TBA) and pentachlorophenol (PCP) to test the question. Subsurface cores from pristine and contaminated sites were obtained to conduct the study.

The objectives of this study were to find answers to the following questions:

1. What are the microbiological characteristics of subsurface soil as compared to surface soil? Are there any differences in the subsurface microbial characteristics of pristine and contaminated soils?
2. Can subsurface microorganisms decompose recalcitrant chemicals such as PCP and TBA? Is it possible to introduce microorganisms into contaminated subsurface soils to facilitate decomposition?

Before this study, there was little, if any, evidence that TBA could be metabolized by microorganisms in mixed or pure culture. This alcohol is used as an additive in certain gasolines, and since it is soluble in water, there is the possibility that it could enter groundwater systems during gasoline spills. PCP is a very recalcitrant compound, but it can be slowly degraded by aerobic or anaerobic microorganisms which have been isolated from sludge and surface soil systems. Until this study, whether groundwater microorganisms could decompose this highly chlorinated and widely used compound was not known. Investigators have hypothesized that subsurface systems may required a long time to effect decomposition of recalcitrant compounds after a chemical spill because of a lack of species diversity, time required to produce a new population, and unfavorable conditions for microbial growth.

We examined the microbial characteristics of several deep subsurface sites and found a significant microbial biomass in all cases at all depths. However, differences in the quantity of live organisms were correlated with subsurface moisture differences. The bacterial species diversity of subsurface soils was less than that of surface soils. With the exception of the isolation of certain yeasts species, no eukaryotes were observed.

Bacteria which could degrade TBA as a sole carbon and energy source were isolated from the contaminated site but not the pristine sites. This is the first time that a pure culture of a TBA degrading microorganism has been isolated. We are examining the physiology and genetics of this unusual, slow-growing bacterium.

We have used enrichment cultures of subsurface soils to determine if PCP-degrading microorganisms are present in various subsurface samples. We have observed chloropentaphenol degradation in several enrichment cultures from the contaminated site after 26 d of incubation at 20° C. These media contained 20 ppb to 40 ppm PCP. Maximum degradation was observed in aerobic and microaerophilic enrichment cultures. PCP degradation was observed in anaerobic enrichments but activity was less than that observed under aerobic conditions. Methlotrophic enrichments were not very successful in achieving PCP degradation. We observed that high concentrations of PCP inhibited the growth of sulfate-reducing bacteria isolated from groundwater. Groundwater sulfate reducers may be more sensitive to the toxic effects of PCP than sulfate reducers isolated from surface waters and soil. However, we observed PCP degradation in the sulfate reducing enrichments after 37 d of incubation when PCP was present at low concentrations.

The subsurface microbial system examined in this study did respond to such recalcitrant substrates as PCP and TBA. However, it may take a long time to induce decomposition *in situ*. The time required to achieve a significant biodegradation response in subsurface soil will be a function of the hydrology, chemistry and abiotic conditions of the aquifer.

Movement and Disappearance of Fungicides in Virginia Soils

R.J. Stipes, D.B. Janutolo, C.W. Conner,
W.H. Elmer, R.M. Cu, and M.J. Weaver
(Presented by R.J. Stipes)

Problem Statement

Fungicides constitute one class of pesticides applied in large amounts in the southeastern Virginia cropping area where they eventually can become a component of the water pollution complex of the Chesapeake Bay and its tributaries. For example, 228 tons of chlorothalonil (Bravo) fungicide are applied per growing season for the control of only one disease on one crop (early leafspot of peanut) in southeastern Virginia. Its fate on plants, in soil and groundwater and in watercourses is unknown, not to mention its effect on soil microflora and microfauna or its interaction with other pesticides. In order to clarify the impact of fungicides, soil movement and disappearance phenomena where investigated.

Objective

The purpose of our series of experiments was to monitor the movement and disappearance of fungicides that are either (1) applied directly to the soil for control of "damping off" or other root diseases, or (2) those that are deposited there as a result of application to above-ground plant parts such as leaves and stems for the control of leafspot and stem or crown lesions. In additional studies, we observed the effect of certain fungicides on population densities of the soil microflora, specifically bacteria (including Actinomycetes) and fungi.

Methods and Materials

Raw soils, that is, freshly sampled soils from either cultivated or uncultivated fields in taxonomically documented soil areas were used in all cases. Soils most commonly employed were Woodstown loamy sand, representative of the southeastern Virginia cropping area near Suffolk and in which peanuts, corn and soybeans are commonly planted; and Lodi loam that occurs in the Virginia highlands. On occasion, other types intermediate in soil texture were used.

Soil mobility was assayed by soil thin-layer chromatography (STLC) and the standard soil column percolation technique. For STLC, glass plates were coated with a 500 micrometer layer of the candidate soil, applied as a mud slurry and allowed to dry. Fungicides were spotted, the plates irrigated with water and the STLC "developed" by bioautography in which a fungicide-sensitive fungus in a nutrient solution is sprayed onto the chromatogram and the plate incubated to allow growth; fungicide mobility levels were determined from Rf values. In soil column tests, fungicide suspensions or solutions were percolated through segmented polyvinylchloride "pipes" or columns filled with candidate soils. Fungicide residues were extracted from soil samples removed from column sections and quantified by standard dosage/response curve techniques when possible.

For soil disappearance (degradation) monitoring, raw soils were amended with fungicides, incubated at various temperatures and times, treated to release residues and the residues quantified. Microbial populations were determined by standard soil microbiological procedures by removing microflora in water suspensions and plating them on selective media that permit the growth of the desired microbial group(s) to be monitored.

Fungicides from four chemical classes were used: (1) dicarboximides — captan and difolatan; (2) imides — dicloran, iprodione and vinclozolin; (3) benzimidazoles — benomyl, carbendazim, and their hydrochloride, phosphate or hypophosphite salts and (4) the acylalanine compound, metalaxyl.

Results

Benzimidadoles were either immobile or poorly mobile in soil, while their salts were significantly more mobile. Tween surfactants greatly enhanced mobility. Iprodione and vinclozolin were mobile in all soils, whereas their analog, dicloran, was relatively poorly mobile. The dicarboximides, captan and difolatan, were both moderately mobile, with captan being more mobile and percolating to a 20 cm depth in the soil columns. Metalaxyl is highly mobile in all soils tested, and percolated readily in soil horizons with high clay content. All compounds degraded in soil (Figure 1A, B, C), due to hydrolytic reactions or to microbial attack in which enzymatic cleavages readily occur. None of the fungicides could be considered as highly residual or "hard." Enhanced biodegradation phenomena were observed with metalaxyl. Some of the fungicides affected soil microflora, while others (benzimidazoles) had no appreciable effect (Figure 2).

Research Implications

Fungicides, as one component of the pesticide complex, constitute a pollution concern to the waters of Virginia. Little is now known of their contributory impact in the overall agricultural industry in Virginia, especially in the southeastern sector where cropping activities are extremely intense and where pesticides, not to mention fertilizers, are deposited by the tons. The interactions of fungicides with other pesticides are virtually unknown. Much remains to be investigated in this relatively unresearched area of soil and water fate of fungicides used in Virginia.

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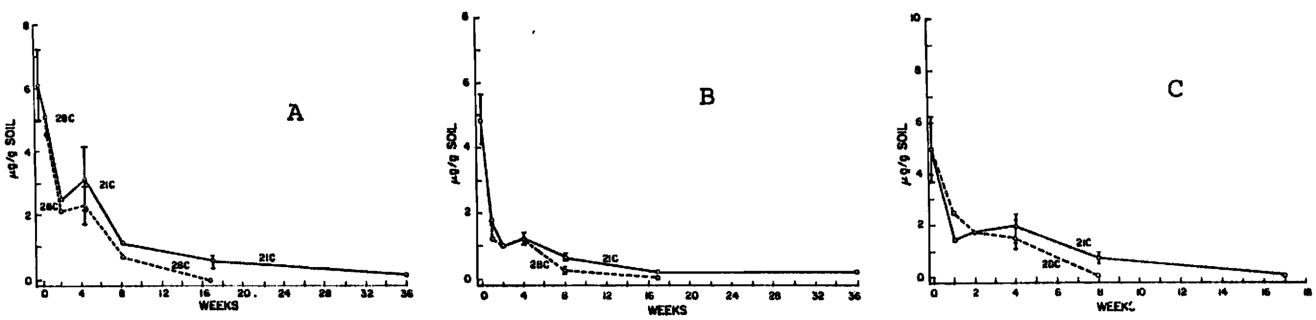

Fig. 1. Disappearance of residues of dicloran (A), iprodione (B) and vinclozolin (C) in Lodi loan soil incubated at 21 and 28° C after a 6-μ/g soil incorporation.

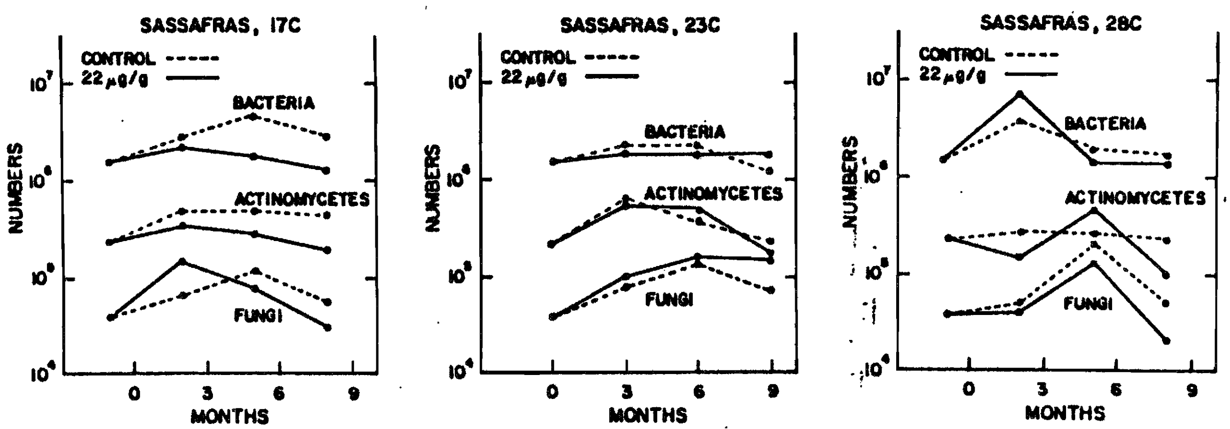

Fig. 2. Effect of carbendazim phosphate incorporated at 22 μ/g in Sassafras soil, horizon A, on microbial populations during incubation at three temperatures.

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