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Project Summary

River Basin Validation of the Water Quality Assessment Methodology for Screening Nondesignated 208 Areas: Volumes I and II

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Techniques for estimating diffuse nutrient loads and their water quality effects throughout large watersheds were tested under various field situations for a wide range of data availability circumstances, water quality parameters, and hydrologic-hydraulic conditions. Loadings were calculated using methods from *Loading Functions for Assessment of Water Pollution from Nonpoint Sources* (EPA-600/2-76-151) for five river basins, including the Sandusky River in Ohio, the Chester and Patuxent Rivers in Maryland, and the Ware and Occoquan Rivers in Virginia. Water quality response to these loads was calculated using methods from *Water Quality Assessment — A Screening Method for Nondesignated 208 Areas* (EPA-600/9-77-023) for the Sandusky, Chester, Patuxent, and Ware rivers and estuaries.

Obtaining sufficient data to operate the model was the biggest problem in applying the loading methodology to specific river basins. Given the inherent inaccuracy in the basic Universal Soil Loss Equation (USLE) approach, use of the national data base provided in the original document was justified, especially if supplemented with specific county cover (R) factors. Despite the inaccuracies resulting from the use of a national data base, two to three person weeks of effort per basin should produce useful inputs to water quality screening assessments.

The loading methods and the water quality methods tested in this study were highly compatible and gave reasonably accurate predictions of instream, lake, and estuary water quality constituent concentrations. The river modeling methods are the most accurate, followed by the techniques for estuaries and then impoundments. Low flow, steady state conditions are better predicted than high flow, unsteady loading situations. Applying these techniques, the watershed management planner should be able to recommend appropriate actions to investigate pollutant problem areas more closely in specific watersheds.

This Project Summary was developed by EPA's Environmental Research Laboratory, Athens, GA, to announce key findings of the research project that is fully documented in two separate reports (see Project Report ordering information at back).

Introduction

In August 1977 the U.S. Environmental Protection Agency (EPA) published *Water Quality Assessment — A Screening Method for Nondesignated 208*

Areas (EPA-600/9-77-023) This document is a compendium of techniques designed to aid in the assessment of water quality problems in large areas that encompass a wide spectrum of human activities and water quality conditions These include agriculture and silviculture, as well as industrial and municipal activities. In this Water Quality Assessment Methodology (WQAM), Tetra Tech, Inc., under EPA contract, brought together a number of methods designed to accommodate both urban and non-urban nonpoint sources, as well as municipal and industrial point sources of pollutants. In addition to the assessment of effluent water quality, WQAM provided for systematic routing of these pollutants through rivers and streams, impoundments, and estuary systems All algorithms were designed to be used as hand calculation tools.

In a separate study, Midwest Research Institute, under EPA contract, developed methods for estimating diffuse loads entering receiving waters. The study was described in *Loading Functions for Assessment of Water Pollution from Nonpoint Sources* (EPA-600/2-76-151).

The primary goal of the study described in this Project Summary was to demonstrate Midwest Research Institute's loading functions and Tetra Tech's water quality screening procedures under authentic field situations. The demonstration was designed to subject the procedures to a wide range of data availability, water quality parameters, and hydrologic/hydraulic situations. In addition to the primary goal, secondary goals were to:

1. Provide a report demonstrating the WQAM, to be used as a guide by planners.
2. Show the degree of compatibility between the nonpoint-loading methods and the water quality screening methods in the WQAM.
3. Develop firmer insight into the strengths and weaknesses of the nonpoint loading methodology.
4. Evaluate the sensitivity of nonpoint load estimates to varying degrees of data availability.
5. Determine how critical or necessary the quality and quantity of nonpoint source details are with regard to reliably modeling instream processes as they are affected by nonpoint loading.
6. Demonstrate strengths and weaknesses of the WQAM screening methodology.

Five river basins were examined. These are the Sandusky River in Ohio, the Chester and the Patuxent Rivers in Maryland, and the Ware and Occoquan Rivers in Virginia. Loading analyses were also performed on the Potomac River Basin and the Susquehanna River Basin.

This summary describes work reported in two volumes — *River Basin Validation of the Water Quality Assessment Methodology for Screening Nondesignated 208 Areas, Volume I. Nonpoint Load Estimation; Volume II. Chesapeake-Sandusky Nondesignated 208 Screening Methodology Demonstration.* Volume I is a discussion of the application of the nonpoint load assessment methodology to a number of river basins Volume II considers the application of the water quality screening methodologies to these same basins. The nonpoint source load estimates given in Volume I were used as inputs to the calculations involving wet weather conditions that are presented in Volume II The two volumes are organized similarly; the river basins were considered in the same order in both. There is cross-referencing in Volume I to portions of Volume II so that the interested reader can see how results obtained in Volume I are used in the second volume.

Although the two volumes are related, each can stand alone as a separate demonstration of the different methodologies.

Volume I

Data Availability — Application of the nonpoint source loading methodology requires a large volume of data in spite of the relative simplicity of the overall approach Therefore, a major problem in this, and probably in any other, application was data availability. A screening analysis should by its nature not require the generation of significant quantities of new data. Those data that are used in the analysis should already be available and should require a minimum of manipulation prior to use. For example, the Sandusky Basin has been well studied, but there was a definite lack of applicable data readily available for this study. Generally, the available data were aggregated to the county level, e.g., land use information. Also, as might be anticipated, in all the basins there was a problem in estimating sediment delivery ratios. Long-term sediment yield data were generally not available for the basins, therefore, average delivery ratios could not be properly estimated. Furthermore, there was a lack of the sediment yield data needed to define variability within the basins. Finally, there was generally, no way to estimate how average delivery ratios might vary with the season. Use of a single average value for the delivery ratio could result in a considerable over- or underestimation of loads for particular subbasins and seasons. This difficulty was nearly universal It was, in fact, a problem of less concern in the Sandusky Basin than for most basins because some sediment measurements were available and because the efficiency of delivery is thought to be relatively uniform throughout the basin Information on pollutant loading rates and pollutant characteristics in urban areas was also not readily available. It was purely a matter of chance that actual measurements were available for use in one of the urban areas (Bucyrus) in one of the basins (Sandusky)

Value of Parameter Refinement — The most important parameter refinements involved land use data and the R, K, and C factors in the universal soil loss equation The national data base used provided R values by the Land Resource Area (LRA). These could easily be replaced by values that more nearly represent each county For example, in the Sandusky, the change was from an annual value of 150 to 125. (Of course, individual event values were calculated for use in the demonstration) Cover (C) factor values were also changed by the refinement process. The C values used for the individual counties reflect changes in the stage of crop growth, which is an improvement over the average annual C values in the data base The level of resolution of soil erodibility values was improved from the LRA level (in the data base) to the county level. In some cases, resolution was at the subbasin level. As much as a 20 to 40% decrease in erodibility value was noted for some subbasins in the Sandusky due to refinements in the K values Land use changes in that basin mostly increased soil loss in the interval between 1967 (data base) and the base year used in the individual basin calculations.

On balance then, as compared to the data base values, the refinements for the Sandusky led to decreases in R, K, and C and, therefore, to a decrease in annual soil loss over that which would be obtained using the data base. Land use changes partially offset the decrease. Again, using the Sandusky Basin as an example, in six out of the eight counties, average soil losses decreased by 20% or more due to the refinements. Given the level of effort required to produce the refinements and the inherent inaccuracy in the approach, the use of the data base is a cost-effective approach. For annual soil loss calculations in the basins studied, the original data base would provide useful results (as compared to the refined values) if one merely modified the R factors for each county and accounted for the major change in cropland. That is, a significant improvement was possible in this case with only a limited amount of effort.

Certain problems occurred in the attempt to improve the estimates for some of the parameters, as already noted. A particular problem was estimating sediment delivery ratios, a problem that was exacerbated in the case of individual subbasins. Reasonable estimates of delivery ratios were essential for accurate estimates of sediment delivered to a stream. Lacking a general approach to the problem, the delivery ratio issue will continue to frustrate many applications of the methodology. Although less difficult, problems also occurred with other parameters as well. The LS and the P factors in the USLE were not modified and were used directly from the existing national data base. Improvement of the estimates used requires substantial information on topography and soil conservation practices in each basin. As already noted, data on the loading rates for pollutants on city streets were generally lacking and recourse must be made to tabulated, crude averages.

Sensitivity Analysis — In the case of urban nonpoint loads, the important matter of sensitivity to assumptions was considered. The major problem centered on determination of street loading rates and use of an annual average approach. For rural nonpoint loads, the various factors used in determining sediment of nutrient loads (except rainfall inputs) were multiplied together to obtain the final result. Therefore, uncertainties in the factors were multiplied. For example, for sediment loads, a 20% error in each factor involved in determining the load gave approximately a 300% error in the load, assuming no compensation among the errors. Similar errors in the case of nutrient calculations yielded a total error of about 400%. Because most of the factors could not be determined with an error of less than 20%, the possible error in the results could be quite large unless there is compensation among the errors. This fact indicated that the results obtained are always rather uncertain.

Uncertainties in land use information in the present application related primarily to the resolution of the information. Agricultural land use data were generally available; however, they were at the county level of resolution. Therefore, specifying land use conditions in a subbasin was difficult. The primary need in land use data was for accurate specification of the cropland — its area and type of crop. Land use affects pollutant load calculations through the C factor in the USLE. In an application in which a pollutant load was needed for a subbasin that covers a fraction of a county and in which land use and other data were available only at the county level of resolution or lower, the loads may be grossly overestimated. This overestimation could occur in a subbasin for which a higher than average fraction (for the county) is cropped, for which slopes are steeper than average, or for which there are no conservation practices applied (P = 1). Poor resolution of needed data can result in substantial errors for particular locations within a basin.

Results were also somewhat sensitive to errors in describing agricultural practices in a basin. The significance of errors in practices related primarily to the problem of timing of agricultural operations and, therefore, the degree of cover on the ground at particular times.

In summary, errors in results were directly proportional to errors in the various parameters used in the analysis because they are multiplicative. Assessment of sensitivity to errors in the description of practices or land use, or the degree or resolution in the available data is an involved exercise that will yield results that vary considerably from basin to basin. Such variability was anticipated because of different rainfall patterns and the degree of non-homogeneity of land use among basins.

Level of Effort Required in an Application — Application of the nonpoint load estimation methodology to basins such as those examined in this study should require on the order of two to three person weeks of effort per basin. This estimate assumes an analyst familiar with the procedure and with the general subject of rural nonpoint source loads. It also assumes familiarity with use of the nonpoint calculator program. The availability and use of more extensive data than considered in this demonstration would increase the time required. Report preparation is not included in the time estimate.

Verification of the Load Estimation Procedures — Considering the lack of measured nonpoint loads (both rural and urban) available for comparison and the long-term average nature of the estimates that have been made, verification of the procedure by direct comparison with measured loads was quite difficult. Comparison with measured instream concentrations was a more promising approach. The results presented in Volume II indicate the level of verification that can be expected for the approach used, particularly in the case of the Sandusky Basin.

Future Applications — In the present study, considerable effort was expended in selecting a series of events for each basin so that consistent flow data were available for use in the instream assessment. This effort was necessary to assure compatibility and to allow an attempt at verification of the results. In actual applications, such a selection of actual events may be unnecessary. A possible approach would be to define typical average events for various stages in cover occurring throughout the year. These "typical" events could be equivalent to events that produce some fraction of the total soil loss that occurs during some fraction of the year. The information needed to define such an event is available in terms of the annual distribution of the R factor. Therefore, in an application it is possible to consider design storms with characteristics that can be defined independently of an actual watershed.

Load Estimation in Specialized Application — Volume I provides an example of the application of much of the basic rural nonpoint source methodology to the problem of estimating long-term nutrient fluxes in streams. This application showed that the procedures can be applied in ways that overcome some of their fundamental weaknesses (e.g., the need for a delivery ratio), while providing useful results. It is likely that other specialized applications can be developed also.

Attainment of Study Goals — The primary goal of the study was to demonstrate the nonpoint loading methodology under actual field conditions. This goal was accomplished. The nonpoint loading procedures and the water quality screening methodology were also shown to be compatible, which was one of the subgoals of the program.

The application under field conditions pointed out the primary strengths of the methodology — its relative simplicity and the ease with which basic calculations can be done — and its weaknesses — dependence on a delivery ratio, a higher level of special aggregation in the case of practical applications in large basins, and the need for large amounts of data. These characteristics were well demonstrated in the studies of the various basins, which illustrated the degrees of data availability likely in practice. These applications indicated that major parameter refinements tend to be time consuming and, in many cases, of limited value. They also indicated the difficulty of determining or assigning sediment delivery ratios in most cases.

Impact of Methodological Shortcomings — Several important features in the rural nonpoint methodology limited the accuracy that can be expected from the results of an assessment. These features include: (a) a high level of spatial aggregation in the analysis — an important fact because the USLE is intended for rather small, homogeneous areas, (b) the use of a delivery ratio to account for sediment transport; (c) the assumption that pollutants such as phosphorus are associated with sediment, and (d) the long-term average, nonhydrologic nature of the USLE

An attempt was made to overcome the lack of suitability of the USLE for analyzing actual events by averaging over many events. Dealing with an average event in this manner was acceptable, however, proper averaging required many events occurring over a long period of time. Data were not always available to carry out such averaging.

Additional shortcomings occurred in the urban methodology used, which dealt with annual loads and which depended upon street loading rates that were not well established.

A screening methodology such as was applied here is intended for relatively easy application using existing data. Overcoming some of the limitations listed above would require greatly increased amounts of data to reduce spatial resolution problems, to provide increased information on sediment transport, and to provide data on runoff needed to allow soluble forms of constituents to be included and to allow a more hydrologically-based approach. Because this demonstration illustrated the fact that needed data may not be available even for the screening approach used, it seems reasonable to conclude that more rigorous approaches can result in even more obstacles due to data limitations, especially when large areas must be considered.

Table 1. *Water Quality Simulation Results Summary for Rivers*

	System	
	Sandusky	*Patuxent*
LOW FLOW		
Temperature	●	●
BOD	*	●
Dissolved Oxygen	●	●
Coliforms	*	*
HIGH FLOW		
Sediment	⊙	
BOD		
Total N		
Total P	⊙	

Key:

● *Results good to excellent*
⊙ *Results fair to good*
* *Simulation performed, no comparative data available*
(blank) No simulation performed

The users of the nonpoint methodology should be well aware of its limitations. These limitations, however, should not prevent the use of the approach. As the present study showed, applications can be made that result in useful inputs to water quality assessments in spite of certain methodological shortcomings of the procedures used The user should always recall that the methodology was intended for screening purposes.

Volume II

Applicability of Techniques — The nonpoint source calculator and the non-designated 208 screening methodology were highly compatible. Outputs from the nonpoint source calculator were easily adapted and in some cases were used directly in the mass balance equations of the screening methods. Event-based urban nonpoint loads were not readily predictable by the nonpoint calculator, but it is questionable whether the non-designated 208 screening methods are applicable under these high flow - unsteady loading scenarios except to provide approximate upper and lower limits of instream pollutant levels.

Loading predicted by the nonpoint source calculator in conjunction with mass balance techniques employed by the non-designated 208 screening methods provided reasonably accurate predictions of instream, lake, and estuary water quality constituent concentrations No effects due to basin size or location were noted that detracted from either the applicability or accuracy of the methods. Generally, loss of accuracy due to a loss in resolution was mitigated by the averaging effects intrinsic to larger systems.

A qualitative assessment of the rivers, estuaries and impoundments methods is shown in Tables 1, 2 and 3. In general, the tables imply that the river methods were the most accurate followed by estuaries and then impoundments. Within each method it should be mentioned that low flow - steady state conditions were more readily reproducible than high flow - unsteady loading situations. The impoundment methods probably required the least time and background skills to apply The riverine methods usually required more time to apply than the estuary methods. The riverine results, however, should be easier to interpret for the uninitiated user than the results of the estuary methods.

Loadings predicted by the nonpoint source calculator in which all parameters were assumed to be correlated with sediment loss were more accurate for sediment and phosphorus than for nitrogen and BOD_5. This was an expected result. In general, predicted nonpoint source nitrogen and BOD_5 loads were too low based on comparison of observed and predicted instream concentrations.

For conservative parameters, linear increases or decreases in load estimates (either point or nonpoint) resulted in approximately linear changes in the concentrations of those constituents in the water bodies. Therefore, an approximate error analysis could be performed directly using load estimates. For nonconservative parameters, changes in stream, lake, or estuary concentrations caused by increases or decreases in loadings could only be determined by routing the pollutants through the receiving water system. An error analysis using loading changes and assuming the constituents behaved conservatively gave an upper limit for the concentration changes likely to be encountered.

Table 2. *Water Quality Simulation Results Summary for Impoundments*

	Occoquan
IMPOUNDMENTS	
Temperature	●
BOD	⊙
Dissolved Oxygen	⊙
Sediment	●
Total N	●
Total P	●

Key:

● *Results good to excellent*
⊙ *Results fair to good*

Although the methods appeared to be a powerful tool for quickly identifying water quality problem areas, the use of the predictive techniques in conjunction with observed data further added to their effectiveness. By doing this, the planner could identify specific problem areas in which quality cannot adequately be described by the simple techniques. In most cases, the planner will be able to recommend action, based on an understanding of the methods he has already applied, to investigate the problem area more closely. These further investigations may include sampling programs or the use of a more sophisticated analytical tool

Rivers and Streams — Hydraulic characterization of rivers and streams was one of the most error-prone steps in the methods A major reason for this was that flow, in many cases, was a function of phenomena that could not be estimated directly from the surface topography Unless the user had groundwater measurements or detailed potentiometric maps, these effects could not be properly characterized.

Table 3. *Water Quality Simulation Results Summary for Estuaries*

	System		
	Chester	*Patuxent*	*Ware*
LOW FLOW			
BOD	⊙		⊙
Coliforms	*		
Total N		●	●
Total P		●	
HIGH FLOW			
Sediment	*		⊙
BOD	O		O
Total N	⊙	*	⊙
Total P	*	*	⊙

Key:

● *Results good to excellent*
⊙ *Results fair to good*
O *Results poor to fair*
* *Simulation performed, no comparative data available*
(blank) No simulation performed

Dissolved oxygen prediction was far more sensitive to errors in estimating *reaeration rates than in estimating* deoxygenation rates Predictive techniques for stream reaeration deserve additional attention Comparison of predicted instream fecal or total coliform concentrations with observed data was impractical

Impoundments — Thermal plots from the impoundment thermal model accurately described water temperature, thermal gradients, and time of the onset of stratification The greatest difficulty in using the thermal profiles lay in the selection of the correct plot to apply in a borderline case In such cases, selection of the maximum depth parameter was aided by also considering the mean impoundment depth. The hydraulic residence time strongly affected the thermal profile of an impoundment.

Accuracy of sedimentation calculations for impoundments depended primarily on accurate load estimates. Although on-site data should be used, the demonstration watershed results indicated that the Universal Soil Loss Equation may be used with some confidence. Adequate knowledge of sediment diameters is required because trapping efficiencies were sensitive to particle size

The ability of the methods to quantitatively predict parameter values associated with eutrophication was limited Plant growth could only be approximated and seasonal effects could not be represented adequately

The hypolimnion dissolved oxygen calculations for impoundments were sensitive to the BOD loading rate and decay rates Qualitatively useful results were predicted by the simplified hypolimnion dissolved oxygen model even when BOD decay rates were not accurately known.

Estuaries — The stratification-circulation method was preferred for estuarine classification, but the required data was not always available To obtain a complete picture of the hydrodynamic variation that an estuary might undergo, the surface velocity, the net freshwater velocity, and the surface and bottom salinity should be available for high and low freshwater inflows Use of the flow ratio method underestimated the degree of vertical stratification.

The tidal prism and modified tidal prism flushing times were related, and their ratio seemed to depend on the estuary volume. The fraction of freshwater method was fairly insensitive to the number of segments used to estimate flushing times. For flushing times derived by the modified tidal prism method that were similar at high and low flows, mechanisms other than advective flow were more important in flushing an estuary The fraction of freshwater and the modified tidal prism methods predicted more similar flushing times for small estuaries

Low flow predictions of pollutant distributions in estuaries were good for conservative constituents. For nonconservative constituents, the modified tidal prism method must be used. Pollutant distributions predicted for unsteady flow or unsteady loading represented upper and lower limit concentrations. Contamination in the estuary caused by replacement waters could be estimated by comparing observed profiles to those predicted by the estuarine methods.

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The complete report consists of two volumes, entitled "River Basin Validation of the Water Quality Assessment Methodology for Screening Nondesignated 208 Areas:"
"Volume I. Nonpoint Source Load Estimation," (Order No. PB 82-260 837; Cost: $15.00, subject to change)
"Volume II. Chesapeake-Sandusky Nondesignated 208 Screening Methodology Demonstration," (Order No. PB 82-260 845; Cost: $19.50, subject to change)

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