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HYDROLOGIC MODELING

for the

CLEAN WATER PARTNERSHIP

A Guidance Document

DRAFT

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Prepared by the

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Division of Water Quality

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1. INTRODUCTION

This guidance document on hydrologic modeling has been developed to assist project sponsors evaluate the options available for using computer modeling in their projects. The document introduces the concepts of computer modeling and the types of models available. It also describes criteria that can be used to select specific models to address a project's particular needs, factors to consider in model use and results analysis, and specific models available for water quality modeling.

Use of computer models in nonpoint source pollution projects is expanding; however, many models are still being developed or expanded. Project sponsors interested in using a model will need to learn much more about any particular model than what will be described in this document. Please refer to the bibliography for model documentation and other related publications.

Please note that this is the first version of the Clean Water Partnership modeling guidance document. As particular needs or information gaps are identified, the guidance document will be revised to address these items.

2. MODELING CONCEPTS

The word "models" in hydrology has many different meanings. Synder and Stall (1965) defined a model as follows:

"A model is simply the symbolic form in which a physical principle is expressed. It is an equation or formula, but with the extremely important distinction that it was built by consideration of the pertinent physical principles, operated on by logic, and modified by experimental judgement and plain intuition."

A hydrologic model can be defined as a mathematical model representing one or more of the hydrologic processes resulting from precipitation and culminating in watershed runoff. Hydrologic models aid in answering questions about the effect of agricultural land management practices on quantity and quality of runoff, infiltration, lateral flow, subsurface flow (both unsaturated and saturated) and deep percolation. Hydrologic models should be used with caution as stated by Artemus Ward (quoted by Burges 1986) "It ain't so much the things we don't know that gets us in trouble, but it's the things we know that ain't so."

Computer hydrologic models are used extensively for hydrologic predictions. Bross (1953) identified the following advantages of models:

(1) A model provides a frame of reference for considering a problem.
(2) Developing a model points out information gaps, and thus suggests needed research.
(3) A model brings out the problem of abstraction in complex systems, and uncovers questions which might not otherwise be raised. It develops understanding.
(4) A model, once expressed, provides relatively easy manipulation of components and a basis for communication.
(5) A model offers a relatively inexpensive way to make predictions.

3. MODEL CLASSIFICATION

Different types of models are developed depending on the state- of-the-art of the knowledge regarding a hydrologic process. The major source of confusion about mathematical models is the variety of types available and the different names used to define each type. There are many academic classifications of mathematical models; however, for practical purposes Fleming (1979) classified mathematical models in three broad categories:

Deterministic Models:

This method treats the processes as if they formed part of a known system, with no attempt made to represent the random processes which may or may not be present in the system. The deterministic methods treat the hydrological processes in a physical way.

Deterministic models are used in water resources assessment to provide more quantitative information on the magnitude, quality, distribution, and timing of available waters and to extend this knowledge by using the model to predict the effects, both direct and indirect, of man's influence on this existing water resource.

Statistical Models:

Statistical models are summaries of the past behavior of hydrologic phenomena. These models are based on methods that treat the interrelationship between processes as governed by the theory of statistics.

Climatologists have done a great deal of statistical modeling. Most planners are familiar with the series of maps that show the magnitudes of storm events that are likely to occur in a given place within a certain time period (e.g., the 10-year 24-hour storm, which is the size of one-day storm that statistically has a 10 percent chance of occurrence in any given year). If based on adequate primary data, a good statistical model can be very useful in engineering, as long as environmental conditions have not changed in such a way as to make the past a poor guide to the future.

Optimum Search Models:

These models are based on a method which evaluates given objectives on one side and sets of conditions (constraints) on the other, and will assess the best plan to adopt to satisfy the objectives within the given constraints.

A brief description of the subclassification of the above type of models is given in Appendix A.

The models should be used with caution and within their span of applicability. Each model is developed for a specific purpose with certain underlying assumptions. Precautions should be taken that these assumptions are not violated. The end goal of a model is successful prediction for the situation in which it is to be used. The final test is a comparison of model results with independent data.
Hydrologic models can be used in two ways:

(1) to assess the existing water quality conditions of a water resource,
(2) to predict future hydrologic conditions, which may develop as a result of changes in land use, climate, or any other physical alteration to the environment.

Most models are quite diverse in their structure and operation, and are also only effective under a certain specified conditions. However, the following characteristics are common to all of them (Chapman and Dunin, 1975).

- The models involve gross simplifications of the true physical system that they represent.
- Time scales are significantly compressed. Observations made over many years in the physical system are reproduced in a much shorter period of time.
- The models use a number of mathematical or graphical representations to describe various hydrologic and hydraulic concepts, each of which is considered to be relevant to the overall hydrologic response of the catchment.
- Data inputs to the model usually apply to discrete time intervals and are not continuous. Consequently, the model output is affected by the size of the time interval used for the input data.
- The mathematical representations are usually controlled by one or more parameters. The selection of these parameters is normally made and verified by simulating catchment behavior using known inputs and comparing the output with measures of known watershed response.

Each of the above features influence the operating characteristics of the model, the successful representation of the watershed behavior, the suitability of the model to widespread application, the usefulness of the results and the acceptability of the model as a design or an operational procedure.

Modeling and Monitoring:

Modeling can never replace monitoring. However, modeling is the least expensive way of evaluating whether a problem exists. As models are developed to represent the complex hydrologic systems, assumptions are incorporated in each and every model. The equations and formulae used to represent a complex hydrologic system are never complete due to the complexity of the system. Modeling a situation will help determine if monitoring is necessary.

Monitoring is always essential if a problem exists. The data collected in monitoring can help us in improving our modeling predictions and development. When deciding whether to evaluate a problem using modeling or monitoring, remember that models are used for analytical convenience. Models are tools for addressing hydrological questions, and they do have limitations. Modeling is feasible only for evaluating problems that are understood well enough to be expressed in concise, quantitative terms. In some situations, modeling may be infeasible or unnecessary.

The following chapters describe the different types of models, model selection and application, and interpretation of results.

4. MODEL SELECTION CRITERIA

Hydrologic models are planning tools that ask "what if" questions (e.g., "What would happen to the water quality of Hypo Lake if the surrounding forest were partially cleared for an apartment building and a golf course?" Traditional water resource analyses of historic records are clearly inappropriate planning tools in that kind of changing environment. Understanding the ways in which historic patterns and trends should be interpreted--not as predictors of the future, but rather as baselines against which the effects of changes can be compared--is essential for effective planning and resource management.

Choosing a hydrologic simulation (or any other analytical tool) is a "third level" task, where the first level is gathering of data and the second level is data analysis. Effective planning and resource analysis requires overcoming a linked set of constraints at all three levels. For that reason, lack of familiarity with the mechanics of hydrologic simulation models can limit our ability to frame appropriate questions or gather necessary data. Proper use of a hydrologic model requires substantial understanding of both the resource being studied and the working of the modeling system. Among other things, a good model simulation does not take a place or region out of context; on the contrary, it is based on a firm understanding of the legal, economic, physical, and human geographic setting of the proposed change.

Basic Principles of Model Selection:

The goal for hydrologic modeling is to obtain estimates regarding rates of water movement overland, subsurface, or within streams; amounts of water stored in the soil or in natural water bodies; or how these rates and amounts vary with time (James, 1982). Good decisions can be made using hydrologic models if the hydrologic processes are carefully represented in the model. Physical laws governing water movement are very complex, and parameters needed for representing the components so variable in time and space, that construction of a universal model is no easy task. Research in the area of understanding and representing physical laws and acquiring physical data for model evaluation is ongoing. It is up to the model user to choose the best model for a given application.

The performance of a model in making decisions for planning and management is the fundamental criterion for the planner in selecting, calibrating, and testing of hydrologic models (James and Burges, 1982). The following points should be considered when choosing a model.

1) What model is best in solving a particular problem in the particular location?
2) What are the data requirements for both model and problem?
3) What computer hardware and staff are required?
4) How much will it cost?
5) How accurate will the model be in representing the real world?
6) What documentation is available?

The model applications can be divided into two categories: decision making, and research and training. Decision-making applications can be subdivided into several schemes. One scheme could be based on the level of decision making, planning, design, and operation (McPherson, 1975). The second important type of hydrologic model application is as a research and/or training tool where the goal is a better understanding of the hydrologic cycle. An essential difference between this category and decision making is that research and training deal with knowledge, whereas decision making involves information (Jackson, 1982).

Model Selection Techniques:

Model selection can be attained keeping two objectives in mind, the first being analysis of cost effectiveness and the second one being step procedure developed by Kazanowski (1968) using the objective of cost effectiveness analysis. The 10-step procedure is:

1) Define desired model goals, objectives, or purposes.

2) Identify model requirements (specifications) that are essential to the attainment of the desired goals.
3) Select alternative models for realizing the goals.
4) Establish criteria (measures) for model evaluation so that model capabilities can be compared with model specifications.
5) Select a fixed-cost or fixed-effectiveness approach (this will be dictated by the circumstances of the practical problem but is usually a non-trivial task).
6) Determine capabilities of all alternative models in terms of evaluating criteria.
7) Generate an array that classifies models in terms of the criteria.
8) Analyze the merits of alternative models.
9) Perform sensitivity analysis.
10) Document the rationale, assumptions, and analyses underlying the previous nine steps.

Application of this technique has been illustrated by Kisiel and Duckstein (1972) for selecting a forecasting model and Fogel et al (1972) for selecting a model for evaluating urbanization on southwestern semiarid watersheds.

A more complete presentation of how cost effectiveness analysis is applied is included in Grimscrud et al (1976). Although the emphasis of this report is on instream water quality, the general technique is widely applicable and the examples most instructive. The technique consists of four phases:

Phase I: Model Applicability Tests
Phase II: Cost Constraint Tests
Phase III. Performance Index Rating-Simplified
Phase IV. Performance Index Rating-Advanced

Models that remain after the elimination procedures in Phase I and II are then subjected to performance index ratings. Baker and Carder (1976) presented a table for evaluating models using these guidelines and objectives (Table 1).

TABLE 1. Basic Criteria for Evaluating Models
(From Baker and Carder, 1976)

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1. Ease of use
   - ease of use by field level user
   - skills required
   - ease of interpreting results
   - type of results display
   - assumptions required by models

2. Availability of data
   - ability to use readily available or estimated data rather than exotic parameters
   - ability to handle small and variable time increments
   - ability to substitute data parameters
   - kinds of input data needed
   - data accuracy
   - data resolution

3. Availability of models
   - ease of accessibility of system and support to train users
   - cost to operate and number of runs needed to provide data necessary to make management decisions

4. Applicability to land use activities
   - ability of models to represent common alternative management activities
   - sensitivity to change in management activities
   - number of parameters predicted

5. Broad geographical areas
   - ability of a model to operate in diverse hydrologic areas
   - extrapolation of model.

6. Accuracy of prediction

   - ability to predict relative change and absolute effects
   - need to calibrate model
   - ability to estimate recovery rates of various types of disturbances
   - accuracy in predicting range of events, i.e., high and low
   - precision of model predictions
   - percent error between actual and predicted values for volumes, peak discharge, and time to peak for both water and sediment.

5. RESULT ANALYSIS

Most of the hydrologic models discussed in the preceding chapter are limited in their aerial extent. A typical size of watershed would be tens to hundreds of acres. Thus, most applications have been limited to small experimental watersheds; techniques on how to expand the modeling to larger watersheds are still in evolution.

It must be understood as with any simulation of the "real world" systems, mathematical models are only a rough approximation. The accuracy and reliability of models is limited. Although many models represent the best available technology for analysis of environmental systems, a common error made by many decision makers is that they accept simulation results as a true absolute result for unknown conditions. In order to avoid disappointments and court challenges, the user should be aware of the limited accuracy of the models.

The most accurate models are hydrologic models simulating runoff from small, uniform, impervious areas, the least reliable (an order of magnitude or more) are the water quality models for large watersheds. When determining pollutant transport, hydrology must be calibrated and determined first, followed by sediment, and finally pollutant transport. Any errors that appear in the hydrologic and erosion components will be transferred and magnified in all dependent components. In spite of the errors involved in modeling complex environmental systems such as nonpoint source pollution, the model as a planning tool cannot be replaced by any "rule-of-thumb" approach which some planners unfamiliar with the capability of models might suggest. The use of models is beneficial and greatly enhances the planning process.

Analysis/Interpretation of Results:

Clearly, the key task in any modeling study is the analysis and interpretation of the model outputs. Since models are simply tools for a quantitative, systematic analysis of specific environmental problems or issues, they do not provide simple YES or NO answers to managers, regulators, or decision-makers. Rather, they usually provide detailed information about the expected response of the system to a given perturbation in order that a more informed, objective decision is made. The mass of the computer output generated by models must be analyzed and interpreted in a logical and consistent fashion in order to answer the decision maker's question: "What do the results mean?" and "How accurate and reliable are they?"

In order to understand the true meaning of modeling results within a decision making framework, both the assumptions of the analysis and accuracy of expectations (i.e., reliability) must be clearly defined. Both of these considerations are difficult, if not impossible, to discuss in general terms without discussing the specific characteristics of the particular model. However, assumptions usually are included, and required, both in how the model is configured or designed, and how it is applied. Thus, one specific model may be used in many applications, with the same set of model assumptions common to all applications, while the application assumptions may differ from one case to another. The decision maker or analyst must be aware of both kinds of assumptions, and their associated limitations, in order to appreciate the validity of the modeling results.

The accuracy associated with the results of modeling studies depends on the specific model used, the accuracy of the input data, the characterization of the environmental system being simulated, and the expertise/experience and resources available to the model user. Decision makers must understand that all these factors determine the ultimate accuracy and reliability of the model results. Even under the best circumstances, the model results should be considered as estimates or approximations, since the model itself is an approximation of a real environmental system. This does not detract from the utility of models; it simply emphasizes the use of the model as a tool. It is also a very valuable learning tool for understanding the critical factors that determine the behavior of the simulated system. With this knowledge, the system can be better managed.

Most models are often more accurate in a relative sense, than in an absolute sense. That is, when models are used to compare alternatives (such as management or control options), the relative differences predicted between alternatives are sometimes more reliable than an absolute value predicted for any one alternative. Models are often used to evaluate these relative differences. When absolute values are needed, such as when estimating the probable exposure concentrations of a chemical needed for comparison with drinking water and/or health effects levels, model results should be supplemented with sensitivity and/or uncertainty analysis in order to analyze the potential "real-world" variability about the model predicted values. In other words, consideration of the uncertainty of the simulated results is at least as important as are the results themselves in any decision making process.

In summary, close interaction between the model user and the decision maker is required throughout the model selection, application, and analysis/interpretation phases, but it is especially critical in this last phase. Only in this way can we insure that reliable information needed for decision making is produced by the modeling effort.

6. AVAILABLE WATER QUALITY MODELS

Mathematical models are used to study water pollution in rivers, lakes, estuaries, wetlands, and rural and urban watersheds. The models currently used for water quality analysis are presented in terms of model description, capabilities, limitations, data requirements, output options, availability, and resource requirements. The above format is selected from the United States Environmental Protection Agency document, *Guide to Nonpoint Source Pollution Control (1987).*

Agricultural Nonpoint Source Pollution Model (AGNPS)

Description:

AGNPS is a single event based model for quantifying the distribution of surface sources of sediment, nitrogen, phosphorus and chemical oxygen demand and estimating their loading into downstream receiving water bodies. This model was developed for agricultural watersheds in Minnesota, and has also been tested in Nebraska and Iowa. The model is grid based and works on a cell basis, for watersheds ranging from 2.5 to 23,000 acres. The minimum cell size is one acre. AGNPS gives estimates of the sediment delivery ratio, sediment enrichment ratio, mean sediment concentration, and total sediment yield in each of the particle sizes of sand, silt, clay, small aggregates and large aggregates. AGNPS is also capable of handling point source input from feedlots, waste water plant discharges, stream bank and gully erosion, and also represents the effects of impoundments on the water quality at the watershed outlet. AGNPS model is user friendly and offers excellent graphics and output capabilities.

Capabilities:

- Evaluates the effect of various Best Management Practices (BMPs) on the downstream sediment load and water quality.
- Analyzes pollution from point sources such as feedlots and wastewater plant discharges.
- Predicts erosion for five different particle sizes (sand, silt, clay, small aggregates, and large aggregates).
- Predicts water quality and erosion on a cell basis and on a watershed basis.
- Incorporates the spatial variation of hydrologic and sediment processes when the watershed is divided into cells.
- Divides pollutant transport into soluble pollutants and sediment-attached pollutants.

Limitations:

- Can be only used for single storm event.
- Need to thoroughly test the pollutant transport component.
- Not adequately tested for particle size distribution during transport.
- Must divide the watershed into equal size cells.
- Pollutants not routed through receiving water bodies.

Input Data:

The input data requirement can be divided into two categories. The first data input is about the entire watershed and the storm to be simulated. The second set of input consists of information about individualized cells. The data needed includes physical information and parameters on field conservation practices. Data required can be obtained from Minnesota Land Management Information Service (LL45 Metro Square, Seventh and Robert, St. Paul, Minnesota 55101), field analysis, maps, topographic and soils data, and the technical publication on the AGNPS manual.

Output Available:

The output from AGNPS includes hydrology, runoff, sediment, nutrient and chemical oxygen demand. The output of the above parameters can be obtained on an individual cell basis or for the entire watershed.

Future Modifications:

AGNPS is currently being annualized. This will take care of the limitation of single event model. Pesticide, lake routing, site specific deposition, and urban runoff components are currently being incorporated to enhance the AGNPS capabilities. On-screen graphics are also being developed for the model.

A Soil-Crop Simulation Model for Nitrogen, Tillage, and Crop Residue Management (NTRM)

Description:

NTRM (Nitrogen-Tillage-Residue Management) is a large, broad-based computer simulation model for tillage, crop-residue, and nitrogen fertilizer management. NTRM model is designed mainly to provide management assistance at the farm extension and engineering levels. The NTRM model simulates physical, chemical, and biological processes in the soil-water-crop continuum using integrated submodels for soil temperature, soil carbon and nitrogen transformations, unsaturated flow of water, crop and root growth, evaporation and transpiration, tillage, interception and infiltration, chemical equilibria processes, solute transport and crop residues. The NTRM model is capable of seasonal and longer-term estimates of soil fertility and its effects on crop yield. Model validation and verification have been obtained for each submodel and for the overall model package. The NTRM model has been made user-friendly, and also has computer graphics capability.

Capabilities:

- Simulates physical, chemical, and biological processes in the soil-water-crop continuum.
- Predicts the effect of soil environment on crop growth.
- Serves as a tool for nitrogen fertilizer management
- Can be used for long term agricultural planning.

Limitations:

- Currently can only simulate corn growth.
- Requires large data input.

- Additional testing required for many components of the model.

Input Data:

Extensive amount of data is needed for individual submodels. Submodels that need input are the soil temperature model, carbon and nitrogen transformations in soil, unsaturated flow model, crop growth model, root growth model, till and surface residue and sensitive potential evaporation submodel, transpiration model, tillage model, model for simulating interception, surface roughness, depression storage, and soil settling, chemical equilibria model, solute transport model and the crop residue model.

Output Available:

The outputs available are related to crop yield and nitrogen availability in soil for example, effect of tillage practices on crop yield, or initial soil nitrogen and fertilizer nitrogen. Outputs can be in the form of graphics, tables, and nomographs.

Storage, Treatment and Overflow Model (STORM)

Description:

The STORM model simulates quantity and quality of runoff from small, primarily urban watersheds; however, nonurban areas are also included. The modeled water quality parameters include total and volatile particulates, biochemical oxygen demand (BOD5) total nitrogen (N), and orthophosphate. These water quality parameters are assumed to be a part of or related to the particulate matter. The model considers the interactions of seven stormwater transport processes. The processes are rainfall or snowfall-snow melt, surface runoff, pollutant accumulation, land surface erosion, treatment rates, storage of stormwater runoff and overflow and from the storage/treatment system.

Capabilities:

- Simulates longer (up to several years) time series of runoff quality and quantity.
- Handles precipitation in the form of snow.

Limitations:

- Assumes daily accumulation rate of pollutants during a dry period.
- Does not route water through the watershed.
- Requires large data input

Input Data:

The input data involves meteorological inputs, land use inputs, degree of impervious layer, street sweeping efficiency, trapping efficiency for sediment detention reservoirs, soils information, and pollutant accumulation rates.

Output Available:

Hydrographs and pollutographs for selected storms can be obtained, along with weekly runoff volumes and pollutant masses.

An Agricultural Chemical Transport Model (ACTM)

Description:

ACTM consists of three submodels dealing with hydrology, erosion, and chemical transport. The primary purpose of the model is to simulate transport of organic chemicals from agricultural lands. The model continuously accounts for soil moisture by balancing infiltration, evapotranspiration, and seepage into lower soil layers. Rainfall in excess of infiltration and surface storage is routed through using kinematic wave concept. The chemical submodel traces the movement of a single application of a chemical through and over the watershed. The erosion-deposition segment predicts soil loss by using the modified Universal Soil Loss Equation.

Capabilities:

- Includes rill and interill erosion.
- Simulates adsorbed or dissolved phosphorous.
- Simulates nitrogen transformations.

Limitations:

- Sorption and desorption process in chemical transport are assumed to happen instantaneously.
- Size of watershed is limited to farm size.

Input Data:

Input data includes soil physical parameters pertaining to Universal Soil Loss Equation, crop growth stage, and meteorology.

Output Available:

The output from ACTM include watershed runoff, peak flow, erosion, carbofuran, and concentration of chemicals simulated.

Aerial Nonpoint Source Watershed Environment Response Simulation (ANSWERS)

Description:

ANSWERS simulates behavior of agricultural watersheds. It is an event-based surface hydrology model that estimates hydrologic and erosion response. In order to use the ANSWERS model, the watershed is divided into square grids with parameter values specified for each grid. The ANSWERS model has been tested in Indiana, a midwestern region. The model simulates interception, infiltration, surface storage, surface and subsurface flow, and sediment detachment, transport and deposition (EPA, 1987).

Capabilities:

- Can evaluates management practices related to erosion control for agricultural fields and construction sites.
- Can evaluate the effect of Best Management Practices by varying infiltration rates and soil surface conditions.
- Can add user-supplied algorithms.
- Accounts for spatial variation in hydrology and sediment processes.

Limitations:

- Simulates single event only.
- Simulates only small watersheds.
- Does not simulate pesticide movement and cannot handle snowmelt processes.

Input Data:

The input data includes rainfall data, soils data, soil surface and land use information, channel descriptions, and individual element information that includes information related to best management practices.

Output Available:

The output capabilities includes the input data, watershed characteristics, information relating to flow and sediment at the watershed outlet, effectiveness of the structural best management practices, net transported sediment yield or deposition for each grid element, and channel deposition.

Agricultural Runoff Management Model (ARM)

Description:

The ARM model simulates runoff (including snow accumulation and melt), sediment, pesticide, and nutrient loadings from surface and subsurface sources for small agricultural watersheds. The hydrologic response of the watershed, sediment production, pesticide adsorption/desorption, pesticide degradation and nutrient transformation are the components that can be simulated by the ARM model.

Capabilities:

- Simulates surface runoff, snowmelt, and subsurface flow.
- Simulates different management practices.
- Simulations completed on an event or continuous basis.

Limitations:

- Model can be only applied to a small agricultural watershed with an area of 1.9 square miles.
- No link between economics with different best management practices.
- No channel routing done in the model.

Input Data:

Extensive data required for simulating hydrology, snowmelt, sediment, pesticides, and nutrients. Parts of the input data have to be generated from the physical watershed and pollutant characteristics, land surface conditions, agricultural cropping, and management practices. Before running the simulations, the data should be calibrated and verified.

Output Available:

The model output includes summaries relating to runoff, sediment, pesticides, and nutrient loss. The output also provides information of various nutrients remaining in the various soil zones. Output can be obtained for a hourly, daily, or monthly basis.

Chemicals, Runoff, and Erosions from Agricultural Systems (CREAMS)

Description:

CREAMS and CREAMS2 are field scale models that simulate surface and subsurface runoff, evapotranspiration, erosion, sediment yield, and plant nutrient and pesticide delivery (EPA, 1987). These two models can evaluate the effect of best management practices. CREAMS can simulate aerial spraying or soil incorporation of pesticides, animal waste management, and alternative agricultural practices such as minimum tillage and terracing. CREAMS2 is more user friendly than CREAMS, and it is an integrated model rather than a sequential model like CREAMS, and also has better options of calculating the various components than CREAMS. The parameters needed for the model are physically measurable and there is no calibration required for individual watershed.

Capabilities:

- Represents soil processes with reasonable accuracy.
- Simulates on a continuous basis; and also considers event loads.
- Can simulate up to 20 pesticides at one time.
- Includes best management practices.

Limitations:

- Requires extensive data inputs.
- Does not simulate subsurface drainage.
- Can only be used on field plots.
- Does not simulate receiving waters.
- Data management and handling capacity is limited.

Input Data:

Extensive data on meteorology, hydrology, erosion, and chemistry of pollutants is required for CREAMS and CREAMS2.

Output Available:

The output is available in a very detailed form, along with output from individual element.

COWS AND FISH
(COWFISH)

Description:

This model helps resource managers analyze the condition of the riparian environment. The environment is analyzed in relation to past and current livestock grazing management and to estimate the compatibility of grazing with associate aquatic resources. This does not replace presently used stream surveys or fish population analyses. However, the existing information is used to derive initial indications of how livestock grazing may affect trout population. Six variables are considered to examine the stream's suitability for trout (1) The extent of the streambank which is undercut, (2) the extent of the stream edge with vegetational overhang, (3) the extent of streams bank showing bare soil as trampling, (4) stream embeddedness, (5) stream width, and (6) stream depth. Two additional variables, the 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 the principles similar to those developed by the U.S. Fish and Wildlife Service in its habitat suitability models. The PSI values are often averaged to compare the stream's existing habitat conditions with its potential habitat suitability index.

Capabilities:

- Can be used for western United States with some modifications.
- Can be used to determine stream habitat productivity any time during the season prior to snow cover.
- Can accurately access current habitat conditions, provided the sampling area is at least 100 feet long.

- If streams are uniform longer sections can be evaluated. 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 rock 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:

Field data related to the description of stream, allotment and sample size being evaluated is required. Specifically, information is needed on sample size, vegetative type, side valley slope gradient, percentage of undercut banks and banks supporting vegetative overhand, embeddedness, streambank alteration, width/depth ratio and stream gradient.

Output Available:

The output is in a tabular form and includes information on optimum number of catchable trout per 300 meters of stream for various stream conditions. Output is also available for number of trout per 300 meters of stream per year, recreation loss in wildlife and fish user days, and economic loss in dollars per 300 meters of stream per year.

MINNESOTA FEEDLOT EVALUATION SYSTEM (MFES)

Description:

The feedlot model 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. Runoff is estimated using the Soil Conservation Service Curve Number approach. The pollutant indicators are phosphorus and chemical oxygen demand. Currently, the MPCA uses this model in its feedlot permit program.

Capabilities:

- Excellent screening tool.
- Evaluates different land management practices.
- Considers both surface and ground water pollution.
- Fast and effective tool.

Limitations:

- Runoff calculations not valid for large areas (more than 100 acres).
- Does not deal with receiving waters.
- Handles potential pollution threats to ground water loosely.

Input Data:

The input data is presented in the manual for the model, except physical dimensions of the feedlot.

Output Available:

The pollutant delivery is present at the discharge point.

GUIDE FOR PREDICTING SALMONID RESPONSE TO SEDIMENT YIELDS IN IDAHO BATHOLITH WATERSHEDS (GAWS)

Description:

GAWS is a guide that provides a standard method for predicting the effect of sediment on stream habitat and fish populations for planning purposes. It estimates sediment yield 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 survived, summer rearing capacity, and winter carrying capacity. The outputs are reasonable estimates intended for use 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:

- Estimates sediment yield.
- Predicts changes in habitat due to sediment yield.
- Predicts changes in fish population due to habitat changes.

Limitations:

- The fish habitat may not be realistically represented for average sediment deposition in high gradient streams.
- The efficiency of high gradient channels for sediment

transport may lead to sediment concentration in downstream channels with lower gradients.

- The 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.

- Since the model was developed and tested only for salmonid species associated with Idaho Batholith, application in other areas (systems) would require testing.

Input Data:

The input data required are (1) estimates of sediment yield, (2) substrata core samples to determine existing conditions and natural conditions (3) measurements of substrata 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 (EPA, 1987): (1) substrata zoning data from several surrounding streams overtime, (2) substate embeddednes 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 geomosphic and channel type,

(6) empirical relationship between sediment yields and fish habitat, and (7) a calibrated watershed model.

Output Available:

Since this is not a computer model, there is no output as such. However, the step-by-step procedure described in the manual can be used to calculate changes in the fish populations.

HYDROLOGICAL SIMULATION PROGRAM - FORTRAN (HSPF)

Description:

HSPF is a comprehensive package for simulation of watershed hydrology and water quality. It is an integrated program, which simulates the hydrology and the behavior of conventional and organic pollutants in surface runoff and receiving waters. Agricultural Runoff Management (ARM) model is used to describe the processes that affect the fate and transport of pesticides and nutrients from agricultural lands. Several main application modules are contained in HSPF: the PERLND (pervious land) and IMPLND (impervious land) modules perform soil simulation for land surfaces; and the RCHRES (reach/reservoir) model simulates the processes that occur in a single reach and at 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. The modules are arranged in a hierarchical structures that permits the continuous simulation of a comprehensive range of hydrologic and water quality processes.

Capabilities:

- Continuous hydrologic simulation can be done.
- Integrates the loading from nonpoint sources (including alternative control practices) and receiving water quality simulation into a single package.
- Analyzes both point and nonpoint source loadings.
- Provides the option of using simplified or detailed representation of nonpoint source runoff.
- Performs risk analysis due to the exposure of aquatic organisms to the toxic chemicals present in receiving waters.

- Incorporates agricultural management practices by changing parameter values.

Limitations:

- Needs calibration before it can be applied to a particular site.
- Requires 2-3 months to learn its operational details.
- Cost associated with different BMPs is not linked to pollutant delivery.
- Computer costs for model operation and data storage can be a significant fraction (10-15 percent) of total application costs depending on the extent to which the model will be used.

Input Data:

Requires extensive data along with meteorological and hydrologic data.

Output Available:

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

Nonpoint Source Loading Model (NPS)

Description:

The NPS model simulates nonpoint source pollution from a maximum of five different land-use categories in a single operation. In addition to runoff, water temperature, dissolved oxygen, snow accumulation and melt, and sediments the NPS model allows for up to five user-specified pollutants for each land-use category. The erosion is simulated both for pervious and impervious areas. The basic indicators for nonpoint pollutant are sediment and other suspended materials.

The NPS model is composed of three major components: MAIN, LANDS, and QUAL. The model operates sequentially, reading parameter values and meteorological data, and performing computation in LANDS and QUAL. The LANDS segment simulates the hydrologic response of the watershed to the precipitation input and the process of snow-melt and accumulation. The QUAL component simulates the erosion process, street refuse accumulation, and sediment and pollutant wash-off from the land surface.

Capabilities:

- Simulates urban, agricultural and silviculture nonpoint source pollution.
- Simulates continuous and event-based conditions.

Limitations:

- Simulates nonpoint source pollution from a maximum of five different land use practices in a single run.

- Does not consider subsurface flow and, therefore ground water pollution transport.
- Ignores channel processes.
- Does not account for pesticide transport.
- Does not simulate the relationship between cost of best management practices and runoff as pollutant loadings.

Input Data:

Extensive input data required for model simulation as well as for parameter evaluation and model calibration.

Output Available:

Output available includes watershed summary, monthly and yearly summaries, and also output to interface with other models.

Stormwater Management Model (Level 1) (SWMM)

Description:

SWMM (Level 1) is a screening tool and provides rough estimates of the quantity and quality of water for storm event that lasts a few hours for an urban watershed. The computations are carried out on a hand calculator. On the basis of land-use characteristics, precipitation, population density, sewerage system, and sweeping operations, the runoff and water quality parameters can be determined.

Capabilities:

- Includes economic analysis of sewerage management practices.

Limitations:

- Provides very rough estimates of quality and quantity of water.
- Neglects the changes in storage in terms of water quality.

Input Data:

- Requires minimum input data.

Output Available:

- Minimal output as calculations done on a calculator.

Stormwater Management Model (Simplified) (SWMM)

Description:

This version of SWMM simulates runoff and nutrient transport in an urban watershed. The model accounts for rainfall characterization, storage-treatment balance, overflow-quality assessment, and receiving water response.

Capabilities:

- Can be linked to a receiving water model.
- Permits continuous or event-based calculations.
- Evaluates pollutant delivery in receiving water.

Limitations:

- Does not account for the change in water quality parameters during storage.
- Does not simulate sediment transport and snowmelt.
- Overflow quantities and qualities must be measured to calibrate the model.

Input Data:

The input data includes hourly precipitation, runoff coefficient, treatment rate, storage volume, and receiving water characteristics.

Output Available:

Time varying overflow, runoff, pollutant loading, and receiving water response are the available outputs.

Stormwater Management Model (SWMM)

Description:

The complete comprehensive model simulates urban stormwater runoff and combined sewer overflow. The runoff is routed through the channels and pipe network. Sediment and nutrients along with receiving water body are simulated.

Capabilities:

- Evaluates both combined and separate sewerage systems.
- Considers treatment in five different storage systems.
- Evaluates water quality changes using various physical and chemical treatment options.
- Estimates the costs for capital, operating and management can be estimated.
- Simulates the effects of pollutant delivery on the quality of receiving waters.

Limitations:

- Requires extensive input.
- Uses a monthly flow routing method.

Input Data:

Detailed meteorological and soils data is required.

Output Available:

The output includes time varying water quality estimates, and hydrographs and pollutographs with daily and hourly variations.

Small Watershed Model (SWAM)

Description:

SWAM is a continuous simulation model that estimates the effect of various land use management practices on the hydrologic, sediment, and chemical response in an agricultural watershed. (CREAM2 Model is used for estimating overland flow and pollutant transport. The model has the capability for analyzing the movement and interactions of sediments, pesticides, and nutrients in the channel network and reservoirs. The model also can simulate surface/ground water interactions.

Capabilities:

- Simulates sediment, nutrients, and pesticide routing through channel, reservoir and ground water.
- Takes into account backwater effects in channel routing.
- A good representation of watershed processes.

Limitations:

- Model is only applicable to watersheds with less than 10km area, and is a complex model to use.
- Not practical for long term simulations (20 years or more, EPA, 1987).
- Model is still being tested.

Input Data:

The necessary input data required is about rainfall, soil characteristics, topography, land use, and management practices.

Output Available:

The appropriate output options are in the development phase.

Pesticide Root Zone Model (PRZM)

Description:

The PRZM model simulates the vertical movement of pesticides in the unsaturated soil, within and below the plan root zone, and extending to the water table using generally available input data that are reasonable in spatial and temporal requirements. The model consists of hydrology and chemical transport components that simulate runoff, erosion, plant uptake, leaching, decay, foliar washoff and volatilization of a pesticide.

Capabilities:

- Relates pesticide leaching to temporal variations of hydrology, agronomy, and pesticide chemistry.
- Simulates snow hydrology.
- Performs simulation for pesticides applied to the soil surface or to plant foliage.

Limitations:

- Some parameters are difficult to estimate.
- Model calibration is limited.

Input Data:

Input data required includes soil characteristics, meteorological data, and pesticide information.

Output Available

Various output options regarding the fate of pesticide in the root zone are available.

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APPENDIX A

Deterministic models are based on physical laws of nature and can be divided into physical models, empirical models, or conceptual models.

Physical Models: Physical models are mathematical models that use known effects or certain characteristics of the prototype system to predict the behavior of the system.

Because physical models are based on sound physical principles, they give good predictions of the real world conditions. However, physical models require large amounts of computer time and can be data intensive.

Empirical Models: These models are based on data. Data is analyzed for the hydrologic component of interest to develop a mathematical relationship that best represents the data. Empirical models are very site specific since data used to develop them is only collected at the point of interest. Hence, care should be taken when applying these models to different locations. An empirical model is generally a representation of the relationships between two or more processes based on experimental observations either in the laboratory or in the field. The relationship is usually expressed by means of a simple function which relates one process to another.

Conceptual Models: These models provide a somewhat artificial representation of the process(es) occurring in the prototype system. Conceptual models are usually developed for situations when the physical laws are unknown or the physically based model is so complicated that it is more appropriate to greatly simplify the model behavior. In the conceptual approach, an attempt is made to represent the time and space varying interaction between all the processes that affect watershed response and to add physical relevance to the parameters used in the mathematical functions which represent the interactions.

Definition of Terms:

Empirical models are component process oriented. These include linked models of individual processes with a main component operator that distributes the flow of water to individual processes in a proper order. Processes described by these models are those that occur in a particular section of the watershed system. An example of this approach of component model could be representing evapotranspiration, erosion, subsurface flow, etc.

Conceptual models are based on the integrated process approach. An integrated model consists of linked component process models, which are driven by an operator that distributes water flow to individual components in a proper order. The component models included can have varying degrees of complexity.

Integrated models are built in a proper flow of components and have a well defined structure, which is normally based on the physical nature of the watershed. Integrated process models may be linear or nonlinear. Linear representation of the mathematical relationship between processes simply means that if one process
was plotted against another then the relationship plotted would lie along a straight line, whereas, a nonlinear relationship would form a curve when two processes are plotted together.

Most processes in hydrology are nonlinear. For example, the variation of flow in a river channel from in-bank to over-bank conditions is nonlinear. The variation of infiltration rate with time for a uniform rainfall intensity is nonlinear. Often nonlinear processes are linearised to simplify the mathematics which can lead to misrepresentation of the interaction between processes.

Another way to classify models used for analyzing hydrologic systems is to look at how they view the area around the watershed. This classification yields lumped models or distributed models.

Lumped models do not keep track of where in the watershed various characteristics are located. Lumping keeps the cost of data acquisition and processing low, but it also limits the ability of the model to predict consequences of changes. A lumped model will treat an area as a single unit and the range in value of any process from one point to another within the area will be represented by an average value. For example, the soil water storage volume at any point in time will vary from one point of a watershed to another, depending on the soil type, vegetation cover, drainage, antecedent precipitation and so on. However, in a lumped model only the average value of the range in soil water storage is used for the whole area.

Distributed models are specifically concerned with the internal arrangement of the watershed characteristics. They represent the variation in a process from point to point within a given area. When compared with lumped models, distributed models are more costly to and require more time to verify the accuracy of their results. As in the previous example of a lumped model, the soil water values would be represented for the selected area of the watershed by dividing the area into a number of subareas or points using a series of square boxes. Each small box would have its own value of soil water and the response of the area would be dependent on the integration of the point-to-point variation in individual values of water storage in the soil.

The time dimension is of major importance in deterministic modeling in hydrology. The hydrological response of a catchment is a continuous and unending process made up of continuous time series of inputs, interaction, and outputs. An individual time series such as rainfall usually consists of a group of numbers representing rain on any day, hour or minute, separated by strings of zero values. There are two methods of representing the time scale in hydrological modeling. These methods are to consider the individual event separately as in discrete models or to represent the complete time series from start to end as in continuous models.

Discrete models would consider a rainfall event and predict the runoff response, assuming static values for the various storages. On the other hand, continuous models represent all time steps whether there is rain or no rain, since other processes are taking place such as evaporation, transpiration, infiltration, percolation, or runoff. Hence, in a continuous model the soil water storages are continuously adjusted to account for losses through runoff, percolation, and evapotranspiration. Thus, when the next rainfall event occurs, the model has already adjusted watershed conditions and no adjustments are required to account for antecedent conditions as would be necessary with the discrete modeling approach.

In statistical modeling there are two sub-classifications, correlation or stochastic. Earlier approaches in statistical modeling concentrated on linear or multiple correlation and regression techniques to relate the dependent variable, for example runoff, to the independent variable, for example rainfall, area, etc. Another approach to statistical modeling is stochastic modeling. Stochastic modeling emphasizes the statistical characteristics of the hydrologic processes. This method assumes random variations in processes based on the laws of probability. For example, if it rains today what is the probability that it will rain tomorrow or on the same day next year. Stochastic modeling is useful for long term planning.

When considering the practical relevance of each methodology, none of the three general methods in mathematical modeling stands along entirely along as a practical approach. Each is mutually compatible with the other methods. For example, the input to a deterministic conceptual model is usually based on measurements of rainfall and evaporation. Where this information is limited, stochastic models can be employed to develop synthetic rainfall records for use in a conceptual model. The output from a deterministic conceptual model is stochastic since the input either measured or generated is stochastic. The input type, however, does not change the fact that the model structure is deterministic.

As another example, the output from a deterministic, conceptual model can be used as data in stochastic analysis. Streamflow from a simulation model, for instance, can be used to obtain the mean and standard deviation parameters in a stochastic model. In this example, the simulation approach can be used to extend existing records based on measured rainfall and the stochastic model used to extend the simulated streamflow record beyond the time scale of any measurements of rainfall or streamflow.