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Guide to Nonpoint Source Pollution Control

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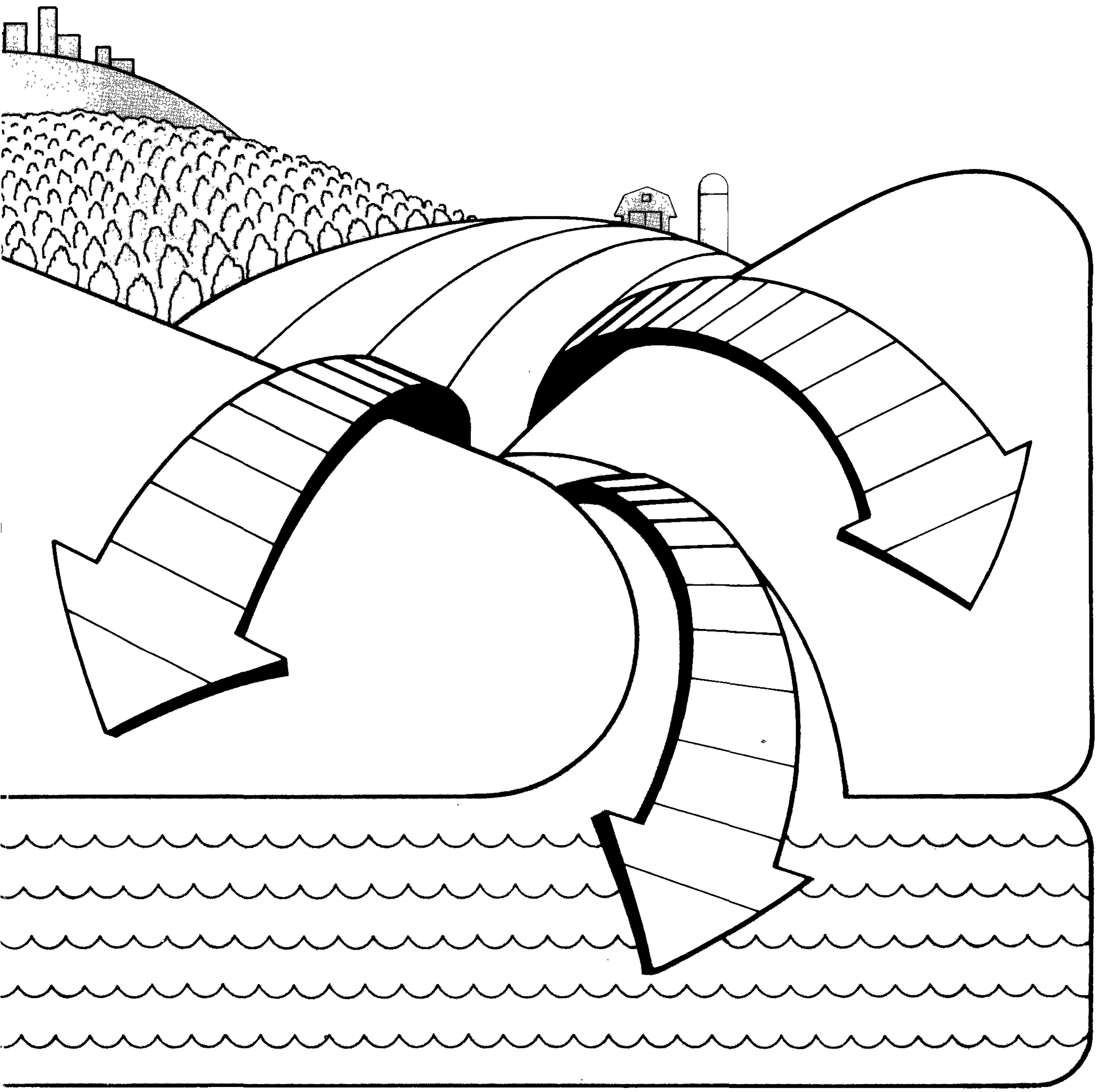

Controlling Nonpoint Source Pollution

a guide

U. S. Environmental Protection Agency
Criteria and Standards Division
Washington, DC

1987

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COVER ART: David Stolar.

Contents

Foreword

This document is designed as a user's guide to the techniques now available for controlling nonpoint source pollution. The reader will find first a general evaluation of nonpoint source modeling and other techniques, followed by a chapter assessing models now in use, and a third chapter summarizing best management practices.

Sources of information used are listed at the conclusion of the text. In the third chapter, end notes are used to substantiate studies referred to in the discussion of best management practices.

This is not, however, a literature search or a summary of research; rather, it has been developed by intensive research and distilled into a practical guide for the decisionmaker who must choose from among many techniques for approaching nonpoint source pollution control.

Introduction

Under the Clean Water Act of 1972 this Nation has steadily progressed toward attaining its national water quality goals—but now that we have regulated the disposal of municipal and industrial waste, we find that our waters still suffer from pollutants. It has been easy to understand how waste flushed into a city's sewers—or discharged directly by a manufacturer—pollutes the water it enters. So, using the provisions of the Clean Water Act, we have cleaned up the waste that continuously pours from pipes.

Unfortunately, only half of our pollutants come from pipes—the rest come from nonpoint sources: our land, our fields, our streets. One might explain the difference between point and nonpoint as "pipe" and "non-pipe," but the real difference lies in the word "continuous." Nonpoint source pollution is extremely variable—because nonpoint source pollution occurs only when it rains.

Rain washes pollutants from our land into our water. Moving water is the driving force; however, the pollutants that enter the water result directly from man's activities on the land, and therefore, vary greatly both by time and space. For example, manure deposited and frozen on an open field during the winter probably won't release its nutrients into a nearby lake until spring, when the thaw is followed by rain.

Understanding this relationship between hydrology and the variability of the specific circumstances is the key to understanding nonpoint source pollution. This relationship dispels the mystery of nonpoint source pollution. While it may not lend itself to traditional collection and discharge control methods, nonpoint source pollution can be analyzed statistically. And that analysis can point the way to the solutions—which can be as diverse as the problems.

Diverse, nonpoint point sources may be, but complex they are not. They must be approached on a logical basis, and they must be solved by us all. Obviously, we cannot maneuver all the nitrogen and phosphorus running off a 40-acre (or even 1-acre) field into a sewage treatment plant that removes these nutrients before they enter the water. Absurd as that task may be, so is placing the sole responsibility for water pollution control on county and State employees hired to do the job.

The water professional's first task is to educate his public. The terms "runoff" and "nonpoint source pollution" must become as familiar to the citizen as "sewers" and "pipes." Citizens must understand that runoff originates in their yards, on their farms, and in their streets, and that when they change some of the ways they do things, they prevent this pollution. The widespread insistence on nonphosphate detergents is an example of public acceptance of such a challenge.

Backed by a knowledgeable public, State and local governments can develop management strategies to control nonpoint source pollution. Although nonpoint sources vary by area, agricultural pollutants are the most pervasive, with urban sources next in importance. In addition, runoff from highways and waste disposal sites, failed septic systems, mining and logging activities, and construction sites all contribute to the problem.

Pollutants carried by these nonpoint sources can be grouped by source and effects:

- **Sediments** resulting from erosion (of both cropland and streambanks), livestock activities, and construction site runoff comprise the greatest volume by weight of materials transported. Sediments—and the pollutants they carry—eventually affect recreational, industrial, and municipal water uses as well as aquatic habitats. Sediments can also fill reservoirs, harbors, and navigable waterways, often necessitating dredging.

- **Fertilizers**, phosphorous and nitrogen, are found in both point and nonpoint discharges, and are largely responsible for accelerating the aging and decay (eutrophication) of lakes and streams. Often, large quantities of organic matter such as manure carry these nutrients into the water. The nutrients in themselves are not pollutants: their effects depend on the chemical form of the material, the concentrations, and the physical properties of the receiving water.
- **Pathogenic** (disease-bearing) microorganisms are introduced from agricultural sources such as livestock feedlots and from leaky septic tank systems and leach bed systems. Although urban stormwater runoff also contributes measurable bacteria, most bacteria originate from animals rather than humans. These microorganisms may encourage the spread of infectious diseases, eventually creating a major public health problem.
- **Pesticides**, herbicides, metals, and other toxics, particularly from agriculture, silviculture, mining, and lawn and landscape care not only threaten surface water but are also being found with increasing frequency in ground water. Where the surface is permeable, the water percolates downward, carrying materials in solution with it. Harmful pollutants carried down into the soil can become fixed to clay or soil particles, perhaps eventually entering a groundwater aquifer. Mining may expose toxic metals that can then be mobilized, usually through the high acidities associated with mine drainage. In northern climates, trace contaminants in road salts also contribute to the release of some metals. Since ground water is used more and more for irrigation, livestock, and human consumption, the effects of these toxic substances must be controlled.

In the 15 years that have passed since the Clean Water Act took the first concrete step toward coping with the pollution of our Nation's

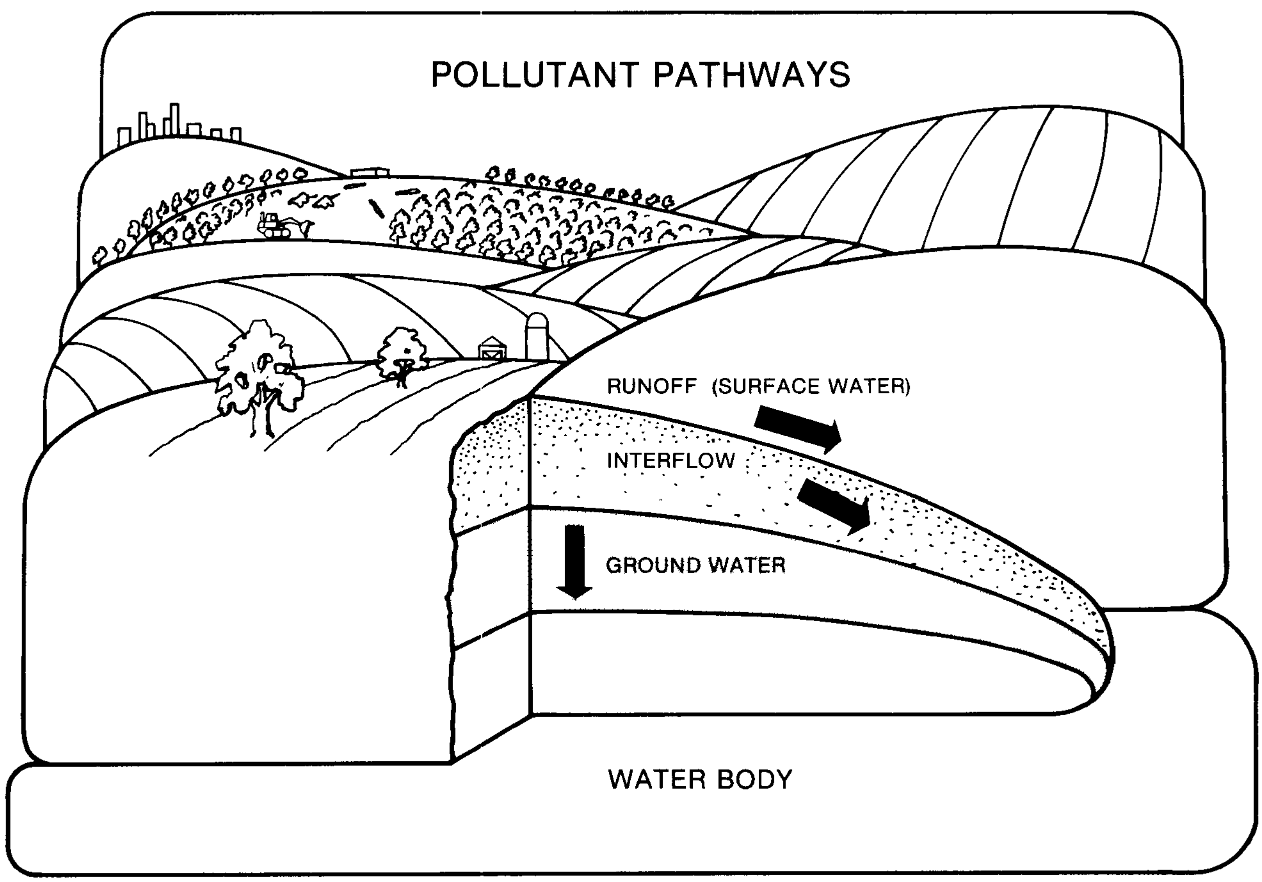


Figure 1. —

waters, we have largely controlled point sources, and learned a great deal about nonpoint sources.

Nonpoint source pollution affects far more than the water clarity: studies demonstrate that controlling nonpoint source pollution produces economic benefits even beyond the obvious relationship between apparent lake water quality and its use by swimmers and boaters. For example, farmers can reduce cultivation costs by using conservation tillage; communities can cut dredging costs and improve recreation by controlling runoff to decrease siltation.

Now, we find we must also be aware of the effects of nonpoint source pollution on human health—not swimmer's itch that one can avoid by staying out of the lake, but disease that comes almost invisibly through our drinking water that is drawn from ground water. Ultimately, a team must be formed to solve this problem: an informed public backing alert State and local professionals who are using the most effective technical solutions to reduce nonpoint source pollution of our surface and ground waters.

Evaluation of Modeling and Other Assessment Techniques

Numerous mathematical models and other assessment techniques have been developed to help make reliable and cost-effective decisions about nonpoint source control methods and their costs, and to relate land use to pollutant transport and effects on water bodies. This section identifies criteria for selecting and evaluating these decisionmaking tools, and describes the most useful categories for managing nonpoint source pollution. Particularly emphasized are those techniques that exhibit three key attributes:

- Account for the role hydrology plays in influencing pollutant behavior.
- Address spatial and temporal variability in pollutant generation, transport, and delivery.
- Relate contaminant concentrations to best mangement practices (BMPs).

The nonpoint source assessment techniques either employ statistics or simulate the transport process. They use hydrologic characteristics to estimate pollutant delivery to receiving waters from land use in agricultural, silvicultural, construction, and urban areas.

The information developed from these techniques can be used to identify the environmental effects of nonpoint source pollution. For example, by applying a probabilistic analytical technique to determine the effect of urban watershed runoff on instream water quality, the mean recurrence intervals for a specific pollutant's concentrations during storm events can be computed from representative values for the stream and runoff conditions. This information helps identify how often pollutant concentrations occur that could be a problem, for example, to the aquatic organisms in receiving waters. Decisionmakers may use such information to evaluate the effects of alternative urban runoff management practices on water quality.

PHYSICAL MODELS

Nonpoint source models are divided into two categories—physical and decision-oriented (see Figure 2). Physical models address the causes and effects in terms of physical variables of a process, and generally estimate either water quality characteristics or mass transport in nonpoint source pollution. Physical models are based on deterministic or stochastic simulation of relevant physical, chemical, and biological processes. The methods can range from simple techniques that estimate average annual pollutant loadings to ones that predict detailed temporal and spatial distribution of pollutants.

Physical models predict runoff and mass transport. They may calculate annual summaries or time-varying pollutant loadings, and may estimate pollutant concentrations in various environmental media. Physical models do not necessarily address every parameter that affects water quality. Users may modify and adapt them on a case-by-case basis. Many physical models also have been extended to link a nonpoint source pollutant loading rate to different receiving water bodies.

DECISION-ORIENTED MODELS

Decision-oriented models go beyond the physical models to calculate cause and effect relationships in terms of decision variables. They may evaluate the effects of a control practice on water quality and mass transport, and also may analyze its environmental impacts based on different criteria for decisionmaking. A control practice such as urban runoff treatment can be evaluated based on an analysis of its effects (for example, protection of aquatic life).

In listing the attributes of both types of models, Figure 2 shows that decision-oriented techniques may go beyond physical models to also

- stress understanding of relationships between management activities and water quality.
- focus on ecosystems and watersheds rather than on individual environmental components.
- permit the evaluation of options and tradeoffs of combinations of BMPs from both effects and cost standpoints.

Assessment tools such as the fish habitat models (for example, COWFISH used by the Forest Service) are decision-oriented. They are designed to evaluate the effect of changes in the riparian environment (such as might be caused by sediment or grazing) on the aquatic resources.

Another example of a decision-oriented technique is an agricultural nonpoint source model that incorporates BMPs such as sedimentation and erosion control systems, plant nutrient loss control, and agricultural waste management. Some of these models can predict a BMP's effects on the ecology and water quality of receiving water bodies. Other models may include an economic analysis component that permits a decisionmaker to compare capital investment and operation and management costs for various BMPs or combinations of them.

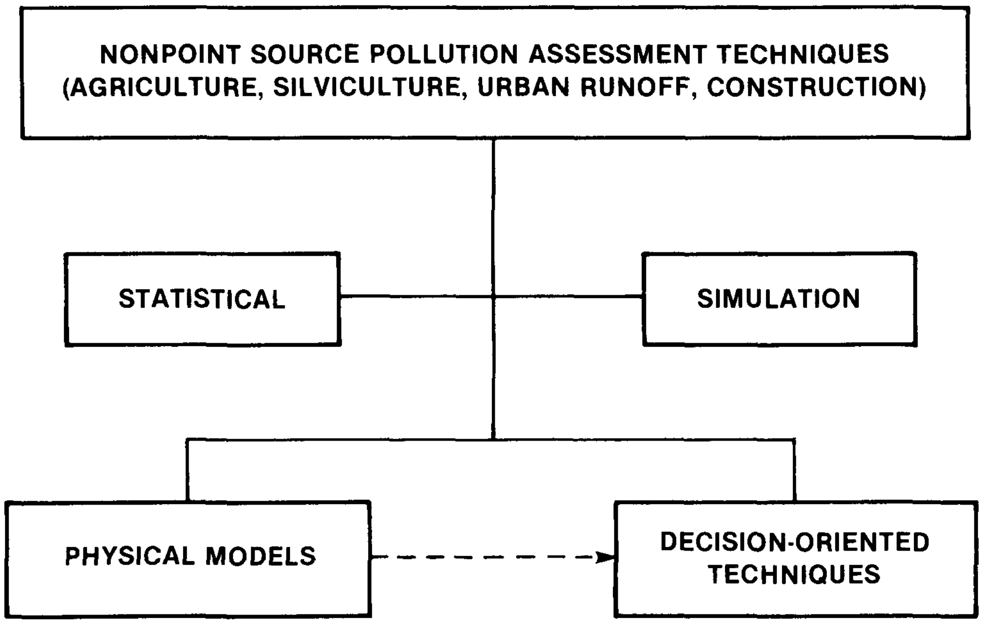
SELECTING THE RIGHT MODEL

The user's specific requirements determine how any model is to be applied. It is important to understand that the two categories may be used together. That is, one may employ a decision-oriented technique to screen a number of different management practices based on a cost-benefit analysis or an environmental impact analysis. Subsequently, physical models can be used to comprehensively analyze the selected processes.

Figure 3 illustrates how to evaluate and select a technique. In this approach, one must first identify those environmental processes and management techniques that may prevent or mitigate the nonpoint source pollution problem. The available models are then characterized as shown in Figure 2. Next, it is important to establish whether the model is operational and has been used successfully. Nonvalidated models should be used only with extreme caution, if at all, because of potential inaccuracies and unacceptability of results.

Validated models should then be evaluated by comparing the information desired with the costs of using the model. Using a pollutant runoff model is worthwhile if the value of the information obtained (ultimately expressed as improved decisionmaking) exceeds the cost of its use. Examples of such values include the model's ability to simulate the parameters (pollutant loadings, runoff, etc.) and the processes (snowmelt, chemical adsorption, biodegradation, etc.) and to assess the effect of BMPs on aquatic environment. An additional value would be an improved data base for future use.

The costs include acquiring the model, collecting data, modifying and calibrating the model, and using it for various scenarios. These values and costs should be carefully studied to determine whether a particular model can achieve the expected goals within resources available.



ATTRIBUTES*:

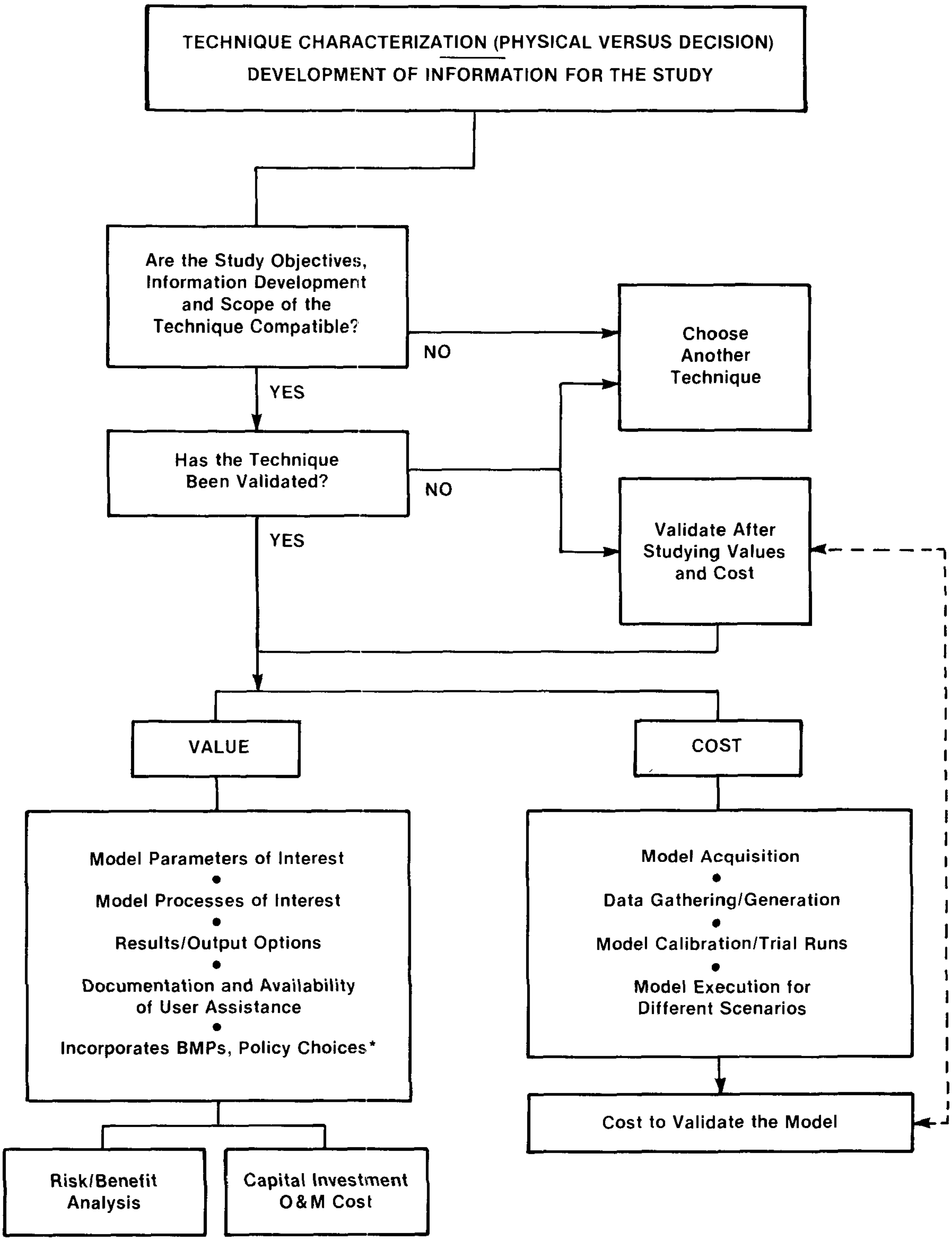
- Predict mass transport and loading
- Calculate average annual or time varying pollutant loads
- Estimate pollutant concentrations in various environmental compartments
- May simulate chemical/physical/biological processes
- May predict water quality changes in receiving bodies

ATTRIBUTES:

- Include BMPs
- Link capital, operation and management cost of BMPs to water quality benefits
- Permit risk/benefit analysis of different BMPs on beneficial receiving water uses
- Address impacts on the environments

*These attributes also may be relevant to Decision-Oriented Techniques.

Figure 2. —



*For Decision Models

Figure 3. — Selection of NPS pollution assessment techniques.

Nonpoint Source Pollution Models

The models discussed in this section estimate one or more of the following parameters: (1) runoff, (2) sediment concentrations, and (3) nonpoint source pollutant loads. Although Tables 1 and 2 list both physical and decision-oriented models, only the latter are described here because they focus on implementation. These models are operational, having been used successfully at least once.

A third category, receiving water models, is listed in Table 3. Although they are not developed specifically for nonpoint source pollution, these models can simulate effects on the receiving water—an ability some of the physical and decision-oriented models lack. Decision-makers can use receiving water models to select appropriate implementation models.

The decision-oriented techniques establish relationships between BMPs and water quality, approach ecosystems and watersheds as an integrated whole, and, in a few instances, permit both a cost and benefit evaluation of BMPs. Many of them are modifications of physical models, which are process-oriented, simulating hydrologic, transport, and other physical, chemical, and biological processes.

This assessment of decision-oriented techniques is based on a number of different criteria. Of course, the model should be operational and validated by successful use. Techniques under development or that need further refinement should be assessed after the models are validated.

The capability of the model to simulate the following parameters also needs to be considered:

- Meteorology (rainfall, temperature, snowfall), hydrology (subsurface flow, surface runoff, stream flow), and water body (lakes, estuaries, oceans).
- Spatial (single catchment, multiple catchments) and temporal (annual, event-based, continuous) simulations.
- Land use (agricultural, silvicultural, construction, urban).
- Policy choices, BMPs, and associated costs of implementation.
- Environmental effects on beneficial use of receiving waters.
- Ability to simulate on a field or land management unit basis.
- Extent of input data requirement (detailed, moderate, minimal), type of data, and relative availability.
- Need to modify or calibrate model for specific applications.
- User-friendliness of the model.
- Availability of user's manuals, reports, and support to facilitate implementation of the program.
- Hardware and software required.
- Costs associated with purchasing necessary items, services, and implementation.

Table 1.–NPS pollution assessment techniques/models: physical models.

TITLE	OBJECTIVE
ACIMO	To simulate runoff and transport from agricultural lands
DR3M	To simulate urban watershed runoff, sediment yield and water quality
EPA Screening Procedures	To estimate nonpoint source loads
ILLUDAS	To estimate urban runoff using an event-based analysis
MUNP	To estimate the accumulation of pollutants on urban streets
PRMS	To evaluate the effects of precipitation, climate and land use or general basin hydrology
PRS	To simulate runoff; and other hydrologic quantities
STORM	To estimate the runoff, sediment and pollutant delivery of urban watersheds
UTM-TOX	To estimate the concentrations of pollutants and their fate and transport in the environment
WLFNPS	To estimate runoff, sediment and pollutant concentrations in runoff in large agricultural watersheds

Table 2.–NPS pollution assessment techniques/models: decision models.

TITLE	OBJECTIVE
AGNPS	To simulate sediment, nutrient and pollutant transport in an agricultural watershed
ARM	To simulate runoff and other contributions in streams
ANSWERS	To predict hydrologic and erosion response of agricultural watersheds
CREAMS/CREAMS 2	To simulate hydrologic quantities, erosion and chemical transport
COWFISH	To assess the effect of current and past livestock grazing on associated aquatic resources
ESRFPP (Feedlot model)	To evaluate and rate the pollution potential of feedlot operations
GAWS	To assess the effect of sediment yields on stream habitat and fish populations for planning purposes
GLEAMS	To simulate pesticides and nutrients leaching from agricultural watersheds
NPS	To continuously simulate hydrologic processes
NURP	To evaluate the effect of urban location, management practices, etc. on urban runoff and receiving water bodies
SWAM	To evaluate the effects of different land use and management practices on a small watershed
SWMM: Level I	To estimate runoff and water quality in an urban watershed
SWMM	To simulate runoff, sediment and nutrient transport in an urban watershed
WRENS	To evaluate the alternative management decisions used in silviculture

Table 3.–Receiving water models.

TITLE	OBJECTIVE
CHNTRN	To simulate time varying distributions of sediments and chemicals in receiving waters
CTAP	To account for dissolved and steady-state concentrations of pollutants in the water column and bed sediment
DEM	To simulate the unsteady tidal flow and dispersion characteristics of an estuary
EXAMS	Rapid screening and evaluation of the behavior of synthetic organic chemicals in freshwater ecosystems
FETRA	To simulate the transport of sediments and contaminants in rivers and estuaries
LAKECO	To evaluate the consequences of remedial measures for lakes
MEXAMS	To estimate the quantities of metals likely to be in solution
MichRIV	To simulate the advective transport of dissolved and adsorbed pollutants
Ms. CLEANER	To evaluate nonlinear, nutrient-algae cycles, multi species and phytoplankton
QUAL-II	To simulate the dispersion and flow characteristics of stream systems and rivers
RECEIV-IT	To evaluate receiving water by representing physical properties
SERATRA	To predict distributions of sediments and toxic contaminants in rivers
SLSA	To analyze chemicals in simplified lake and stream settings
TODAM	To simulate sediment transport, dissolved contaminant transport, and sorbed contaminant transport
TOXIC	To simulate the behavior of pesticides in a reservoir and bioconcentration of pesticides in aquatic life
TOXIWASP	To simulate the transport and transformation of organic toxic chemicals in the water column and the sediment of stratified lakes, reservoirs, rivers, estuaries and coastal waters
WASP/AESOP	To allow the specification of time-variable exchange coefficients, advective flows, wasteloads, and water quality boundary conditions
WASTOX	To simulate the transport and transformation of organic chemicals in the water column and the sediment of streams and estuaries

Description

AGNPS is a single-event based model intended to simulate sediment and nutrient transport from agricultural watersheds in Minnesota. It is also being used and tested in neighboring States (principally Nebraska and Iowa), with the intention of adding pesticide simulation. The model works on a cell basis, and the watershed (ranging from 2.5 to 23,000 acres) can be divided into 1-acre elements. *The model predicts runoff volume and peak rate, eroded and delivered sediment*, nutrient (nitrogen and phosphorous) concentration, and chemical oxygen demand in the runoff, and the sediment for single storm events for all the cells in the watershed.

Capabilities

- Compares the effects of various BMPs.
- Analyzes pollutant loads from feedlots.
- Estimates water quality parameters at intermediate points throughout the watershed network.
- Estimates erosion for five different particle sizes (clay, silt, small aggregates, large aggregates, and sand).
- Subdivides transport portion into soluble pollutants and sediment-attached pollutants.

Limitations

- Used only for single events.
- Has undergone only limited testing for pollutant transport.
- Not adequately tested for particle size distribution during transport.
- Does not simulate receiving waters.

Input Data

Classified into two categories: watershed data that includes information that applies to the entire watershed and to the storm event to be simulated, and cell data that includes physical information and parameters based on the land conservationpractice. Data required may be obtained through Minnesota Land Management Information Service (LL45 Metro Square, 7th and Robert, St. Paul, Minnesota 55101), visual analysis, maps, topographic and soils data, technical publications, or the AGNPS manual.

Output Description

The basic output from AGNPS includes hydrology; runoff; and sediment, nutrient, and chemical oxygen demand. The output can be examined for a single cell or for the entire watershed. Detailed sediment and nutrient analyses (weighted and mean) are also available.

Availability

AGNPS is a fairly new model. The manual written by Robert A. Young and others in 1986 provides a list of references for additional data and a number of individuals to contact for further information. The Guide to Model Users is in press. For further information, contact Robert A. Young, Agricultural Research Service, USDA, North Central Soil Conservation Research Lab, Morris, Minn. 56267; phone 612/589-3411.

Resource Requirements

AGNPS is written in FORTRAN IV computer and developed on a Hewlett-Packard 1000 computer. A IBM-PC compatible version requiring 256K memory is available for monochrome screen (version 1.0) or graphics (version 1.1).

Aerial Nonpoint Source Watershed Environment Response Simulation

ANSWERS

Description

ANSWERS is an event-based surface hydrology model that estimates hydrologic and erosion response of agricultural watersheds. The area to be studied must be subdivided into a finite number of square grids, with parameter values specified for each grid. The model simulates interception, infiltration, surface storage, surface and subsurface flow, and sediment detachment, transport, and deposition. Has been extensively validated in the Midwest.

Capabilities

- Can evaluate different erosion control management practices for agricultural lands and construction sites.
- BMPs can be evaluated by modifying soil infiltration values and surface conditions.
- Modular program structure permits modification of existing program code and the addition of user-supplied algorithms.
- Grid analysis allows for consideration of spatial variation of hydrologic and sediment processes.

Limitations

- Simulates only single events.
- Pesticide fate/transport and snowmelt processes cannot be simulated.
- Watershed site is small.
- Does not process on a land management unit basis.

Input Data

Input information for the ANSWERS model contains simulation requirements, rainfall information, soils data, land use and surface information, channel descriptions, and individual element information that includes BMPs.

Output Description

The output listing consists of input data, watershed characteristics, flow and sediment information at the watershed outlet, effectiveness of structural BMPs, net transported sediment yield or deposition for each element, and channel deposition.

Availability

Documentation and user support, including a User's Manual, are available free from U.S. EPA Region V. The ANSWERS program was developed by D. B. Beasley and L. F. Huggins at Purdue University under EPA sponsorship. For further information, contact Professor Beasley, Department of Agricultural Engineering, Purdue University, West Lafayette, Ind. 47907; phone 317/494-1198.

Resource Requirements

Written in Fortran, the program will run either on a PC or a mainframe. Requires a large memory, especially to simulate large watersheds. The data files have been designed to use Soil Conservation Service soil surveys, U.S. Geological Survey topographic maps, and crop and management surveys.

Agricultural Runoff Management Model

ARM

Description

The ARM model simulates the hydrologic, sediment production, pesticide, and nutrient processes on the land surface and in the soil profile that determine the quantity and quality of runoff in small agricultural watersheds. The major components of the model individually simulate the hydrologic response of the watershed, sediment production, pesticide adsorption/desorption, pesticide degradation, and nutrient transformations.

Capabilities

- Can simulate surface runoff, subsurface flow, and snowmelt.
- Both event-based and continuous simulations are available options.
- Includes different management practices.

Limitations

- Application is limited to agricultural watersheds less than 5 km^2 (1.9 sq. miles).
- No channel routing procedures are included.
- Model does not link the cost associated with different BMPs to pollutant loadings.

Input Data

Detailed input data are required for simulating hydrology, snowmelt, sediment, pesticides, and nutrients. Some data must be generated from physical watershed and pollutant characteristics, land surface conditions, agricultural cropping, and management practices. Calibration and verification data are also required.

Output Description

The printout provides summaries of runoff, sediment, pesticides, and nutrient loss in addition to nutrients remaining in the various soil zones. Generally, the output summaries are printed daily or monthly, but can be obtained hourly.

Availability

The model was developed by Hydrocomp, Inc., Palo Alto, Calif., and is available through Tom Barnwell at the Water Quality Modeling Center, Environmental Research Laboratory, U.S. EPA, College Station Rd., Athens, Ga. 30613; phone 404/546-3175. The model is adequately documented.

Resource Requirements

The model has been tested on the IBM 370/168 using the FORTRAN H compiler. The program requires approximately 360K bytes of storage for compilation of the largest subroutine, whereas program execution requires up to 230K bytes of storage, depending on the model options selected. However, Version II of the ARM model has been adapted to run on a Hewlett-Packard 3000 Series II computer, which is substantially smaller than the IBM machines on which the model was developed and tested.

Chemicals, Runoff, and Erosion from Agricultural Systems

CREAMS

Description

CREAMS and CREAMS 2 are field-scale models that simulate surface and subsurface runoff, evapotranspiration, erosion, sediment yield, and plant nutrient and pesticide delivery. One purpose of these models is to evaluate BMPs. User-defined management activities simulated by CREAMS 2 include aerial spraying or soil incorporation of pesticides, animal waste management, and alternative agricultural practices such as minimum tillage and terracing. USDA is modifying CREAMS 2 to make the model more user friendly. The model does not need to be specifically calibrated for a given watershed. Most of the required parameter values are physically measurable.

Capabilities

- Represents soil processes with reasonable accuracy.
- Simulates continuously; considers event loads.
- Can simulate up to 20 pesticides at one time.
- Includes BMPs.

Limitations

- Subsurface drainage is not simulated.
- Data management/handling capabilities are limited.
- Maximum size of simulation area is limited to field plots.
- Receiving waters are not simulated.

Input Data

CREAMS and CREAMS 2 require extensive data on meteorology, hydrology, erosion, and chemistry of the pollutants.

Output Description

Output can be very detailed. Erosion data are available for each element considered.

Availability

Program manuals, tapes, and floppy disks can be obtained from the USDA-ARS Southeast Watershed Research Laboratory, P.O. Box 946, Tifton, Ga. 31793; phone 912/386-3462.

Resource Requirements

The model can be run on mainframe computers (IBM) or on personal computers (IBM-PC, AT&T).

Description

The COWFISH model is designed to assist resource specialists analyze the condition of the riparian environment in relation to past and current livestock grazing management and to estimate the compatibility of grazing with associated aquatic resources. It is not intended to replace presently used stream surveys or fish population analyses. Rather, it uses existing information to derive an initial indication of how livestock grazing may be affecting trout populations.

The model considers six variables in determining a stream's suitability to support trout: (1) the extent of the streambank which is undercut, (2) the extent of the stream edge with vegetational overhang, (3) the extent of the streambank showing bare soil or trampling, (4) stream embeddedness, (5) stream width, and (6) stream depth. Two additional variables, stream gradient and the drainage soil type, are used to calculate fish production and recreational and economic value.

The field value obtained for each variable is converted to a parameter suitability index (PSI) based on principles similar to those developed by the U.S. Fish and Wildlife Service in its habitat suitability index models. The PSI values are then averaged to compare the stream's existing habitat conditions with its potential habitat suitability index.

Capabilities

- Although originally developed for the mountainous regions of central Montana, after some adjustments this model can be used throughout the western United States.
- Can be used to determine stream habitat productivity any time during the season prior to snow cover.
- Can accurately assess current habitat conditions, provided the sampling area is at least 100 feet long.
- Can be used to evaluate larger sections of uniform streams. Data from five sites per stream mile would be needed to provide a 10 percent sampling of the study area.
- Can analyze a wide variety of riparian and stream types (the variation being in dimensions, flow conditions, streambank conditions, and surrounding environment).

Limitations

- Accuracy diminishes when the estimated analysis of grazing effects on fish production does not immediately follow the modeled livestock use.
- Less accurate for use along streams with rocky streambanks that do not follow the natural development of undercut banks.
- When sample areas smaller than 100 feet are used, the results will reflect population numbers only for the immediate area.

Input Data

Requires field data that include descriptive information about the stream, allotment, and sample size being evaluated. Specifically, information is needed on sample size, vegetative type, side valley slope gradient, percentage of undercut banks and banks supporting vegetative overhang, embeddedness, streambank alteration, width/depth ratio, and stream gradient.

Output Description

The printout is in tabular form and contains information on the optimum number of catchable trout per 300 m of stream for (1) optional conditions for this stream and (2) existing conditions. The losses from optional conditions are also displayed, that is, the number of trout per 300 m of stream per year, recreation loss in wildlife and fish user days, and economic loss in dollars per 300 m of stream per year.

Availability

The model was developed by the U.S. Forest Service's Northern Region Wildlife and Fish Habitat Relationships Program. Copies are available from USDA Forest Services, Federal Bldg., P.O. Box 7669, Missoula, Mont. 59807; phone 406/329-3101.

Resource Requirements

The user may obtain the results either manually by following the Guide to the Field Form or through a computer by recording the variables in the field and using the Data General software program developed for this model. The manual procedure provides the flexibility of obtaining the results while still on the site. No programing knowledge is required.

Description

The animal lot evaluation system, developed to evaluate and rate the pollution potential of feedlot operations, consists of two parts: (1) a simple screening procedure that evaluates the potential pollution hazard associated with the feedlot, and (2) a more detailed analysis that is better able to identify feedlots that are not potential pollution hazards. The Soil Conservation Service's curve number method is used to estimate the runoff. Chemical oxygen demand and phosphorous are the two parameters used as the pollutant indicators. The ESRFPP model has been tested in several States. Currently, the Minnesota Pollution Control Agency requires that all animal lots in the State be rated by employing this model.

Capabilities

- Estimates pollutant discharge using simple techniques.
- Can be used as a screening procedure.
- Considers both surface and groundwater pollution potential.
- Evaluates the effects of different land management practices.

Limitations

- Runoff calculations may not be valid for large tributary areas (more than 100 acres).
- Model does not deal with receiving water bodies.
- The discharge point defined in the model may be difficult to apply in the field.
- Potential pollution threats to ground water are treated lightly.

Input Data

Data requirement is minimal. Most of the required data are presented in the ESRFPP manual.

Output Description

The model estimates the concentration of pollutant indicators at the discharge point.

Availability

The method is well documented in the ESRFPP manual. Further assistance is available from Robert A. Young, North Central Soil Conservation Research Lab, Agricultural Research Service, USDA, Morris, Minn. 56267; phone 612/589-3411.

Resource Requirements

All the calculations can be performed using a small desktop calculator. Programs have been developed to use with Hewlett-Packard 67/97/41C, Monroe 325, and Compucorp 327 calculators.

Evaluation System To Rate Feedlot Pollution Potential

ESRFPP

Groundwater Leaching Effects on Agricultural Management Systems

GLEAMS

Description

GLEAMS is an extension of USDA's CREAMS models. GLEAMS simulates leaching of pesticides and nutrients from agricultural watersheds. The leaching behavior of pesticides in root zones has been tested and validated. The model is being modified to incorporate subsurface nutrient transport and the effects of variability in soil porosity at different depths. The GLEAMS model is in development/testing stage. For more information, contact Walter G. Knisel, Jr., USDA-ARS, Southeast Watershed Research Laboratory, P. O. Box 946, Tifton, Ga. 31793; phone 912/386-3462.

Guide for Predicting Salmonid Response to Sediment Yields in Idaho Batholith Watersheds

GAWS

Description

Sometimes referred to as GAWS, this guide is not a computer program. It provides a standard method for predicting the effect of sediment on stream habitat and fish populations for planning purposes. GAWS estimates sediment yields resulting from past activities such as fire, road construction, and logging. On-site erosion is modified according to general characteristics and delivered to a stream channel where it is routed to a critical stream reach—a segment of the stream that biologists select to predict changes in fish habitat, fish embryo survival, summer rearing capacity, and winter carrying capacity. Model outputs are reasonable estimates that are intended to be used with sound biological judgment. The model will help land managers quantify existing and potential impacts and evaluate trade-offs to fish resources from forest management.

Capabilities

- Can determine sediment yields.
- Can predict habitat changes resulting from sediment yields.
- Can predict fish population changes caused by habitat changes.

Limitations

- Average sediment deposition in high gradient streams may not realistically represent deposition in fish habitat.
- The efficiency of high gradient channels for sediment transport may lead to sediment concentration in downstream channels with lower gradient.
- Increased sediment production from land types drained by high gradient channels may have a greater impact downstream than analysis of only high gradient channel drainage would indicate.
- The laboratory-determined response of salmonid fish populations to increased sediment levels that the model uses may not approximate the response in the field.
- The model was developed and tested only for salmonid species associated with the Idaho Batholith. Application in other systems would require testing.

Input Data

The following types of data are needed to operate this model: (1) estimates of sediment yield, (2) substrate core samples to determine existing conditions and natural conditions, (3) measurements of substrate embeddedness in critical reaches, (4) stratification of stream by channel type, and (5) sufficient information on the fish populations.

The following additional types of data would assist in interpreting the results: (1) substrate coring data from several surrounding streams over time, (2) substrate embeddedness for most of the fish production areas, (3) redd count or adult escapement data, (4) fish density/standing crop data, (5) classification of the stream by geomorphic and channel type, (6) stock-recruitment data over time, (7) empirical relationships between sediment yields and fish habitat, and (8) a calibrated watershed model.

Output Description

No special output as such. The step-by-step procedure described in the manual can be used to calculate changes in the fish populations.

Availability

This guide was developed by and may be obtained from the U.S. Forest Service's Northern Region and Intermountain Region, Federal Bldg., P.O. Box 7669, Missoula, Mont. 59807; phone 406/329-3101.

Resource Requirements

Since a computer is not required for using this guide, minimal resources are needed.

Hydrological Simulation Program — Fortran

HSPF

Description

The HSPF is a series of fully integrated computer codes that simulate watershed hydrology and the behavior of conventional and organic pollutants in surface runoff and receiving waters. The processes that affect the fate and transport of pesticides and nutrients from agricultural land are derived from the Agricultural Runoff Management (ARM) model, whereas the sediment delivery algorithms are from the Nonpoint Source (NPS) model. The HSPF contains three application modules: the PERLND (pervious land) and IMPLND (impervious land) modules perform the land and soil simulation for those land surfaces; the RCHRES (reach/reservoir) module simulates the processes that occur in a single reach and the bed sediments of a receiving water body (a stream or well-mixed reservoir). Extensive and flexible data management and statistical routines are available for analyzing simulated or observed time series data.

Capabilities

- Consists of systematic modular framework that allows a variety of operating modes, including continuous hydrologic simulation.
- Nonpoint source loading (including alternative control practices) and receiving water quality simulation are integrated into a single package.
- HSPF can analyze relative contributions and impacts of both point and non-point source loadings; offers options to use either simplified or detailed representations of nonpoint source runoff processes.
- Models risk assessment of the exposure of aquatic organisms to toxic chemicals delivered to receiving waters.
- By adjusting parameters, can include different agricultural management practices.

Limitations

- Calibration is usually needed for site-specific applications.
- A long time period (2-3 months) may be required to learn the operational details of applying HSPF if the user has no prior experience.
- Model does not link the cost associated with different BMPs to pollutant delivery.
- Depending on the extent of model use, computer costs for model operation and data storage can be a significant fraction (10-15 percent) of total application costs.

Input Data

If all modules are selected for model implementation, the HSPF requires an extensive amount of data. The meteorological and some hydrologic data are time series inputs.

Output Description

The HSPF output includes system state variables, temporal variation of pollutant concentrations at a given spatial distribution, and annual summaries describing pollutant duration and flux. A summary of time-varying contaminant concentrations is provided along with the link between simulated receiving water pollutant concentration and risk assessment.

Availability

HSPF is in the public domain and can be obtained from the Center for Water Quality Modeling, Environmental Research Laboratory, U.S. EPA, College Station Road, Athens, Ga. 30613; phone 404/546-3175. The EPA Water Quality Modeling Center provides user assistance on an ongoing basis, periodically scheduling free training sessions.

Resource Requirements

HSPF requires a FORTRAN compiler that supports direct access I/O. Twelve external files are required. The system requires 128K bytes of instruction and data storage on virtual memory machines or about 250K bytes with extensive overlaying on overlay-type machines. It has been installed on several systems, including IBM, DEC, VAX, System 10/20, Data General, MV4000, CDC Cyber, HP3000, HP1000, and Burroughs and Harris.

Description

The NPS model continuously simulates hydrologic processes, including snow accumulation and melt, and pollutant accumulation, generation, and washoff from the land surface. Sediment and other suspended material are used as basic indicators of nonpoint pollutants. Simulates erosion on both pervious and impervious areas.

Capabilities

- Can simulate urban, agricultural, and silvicultural nonpoint source pollution.
- Both event-based and continuous simulations are available options.
- Can simulate nonpoint pollution from a maximum of five different land use practices in a single simulation run.
- Different agricultural and construction management practices can be simulated.

Limitations

- Does not consider subsurface flow, groundwater pollution, or channel processes.
- Simulates only sediment and nutrient transport processes; does not estimate pesticide delivery.
- Does not simulate the relationship between cost of BMPs and runoff as pollutant loadings.

Input Data

Requires extensive input data, including those related to model operation, parameter evaluation, and calibration.

Output Description

The output from the NPS model includes (1) output heading (summary of the watershed characteristics, simulation run characteristics, and input data), (2) time interval output (can be for 15-minute intervals) and storm summaries, (3) monthly and yearly summaries, and (4) output to interface with other models (optional).

Availability

This model, developed by A. S. Donigian and N. H. Crawford of Hydrocomp, Inc., Mountain View, Calif., under U.S. EPA sponsorship, is available through EPA's Water Quality Modeling Center, Environmental Research Laboratory, College Station Rd., Athens, Ga. 30613; phone 404/546-3175. The model is well documented and has been tested for the simulation of nutrient loadings in surface runoff.

Resource Requirements

The NPS model was developed on IBM 360/67 and 370/168 computers. Later, it was adopted to UNIVAC 1108, CDC 6000, and Honeywell Series 32. The computer core requirements for compilation and execution can be as high as 194K and 144K bytes, respectively. With a reasonable level of technical support, it is expected that 2 to 3 man-months will be required to use and apply the NPS model.

Nationwide Urban Runoff Program

NURP

Technique Description

The NURP is not a computer model: rather, it may be considered to be a statistical-based technique that addresses the effects of urban locations, management practices, etc., on urban runoff and receiving waters.

EPA used the NURP to build on prior work on urban stormwater pollution and to provide practical information and insights to guide policy and planning. The NURP program included 28 projects, all of which were involved in one or more of the following activities:

- Characterizing pollutant types and their effects on receiving water quality.
- Determining the need for controlling stormwater pollution.
- Evaluating alternatives for controlling stormwater pollution.

Capabilities

- Includes methodologies and information on urban runoff characteristics and controls, stormwater management, data analysis, results interpretation, and receiving water quality effects of urban runoff.
- Facilitates decisionmaking by using qualitative statements, quantitative estimates, and graphic illustrations.

Availability

A large number of reports (about 77) resulted from this program. The program report, Results of the Nationwide Urban Runoff Program, Complete Set, published by EPA in 1984, consists of the executive summary, final report, appendices, and data appendix. Other reports include case studies. The reports are available from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161; phone 703/487-4650. For additional information, write to the EPA Headquarters Nonpoint Sources Branch, WH-585, 401 M St. SW, Washington, DC 20460. A floppy disk containing the program also is available from that office.

U.S. EPA's SWMM package has several versions whose use depends on the level of effort available and the amount of information required to estimate runoff and water quality in an urban watershed. These versions include:

- SWMM—Level I
- Simplified SWMM
- SWMM

Description

SWMM—Level I is designed as a screening tool to provide a rough estimate of quantity and quality during a precipitation event that lasts a few hours in an urban watershed. The calculations can be performed with a hand calculator. Runoff and water quality parameters are determined on the basis of land use characteristics, precipitation, population density, sewerage system, and street sweeping operations. A graphic procedure permits the analyst to examine a wide variety of control options operating either parallel or in series with one another.

Capabilities

- No computer expenses.
- Includes economic analysis of sewerage management practices.

Limitations

- Relatively crude model.
- Does not consider the water quality changes in storage.

Input Data

Does not need a great deal of input data.

Output Description

Minimal output: the calculations are performed with a hand calculator.

Availability

The technical manual for this preliminary screening procedure is available from EPA. Write to the Nonpoint Source Branch, WH-585, 401 M St. SW, Washington, DC 20460.

Resource Requirements

Requires few resources because the data need is minimal and computers are not used.

SWMM Simplified

Description

The simplified SWMM simulates runoff and nutrient transport in an urban watershed. The five tasks performed in this model include data preparation, rainfall characterization, storage-treatment balance, overflow-quality assessment, and receiving water response. Each task generally combines small computer programs with hand calculations.

Capabilities

- Can be linked to simplified, single-event receiving water model.
- Available options include continuous and event-based simulations.
- Models effect of pollutant delivery on receiving waters.

Limitations

- Does not consider water quality change or treatment during storage.
- Does not simulate snowmelt and sediment transport.
- Overflow quantities and qualities must be measured to calibrate model.

Input Data

Input data include hourly precipitation, runoff coefficient, treatment rate, storage volume, and receiving water characteristics.

Output Description

Output contains time-varying overflows and runoff and summation of these data. Pollutant loadings and receiving water response also are included.

Availability

The various SWMM models are available from EPA's Nonpoint Source Branch, 401 M St. SW, Washington, DC 20460. However, incomplete documentation and inadequate user support are problems with using the model.

Resource Requirements

The computer programs for simplified SWMM have been developed on an IBM 360/67 digital computer. The storage-treatment program has been used successfully on Xerox 560 and IBM 1130 computers.

Description

SWMM is a comprehensive, mathematical model capable of representing urban stormwater runoff and combined sewer overflow phenomena. Level surface runoff generated by precipitation is routed through channels and pipe networks. The analysis uses finite difference approaches. The water quality parameters simulated in SWMM include sediment and nutrients.

SWMM contains its own receiving water model, RECEIV. It also can be linked to STORM, QUAL-II, and other simplified receiving water models.

Capabilities

- Both combined and separate sewerage systems may be evaluated.
- Considers treatment in five different storage systems.
- Includes several physical and chemical treatment options to evaluate water quality changes.
- Includes capital and operating and management costs for treatment options.
- Can simulate the effects of pollutant delivery on the quality of receiving waters.
- Different storage and treatment techniques may be considered as options for controlling nonpoint source pollution.

Limitations

- Is a large model with complex and detailed input requirements.
- Statistical summaries are limited.
- Uses a monthly flow routing method that can be costly because it requires short time steps.
- It is comprehensive, but data management capabilities are not advanced.

Input Data

Detailed input data sets are required. Some of the input information typically required includes precipitation, air temperature, wind speed, channel, pipe networks, land use patterns, and storage and treatment facilities.

Output Description

Output consists of summaries of treatment options and costs, variation of water quality with time, and hydrographs and pollutographs with daily and hourly variations.

Availability

The model is well documented and available from EPA in four versions: Final Report, Verification and Testing, User's Manual, and Program Listing. The existence of established user groups that meet semiannually is considered an important factor that promotes its use. For a copy, write to EPA's Nonpoint Source Branch, 401 M St. SW, Washington, DC 20460.

Resource Requirements

The computer hardware system should be the equivalent of the IBM 360/65 with peripheral storage devices and a usable core capacity of no less than 360K bytes. Data requirements are common to engineering design and analysis, and are mainly descriptive of the real system.

Small Watershed Model

SWAM

Description

SWAM is a continuous simulation model that estimates change in hydrologic, sediment, and chemical characteristics of a small agricultural watershed in response to different land use and management practices. The overland flow and pollutant transport are estimated by CREAMS 2. The movement and interactions of sediments, pesticides, and nutrients in the surface drainage (channel network), and surface retention basins (reservoirs) are simulated. The model also can simulate surface/groundwater interactions.

Capabilities

- Is an integrated watershed model that uses a dynamic version of CREAMS 2 together with channel, reservoir, and groundwater routing of water, sediment, nutrients, and pesticides.
- Incorporates backwater effects in channel routing.
- Provides a detailed representation of soil and watershed processes.

Limitations

- A complex model to use.
- Watershed area is less than 10 km^2.
- Not practical for long-term (20 years or more) simulations.

Input Data

Input data include rainfall, soil characteristics, topography, land use, and management practices.

Output Description

The model developers are still working on output structure.

Availability

Model is still being tested and has not been released yet. Intended as a research model that can later be upgraded to basin scale. The model will be available from Dr. Donald DeCoursey, USDA-ARS, P.O. Box E, Fort Collins, Colo. 80522; phone 303/221- 0578.

Resource Requirements

Initially written in FORTRAN for mainframe computers.

Description

WRENS is a procedural handbook for evaluating the effects of forest-related activities on water quality and making management decisions.

WRENS describes procedures that can be used for quantitatively estimating changes in the stream flow, surface erosion, soil movement, sediment discharge, and temperature. In addition, WRENS includes qualitative assessment of forestry activities on pesticide concentration, nutrients, organic matter, and dissolved oxygen. WRENS also lists criteria for selecting appropriate control measures to minimize adverse effects of forestry activities on water resources.

Runoff volumes necessary for water quality analyses can be estimated from precipitation and daily minimum-maximum air temperature data. One procedure (WATBAL) is used to calculate runoff calculation in areas where snowmelt is the major source of energy. The other procedure (PROSPER) is used for nonhuman areas. WRENS uses the modified soil loss equation (MSLE) to calculate sediment erosion in forests.

Capabilities

- No computer required.
- WRENS handbook is self-contained and includes examples.
- Handbook identifies BMPs.

Limitations

- Designed only for small site-specific areas.
- Nutrients, pesticides, dissolved oxygen, and organic mater are evaluated only qualitatively.

Input Data

Input information includes watershed hydrology and daily meteorological data.

Output Description

No special output as such. Procedures described in the handbook can be used to estimate some physical and chemical characteristics.

Availability

Handbook available from the National Technical Information Service, U.S. Department of Commerce, 5825 Port Royal Rd., Springfield, Va. 22161; phone 703/487-4650. Specify No. EPA 600/8-80-012. Cost: $58.95.

Resource Requirements

Resource requirements for this analysis are minimal.

Suggestions to Improve Models

Models can be important tools for assessing nonpoint source pollution as well as projecting the effects of BMPs. However, most of the existing decision-oriented models have distinct limitations and require further refinement. The following improvements could be most useful:

- Develop the ability to simulate processes in grids or cells so that one computer run could evaluate different BMPs for different spatial distributions of a given watershed.
- Improve the capability for analyzing the cost/benefit relationship.
- Improve the ability to simulate environmental impact and risk analysis: for example, pesticide levels toxic to various organisms in receiving waters, eutrophication of receiving water bodies by nutrient loadings, and effects of biochemical oxygen demand on dissolved oxygen level in streams and consequent strain on aquatic organisms.
- Develop the ability to evaluate total impact resulting from redispersion of the bottom sediments and sorbed or settled pesticides and nutrients.
- Improve the models' capabilities for handling data and results for statistical analyses and interpretations.
- Incorporate graphic illustrations in the outputs.
- Simulate nonpoint source pollution of ground water from subsurface runoff. This problem, that is, separation of interflow from surface hydrograph, is not adequately addressed in most of the existing models. More fundamental work should be done on hydrograph separation.

Best Management Practices

Since nonpoint source pollution can be attributed to various land disturbances, specific methods have been developed to minimize both these disturbances and the runoff they generate. These methods are known as BMPs, for .best management practices.

Synonymous with prevention, BMPs use the land in the wisest possible ways—whether it be for growing crops or grazing cattle, building highways or cutting trees. BMPs are exactly what the phrase implies: coordinated, judicious timing of activities and use of vegetation and materials (including some structures), as components within a total land management system.

Rarely viewed as remedies to past problems, BMPs function as ingredients in a so-called "prescription" to control a specific nonpoint source effect. Perhaps the best example of this approach can be seen in farming, where a management scenario might combine half a dozen practices and structures—from contour terraces and no-till planting to buffer strips and dikes. Each specific practice would be selected and applied according to the overall use of the land.

Applications for best management practices overlap: fertilizer and pest management techniques, for example, can be applied to both agriculture and forestry. BMPs also vary with specific application, with standard practices taking on different forms when used, for example, in a mining situation as opposed to highway construction.

In an attempt to describe the most commonly-used BMPs, this Guide classifies them into broad categories defined by land use:

- agriculture
- construction/urban runoff
- silviculture
- mining

A last classification—multicategory—includes BMPs that are used in all the others.

Agriculture: Agricultural BMPs are particularly well-known (and numerous) because agriculture is regarded as the primary source of pollution to rivers and lakes, contributing at least half of the sediment deposited in streams and lakes. The American Water Works Association has named agricultural runoff as the largest contributor of nitrogen and phosphorus to water.

More detailed information about agricultural BMPs is available from the National Water Quality Evaluation Project (NWQEP), a USDA-EPA cooperative venture to determine the most effective ways for controlling agricultural nonpoint source pollution at the watershed level. NWQEP's 1985 Annual Report describes 20 projects that studied watershed controls intensively. The report is available from North Carolina State University at Raleigh.

Mining: Commercially-mined and processed minerals range from fuels such as coal and oil to metals to nonmetallic minerals like sand and gravel, stone, phosphate, and clays. Mining operations include deep mining, strip mining, auger mining, open pit mining, placer mining and dredging, well extraction, solution mining, and other types.

In addition to the extraction of minerals, mining involves transport, exploration, processing, storage, and waste disposal. Each phase has its own activities—and its own potential for polluting water, either during operation or following shutdown.

Specific preventive measures must be designed for each operation on the basis of an examination of the site and the consequences expected from its use for mining. EPA has developed a list of 17 general control principles that should be applied to selecting and designed BMPs for mining:

1. Choose least hazardous methods.
2. Manage water.
3. Control erosion and trap sediment.
4. Segregate water from toxics.
5. Collect and treat runoff when other approaches fail.
6. Quickly stabilize disturbed area.
7. Properly store minerals and dispose of mineral wastes.
8. Correct pollution-causing hydrologic disturbances.
9. Prevent and control pollution from roads.
10. Avoid disturbing streambeds, streambanks, and natural drainageways.
11. Use stringent controls in high risk areas.
12. Apply sound engineering.
13. Properly locate and seal shafts and boreholes.
14. Control fugitive dust.
15. Maintain control measures.
16. Use temporary stabilization and control when needed.
17. Prevent and control pollution after closedown.

The mining section describes several specific BMPs used in mining that are based on the cited control principles.

The matrix in Table 4 relates the individual BMPs in all categories to one another, and to the total management plan.

By combining Table 4 with the text, which includes cost information for each BMP, the reader will have the tools to weigh alternative solutions to specific nonpoint source pollution problems.

Table 4. — Best management practice activity matrix.

BMP	NUTRIENT REDUCTION	STRUCTURAL CONTROL	NONSTRUCTURAL CONTROL	AGRICULTURE	SILVICULTURE	CONSTRUCTION	RUNOFF
AGRICULTURE							
Conservation tillage			●	●			
Contouring			●	●			
Contour strip cropping			●	●			
Cover crops			●	●			
Integrated pest management	●			●	●		
Range and pasture management	●			●	●		
Sod-based rotations	●		●	●			
Terraces		●		●		●	●
Waste management practices	●	●		●			
CONSTRUCTION & URBAN RUNOFF							
Structural control practices	●	●			●	●	●
Nonvegetative soil stablization	●	●	●		●	●	●
Porous pavements	●	●					●
Runoff detention/retention	●	●		●	●	●	●
Street cleaning	●		●			●	●
Surface roughening			●			●	
SILVICULTURE							
Limiting disturbed areas	●		●		●	●	
Log removal techniques	●	●			●		
Ground cover			●		●	●	
Removal of debris			●		●		
Proper handling of haul roads			●		●		
MINING							
Water diversion	●	●					
Underdrains	●	●					
Block-cut or haul-back	●		●				
MULTICATEGORY							
Buffer Strips		●	●	●	●	●	●
Grassed waterway	●	●	●	●		●	
Devices to encourage infiltration	●	●		●		●	●
Interception/diversion	●	●		●	●	●	●
Material ground cover	●	●		●	●	●	●
Sediment traps		●		●	●	●	●
Vegetative stabilization/mulching			●	●	●	●	●

Agriculture

Conservation tillage refers to any planting system that reduces soil disturbance and water loss by retaining crop residues on the land (covering at least 30 percent) and leaving the surface rough, porous, cloddy, or ridged. Identified under several different names—minimum tillage, reduced tillage, stubble mulching—conservation tillage includes no-till, ridge-till, strip-till, mulch-till, and reduced-till. Conservation tillage reduces runoff and directly benefits farmers, but may require special equipment and additional costs.

■ Experience and Application

The conservation tillage system that best fits a farm operation depends on the climate, soil characteristics, and the crops grown. While lower yields have been experienced on some soils, research has generally found no significant yield differences between conventional and conservation tillage practices.[1] Conservation tillage also reduces labor, time, fuel usage, and machinery wear. The preferred conservation tillage method depends on the soil. Although applicable to a wide range of soils, **reduced tillage** is considered more suitable to cold and wet soils than no-till, with soil drainage largely determining its economic success. Reduced tillage maintains productivity because it reduces erosion and soil compaction and conserves moisture, improving soil structure and optimizing land resources. Reduced tillage is more widely adaptable than no-till planting but is somewhat less effective in controlling water pollution. **No-tillage** is most applicable on highly erodible, well-drained, coarse to medium-textured soils planted in dormant grass or small grain crops. Farm use of conservation tillage is increasing rapidly, from about 27 million acres in 1972 to 74 million acres in 1979, and 99.6 mil-

lion acres in 1985.[2] The Conservation Tillage Information Center in 1986 estimated a 2.8 million-acre increase in conservation tillage practices from 1984 to 1985. The Center also compared 1984 and 1985 according to conservation tillage type: no-till increased by 700,000 acres; ridge-till by 45 percent; strip-till declined by 50,000 acres; and mulch-till, accounting for 64 percent of all conservation tillage, grew by 6.7 million acres.[3]

Capital and Operating Costs

An important reason for the increasing use of conservation tillage is the decreased overall capital expense and increased net return. One study found the average diesel fuel consumption for reduced-till was 1.4 gallons/acre and 1.0 gallon/acre for no-till, compared to 4.2 gallons/acre for conventional tilling.[4] An analysis of crop production costs indicated that reduced tillage decreased equipment and labor costs by about 8 percent and no-tillage by about 10 percent.[5] Another researcher concluded that increased material costs for conservation tillage practices were more than offset by reduced costs for machinery and items.[6] To encourage conservation tillage, Virginia and North and South Carolina offer farmers a state income tax credit of 25 percent (to a maximum $2,500 per year) for purchasing no-till farm equipment.

Effectiveness

All conservation tillage practices reduce erosion potential below that of conventional tillage, in some estimates by 30 percent, with runoff declining by about 61 percent. Leaving crop residue in the field protects the soil surface from the erosive forces of rain water and snowmelt by preventing surface sealing, which increases infiltration and decreases the volume and velocity of runoff. Conservation tillage is particularly effective in controlling sediment loss and phosphorus and pesticide transport, although declines in transport vary with the type of soil and reductions in sediment. On-site effectiveness of preventing these pollutants from entering surface waters ranges from 40 to 90 percent reduction for conservation tillage to 50 to 95 percent reduction for no-tillage.[7] In South Dakota, researchers found that as much as 7.5 cm rainfall produced no surface runoff with conservation tillage, while only 2.0 cm rainfall produced run-

off with conventional tillage.[8] Another study found that surface runoff averaged 1 mm per season for no-till plots and 11 mm per season on conventionally tilled plots.[9] Conservation tillage may increase groundwater contamination if it relies more on more pesticide usage than conventional tillage. Research has shown, however, that conservation tillage does not necessarily require more pesticide usage.[10] The Integrated Pest Management BMP discusses this issue in more detail.

Plowing follows the contours of the field (perpendicular to the slope of the land). Crops are then planted along these tilled contours.

■ Experience and Application

Especially applicable on cropland with 2 to 8 percent slope, contouring provides more protection from erosion than tilling parallel to the slope. Contouring is limited by soil, climate, and topography, and may not be usable with large farming equipment under some topographic conditions.

■ Capital and Operating Costs

Contouring costs are slight because it does not require any specialized farming equipment, nor does it affect fertilizer and pesticide application rates. However, a proper plowing design must be established.

■ Effectiveness

Contour plowing can reduce average soil loss (and therefore phosphorus and pesticide runoff) by 50 percent on moderate slopes, less on steep slopes. Contouring loses its effectiveness if the rows break down, so for long slopes terraces may be needed. The contours provide excellent erosion control during moderate rainstorms, collecting water and thereby reducing runoff velocity and increasing the infiltration time. However, contouring loses its effectiveness during extreme storms when rainfall exceeds the surface storage capacity. When practiced alone on gentle slopes, or in combination with strip cropping or terracing on moderate slopes, contouring reduces erosion.

Strip-cropping

agriculture

Stripcropping alternates plowed strips of row crops and close- grown crops such as pasture, hay, or grasses to reduce erosion on tilled soils. Strips of close-growing crops are planted between tilled row crops to serve as sediment filters or buffer strips in controlling erosion. The system of cropping where the strips are laid out nearly perpendicular to the direction of the slope is referred to as contour stripcropping.

■ Experience and Application

Stripcropping is particularly applicable on cropland with 8 to 15 percent slope, its primary advantage being that it permits row crops on slopes. Contour stripcropping is nearly twice as effective in controlling erosion as seeding grain in the fall to replace pasture. However, for contour stripcropping, the farming area must be suited for across-slope farming and for using pasture as part of a crop rotation. Alternating corn with spring grain is not effective for stripcropping.

Capital and Operating Costs

Costs are slight because contour stripcropping does not require the purchase of specialized farming equipment, nor does it affect fertilizer and pesticide application rates. However, a farmer must have a use for both crops, and may suffer some production loss because of the alternating system of planting. On some topographies, contouring may not be compatible with the use of large farming equipment.

Effectiveness

The practice reduces the velocity of the water as it leaves the tilled areas, because the buffer strip absorbs runoff and retains soil particles, thus minimizing nutrient and pesticide entry into surface water bodies. Planting row crop and hay in alternate 50- to 100-foot strips reduces soil loss by about 50 percent compared to the same rotation contoured only.

Cover crops are grown when the ground is normally bare, to protect the soil from leaching and erosion. Grasses and other crops offer better protection than row crops such as corn and grain sorghum. Crops that leave large quantities of residue after harvest offer more soil protection than crops with small quantities of residue.

Experience and Applications

The cover crop technique is applicable to all cropland. In appropriate climates winter cover crops provide a good base for slot-planting the next crop. For example, winter rye can be seeded immediately after a corn crop is harvested for silage. The growing rye protects the soil during the fall, winter, and early spring when the field would otherwise be bare and subject to erosion. Many cover crops are left on the soil as a protective mulch or are plowed under to improve the soil. Cover crops also may reduce input costs and increase soil productivity. Heavy soil cover, such as chopped corn or sorghum stalks or straw, usually provides as much soil protection as winter cover crops.

Capital and Operating Costs

The cost of using cover crops is moderate. No special equipment is needed to incorporate winter cover crops into a farming operation; however, planting the cover crop will involve additional man hours, machine use and maintenance, fuel, and seed. Research also has suggested that water use by winter cover may reduce the following year's cash crop yield.[11]

Effectiveness

Cover crops reduce soil and water loss, thus minimizing loss of nutrients (and pesticides, if present). Winter cover crops reduce erosion where corn stubble has been removed and low-residue crops harvested. They may reduce leaching of nitrate. If the cover crop is chemically killed and left in place for no- till planting of a row crop, it provides excellent control during the crucial erosion period. One study reported that a winter cover crop significantly reduced both soil and water loss for no- till corn harvested for silage, compared to growing the corn without using winter cover.[12] In general, cover crops provide better protection from the erosive effects of precipitation than continuous intertilling of crops. Cover crops reduce pollutant transport to adjacent surface water bodies by 40 to 60 percent.[13]

Fertilizers are used to increase the productivity of the land. However, the very act of adding them to the land increases the potential amount of pollutants that can be carried away by rainfall. Judicious use of fertilizers is therefore advisable to achieve both increased productivity and minimal effect on water.

Experience and Application

If the quantity and composition of fertilizers applied are based on crop needs and soil fertility, plants will use the nutrients, thereby reducing the amount of nutrients lost in runoff. Fertilizers also may increase root density, which will make the soil more permeable. On the other hand, if too much fertilizer is used a nutrient imbalance may result; followed closely by heavy rainfall, the potential for polluting water bodies may be great. Fertilizer transport to water varies with *crop absorption rates, rainfall*, slope, soil type, the closeness to a waterway, and the fertilizer's propensity for movement by water or sediment. When more than an inch of rainfall occurs within a week of application, the delivery rate may increase substantially. The consensus reached at an EPA workshop in June 1986 was that to minimize groundwater pollution, both fertilizers and pesticides must be better managed. The following summary is based on the conclusions of EPA's Great Lakes National Program Office Special Workshop:

> Conservation tillage does not differ radically from conventional tillage, and therefore, fertilizer management is similar. The types of chemicals may differ, but not the total quantity used: for example, nitrogen fertilizer rates are similar with both. However, nitrogen leaching is a problem for all tillage systems, although potentially greater for no-till. Good fertilizer management can include
>
> - optimizing crop planting time
> - optimizing fertilizer formulation
> - optimizing time of day for application
> - optimizing date of application
> - using lower application rates

Capital and Operating Cost

Improved fertilizer management is extremely cost effective; in fact, the NWQEP 1985 Annual Report found this to be the most cost-effective BMP for reducing nutrient losses in most of the studies described. Wise management of fertilizer application can actually reduce the capital invested in fertilizer, and may reduce the man-hours and equipment and fuel cost of applying it.

Effectiveness

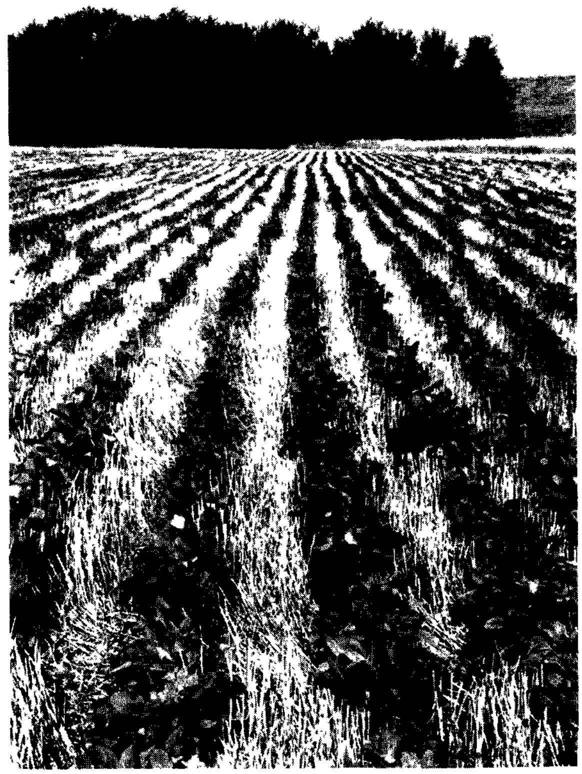
Fertilizer (and pesticide) management is emphasized in all Rural Clean Water Program (RCWP) projects as part of an EPA-USDA effort to limit contamination of ground water. Using conservation tillage without appropriate fertilizer/pesticide management is not considered an acceptable BMP.

Integrated pest management combines traditional pest control methods (such as crop rotation and pesticides) with sophisticated measures such as trapping insects and analyzing their life cycles to determine how best to destroy them, and monitoring pests to improve the efficiency of pesticides and other controls. Pesticides are applied at a minimal rate, the method and timing carefully selected according to the targeted pest, and using pesticides with the least persistence and volatility.

Experience and Application

To reduce environmental impacts, agricultural pesticides have changed in recent years, with EPA also mandating application requirements to minimize problems. The newer pesticides are less persistent in the environment and, therefore, have fewer long- term impacts, but they are also more likely to be water soluble. This means that water (instead of sediment) may carry them to the water bodies. Because their water-soluble forms may be more biologically available when freely waterborne than sediment-bound forms, these toxic chemicals may cause serious short-term surface water problems and eventually degrade groundwater resources.

Pesticide transport to water bodies varies with crop adsorption rates, rainfall, slope, soil type, the proximity of the land to a waterway, and the pesticide's propensity for movement by water or sediment. Normally, only about 5 percent of total pesticides applied enter water bodies; however, when more than an inch of rainfall occurs within a week of pesticide application, the delivery rate increases substantially and fish may be killed. With this in mind, it is obvious that pesticides must be managed better for all types of tillage, including more care with application rates, timing, and methods.



Conservation tillage may increase groundwater contamination. The consensus reached at an EPA workshop on this subject in June 1986 was that to minimize groundwater pollution, pesticides and fertilizers must be better managed for all types of tillage. The following summary is based on the conclusions of the EPA's Great Lakes National Program Office Special Workshop.

Conservation tillage does not differ radically from conventional tillage, and, therefore, pesticide/fertilizer management is similar. The types of pesticides may differ, but not the total quantity used: for example, nitrogen fertilizer rates are similar with both. However, nitrogen leaching is a problem for all tillage systems, but is potentially greater for no-till. Farmers may use more insecticides and herbicides as they begin to practice conservation tillage, but often decrease these inputs as they become more experienced with the system.

Farmers can help control pesticide losses in a number of ways, including

- combining mechanical cultivation with disease-resistant crop varieties,
- trying other pesticides,
- optimizing pesticide placement with respect to loss,
- rotating crops,
- using resistant crop varieties,
- optimizing crop planting time,
- optimizing pesticide formulation,
- using mechanical control methods,
- reducing excessive treatment, and
- optimizing time of day for pesticide application.

Other practices that have limited applicability include optimizing date of pesticide application,

- using integrated control programs,
- using biological control methods,
- using lower pesticide application rates,
- managing aerial applications, and
- planting between rows in minimum tillage.

Capital and Operating Costs

The costs of an integrated pest management program can vary widely according to practices chosen. However, pesticide management is highly cost effective and maximizes profits and input costs.[14]

Effectiveness

An effective integrated pesticide management program can reduce pollutant loadings by 20 to 40 percent, depending on the practices used. A 1983 Report to the Great Lakes Water Quality Board claims a 50 to 90 percent reduction in pollutant loading, as well as a direct impact on instream water quality. Pesticide and fertilizer management is being emphasized in all Rural Clean Water Program (RCWP) projects, as part of an EPA/USDA effort to limit contamination of ground water. Using conservation tillage without appropriate pesticide/fertilizer management is not considered an acceptable BMP.

Rangeland and pastureland can be managed to reduce erosion. Lands used for grazing vary in climate, topography, soils, and vegetative type and condition, a diversity that creates the potential for varying degrees of erosion. Erosion from grazing land can be prevented and controlled by minimizing the intensity of livestock use, and/or increasing the productivity of the vegetation. Grazing management practices should restrict livestock use to the carrying capacity of the land, thus minimizing erosion.

Experience and Application

Overgrazing changes the soil structure because the soil compacts, therefore becoming less permeable. Overgrazing also can change the density, vigor, and species composition of vegetation, thus exposing the soil to the erosive forces of wind and water.

An *adequate grazing regime* should use recommended stocking rates, discourage animal congregation in critical areas, break up animal distribution, and incorporate or remove manure accumulations. Following are some practices recommended for rangeland and pastureland management:

- Rotation grazing permits intensive use of fields or portions of fields on an alternating basis. The nonuse period allows vegetation to recover before the livestock return.
- Water supply dispersal distributes the livestock better, thus reducing overuse or overgrazing near water supplies, and subsequent erosion hazards.
- Ponds in pastures conserve water while providing water for livestock.
- Seasonal grazing that is compatible with the specific vegetation's most productive period permits recovery and reseeding.
- The dispersal and occasional relocation of salt, mineral, and feed supplement sites avoids concentrated overuse of these areas.

Capital and Operating Costs

Most of these management practices involve applying common sense and thoughtful management to range and pasture use; they should not require significant investments by farmers or ranchers. However, to use the various practices most effectively, a farmer or rancher must know such factors as stocking rates and vegetation types and conditions.

Effectiveness

Restricting animal access to highly erodible areas such as bare slopes will reduce erosion and improve surface water quality.

Sod-based crop rotation involves planting a planned sequence of crops in regular succession on the same land, rather than cultivating one crop continuously. Sod-forming grasses and legumes are used, with hay a part of the cycle. Meadowless rotation (using crops that do not form sod) employed by farmers to restore fertility to their soils is far less successful than sod-based rotation in combatting erosion. However, meadowless rotations do help control disease and pests and may provide more continuous soil protection than one-crop systems.

■ Experience and Application

Sod-based rotations' may be used on all cropland, particularly those farm operations with livestock that can eat the hay grown as part of the cycle. This system has been used for many years to reduce erosion from the conventional plow-based systems in regions adapted to rotating pasture for one or more years. Soil and water loss from a good quality grass and legume meadow is negligible, and plowing the sod improves infiltration and reduces erosion. Sod is most frequently used in two- to four-year rotations. Legumes in the meadow mixture can help restore the soil's nitrogen balance through fixation of atmospheric nitrogen. Sod- based rotations help control some diseases and pests and also give the farmer more fertilizer placement options. Along with increased labor requirements, some climatic restrictions are associated with sod-based rotation farming.

■ Capital and Operating Costs

Sod-based rotations can be costly since the farm's income is reduced by substituting hay for as feed. Other than that, no additional equipment or accessories need be purchased;

major crops for one year during the rotation cycle. This is less of a problem where livestock are part of the operation, since hay can be used however, labor hours may increase and cash sales decline.

Effectiveness

Sod-forming grasses and legume crops used in rotation with row crops are highly effective in maintaining the soil structure and tilth. In addition, this type of rotation cycle can reduce soil and nutrient losses by 20 to 50 percent. The rotation of crops often provides for planting both shallow- and deep-rooted plants; this pattern improves the physical condition and the internal drainage of both the soil and the subsoil.

Hay fields lose virtually no soil and reduce erosion from succeeding crops. Total soil loss is greatly reduced; however, losses are unequally distributed over the rotation cycle. The potential for transport of water-soluble phosphorus increases. Sod-based rotations improve weed and insect control, thus reducing pesticide applications and the possibility of groundwater contamination.

A terrace is a ridge or embankment constructed across a slope to control erosion. Terraces reduce the slope and divert or store surface runoff instead of permitting it to flow uninterrupted down the slope. Terraces break the length of the slope into shorter segments, reducing the slope effect on erosion rates by dividing the field into segments with lesser or even near-horizontal slopes. The excess water either is conveyed from the terraces to grassed outlets or removed by subsurface drains. Some terraces on permeable soils are designed to stop runoff and hold the water until it is absorbed.

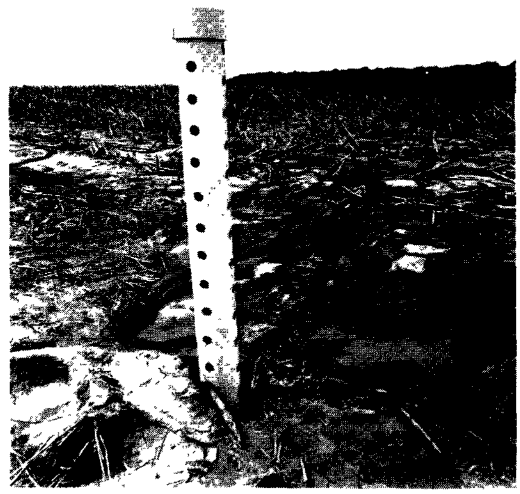
■ Experience and Applications

Terracing is generally applied to fields where contouring, strip- cropping, and tillage operations do not protect the soil adequately. Particularly applicable on land with up to 12 percent slope, terraces fill a niche in cropland conservation systems that no other practice can by controlling sheet, rill, and gully erosion on steeper, longer slopes. In 1977, terraces were used on

31.3 million acres in the United States.[15] Terrace design requires detailed knowledge of probable rainfall totals and intensity, soil characteristics, and cropping systems. Terraces often require new management practices to maintain their desired effects. They should be planned to permit farming with large, modern equipment. If terraces are improperly designed or used with poor cultural and management practices, they may increase rather than reduce soil losses. Terracing can facilitate more intense cropping and reduce downstream flood peaks.

Capital and Operating Costs

Terraces involve substantial initial cost, along with some periodic maintenance costs; however, in the long term, income usually increases. Conventional gradient terraces have been incompatible with use of large equipment, but new designs have alleviated this problem. Terraces can be constructed with a moldboard or disk plow, whirlwind terracer, bulldozer, motor grader, scraper, or similar equipment. Many computer programs are available to select the best terracing design.



Effectiveness

By shortening long sloping areas, terracing slows runoff and prevents the formation of gullies, reduces soil loss, and conserves soil moisture. Terraces have proven to be more effective in reducing erosion than in reducing total runoff volume per se. Farmers report better water management, higher yields, and fewer wet spots on terraced fields. One study reported that a terrace with a vegetative outlet traps 60 to 80 percent of the sediment moving into the terrace channel.[16] A terrace with a closed outlet traps 92 to 98 percent of the sediment moving into the channel. The Conestoga Rural Clean Water Project in Lancaster County, Pennsylvania, is trying to assess the impact of terraces on groundwater quality by monitoring ground water before and after terraces are built. The monitoring has not yet continued long enough for any conclusions to be made.

Waste storage structures temporarily store animal waste until they can be safely used. Although usually constructed of reinforced concrete or coated steel, earthen berms may also be used to build ponds that can handle liquid and solid animal wastes and runoff containing various pollutants. However, earthen waste storage ponds may leak, thus increasing the potential for groundwater pollution. Diversions and dikes can be used to direct contaminated runoff into the storage pond or to route uncontaminated runoff away from a confined animal facility. Waste storage ponds must be designed to handle expected precipitation and runoff as well as the estimated volume of waste.

Experience and Application

Animal waste management practices must be designed to meet the site conditions, type of animal wastes, and farm management practices. In addition to storage facilities for animal waste, runoff diversion structures are often needed in barnyard areas to reduce waste transport. Given the variability of site topography and layout of barns, each farm requires an individually-designed waste management system. Proper design factors also must incorporate estimates of land application frequency and duration. If convenient to operate, these systems can directly control the animal waste as well as concentrate the manpower work load.

Piling or spreading animal wastes on frozen ground (commonly done in northern states) or during periods of high rainfall can increase nutrient and organic loadings to water bodies. An interesting example of the effectiveness of manure storage has been demonstrated in an EPA Clean Lakes project on the Cobbossee watershed near August, Maine. Applying manure to the fields during the winter months was identified as the major source of pollution to the lakes in the watershed. A cost-sharing program with USDA along with some pressure applied by the Cobbossee Watershed District convinced most of the farmers in the watershed *to construct manure hold facilities: in 1980,* some 30 separate agricultural waste management facilities were built at a total estimated cost of $662,000. These facilities store manure for approximaley 80 percent of the animal units in the watersheds of the three lakes. Ongoing monitoring of water quality in the watershed's lakes is proving the effectiveness of this management system. Lake Parker, located in northeastern Vermont, suffered from weeds, algae, and bacteria growths over the past decade. The Vermont Department of Water Rescurces determined that the lake's problems were caused by excessive phosphorus and bacteria loads from 8 of the 11 dairy farms located in the watershed. The Soil Conservation Service, of the town of Glover, and other sponsors joined together to implement a Resource Conservation and Development Project. All eight farms participated in the pollution control project, which included proper use and disposal of wastes through manure storage, barnyard runoff control, and milkhouse waste management. The project began in January 1981 and ended in June 1982. The Lake Parker Association claims that the project has been highly successful; however, like the Cobbossee watershed, a longer period of evaluation will be needed to establish trends in the lake's response.

■ Capital and Operating Costs

Waste management practices are generally costly, requiring farmers to make significant personal investments in agricultural pollution control (see Table 5). In considering the high cost of building a waste storage structure, farmers must be assured that manure storage systems not only control pollution but benefit farm management and farm productivity. Often the motivation for implementing these practices is not better water quality but convenience to the farmer. Runoff controls are the cheapest waste management practice to implement and have been found to be very cost effective.

■ Effectiveness

Effective containment of animal waste can reduce phosphorus runoff by as much as 50 to 70 percent, thereby minimizing water quality impacts and consverving fertilizer for food production during the summer months. Waste storage structures have advantages over less expensive waste storage ponds such as less potential for groundwater pollution and fewer odor problems.

Table 5. — Typical manure storage facilities and costs.

TYPE FARM	MANURE SYSTEM COMPONENTS	*TOTAL COST
Dairy	50' x 80' x 10'	
	Concrete storage	39,578
90 milkers	with push off ramps	3,080
20 youngstock	and roof	14,168
freestall	Equipment	4,774
		$61,600
Dairy	40' x 40'	
28 milkers	Asphalt Pad with	1,848
20 youngstock	8' Concrete headwall	9,856
stanchion	and earth sides	2,772
	Equipment	6,776
		$21,252
Dairy Replacement	37' x 37' x 4'	
20 animals	Concrete storage	7,469
stanchion	Asphalted barnyard	3,234
	Runoff controls:	
	holding basin	693
	450' diversion	2,310
		$13,706
Poultry Litter Stacking Site		
20,000 Broilers	40' x 40'	
	Concrete Pad	4,466
	with earth berms	4,774
		$ 9,240

* Costs have been updated to 1985 dollars Source U S EPA, 1980c

Urban and Construction

Structural controls are used when vegetation alone will not provide the desired degree of protection, or when flow concentrates in a specific area, as it does in drainage courses. Structural measures include drop spillways, box inlet spillways, chute spillways, pipe drop inlets, sod flumes, debris basins, and other grade controls. These structures supplement sound conservation measures, trap sediment, and reduce the grade in water courses, the velocity of flowing water, and peak water flows. Common structural controls for construction sites include filters (principally the gravel inlet and the filter berm), traps, basins, and diversion structures. Diversion structures, basins, and similar practices also are used in other urban environments.

■ Experience and Application

Standard designs may be available for sediment control structures such as inlet filters and other small structures. Structures should be built to provide maximum site protection. On urban construction sites and major highway projects where storm drains are used, preventing sediment damage to the drainage system becomes especially important. Failure to trap much of the sediment before it reaches an inlet may result in costly damage to the storm drainage system. It is also important to routinely remove sediment from settling ponds and sediment basins, and to dispose of it in a manner that will preclude its return to downstream areas during storms. Usually a sediment pond is cleaned out when it has reached 50 percent of its sediment storage capacity.

In drainageways, bank protection and grade stabilization structures help control channel erosion. Bank protection structures involve either protective riprap placed directly on the bank or in-channel structures that deflect or dissipate the velocity of the flow impinging on the bank. Grade stabilization structures consist of a series of check dams (energy dissipators) that both dissipate the energy of the flowing water and physically restrict downcutting of the channel.

■ Capital and Operating Costs

Costs vary widely according to the complexity of the structure and its maintenance requirements. Some sediment control structures such as sandbag and straw bale sediment barriers may require daily inspection because they are subject to vandalism. Diversion dikes, filter berms, flexible downdrains, interceptordikes, level spreaders, sediment retention basins or ponds, and other structures require inspection after each rainstorm. Actually, the best time to inspect most structural controls is during a major storm. Corrective decisions made on-site at that time can reduce sediment damages and operating costs in the long run.

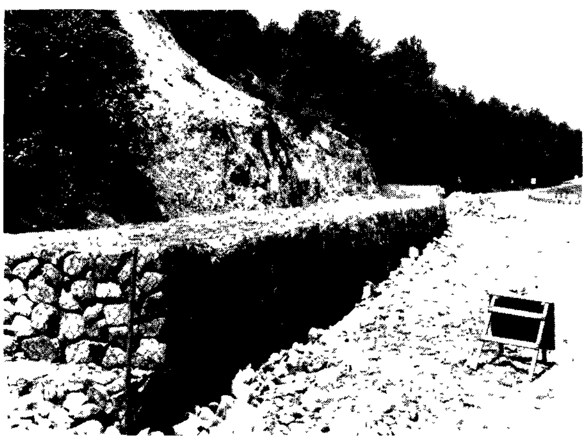
■ Effectiveness

Based on the present state of the art, it is difficult to assign an accurate universal effectiveness value to a sediment control practice or combination of practices. Many complex factors influence effectiveness, including soil erodibility, climate, types of control practices being used, physical characteristics of the sediment, and flow characteristics. Also, adequate standard design and construction criteria are not available for many sediment control practices for different slope conditions. Techniques are available, however, for determining trapping efficiency in large reservoirs. Sediment basins are generally designed to have a minimum of 70 percent effectiveness.

Nonvegetative soil stabilization can be either temporary or permanent. Temporary stabilization uses covers and binders to shield the soil surface from rainfall and runoff or to bind the soil particles into a more resistant mass. Permanent nonvegetative soil stabilization usually consists of a protective blanket of coarse crushed stone, gravel, or other durable materials. On very steep slopes, more rigid materials are required, such as concrete, wooden or metal retaining structures, or concrete or asphalt pavements.

Experience and Application

Temporary stabilization protects the land during grading and construction, while permanent vegetation is developing or until another BMP is completed. Nonvegetative stabilization can be used anywhere erosive gradients exist, particularly at gully headlands. Various chemical emulsions recommended for erosion control include polyvinyl acetate, vinyl acrylic copolymer, and copolymer emulsions of methacrylates and acrylates. Hydrated lime and cement can be used for stabilizing clayey soils. Other temporary stabilizers include mulches, nettings, and textile blankets and mats.



Permanent stabilization becomes necessary where vegetation cannot be used, such as excessively steep slopes, graded areas with groundwater seepage, draughty or toxic soil, and soil surfaces in waterways exposed to high velocity concentrated flow.

Where both bank and channel erosion are problems, complete channel linings can be used; however, they should incorporate a means for dissipating flow energy to prevent serious erosion at the downstream terminus.

Various materials used for grade stabilization in waterways include stone (used both as riprap or in wire gabion baskets), concrete (used as riprap, interlocking blocks, paving, or in concrete filled mattresses), and wood.

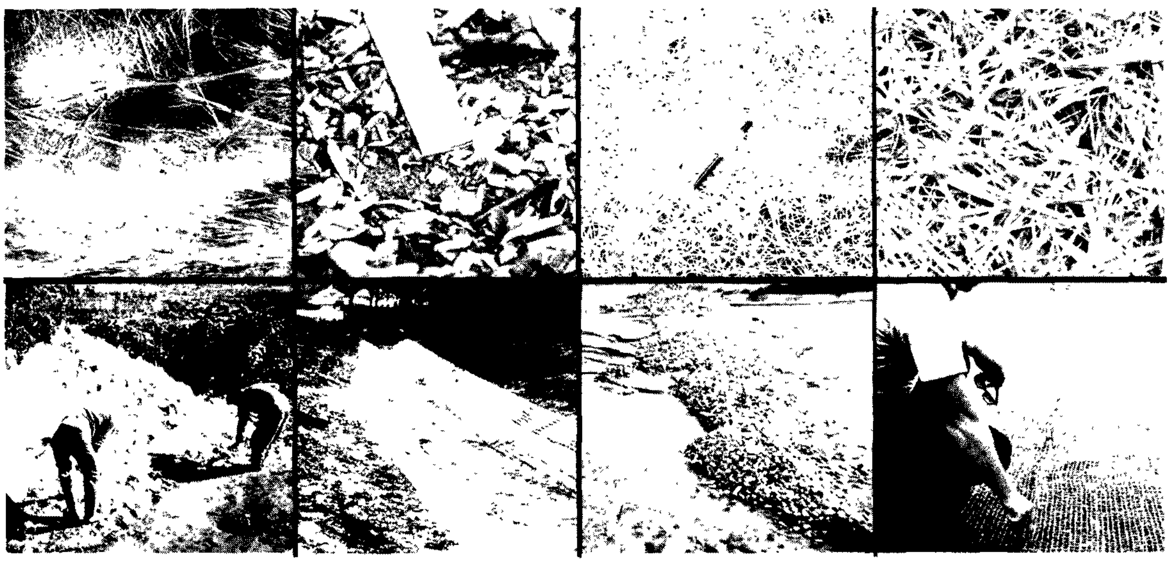
Although effective, this technique does not address the cause of the suspended solids problem, has no effect on soluble pollutants and requires technical assistance.

Capital and Operating Costs

The cost of nonvegetative soil stabilization can vary greatly because there are many available techniques.

Effectiveness

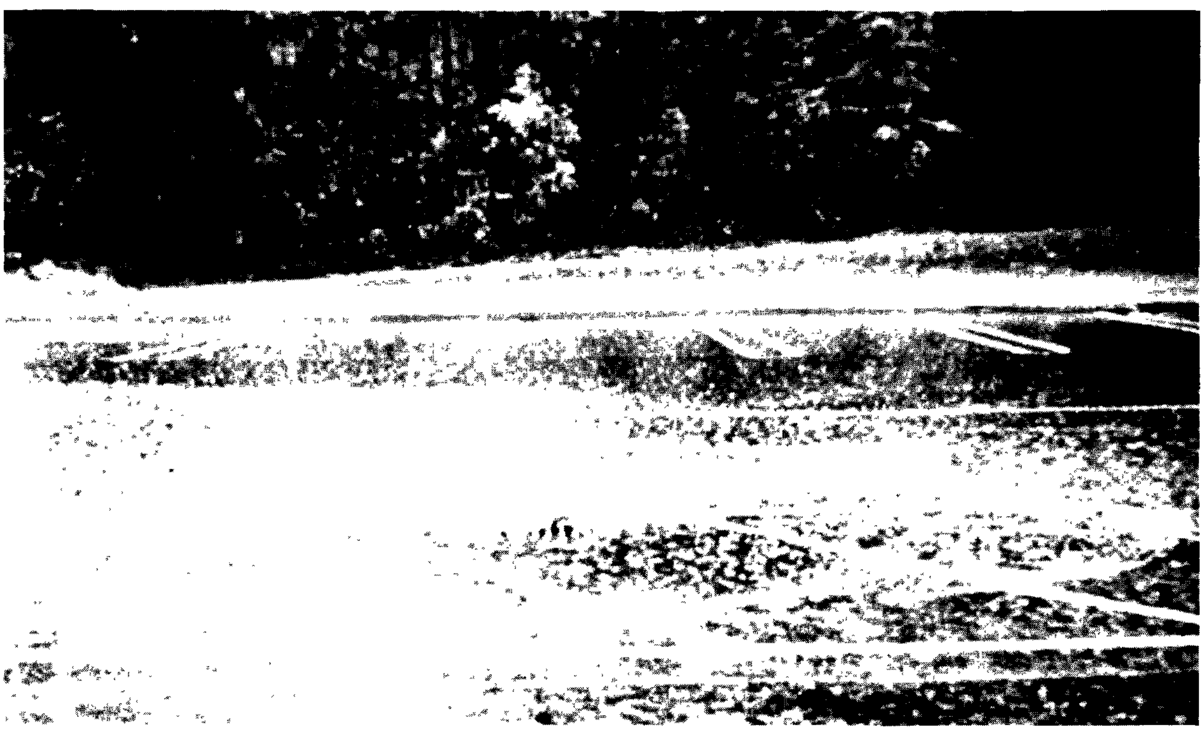
Straw mulch (small grain) has proven effective on 12 percent slopes at application rates of 5 ton/ha and on a 15 percent slopes at an application rate of 10 ton/ha. On-site nonvegetative soil stabilization reduces erosion by 75 to 90percent.17 Straw mulching loses its effectiveness on steep slopes because of rill formation and its tendency to be washed away by overland flow.



Most porous pavements are made from asphalt in which the fine filling particles are missing. The porous asphalt mixture is installed on a gravel base. If the pavements are designed properly, most of the runoff can be stored and allowed to infiltrate into the ground. Where permeability of underlying natural soil is not adequate or porous pavement is installed over an impervious base, a drainage system can be installed. If the drains are not installed, the subgrade may soften.

Experience and Application

First used in Philadelphia, porous pavements have been used in a number of States as well as Denmark and Germany. Porous pavements can be installed over existing impervious pavements, an advantage in cities with combined sewers (because it reduces the frequency of overflow) or in areas with inadequate storm drainage. The primary benefit of porous pavements is that they significantly reduce runoff from otherwise impervious areas. Other benefits include dissipation of runoff energy and associated suspended sediment loss, infiltration of soluble pollutants and some fine materials, and elimination of most hydraulic collection systems. Care should be taken to prevent porous pavements from polluting ground water.



Capital and Operating Costs

Porous pavements may sometimes cost slightly more than conventional surfaces for parking lots, roads, and other urban surfaces; however, their benefits and savings on sewer and drainage capacities, as well as on treatment, will offset any the additional cost of the pavement. Dust and dirt that accumulate on top of the pavement must be periodically removed or clogging may occur. Therefore, porous pavements rely on proper maintenance to achieve maximum benefit.

Effectiveness

Pollution loading by surface runoff from a porous pavement should be zero if all water infiltrates. However, this may not happen, especially if the porous pavement is installed on an impervious surface. In this case, the porous pavement and the base act as a filter. Even when the ground is impervious, the porous base and pavement are beneficial. The gravel base serves as a storage area, and if the storm water requires treatment, it may be stored in the porous media until treatment capacity becomes available.

Runoff storage facilities can prevent or reduce storm water runoff, keeping associated pollutants from entering combined sewers and surface water bodies, and, if properly designed, ground water. Detention facilities treat or filter out pollutants, or hold the water for treatment prior to release. A retention facility controls surge flows such as runoff from storm events, but provides no treatment. The water in a retention facility either evaporates or infiltrates into the ground.

■ Experience and Application

Many variations of runoff storage facilities are used on construction sites and in different types of urban settings. A storage basin or a sewer's storage can be used to contain storm discharge or combined sewer overflow before releasing it gradually—either after treatment into receiving waters, or after a storm into a centralized treatment facility. Storage facilities used for this purpose can be either in-line or off- line and include ponds or surface basins, underground tunnels, excess sewer storage, and underwater flexible (collapsible) holding tanks. A relatively new approach used in northern Europe and now being considered by several U.S. cities, is the use of floating detention basins in lakes or harbors to hold runoff for treatment.

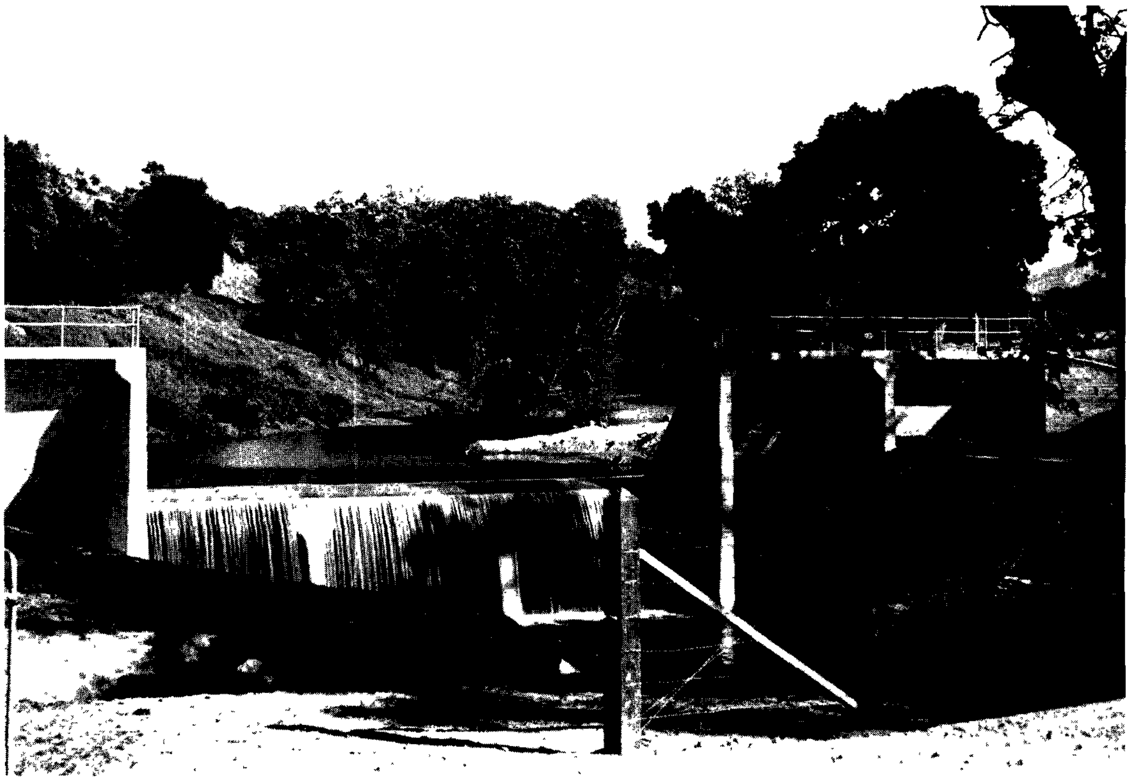
Retention facilities can be important sources of groundwater recharge in highly impervious urban areas; however, groundwater pollution from these facilities must be considered.

Detention facilities can reduce the peak runoff flow volumes from storms to trap sediment. Detention basins can be either dry (conventional storm water management basins) or wet (designs that maintain a permanent water pool). Dry basins are designed to attenuate peak runoff rates and, therefore, only briefly detain portions of flow from larger storms. Overall, detention basins can very effectively remove some pollutants in urban runoff; however, the design and the size of the basin in relation to the urban area served have a critical influence on this capability.

Retention basins are increasingly being incorporated in highway designs to contain runoff. One variation is to construct and contour highway interchanges so that open grassed areas can be used as runoff storage. However, as with all simple retention systems, this design can adversely affect ground water. Water quality can be protected by designing runoff control structures to prevent infiltration of pollutants into ground water, and to provide for settling, filtration, or more substantial treatment prior to discharge to surface water or ground water.

Runoff storage devices include small check dams and earthen berms that increase the storage capacity in existing streams and wetland areas; natural or excavated depressions that store stormwater flows and slowly discharge into the drainage system; grassed waterways (swales) that moderately improve urban runoff quality; roof tops and parking lots designed to serve as short-term detention facilities in highly developed areas; and depressed local recreational areas used for temporary storage of runoff from adjacent areas.

Designs and general specifications for retention basins can be found in a manual developed by the Nationwide Urban Runoff Program (NURP): Retention/Detention and Infiltration Devices for the Control of Urban Runoff. For a copy, write to EPA's Nonpoint Source Branch, 401 M St. SW, Washington, DC 20460.



Capital and Operating Costs

Capital and operating costs largely depend upon the type and size of the runoff storage facility. Check dams and earthen berms may be built inexpensively, but more expensive storage systems (concrete vault storage structure) may require significant excavation and construction.

According to NURP, on-site wet ponds serving relatively small urban areas range from $500 to $1,500 per acre of urban area served; approximately $100 to $250 per acre for relatively large urban areas. The costs include both capital and initial operating costs; the range reflects differences in size needed to remove 50 to 90 percent of particulates. Annual operating costs per acre of urban area served are estimated at $60 to $175 for on-site applications, and $10 to $25 for off-site applications.[18]

Effectiveness

Storage and gradual release of storm water lessens the downstream impacts caused by flooding, stream bank erosion, resuspension of bottom deposits, and disruption of aquatic habitats. Detention basins designed to control a peak flow rate from a two-year storm can reduce peak flows over 90 percent on the average flow of that storm. Depending on the storage volume and settling characteristics of suspended pollutants, detention basins can reduce pollutant loadings to downstream water bodies. NURP found wet basins provide more water quality benefits than dry basins. According to NURP, wet basins have the greatest performance capabilities, with pollutant reductions varying from excellent to very poor in the basins that were monitored. This variability in effectiveness demonstrates that the design and the size of the basin in relation to the urban area served are critically important. As indicated by NURP data, dry basins are essentially ineffective for reducing pollutant loads.

Wetlands and marshes have proven to act as giant sponges in removing phosphorous and suspended solids from runoff. It has been demonstrated that a 7.5-acre wetland retained 77 percent ofall phosphorus and 94 percent of total suspended solids draining from a 65-acre sub-watershed of Lake Minnetonka, Minn.[19]

Street cleaning practices include sweeping streets and parking lots using mechanical vehicles or flushing from tanker trucks. Sweeping handles coarser dust and litter particles, whereas flushing carries away the finer fractions.

Experience and Application

Sweeping is more common in the United States, whereas street flushing is practiced mainly in Europe. Street cleaning or sweeping actually removes solids from the street, and therefore reduces the volume, weight, and concentrations of pollutants that can reach receiving waters. Flushing does not remove the particles from the street; it only moves the street refuse toward the drainage system. For this reason, flushing has a negligible effect on reducing pollution. However, street flushing may be advantageous in areas with combined sewer systems.

Capital and Operating Costs

Two types of sweepers are presently used to remove solids from impervious urban surfaces. The most common design is a mechanical street cleaner that combines a rotating gutter broom with a large cylindrical broom to carry the material onto a conveyor belt and into the hopper. A vacuum-assisted street cleaner uses gutter and main pickup brooms to loosen and move street refuse into the path of a vacuum intake. At present, a new mechanical street cleaner can cost approximately $62,000, whereas a vacuum-assisted street cleaner is slightly more ($68,000 - $72,000). The average operator receives $9/hr.

Effectiveness

Studies indicate that street cleaning is most effective in controlling heavy metals, and moderately effective in controlling oil and grease, floating matter, and salts. Street sweeping has not proven to be effective in controlling sediment, nutrients, and oxygen-demanding materials. The performance of a street cleaning program depends on the condition of the street surface, the particle size distribution of pollutants, the amount of pollutants present initially, the number of passes per treatment, and the interval between treatments. Cars parked on congested urban streets can reduce the effectiveness of street sweeping to zero. Street flushing is not affected by parked cars. In spite of relatively low sweeper efficiencies, one study reported water quality improved significantly in areas with regular sweeping practices. Water flushed from unswept streets contained on the average 2.3 times more suspended solids and heavy metals than that from swept and cleaned streets.[20] Current street sweeping is mostly for aesthetic purposes, with sweepers removing little of the finer dust and dirt fractions.

Based on five projects that evaluated street sweeping as a management practice to control pollutants in urban runoff, the Nationwide Urban Runoff Program (NURP) found street sweeping generally ineffective. Four of these projects concluded that street sweeping was not effective for this purpose and the fifth, which had a defined wet and dry season, believed that sweeping just prior to the rainy season could reduce some pollution in urban runoff.

Surface roughening is designed to decrease the rate of water runoff by slowing the downhill movement of water. It is routinely used at construction sites. One type of surface roughening, scarification, roughens the soil along the contour of a graded slope. Grooves retain runoff and increase the rate of water infiltration. Horizontal grooves also retain soil additives, seeds, and mulch that may be washed down the slope. Softening the soil also permits plant roots to develop more readily. Other variations of soil roughening include tracking and serrating slopes.

■ Experience and Application

This practice may be used where the physical site requires some means of runoff control. Scarification and serrating slopes are used more commonly on gradual slopes, whereas tracking is more adaptable on steep slopes. Compacted surfaces from tracking may be more beneficial on long, steep slopes exposed to high rainfall. The construction sites should be roughly graded as soon as possible after excavation to avoid the formation of soil mounds that easily erode.

Capital and Operating Costs

Surface roughening is inexpensive to perform but requires timing and coordination of construction activities. Since these practices are carried out with typical construction equipment (i.e., bulldozers), no additional equipment need be purchased. Areas disturbed during construction can be roughened while the construction is taking place, thus minimizing the cost of additional labor to perform the erosion control practice.

Effectiveness

Construction typically disturbs areas by removing vegetation and moving earth from one place to another. Unprotected soils will be subject to erosion unless pollution reduction controls are practiced. Surface roughening is a very effective, cost-efficient method for preventing soil erosion.

Silviculture

Limited disturbance restricts the areas where work takes place to the most effective use of space, personnel, and equipment at any given time. An operational area may be defined by the maximum number of active cut blocks, maximum number of acres without seeding, or maximum miles of roads without permanent erosion controls.

Experience and Application

In large logging areas, it is especially useful to limit the amount of space in which work is being done. Exposing large areas of soil to direct rainfall may alter the soil's structure, reducing infiltration rates so that more rain becomes runoff and overland flow. The use of large equipment also compacts the soil, resulting in the same effects.

Capital and Operating Costs

This practice will generally not increase costs if it is fully integrated into operations to make the most effective use of equipment, labor, and management. Operating costs may decline because management is concentrated on a smaller area of operation.

Limiting Disturbed Areas

silviculture

Effectiveness

By limiting the logging operation to a clearly defined area, greater control can be exercised over the potential causes of nonpoint source pollution, significantly reducing negative effects. The clear area should be cleaned up as much as possible as the logging operation moves to the next defined area. Restoration can begin as soon as leftover material is disposed of, with reforestation proceeding even as the logging continues in another area.

Log transport (yarding) methods that move logs from the felling location to a landing or transfer point can vary drastically in their effect on the environment. Yarding methods and the access roads associated with them are primary causes of erosion and sedimentation. Various log transport methods include tractor, high lead, skyline cable, balloon, and helicopter.

■ Experience and Application

Research has shown that silvicultural operations can temporarily change water quality characteristics in streams draining forest land, increasing sediment concentrations if erosion accelerates, and stream temperatures if shade is removed. Accumulations of slash (logging debris) in a stream can deplete its dissolved oxygen. Harvesting or application of pesticides and fertilizers can increase organic and inorganic chemical concentrations.[21]

Tractor skidding is the most common transport method employed in the Northeast and South, and on lands with less than 30 percent slope in the Intermountain, Northwestern, and California regions. To minimize scarification, a skid pan and a high-wheeled arch yarder are commonly used, sometimes with a winch to snake logs to the tractor before skidding them to the yarding area.

A high lead log transport system uses a metal tower about 23 meters (75 feet) high mounted on a mobile frame. Guy lines hold the tower in place, from which a winch and set of cables drag the logs along the ground to a yarding area, where they are loaded into a truck.

Skyline cable and balloons are recommended for clearout logging operations. A skyline cable system employs a cable to carry the full weight of the logs as they are transported. Aerial cables attached to the towers at opposite ends of the logging site mechanically lift the logs off the ground and move them along the cable to the landing area, which is usually near one of the towers. Skyline cable systems are typically used for a large volume of timber and the system can operate at distances of more than 900 m (3,000 ft.). Cables should be installed at a height that will ensure that logs are lifted off of the ground during most of the transport opertion.

The balloon method uses a large balloon usually filled with helium and capable of static lifts of 5 to 10 tons (4.5-9 metric). A cable system similar to high lead is used to control the horizontal movement of the balloon over the logging site. A snubbing line may be required to winch the unloaded balloon close to the ground. Balloon logging is adapted to steep slopes (45 to 90 percent) with unstable soils. A minimum logging yield of 70 m^3 per hectare (12,000 board-feet per acre) is necessary to justify this type of log transport.

Helicopter log transport is recommended for transporting valuable timber in inaccessible areas where aesthetic values command high priority. With this system, the helicopter lifts the logs from the ground at the point of felling and transports them to the loading area.

Capital and Operating Costs

Balloons and helicopters transport timber without causing extensive soil erosion and sedimentation, but they are more expensive than the other techniques. Actual cost is difficult to determine because balloons or blimp-like lifting vehicles are only in the experimental stage in the United States. Heavy lift helicopters are very expensive to purchase and maintain, and their use has generally been restricted to more inaccessible terrain.

Effectiveness

Tractor skidding is the worst technique in terms of erosion control, and even on level to rolling land tractors will expose more bare soil than other methods. The pollution potential for high lead log transport systems is generally less than that for tractor skidding, although when logs are repeatedly yarded over a high spot on the ground, deep profile cuts into the soil may occur.

A skyline cable system has less potential for pollution than the other two systems because it requires only one-tenth as much road construction as more conventional methods. Lifting logs off the ground, it thereby avoids cutting the forest floor and confines soil disturbance to yarding and loading areas.

Balloon and helicopter logging causes minimal soil disturbance and erosion. Helicopter logging requires fewer access roads and is a very versatile system for moving logs from felling sites to loading areas.

Log Removal Techniques

silviculture

Maintaining ground cover in a disturbed area will help prevent erosion while the vegetation eventually reestablishes. Grass, shrubs, small trees, and sod provide good ground cover for forest areas disturbed by logging.

Experience and Application

In most situations, ground cover can be introduced successfully to areas disturbed by logging operations, usually after logging debris has been removed from the ground. Grass cover can be difficult to establish on arid or sterile soils or on all slopes over 1:1. Jute mats or excelsior pads may be required to hold seeds in these critical areas.

Capital and Operating Costs

The costs incurred for this pollution management practice include the purchase of plant materials and fertilizer, and the labor for planting and applying the fertilizer.

Effectiveness

Vegetation retains moisture, thus preventing dry soil masses and saturation of the subsoils. Vegetative ground cover also protects the soil from heavy rainfall that may carry soil particles downhill. This practice enhances infiltration and reduces overland water flow, as it encourages growth of vegetation required to return the site to prelogging conditions.

Debris such as tree tops and slash must be properly disposed of away from waterways. Streams near logging operations must be properly and regularly checked for buildup of such debris, to prevent it from damming the waterway and scouring sediment from stream banks.

■ Experience and Application

In any work near waterways it is very important to prevent build up of woody debris. Logging operations may increase the amount of woody debris in waterways, and it must be cleaned up during and after timber harvesting. Although all slash should be removed, the old debris anchored in the streambed and around which the channel has formed should be left in place.

■ Capital and Operating Costs

Ultimately, this management practice should cost nothing. The only requirement is enough supervision over logging operations to ensure the proper removal and disposal of debris.

When cleanup has been necessary, hand cleaning costs were estimated at $160 to $800 (updated to 1985 dollars) per 100 foot of stream, averaging about $500 per station when about 5 tons of material were removed.[22]

■ Effectiveness

Maintaining stream channels by preventing the buildup of debris from logging activities will significantly reduce the impact on the water course. Debris that deflects or constricts waterflow accelerates bank and channel erosion.

Construction, use, and maintenance of access roads and skid trails expose the ground surface to rainfall and can alter drainage patterns to intensify erosive forces. Appropriate location and design of haul roads will help prevent erosion in disturbed areas.

Experience and Application

Logging roads must be constructed properly to prevent nonpoint source pollution. Roadways should be built away from water courses and according to recommended guidelines for gradient, drainage, soil stabilization, and filter strips in the area. Where possible, roads should be routed across, rather than up and down slopes, with artificial drainage where normal patterns are disrupted seriously. Use should be restricted during wet weather. Skid trails should be limited in number and avoided when logging on very steep grades.

Capital and Operating Costs

Although road construction may cost the logging company a great deal before operations begin, it is very important to provide a roadway that functions as a route for tree removal and also causes the least environmental impact. Road surfacing will affect operating cost. In one study, grass (plus fertilizer) cost $5.37/30 m roadbed; crushed rock (15 cm), $179.01/30 m roadbed; and 20 cm rock, $265.67/30 m roadbed.[23] Grasses may be cheaper but may require more maintenance and periodic replanting.

Proper Roads and Trails

silviculture

Effectiveness

Properly designed and constructed road and skid trails help pre- vent erosion in forest areas. Roadways must be designed to consider erosion potentials from various cross sections of the road, choosing a crown-with-ditch-and-culvert design that has the least impact on the area. Roads must be graded and aligned to minimize mileage on steep slopes.

Road coverings such as grass or gravel also reduce sediment loss. A study discovered that losses of sediment from roadbeds without surface covering were eight times the losses from roadbeds covered by 15-20 cm gravel.[24] In a study of types of coverings, the mean soil loss rates on five mountainous roadways were estimated as follows:

- bare soils, 1.2 ton/ha roadbed/cm rain
- grass, 0.65 ton/ha roadbed/cm rain
- crushed rock (15 cm), 0.1 ton/ha roadbed/cm rain.[25]

Adequate gravel cover will last for several years whereas grasses must be replenished routinely and may not be effective on highly traveled roads.

Good practices include closing temporary timber access roads when not in use, closing roads during wet periods of the year to prevent sediment from being produced, and—when logging operations cease—restoring the main haul roads to conditions that will prevent erosion.

Mining

Water diversion involves collecting the water before it enters the mine, then conveying it around the mine site. Ditches, flumes, pipes, trench drains, and dikes are commonly used for water diversion. Riprap and dumped rock are sometimes used to reduce water velocity in the conveyance system. Ground water can be diverted by using a well to intercept it and then pump it away from its normal flow path before it enters the mine, or by using drainways to carry the ground water out of the mine before it contacts pollution-forming materials.

Experience and Application

A water diversion system should be properly designed to accommodate expected volumes and water velocities. If the capacity of a ditch is exceeded, water can erode the sides and render the diversion structure useless for any amount of rainfall. Ditches are usually excavated upslope of the surface mine. Flumes and pipes are used to carry water down steep slopes or across regraded areas. Surface water diversion can be applied to many waste piles, diverting water around or conveying it via closed channels through the waste material.

Capital and Operating Costs

Costs vary according to the site, the type of mine and operation, and the design and materials used. However, water diversion reduces water treatment costs by reducing the volume of water that needs to be treated. Where ground water is concerned, it may be cheaper to drill holes and pump ground water away than to treat the water after it passes through the mine.

Effectiveness

Surface water diversion is an effective technique for preventing water pollution: it can be applied to almost any surface mine orwaste pile. This procedure decreases erosion and reduces pollution.

Underdrains of tile, rock, or perforated pipe can be placed below pollution-forming materials to quickly discharge infiltrating water. These devices shorten the flow path and residence time of water in the waste materials.

Experience and Application

Underdrains are designed to provide zones of high permeability to collect and transport water from the bottom of the piles. A common construction method is to use trenches filled with rock. Underdrains can be used with large tailings accumulations, but should be installed before the pile is created. Care must be taken during design to preclude the possibility of fines clogging the underdrain. Filter fabric is used for this purpose.

Capital and Operating Costs

Construction should be relatively inexpensive, higher if the underdrains must be installed in existing waste piles.

Effectiveness

Underdrains are recommended for use with head-of-hollow mining technique, but should not be used where the pile has been inundated, because the underdrains will drain the pile and cause adverse effects. Underdrains should be used only in piles where the water table fluctuates and flow is in direct response to rainfall.

The block-cut method is a simple innovation of the conventional contour strip mining method for steep terrain. Instead of casting the overburden from above the coal seam down the hillside, it is hauled back and placed in the pit of the previous cut. No spoil is deposited on the downslope below the coal seam, topsoil is saved, overburden is removed in blocks and deposited in prior cuts, the outcrop barrier is left intact, and reclamation is integrated with mining.

Experience and Application

Once the original cut has been made, mining can be continuous,working in either one or both directions around the hill. The cuts are mined as units, thereby making it easier to retain the original slope and shape of the mountain after mining. In all cuts, an unmined outcrop barrier is left to serve as a notch to support the toe of the backfilled overburden.

Capital and Operating Costs

The block-cut method is no more expensive and may be less than conventional dragline pull-back mining—an estimated 33 cents per ton less in Pennsylvania. Reclamation costs are lower, as the overburden is handled only once instead of two or three times.

Effectiveness

Block-cut mining makes it possible to mine on steeper slopes without the danger of slides and with minimal disturbance: approximately 60 percent less total acreage is disturbed than by other mining techniques. There is significant visual evidence that the block-cut method is less damaging than the old practice of shoving overburden down the side of the mountain. The treeline below the mined area and above the highwall is preserved, with results of the operation generally hidden from view. Landslides caused by spoil on the downslopes have been totally eliminated. Erosion is significantly reduced and more easily controlled because of concurrent reclamation with mining.

Multicategory

Buffer Strips

multicategory

Buffer zones are strips of grass or other erosion-resistant vegetation planted between a waterway and intensively-used land. Buffer strips can be located on the edges of fields or along streambanks. Grass buffer strips reduce the velocity of runoff and cause suspended sediments to settle out of storm flows. Buffer strips reduce nonpoint pollution from agricultural, construction, and silvicultural activities.

Experience and Application

Vegetative strips trap sediment and pollutants in surface runoff because they retard water flow, thereby increasing infiltration and detention of particulate matter. This technique is applicable to all areas where streams, lakes, and open channels exist.

Grass filter strips provide excellent trapping efficiency for suspended solids, especially for construction sites and farms. Grass strips can also be used to control barnyard and feedlot runoff and to reduce soil and pollutant loss from agricultural fields. This BMP does not address the source of pollutants, and may remove agricultural land from production and valuable land from development.

Capital and Operating Costs

Buffer strips require moderate expenditures to implement and should be incorporated as needed along natural waterways.

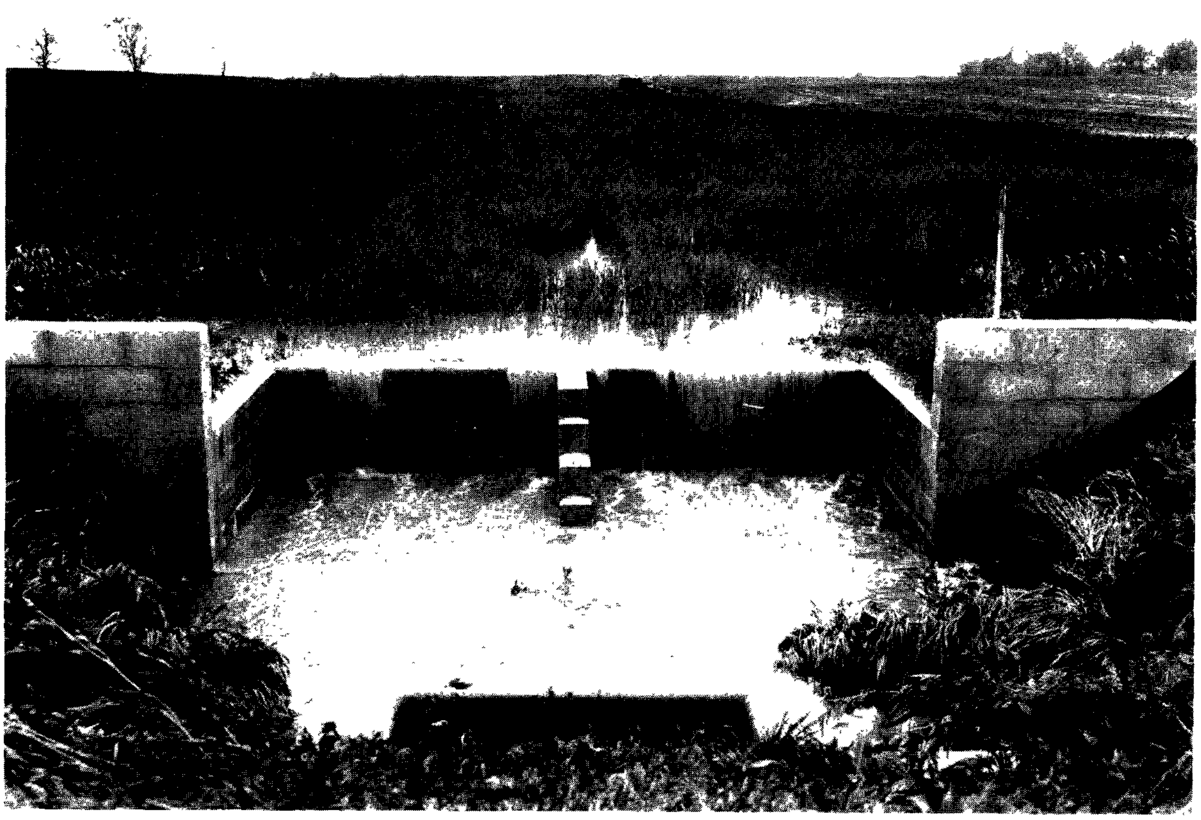
Effectiveness

A 2.5 m grass strip can remove a minimum of 85 percent sediment during shallow overland flow. Although effective in controlling erosion, most grassed areas do not reduce pollution. Grass buffer strips have been used only recently to control agricultural pollution, and, like grassed waterways, more research is needed to quantify their effectiveness. Cropped buffer strips on a 4 percent slope have reduced feedlot runoff by 67 percent and runoff of total solids by 79 percent. In the same study, movement of nitrogen and phosphorus in the runoff decreased by an average of 84 and 83 percent, respectively.[26]

Grassed waterways are natural or constructed drainage channels used to conduct surface runoff. The waterways are usually broad and shallow, covered with erosion-resistant grasses. Agricultural grassed waterways are used for safe disposal of runoff from fields, diversions, and terraces, and for other conservation measures. Also, grassed waterways serve as nonpoint pollution control in residential and construction areas.

■ Experience and Application

Grassed waterways are a basic conservation practice commonly used by farmers. The ideal location for a waterway is a well-vegetated natural draw; however, this technique can be used only on up to 80 percent of all cropland. A pasture or meadow strip lying in a drainageway may be used instead of a constructed or natural waterway. The waterway design should ensure that the strip is wide enough to carry the volume of flow, and that the type and density of vegetation are adequate to withstand expected flow velocities. Vegetative cover such as reed canary grass and Kentucky 31 tall fescue (unmowed) provide excellent cover.



Capital and Operating Costs

Although the cost to implement grassed waterways is moderate, this technique is probably the most effective and economic means of conveying water. If waterways are designed properly, in-channel erosion should be minimal, and the grass lining may even serve as a sediment trap.

Agricultural grassed outlets involve costs to establish and maintain and may interfere with the use of large equipment. Some shaping or enlarging may be required to handle the increased flow; if this is the case, the design and construction should provide a stable channel.

Effectiveness

Agricultural grassed outlets facilitate drainage of graded rows and terrace channels with minimal erosion. By encouraging drainage, this practice increases runoff volume and decreases soil infiltration. Grassed waterways also allow for disposing of excess surface water from construction sites and urban areas without causing erosion. Grassed waterways can prevent 60 to 80 percent of suspended particles from moving to adjacent surface waters.

The most popular method of increasing infiltration—the gradual downward movement of water from the surface into the subsoil—is through trenches or ponds. Trenches usually are shallow excavations with a permeable bottom material such as gravel or sand laid over a permeable substrate, thereby allowing runoff water to percolate freely into the ground water. Other ways to induce infiltration include dry wells, wet and dry ponds, evaporation ponds, and special impoundments. Infiltration systems are used to control runoff along highways and manage storm water in urban developments. (See Runoff Detention/Retention).

■ Experience and Application

Infiltration devices can be an acceptable approach to managing stormwater runoff, but they must be limited to good quality storm water so as to prevent contamination of the ground water. In addition, adequate clearance must be maintained between the bottom of the structure and the groundwater table. Some type of sediment trap should be provided to remove sediment and other debris from the runoff before it enters the infiltration area.

Infiltration systems can replenish ground water and increase stream flows during low flow periods. Their use depends on soil permeability, aquifer conditions, and the topography as well as the depth of the groundwater table. A pervious subsoil is necessary to dispose of water at an adequate rate.

Capital and Operating Costs

These systems may require a high degree of maintenance because of the tendency of the coarse bottom material to clog with fine particles. This can be corrected by routing the water over grass, vegetative filters, or sediment traps before it enters the infiltration area.

Effectiveness

Increased infiltration improves recharge into groundwater aquifers. In addition, infiltration may totally remove fine soil particles and other particulates as well as dissolved solids.

Interception/ Diversion Practices

multicategory

Diversion structures are conveyances designed to change the direction of water flow. They represent any modification of the surface that intercepts and diverts runoff while increasing the distance of flow to a larger channel system. Basically, diversion structures are designed to intercept runoff before it has a chance to come in contact with an erodible soil surface. Diversion structures include soil or stone dikes, ditches (or swales), terraces, and benches. These structures can be temporary or permanent and should not cause in-channel erosion. They often are constructed to divert up-slope runoff from a source of nonpoint pollution (disturbed area), and can be used on construction sites, urban areas, or agricultural lands.

Experience and Application

Diversion structures may be used to protect bottom land from hillside runoff, divert water from areal sources of pollution, or protect structures from runoff. This technique is particularly applicable on slopes up to 12 percent and above feed lots on any slope. The diversion structure should allow a shallow, random flow. It can also be used at the top of graded slopes to divert offsite runoff away from an erodible surface. For example, this technique has been used to a great extent to divert runoff along highways. Diversion structures can be used in urban developments, but require an adequate analysis of the hydrology, geology, and soils in the area. On agricultural lands, they are generally built above cropland fields, gully headcuts, or other critical erosion areas. Other BMPs should be used in areas subject to slumping and landsliding.

Diversion structures should have adequate outlets that will convey runoff without causing erosion, such as natural or constructed vegetated outlets capable of safely carrying the discharge, properly designed and constructed grade stabilization structures, or storm sewers. If the diversion structure is used to collect runoff from a disturbed area, its outlet should open into a sediment trap or basin. Disadvantages of using this technique: it may interfere with cultivation, maintenance may be required, and it is relatively costly.

Capital and Operating Costs

Diversions require some engineering design and structure, and could be more expensive than source controls. The cost of a diversion structure could vary greatly from an inexpensive earth channel to a large concrete diversion.

Effectiveness

This technique can be a very effective way of preventing excessive erosion, but only if it is designed, installed, and maintained correctly. Diversion structures can reduce pollutants (particularly total phosphorus, suspended solids, pesticides and total nitrogen) entering adjacent water bodies from 30 to 60 percent. The structure's effectiveness depends on the physical characteristics of the development site as well as climatic factors.

Loose rock, aggregate, mulches, or fabric can be layered over an erodible soil surface, providing an excellent erosion control for all nonpoint sources.

■ Experience and Application

Riprap, the common term for loose rock or aggregate, is used where soil conditions, water turbulence and velocity, expected vegetative cover, and groundwater conditions are such that soil may erode under certain flow conditions. Riprap may be used at such places as storm drain outlets, channel banks and bottoms, roadside ditches, lake shores, and drop structures. The area to be riprapped can be shaped with heavy equipment or the rock can be placed along the bank without any bank modification. Vinyl or geo-fabric materials, often of fine mesh construction, should be placed beneath riprap to prevent flowing water from pulling sediments through voids in the riprap.

Deflectors constructed of large rocks, logs, or wire mesh (gabions) also can be put in place to control water flow.

■ Capital and Operating Costs

The cost of using one of these materials to prevent erosion could vary tremendously, depending on the type and availability of the material, whether or not the site must be modified by heavy equipment, and how large an area needs to be covered. The initial cost of material varies from State to State and from community to community. A good example of the variability in the cost of riprapping was demonstrated in 1982 on three South Dakota Lakes (Lake Kampeska, Oakwood, and Swan) under EPA's Clean Lakes Program. In summary, Lake Kampeska cost $39 per foot of shoreline, Oakwood Lake cost $38.50 per foot of shoreline, and Swan Lake cost $5.22 per foot of shoreline. The low cost of riprapping Swan Lake can be attributed to the extensive local donations and the fact that little or no reshaping was done to the shoreline prior to riprapping.[27]

Effectiveness

The materials described can be very effective in reducing erosion on unstable banks. A good example of the effectiveness of riprap was demonstrated on the South Dakota Lakes where, in all three cases, visual inspections have concluded that the riprap has protected severely eroded shorelines and is expected to discourage further erosion.

Sediment traps are small, temporary structures used at various points within or near disturbed areas to detain runoff for a short period and trap coarser sediment particles. They are generally thought of as smaller detention structures used to trap the coarser sediment. Various types of sediment traps include sandbags, straw bales, stone or prefabricated check dams, log and pole structures, excavated ditches, and small pits. A structure called a stone trap can be placed across stream channels to temporarily detain flow and trap sediment. This type of trap consists of a dike of randomly placed stone, sized according to expected flow rates.

■ Experience and Application

Sediment traps are considered on-site practices. Traps may be placed around storm drain inlets and in ditches and other small drainage ways. Sediment should be removed and the trap restored to its original dimensions when the accumulated sediment reaches 50 percent of the trap's depth.

Capital and Operating Costs

Sediment traps are usually inexpensive to build and can be incorporated into any construction project. Although sediment traps must be inspected occasionally, cleaned periodically, and promptly maintained if they are to function adequately, such costs are minimal.

Effectiveness

When these structures are positioned at regular intervals along a drainage way or at storm drain inlets, a high degree of trapping efficiency for coarser particles can be achieved. They have little effect on retaining fine soil particles and their associated pollutants.

Vegetative Stabilization

multicategory

Vegetation can be established to stabilize the soil either temporarily or permanently. Temporary stabilization uses fast-growing annual and perennial plants that provide interim protection for less than a year. Permanent stabilization uses long-lived perennial plants. Selected according to specific site conditions, these plants include grasses, legumes, ground cover, vines, shrubs, and native herbaceous plants and trees. Areas around vegetative cover can be mulched (with plant residues) or geo-fabrics can be installed to further reduce erosion and protect the ground. Vegetative stabilization and mulching are applicable to agricultural, construction, urban, mining, and silvicultural areas.

Experience and Application

Vegetation is a very desirable material for controlling soil erosion. Vegetative cover performs a number of important functions, including shielding the soil from the impact of the raindrops, retarding surface flow of water and thereby permitting greater infiltration, maintaining a pervious soil surface capable of absorbing water, and removing water from the soil between storm events by transpiration. The installation of plant material requires good soil preparation and proper planting techniques. Site factors that may prevent plants from becoming established on exposed materials typical of construction sites include the chemical and physical properties, steepness of slopes, and the site's biological features.

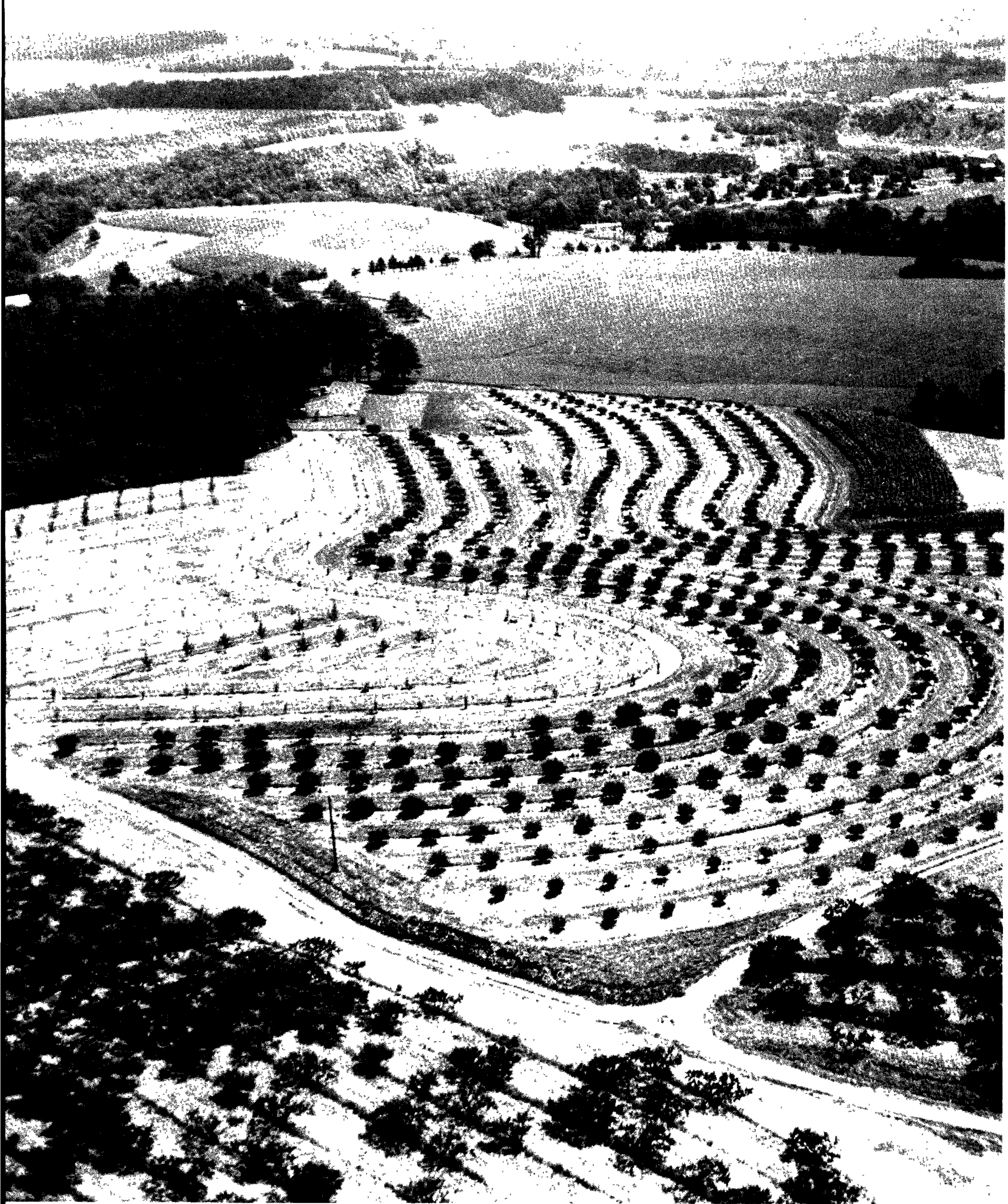
Grasses and legumes are considered superior to trees, shrubs, and ground covers for initial soil stabilization because their fibrous root systems characteristically bind soil particles, encourage the formation of water-stable soil aggregates, protect the soil surface from erosion by water and wind, and grow quickly. Vegetative cover not only reduces pollution to lakes and streams but improves the aesthetics of the environment and, where desirable, provides wildlife habitat.

Capital and Operating Costs

The cost of vegetative stabilization varies greatly, depending on the size of the area to be stabilized and the difficulty of surface preparation as well as the type of vegetation used. Ground cover along highways can be much less costly than elaborate landscape design incorporated into urban developments. After the vegetative cover becomes established, regular maintenance is required to achieve a long-term cover that adequately controls soil erosion. However, plant materials vary in the amount of maintenance required to sustain them. For example, on inaccessible slopes, a low maintenance cover would be desirable.

Effectiveness

Vegetation in any form is a very effective means of controlling soil erosion. However, the condition of the installed vegetation will determine its effectiveness. For example, a cover of vegetation that is not properly established or maintained will not be fully effective in controlling erosion. Various grass species reduce soil loss by 95 to 99 percent compared to bare surfaces. Overall, research must continue into determining the effectiveness of vegetative stabilization as an erosion control practice.



End Notes

[1]Wendt, R. C. and R. E. Burwell. 1985. Runoff and soil losses for conventional, reduced, and no-till corn. J. Soil Water Conserv. Sept.-Oct. 450-4.

[2]Novotny, V., and G. Chesters. 1981. Handbook of Nonpoint Pollution Sources and Management. Van Nostrand Reinhold Environmental Engineering Series, New York.

[2,3]Conservation Tillage Information Center. 1986. 1985 National Survey Conservation Tillage Practices Ohio County Summary. Natl. Ass. Conserv. Distr.

[4]Mueller, D., T. Daniel, and R. C. Wendt. 1981. Conservation tillage: Best management practice for nonpoint runoff. Environ. Manage. 5(1)33-53.

[5]Loehr, R. C. 1984. Pollution Control for Agriculture. 2nd ed. Academic Press, Inc., New York.

[6]Yaksich, S. M. 1983. Summary report of the Lake Erie wastewater management study. U.S. Army Corps of Engineers, Buffalo District, New York.

[7]Report to the Great Lakes Water Quality Board. 1983. Nonpointsource abatement in the Great Lakes basin. An overview of post— PLUARG development. International Joint Commission. Windsor, Ontario.

[8]Onstad, C. A. and T. C. Olson. 1970. Water budget accounting on two corn-cropped watersheds. J. Soil Water Conserv. 25:150-152.

[9]Harrold, L. L., and W. M. Edwards. 1970. Watershed studies of agricultural pollution. Ohio Rep. 55(4):85-96.

[10]Myers, Carl F., July 9, 1986. Memorandum To: William A. Whittington, Director, Office of Water Regulations and Standards (WH-551). Subject: Pesticides in groundwater from agricultural use.

[11]Novotny, V., and G. Chesters. 1981. Handbook of Nonpoint Pollution Sources and Management. Van Nostrand Reinhold Environmental Engineering Series, New York.

[12]Wendt, R. C., and R. E. Burwell. 1985. Runoff and soil losses for conventional, reduced, and no-till corn. J. Soil Water Conserv. Sept.-Oct. 450-4.

[13]Report to the Great Lakes Water Quality Board. 1983. Nonpoint source abatement in the Great Lakes basin. An overview of post— PLUARG development. International Joint Commission. Windsor, Ontario.

[14]Report to the Great Lakes Water Quality Board. 1983. Nonpoint source abatement in the Great Lakes basin. An overview of post— PLUARG development. International Joint Commission. Windsor, Ontario.

[15,16]Highfill, R. E. 1983. Modern terracing systems. J. Soil Water Conserv. 38(4):336-8.

[17]Report to the Great Lakes Water Quality Board. 1983. Nonpoint source abatement in the Great Lakes basin. An overview of post— PLUARG development. International Joint Commission. Windsor, Ontario.

[18]U.S. Environmental Protection Agency. 1983. Results of the nationwide urban runoff program. Executive summary. Water Planning Division, U.S. Environ. Prot. Agency, Washington, DC. Natl. Tech. Inform. Serv., Springfield, VA. NTIS #PB84-185545.

[19]Hickock, E. A., M. C. Hannaman, and N. C. Wenck. 1977. Urban Runoff Treatment Methods. Vol. I. Nonstructural wetland treatment. EPA-600/2-77-217. U.S. Environ. Prot. Agency, Washington, DC.

[20]Malmquist, Per-Arne. 1978. Atmospheric fallout and street cleaning—effect on urban storm water and snow. Prog. Water Tech. 10:495-505.

[21]Brown, G. W. 1985. Controlling nonpoint source pollution from silvicultural operations: What we know and don't know. Pages 332-3 in Perspectives on Nonpoint Source Pollution, Proc. Natl. Conf. EPA 440/5-85-001. U.S. Environ. Prot. Agency, Washington, DC.

[22]Dykstrat, D.P., and H.A. Forehlich. 1976. Cost of stream protection during timber harvest. J. Forestry October: 684-7.

[23,24,25]Swift, L. W., Jr. 1984. Gravel and grass surfacing reduces soil loss from mountain roads. Forest Sci. 30(3):657-70.

[26]Young, R., T. Huntrods, and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. J. Environ. Qual. 9(3): 483-7.

[27]Final Report: Swan lake restoration project. 1982.

Sources

Models and Assessment Techniques

Alley, W. M., and P. E. Smith. 1982a. Distributed routing rainfall-runoff model - version II. Computer program documentation user's manual. Open File Rep. 82-344. U. S. Geological Survey, NSTL Station, MS.

__________. 1982b. Multi-event urban runoff quality model. computer program documentation user's manual. Open File Rep. 82- 764. U. S. Geological Survey, NSTL Station, MS.

Ambrose, R., S. Hill, and L. Mulkey. 1983. User's manual for the chemical transport and fate model TOXIWASP. Version I. Draft document. Office of Research and Development, U.S. Environ. Prot. Agency, Athens Research Laboratory, Athens, GA.

Beasley, D. B., E. J. Monke and L. F. Huggins. 1980. ANSWERS: A model for watershed planning. Trans. Am. Soc. Agric. Eng. 23(4): 938-44.

Beasley, D. B. and L. F. Huggins. 1981. ANSWERS users manual. EPA 905/9-82-001. U. S. Environ. Prot. Agency, Region V. Chicago, IL.

Burns, L. A., D. M. Cline, and R. R. Lassiter. 1982. Exposure analysis modeling system (EXAMS) user manual and system documentation. EPA 600/3-82-023. U. S. Environ. Prot. Agency, Athens, GA.

Computer Sciences Corporation. 1980. Pesticide Runoff Simulator User's Manual. Office of Pesticides and Toxic Substances, U.S. Environ. Prot. Agency, Washington, DC.

Connolly, T. P. 1982. Preliminary estuary and stream version documentation of WASTOX. EPA Cooperative Agreement No. R807 827- 02. U.S. Environ. Prot. Agency, Gulf Breeze, FL. Manhattan College, Bronx, NY.

DeCoursey, D. G. 1982. ARS small watershed model. Paper No. 82- 2094. Am. Soc. Agric. Eng. Summer Meeting, University of Wisconsin, Madison, WI. June 27-30.

DePinto, J. V., W. L. Richardson, K. Rygwelski, et al. n.d. Technical guidance manual for performing waste load allocations. Draft rep. U.S. Environ. Prot. Agency, Washington, DC.

DiToro, D. M., J. J. Fitzpatrick and R. V. Thomann. 1983. Documentation for water quality analysis simulation program (WASP) and model verification program (MVP). Prepared for the Office of Research and Development, U.S. Environ. Prot. Agency, Duluth, MN, by Hydroscience, Inc. (presently HydroQual, Inc.), under Contract No. 68-01-3872.

Donigian, A. S., Jr. and N. H. Crawford. 1977. Simulation of nutrient loadings in surface runoff with the NPS model. EPA 600/3-77-065. U. S. Environ. Prot. Agency, Athens, GA.

__________. 1979. User's manual for the nonpoint source (NPS) model. U.S. Environ. Prot. Agency, Environmental Research Laboratory, Athens, GA.

Donigian, A. S., Jr., D. C. Beyerlein, H. H. Davis, Jr. and N. H. Crawford. 1977. Agricultural runoff management (ARM) model version II: Refinement and testing. EPA 600/3-77-098. U. S. Environ. Prot. Agency, Environmental Research Laboratory, Athens, GA.

Donigian, A. S. Jr., and D. C. Beyerlein. 1985. Review and analysis of available NPS and integrated watershed models. Woodward-Clyde Consultants, Walnut Creek, CA.

Donigian, A. S. Jr., J. L. Baker, D. A. Haith, and M. F. Walters. 1983. HSPF parameter adjustments to evaluate the effects of agricultural best management practices. U.S. Environ. Prot. Agency. PB83-247171 Natl. Tech. Inf. Serv., Springfield, VA

Evenson, D. E., J. R. Monser, W. R. Norton, and W. R. Roesner. 1974. Computer program documentation for the stream quality model QUAL-II. Prepared for U.S. Environ. Prot. Agency, Systems Development Branch, Washington, DC, by Water Resources Engineers, Inc., under Contract No. 68-01-0713.

Felmy, A. R., S. M. Brown, Y. Onishi, R. S. Argo and S. B. Yabusaki. 1982. MEXAMS - The metals exposure analyses modeling system. Battelle, Pacific Northwest Laboratories, Richland, WA. Contract No. 68-03-3089.

Frere, M. H., C. A. Onstead and H. N. Holton. 1975. ACTMO—An agricultural chemical transport model. Publ. No. ARS-H-3. Hyattsville, MD. Agricultural Research Service. U. S. Dep. Agric.

Genet, L. A., D. J. Smith, and M. B. Sonnen. 1974. Computer program documentation for the dynamic estuary model. Report by Water Resources Engineers, Inc., Walnut Creek, CA, to U. S. Environ. Prot. Agency, Systems Development Branch, Washington, DC.

Haith, D. A., and L. J. Tubbs. 1981. Watershed loading functions for nonpoint sources. J. Environ. Eng. 107(EE1):121-37.

Heaney, J. R., W. C. Huber, and S. J. Nix. 1976. Storm water management model, level I. Preliminary screening procedures. EPA 600/2-76-275. U. S. Environ. Prot. Agency, Cincinnati, OH.

Huber, W. C., J. P. Heaney, M. A. Medina, W. A. Peltz, H. Sheikh, and G. F. Smith. 1975. Storm water management model user's manual, version II. EPA 670/2-75-017. U.S. Environ. Prot. Agency, Cincinnati, OH.

HydroQual, Inc. 1981. CTAP documentation - chemical transport analysis program Prepared for Chemical Manufacturers Association, Washington, DC.

__________. 1982. Application guide for CMA - HydroQual chemical fate models. Prepared for Chemical Manufacturers Association, Washington, DC.

Johanson, R. C., J. C. Imhoff, H. H. Davis, J. L. Kittle, Jr. and A. S. Donigian, Jr. 1984. User's manual for hydrological simulation program - FORTRAN (HSPF): Release 7.0. U. S. Environ. Prot. Agency, Athens, GA.

Knisel, W. G. 1986. Personal communication. Southeast Watershed Research Laboratory, Argicultural Research Service, U. S. Dep. Agric. Tifton, GA.

Leavesley, G. H. R. W. Lichty, B. M. Troutman and L. G. Saindaon. 1983. Precipitation-runoff modeling system: user's manual. Water Resources Investigation Rep. 83-4238. U. S. Geological Survey, Denver, CO.

Lynch, J., E. Corbett and K. Mussallem. 1985. J. Soil Water Conserv. 40(1):164-7.

McElroy, A. D. S. Y. Chiu, J. W. Nebgen, A. Aleti and F. W. Bennett. 1976. Loading functions for assessment of water pollution from nonpoint sources. EPA 600/2-76-151. U. S. Environ. Prot. Agency. Washington, DC.

Mills, W. B., J. D. Dean, D. B. Porcella, S. A. Gherini, R. J. M. Hudson, W. E. Frick, G. L. Rupp and G. L. Bowie. 1982. Water quality assessment: A screening procedure for toxic and conventional pollutants. EPA 600/6-82-004a,b. Vol. I and II. U. S. Environ. Prot. Agency, Washington, DC.

Onishi, Y. 1981. Sediment-contaminant transport model. J. Hydraul. Div. Am. Soc. Civil Eng. 107(HY9) Proc. Pap. 16505:1089-1107.

Onishi, Y., and S. E. Wise. 1982. Users manual for the instream sediment-contaminant transport model SERATRA. EPA 600/3/82-055, U.S. Environ. Prot. Agency, Environmental Research Laboratory, Athens, GA.

Onishi, Y., G. Whelan, and R. L. Skaggs. 1982. Development of a multimedia radionuclide exposure assessment methodology for low- level waste management. PNL-3370. Battelle Pacific Northwest Laboratory, Richland, WA.

Onstad, C. A. and T. C. Olson. 1970. Water budget accounting on two corn-cropped watersheds. J. Soil Water Conserv. 25:150-2.

Orlob, G. T. 1975. Ecological simulation for aquatic environment. In B. C. Patten, ed. System Analysis and Simulation in Ecology. Vol. III. Academic Press, NY.

Park, R. A., C. D. Collins, D. K. Leung, C. W. Boylen, J. Albanses, P. deCaprariis, and H. Forstner. 1978. The aquatic ecosystem model MS CLEANER. Center for Ecologic Modeling, Rensselaer Polytechnic Institute, Troy, NY.

Patterson, M. R., T. J. Sworski, A. L. Sjoreen, M. G. Browman, C. C. Coutant, D. M. Hetrick, B. D. Murphy and R. J. Raridon. 1983. A users manual for UTM-TOX, a unified transport model. Draft.

Prepared by Oak Ridge National Laboratory, Oak Ridge, TN, for U. S. Environ. Prot. Agency Office of Toxic Substances, Washington, DC.

Reckhow, K. H., J. R. Butcher, and C. M. Marin. 1985. Pollutant runoff models: Selection and use in decision making. Water Resour. Bull. 21(2):185-95.

Schnoor, J. L., and D. C. McAvoy. 1981. A pesticide transport and bioconcentration model. J. Environ. Eng. Div.

Sutherland, R. C., and R. H. McCuen. 1978. Simulation of Urban Nonpoint Source Pollution. Water Resour. Bull. 14(2):409-28

Terstriep, M. L., and J. B. Stall. 1974. The Illinois Urban Drainage Area Simulator, ILLUDAS. Bull. 58. Illinois State Water Survey. Urbana, IL.

U.S. Department of Agriculture. 1980. CREAMS2: A field scale model for chemicals, runoff, and erosion from agricultural management systems. Conserv. Res. Rep. No. 26. Science and Education Administration, U.S. Dep. Agric., Tifton, GA.

U.S. Environmental Protection Agency. 1971. Storm water management model, Vol. 1 - final report. Water Quality Office, Water Pollut. Control Res. Series: 11024, Doc 07/71.

__________. 1976a. Storm water management model, level 1, preliminary screening procedures. EPA 600/2-76-275. Cincinnati, OH.

__________. 1976b. Development and application of a simplified stormwater management model. EPA 600/2-76-218. Cincinnati, OH.

__________. 1977. Simulation of nutrient loadings in surface runoff with the NPS model. Environmental Research Laboratory, Athens, GA.

__________. 1978. User's manual for agricultural runoff management (ARM) model. EPA 600/3-78-080. Environmental Research Laboratory, Office of Research and Development, Athens, GA.

__________. 1980. User's manual for hydrological simulation program - FORTRAN (HSPF). EPA 600/9-80-015. Environmental Research Laboratory, Athens, GA.

__________. 1981. ANSWERS user's manual. EPA 905/9-82-001. Chicago, IL.

__________. 1983. Results of the Nationwide Urban Runoff Program, Complete Set. Water Planning Division. PB84-185537. Natl. Tech. Inf. Serv., Springfield, VA.

U.S. Forest Service. 1980. An approach to water rsources evaluation of nonpoint silvicultural sources (a procedural handbook). EPA-600/8-80-012. U.S. EPA, Athens, GA.

__________. 1983. Guide for Predicting Salmonid Response to Sediment Yields in Idaho Batholith Watersheds. Northern Region, Missoula, MT.

__________. 1986. COWFISH, habitat capability model. Northern Region, Missoula, MT.

Ward, A. J., C. T. Haan, and B. J. Barfield. 1977. Simulation of sediment detection basins. Res. Rep. No. 103. Water Resources Research Institute, University of Kentucky, Lexington.

Woodward-Clyde Consultants. 1985. Summary of available models for receiving water impacts from nonpoint sources. Prepared by HydroQual, Inc., Mahwah, NJ.

Yeh, G. T. 1982. CHNTRN: A channel transport model for simulating sediment and chemical distribution in a stream/river network. ORNL-5882. Oak Ridge National Laboratory, Oak Ridge, TN.

Young, R. A., M. A. Otterby, and Amos Roos. 1982. An evaluation system to rate feedlot pollution potential. Agricultural Reviews and Manuals. ARM-NC-17. Agricultural Research Service, U. S. Dep. Agric.

Young, R. A., C. A. Onstad, D. D. Bosch, and W. P. Anderson. 1986. Agricultural nonpoint source pollution model: A watershed analysis tool. Agricultural Research Service. U. S. Dep. Agric., Morris, MN.

Best Management Practices

Anonymous. 1986. Virginia Offers Tax Credit for No-Till. J. Soil Water Conserv. 41(1):36.

Bilby, R. E. 1984. Removal of woody debris may affect stream channel stability. J. Forestry 82(10):609-13.

Chesters, G. and L. Schierow. 1985. A primer on nonpoint pollution. J. Soil Water Conserv. 40(1):9-13.

Conservation Tillage Information Center. 1984. 1984 National Survey Conservation Tillage Practices.

Croft, R. J. 1985. A project to manage agriculture wastes has improved the quality of Vermont's lake parker. Pages 153-6 in Perspectives on Nonpoint Source Pollution. Proc. Natl. Conf. EPA 440/5-85-001. U.S. Environ. Prot. Agency, Washington, DC.

Gordon, T. 1980. Local commitment to lake restoration: The Cobbossee watershed example. In Restoration of Lakes and Inland Waters. Proc. Natl. Conf. U.S. Environ. Prot. Agency, Washington, DC. PB82-158478. Natl. Tech. Inf. Serv., Springfield, VA.

Herman, F. R. 1960. A test of skyline cable logging on steep slopes--a progress report. USDA Forest Service Station Paper No. 53, October.

Impact of Land Treatment on the Restoration of Skinner Lake, Noble County, Indiana. 1982.

Inside EPA. 1986. 7(3):January 17.

Kao, D. T. Y., B. J. Barfield, and A. E. Lyons. 1975. On site sediment filtration using grass strips. Proc. Natl. Symp. Urban Hydrology and Sediment Control. University of Kentucky, Lexington. July 28-31.

Lake Fenwick Restoration Project. 1981.

Lake Kampeske Shoreline Protection Project Final Report. 1982.

Lyles, L., J. Tatarko, and J. D. Dickerson. 1984. Windbreak effects on soil water and wheat yield. Trans. Am. Soc. Agric. Eng. 27(1):69-72.

Mannering, J., and C. Fenoter. 1983. What is conservation tillage. J. Soil Water Conserv. 38(3):141-3.

Merritt, D. S., ed. 1968. Standard Handbook for Civil Engineers. Section 21. McGraw Hill, NY.

Moldenhauer, W., G. Langdale, W. Frye, D. McCool, R. Papensick, D. Smika, and D. Fryrear. 1983. Conservation tillage for erosion control. J. Soil Water Conserv. 38(3):144-51.

Moore, I. C., F. W. Madison, and R. R. Schneider. 1979. Estimating phosphorus loadings from livestock wastes: Some Wisconsin results. Pages 175-92 in R. C. Loehr, ed. Best Management Practices in Agriculture and Silviculture. Ann Arbor Science, Ann Arbor, MI.

Oakwood Lake Bank Shoreline Protection Project Final Report. 1982.

Pitt, R. 1979. Demonstration of nonpoint pollution abatement through improved street cleaning practices. EPA 600/2-79-161. U.S. Environ. Prot. Agency, Washington, DC.

Porter, K. S., ed. 1975. Nitrogen and Phosphorus: Food Production, Waste, and the Environment. Ann Arbor Science Publishers. Ann Arbor, Mich.

Soil Conservation Society of America. 1985. Nonpoint water pollution, a special issue. J. Soil Water Conserv. 40(1).

Stewart, B. A., D. A. Woolhiser, W. J. Wishmeiser, J. H. Caro, and M. H. Frere. 1975. Control of water pollution from cropland. Vol. I. EPA 600/2/75-026a. U.S. Environ. Prot. Agency, Washington, DC.

Stoeckeler, J. H. 1962. Shelterbelt influence on great plains field environment crops. Prod. Res. Rep. No. 62. U.S. Dep. Agric.

Tinus, R. W., ed. 1976. Shelterbelts on the great plains. Proc. Symp. Great Plains Agric. Council Publ. No. 78.

Unger, D. G. 1986. Comments on decision maker's guide on nonpoint pollution control. U.S. Dep. Agric., Watershed and Air Management, to U.S. Enviro. Prot. Agency, Nonpoint Source Branch, Washington, D.C. August 14.

U.S. Environmental Protection Agency. 1973a. Methods for identifying and evacuating the nature and extent of nonpoint sources of pollution. EPA 430/9-73-014. Office of Air and Water Programs, Washington, DC.

__________. 1973b. Methods and practices for controlling water pollution from agricultural nonpoint sources. EPA 430/9-73-015. Office of Water Program Operations, Water Quality and Nonpoint Source Control Division, Washington, DC.

__________. 1973c. Processes, procedures, and methods to control pollution resulting from all construction activity. EPA 430/9-73- 007. Office of Air and Water Programs, Washington, DC.

__________. 1979. Demonstration of nonpoint pollution abatement through improved street cleaning practices. EPA 600/2-79-161. Municipal Environmental Research Laboratory, Cincinnati, OH.

__________. 1980a. Clean Lakes Program Guidance Manual. Prepared by JACA Corporation, Ft. Washington, PA. EPA 440/5-81-003.

__________. 1980b. An approach to water resources evaluation of nonpoint silvicultural sources (a procedural handbook). EPA 600/8-80-012. Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, GA.

__________. 1980c. Capsule report: lake restoration in Cobbossee watershed. Technol. Transfer EPA 625/2/80-027.

__________. 1980d. An approach to water resources evaluation of nonpoint silvicultural sources (A procedural handbook by the Forest Service). EPA 600/8-80-012. Athens, GA.

__________. 1981. Clean Lakes Program Status 1975-1981. EPA 440/5- 82-024. Office of Water Regulations and Standards, Washington, DC. EPA 440/5-82-024.

__________. 1984. Report to Congress: Nonpoint Source Pollution in the United States. Office of Water Program Operations, Water Planning Division, Washington, DC.

__________. 1985a. Perspectives on Nonpoint Source Pollution. Proc. Natl. Conf. Coordinated by N. Am. Lake Manage. Soc., Kansas City, MO, May. EPA 440/5-85-001.

__________. 1985b. Clean Lakes Program. A review of the first decade. EPA 440/5-85-033. Office of Water Regulations and Standards, Washington, DC.

U.S. Soil Conservation Service. 1978. Water management and sediment control for urbanizing areas, Columbus, Ohio. U.S. Dep. Agric.

Woodruff, N.P., L. Lyles, F. H. Siddoway, and D. W. Fryrear. 1972. How to control wind erosion. U.S. Dep. Agric. Info. Bull. No. 354.

Glossary

Aeration of lawns - Periodic perforation of lawns to increase infiltration. Usually performed by punching holes into the lawn by mechanical means. Urban lawns have very low infiltration rates in comparison to woods and grasslands.

Best management practices (BMPs) - Measures, sometimes structural, that are determined to be the most effective, practical means of preventing or reducing pollution inputs from nonpoint sources to water bodies.

Buffer strip or zone - Strips of grass or other erosion-resistant vegetation between a waterway and an area of more intensive land use.

Calibration (Model) - Determination of some model parameters that depend on the application (site, process, etc.).

Chisel plowing - Seedbed preparation by plowing (with a chisel cultivator or chisel plow) without complete inversion of the soil, leaving a protective cover of crop residues on the surface for erosion control.

Combined sewer - A sewer receiving both intercepted surface runoff and municipal sewage.

Conservation tillage - Any tillage and planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion by water; where soil erosion by wind is the primary concern, maintains at least 1,000 pounds of flat, small grain residue equivalent on the surface during the critical erosion period.

Contour farming - Conducting field operations, such as plowing, planting, cultivating, and harvesting on the contour (across the slope).

Contour stripcropping - Farming operations performed on the contour with crops planted in narrow strips.

Conventional tillage - Standard method of preparing a seedbed by completely inverting the soil and incorporating all residues with a moldboard plow. The field is gone over more than once in order to prepare a smooth, fine surface.

Cover crop - A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production or between trees and vines in orchards and vineyards.

Crop residue - The portion of a plant or crop left in the field after harvest.

Crop rotation - The growing of different crops in recurring succession on the same land, as opposed to continuous culture of one crop.

Detention - The slowing of flows--either entering the sewer system or draining over the surface--by temporarily holding the water on a surface area in a storage basin or within the sewer.

Detention dam - A dam constructed for temporary storage of stream flow or surface runoff and for releasing the stored water at controlled rates.

Diversion - Individually designed conveyances across a hillside. They may be used to protect bottom land from hillside runoff, divert water from areal sources of pollution or protect structures from runoff.

Ecology - Interrelationship between organisms and the environment.

Ecosystem (ecological system) - a functional system that includes the organisms of a natural community together with their environment.

Erosion - The wearing away of the land surface by running water, wind, ice, or other geological agents.

Eutrophication - The process of enrichment of water bodies by nutrients. Eutrophication of a lake normally contributes to its slow evolution into a bog or marsh and ultimately to dry land. Eutrophication may be accelerated by human activities.

Filter berm - A large stone or gravel dike placed across graded areas where runoff concentrates or at the disposal points along diversion dikes.

First flush - The condition, often occurring in storm sewer discharges and combined sewer overflows, in which a disproportionately high pollutional load is carried in the first portion of the discharge or overflow.

Gravel inlet filter - A pile of stone or gravel placed around or in front of an inlet to a culvert or other type of drainage device.

Grassed waterway - A natural or constructed waterway (usually broad and shallow covered with erosion-resistant grasses) used to conduct surface runoff.

Ground cover - Any vegetation producing a protecting mat on or just above the soil surface. In forestry, low-growing shrubs, vines, and herbaceous plants under the trees.

Ground water - Subsurface water in the zone of saturation.

Herbicide - A chemical substance used for killing plants, especially weeds.

Impoundment - Generally an artificial collection or storage of water, as a reservoir, pit, dug out, sump, etc.

Infiltration - The gradual downward movement of water from the surface into the subsoil.

Intensive cropping - Maximum use of the land by means of frequent succession of harvested crops.

Leaching - The removal of materials in solution from the soil.

Minimum tillage - See reduced tillage.

Model - A set of algorithms organized in a logical structure that represents a process.

Mulch - Any material such as straw, sawdust, leaves, plastic film, etc., that is spread on the surface of the soil to protect the soil and plant roots from the effects of raindrops, freezing, evaporation, etc.

Mulch-till - The total soil surface is disturbed by tillage prior to planting. Tillage tools such as chisels, field cultivators, discs, sweeps, or blades are used. Weed control is accomplished with a combination of herbicides and cultivation.

Nonpoint source (NPS) pollution - Pollution caused by sediment, nutrients, and organic and toxic substances originating from land-use activities and/or from the atmosphere, which are carried to lakes and streams by runoff. Nonpoint source pollution occurs when the rate at which these materials entering water bodies exceeds natural levels.

No-tillage - A method of planting crops that involves no seedbed preparation other than opening the soil for the purpose of placing the seed at an intended depth. This usually involves opening a small slit or punching a hole into the soil. Planting is completed in a narrow seedbed approximately 1-3 inches wide. Chemical weed control is normally used. Also referred to as "zero tillage" or "no-till."

Nutrients - Elements or substances, such as nitrogen or phosphorus, that are necessary for plant growth. Large amounts of these substances reaching water bodies can become a nuisance by promoting excessive aquatic algae growth.

Pesticide - Any chemical agent used for control of specific organisms; such as insecticides, herbicides, fungicides, etc.

Plow-plant - Plowing and planting a crop in one operation, with no additional seedbed preparation.

Point source pollution - This type of water pollution results from the discharges into receiving waters from sewers and other identifiable "points." Common point sources of pollution are discharges from industries and municipal sewage treatment plants.

Porous pavement - A surface that will allow water to penetrate through and percolate into soil (porous asphalt pavement). Pavement is comprised of irregular shaped crush rock precoated with asphalt binder. Water seeps through into lower layers of gravel for temporary storage, then filters naturally into the soil.

Reduced tillage - Any tillage system that involves less soil disturbance and retains more plant residue on the surface than conventional tillage. Any tillage and planting system that meets the 30 percent residue requirement. Sometimes called "conservation" or "minimum" tillage. Common practices include plow-planting, double-disking, chisel plowing, and strip tillage.

Retention - The prevention of runoff from entering the drainage system by storing it on a surface area or in a storage basin.

Ridge till - The soil is left undisturbed prior to planting. Approximately 1/3 of the soil surface is tilled at planting with sweeps or row cleaners. Planting is completed on ridges usually 4-6 inches higher than the row middles. Weed control is accomplished with a combination of herbicides and cultivation. Cultivation is used to rebuild ridges.

Riprap - A facing layer or protective mound of stones placed to prevent erosion or sloughing of a streambank or embankment.

Row crop - A crop planted in rows, normally to allow cultivation between rows during the growing season.

Runoff - The portion of rainfall, melted snow, or irrigation water that flows across the surface or through underground zones and eventually runs into streams. The runoff has three components: surface runoff, interflow, and groundwater flow. Runoff may pick up pollutants from the air or the land and carry them to receiving waters.

Sediment - Transported and deposited particles derived from rocks, soil, or biological materials.

Sedimentation - Erosion, transport, and deposition of detached sediment particles by flowing water or wind.

Serrating - Serrations made on the contour on cut slopes by conventional bulldozers at varying intervals.

Simulation - The process that mimics some or all of the behavior of one system with a different, dissimilar system, particularly with computers or models.

Slash - Debris from logging activities littering a clearing in a forest.

Slumping - To sink down suddenly or collapse.

Skid trails - Ruts caused by dragging logs from stump area to loading station.

Stochastic - Pertaining to random variables (statistical).

Storm sewer - A sewer that carries only surface runoff, street wash, and snow melt from the land. Storm sewers are completely separated from those that carry domestic and industrial and commercial wastewater.

Stripcropping - The crop growing practice that requires different types of tillage, such as corn and alfalfa, in alternate strips.

Strip-till - The soil is left undisturbed prior to planting. Approximately 1/3 of the soil surface is tilled at planting time. Tillage in the row may consist of a rototiller, in-row chisel, row cleaners, etc. Weed control is accomplished with a combination of herbicides and cultivation.

Stubble mulch - The stubble of crops or crop residues left essentially in place on the land as a surface cover during fallow and the growing of a succeeding crop.

Surface roughening - Any practice that provides for rougher, more permeable surfaces that will slow runoff velocity and reduce erosion potential. Porous pavements, grassed, and gravel driveways are examples.

Surface runoff - Precipitation excess that is not retained on the vegetation or surface depressions and is not lost by infiltration, and thereby is collected on the surface and runs off.

Terraces - An embankment, or combination of an embankment and channel, constructed across a slope to control erosion by reducing the slope and by diverting or storing surface runoff instead of permitting it to flow uninterrupted down the slope.

Tillage - The operation of implements through the soil to prepare seedbeds and rootbeds.

Tilth - The state or degree of being tilled.

Time Series - A series of chronologically ordered values giving a discrete representation of the variation in time of a given entity.

Tracking - Moving a cleated dozer up and down a graded slope to provide a roughened, serrated slope. More adaptable to steep slopes than scarification and serrating.

Urban runoff - Surface runoff from an urban drainage area that reaches a stream or other body of water or a sewer.

Validation (Models) - The testing of a model for compliance with existing data or information.

Watershed - The total land area drained by a stream, lake, or river system. Also, the area of land that contributes runoff of a given point in a drainage system.

Wheel-track planting - Plowing and planting in separate operations with the seed planted in the wheel tracks.

Windbreak - A living barrier of trees or combination of trees and shrubs located adjacent to farm or ranch headquarters and designed to protect the area from erosion, winds and drifting snow. Windbreaks also may be used in urban and recreational settings, and to protect livestock.

Wind erosion - The detachment and transportation of soil by wind.

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