CHAPTER 8

TABLE OF CONTENTS

Page

8.00 MODELS AND MODELING

This chapter will provide the user with a basic understanding of runoff characteristics and flow-routing procedures. These concepts provide the mathematical basis for many of the computer models discussed at the end of this chapter. It is important to have a good understanding of hydrological principles before attempting to use any computer models to design stormwater systems and structures. All models have limitations and are designed for relatively specific application.

The guidance introduces the concepts of computer models and the types of models available. It also describes criteria that can be used to select models that address a project's particular needs, as well as to consider in model-use-and-results analysis. Some models available for water quantity and quality modeling are also discussed.

Computer modeling can be one of the more effective and efficient methods for predicting the quantity and nature of runoff, and the effectiveness of best management practices (BMPs). However, computer simulations and models have inherent limitations that users should be aware of and should factor into their decision-making processes. Usually, the best source for finding model limitations is the user manual, but sometimes this is not the case.

8.10 MODELING CONCEPTS

What Is a Model?

The word "model" has many meanings. This is how Snyder and Stall (1965) defined "model": "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 judgment 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 land-management practices on quantity and quality of runoff, infiltration, lateral flow, both saturated and unsaturated subsurface flow, and deep percolation.

Hydrologic models are planning tools that ask "what if" questions (*e.g.,* What would happen to the water quality of a 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.

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 thing we know that ain't so." While models can be extremely useful in determining the effects of projects on water quality and quantity, a model is most accurate when it is used with actual data and measurements. Also, the more actual measurements properly applied to calibrate a model, the more accurate the model will be.

Advantages of Models

Bross (1953) identified the following advantages of models:

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

Disadvantages of Models

- Most models are only effective under certain specified conditions (Chapman and Dunin, 1975).
- 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.
- 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.

Selecting Models and Modeling Protocols

Hydrologic models can be used in two ways:

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

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 the successful prediction for the situation in which it is to be used. The final test is a comparison of the model results with independent data.

Monitoring is always essential. Modeling can never replace monitoring. However, modeling is usually an effective way to evaluate the nature of a problem. The data collected in monitoring can help improve modeling predictions and development. Modeling is feasible only for evaluating problems that are understood well enough to be expressed in concise, quantitative terms. As models are developed to represent complex hydrologic systems, assumptions are incorporated in each model. The equations and formulas used to represent a complex system are never complete, due to the complexity of the system. In some situations, modeling may not be feasible or necessary. Modeling a situation may help determine whether monitoring would be beneficial. Models are used for analytical convenience. As tools for addressing hydrological questions, models do have limitations.

The Process

The steps in developing a monitoring and modeling protocol are:

1. Determine the issues of concern (what you want to find out).
2. Determine the available data.
3. Determine the available analytical tools and methods.
4. Determine the project constraints.
5. Determine the additional data needs.
6. Determine the acceptable levels of assurance within project constraints. If assurance levels are acceptable, proceed; if not, return to step 1.

Model Selection

The following points should be considered when choosing a model:

- What model is best for solving a particular problem in a particular location?
- What are the data requirements for both model and problem?
- What computer hardware and staff are required?
- What documentation is available?
- How much will it cost to apply the model?
- How accurate will the model be in representing the real world?

Basic Criteria for Evaluating Models (from Baker and Carder, 1976)

In selecting a model, one must consider (1) the ease of running the model and interpreting the results, (2) availability of data, (3) availability of models, (4) applicability to land-use activities, (5) applicability to broad geographic areas and (6) accuracy of prediction.

1. Ease of running the model and interpreting the results

- user friendliness by field-level user
- skills required
- ease of interpreting results
- type of results displayed
- assumptions required by the model

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

- 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 model to represent common alternative management activities
- sensitivity to change in management activities
- number of parameters predicted

5. Broad geographical areas
- ability of the model to operate in diverse hydrologic areas
- extrapolation of the 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 the model's predictions
- percent error between actual and predicted values for volumes, peak discharge and time to peak for both water and sediment

Model Verification

A model should generally be verified by running the model against known conditions to compare modeled versus monitored results. This type of analysis is much more difficult to do accurately than it would first appear. Many modelers warn against this type of verification, stating that certain models are better used for comparison projections than for finding exact values.

Monitoring error or interpretation of monitored data can be one of the main sources of error in model verification. Rainfall can vary significantly within short distances, even fractions of a mile. If monitoring stations do not cover the entire basin, assumptions must be made about the distribution of rainfall in the basin. Grab samples do not show variability of concentration with flow unless flow data are correlated with concentration and a significant number of samples are taken. Any averaged or composited sample methods tend to miss the extreme events. Flow-weighted mean samples depend on good sample values for each representative unit of flow. Small flow-measurement errors or unrepresentative sample values can significantly affect any loading estimate.

The variation can be random or correlated with other factors. Flow almost always correlates with loading. But concentration of a parameter may vary directly or inversely with flow. The assumptions made about variability such as this can affect the model output considerably.

Random judgment errors or estimation errors can accumulate or cancel each other out with a sufficient number of trials. Systematic errors, such as using the highest possible values, may be desirable for "worst-case scenarios" but they also tend to multiply in an unrealistic manner if not properly utilized.

Sensitivity Analysis

Sensitivity analysis tells us how much the model changes the results when specific assumptions are changed. Most models rely on hydrologic components, such as rainfall and runoff predictions. These factors can be correlated to pollutant concentration, loading and expected treatment in stormwater-treatment facilities. Even if the model is appropriate for the application, there may be variables that must be estimated. For example, one of the primary variables, with regard to hydrologic analysis, is the runoff coefficient utilized by the various models. The effect of changing these variables can be significant especially when there may be a variety of possible future conditions.

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 can be made. The computer output generated by a model must be analyzed and interpreted in a logical and consistent fashion to answer the decision-maker's questions, "What do the results mean?" and "How accurate and reliable are they?"

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, a 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 to appreciate the validity of the modeling results.

The accuracy associated with the results of modeling studies depends on the 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 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 models as tools. 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 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.

8.20 STORMWATER RUNOFF AND PEAK DISCHARGE

A wide variety of stormwater-runoff models exist. Quantity models vary from those that estimate peak discharges for a single summer storm to those that provide continuous streamflow simulation for months and years, summer and winter. This chapter outlines the basic components or processes included in stormwater-watershed modeling and attempts to address assumptions associated with the various processes. While stormwater models can be very useful in many situations, other methods, such as gage data statistical analyses or peak discharge regression equations, should also be considered.

Watershed or catchment runoff models combine various mathematical relationships representing processes or components of the hydrologic cycle to simulate peak flows or flow hydrographs. Measured data to varying degrees are used as part of individual components. Assumptions are made by the model and modeler that dictate how well the simulated processes simulate the result to be achieved. Errors associated with measured data will also impact the ability of the model to reliably produce the desired simulation.

Federal agencies, such as the U.S. Army Corps of Engineers (COE), U.S. Department of Agriculture Natural Resources Conservation Service (NRCS, formerly the SCS, or Soil Conservation Service), the U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Service (USGS) have developed much documentation related to models, methods used and assumptions involved. Documentation, technical publications and models are electronically available from agency Internet sites: http://www.wrc-hec.usace.army.mil/ for the COE Hydrologic Engineering Center (HEC) and http://www.wcc.nrcs.usda.gov/ for the NRCS National Water and Climate Center (WCC). Web search engines can also lead the user to extensive documentation on models and their use.

General

Single-event rainfall-runoff models, such as TR-20 and HEC-1, simulate streamflow hydrographs at locations throughout a watershed. These models are generally used to simulate the watershed-runoff characteristics of a single-precipitation event of a specific frequency and duration.

Single-event rainfall-runoff models generally operate in the following manner: The precipitation event is first described in terms of total volume, time and area of distribution. Losses, consisting of interception and infiltration, are simulated and subtracted from the precipitation, resulting in direct runoff or rainfall excess. Direct runoff is transformed into a direct runoff hydrograph usually by unit hydrograph methods. Base flow is simulated and added to the direct runoff hydrograph, resulting in the total runoff hydrograph. The total hydrograph is routed downstream through a reservoir or channel reach, as needed to produce the downstream hydrograph. Hydrographs from smaller watersheds are combined as needed to simulate the flow hydrograph at locations throughout the watershed or basin.

Continuous models, such as SWMM or HSPF, continuously account in time for climate and watershed processes, usually in a more comprehensive manner than single-event models.

Precipitation

Whether it occurs as rain or snow, precipitation is the principal source of surface runoff in small watersheds and is variable over time and area. The areal of distribution of the storm and the time distribution of rainfall throughout the duration of the storm are two major factors, in addition to the total amount, or depth, that affect the peak rate of runoff.

In calibration and especially in verification, assumptions made to distribute the measured rainfall over the watershed and throughout the time distribution of the precipitation event may greatly impact the simulation results. The farther the precipitation-monitoring station is from portions of the watershed, the less likely the data from the station will adequately represent the depth or time distribution that actually occurred in that portion of the watershed.

The storm line distribution can be thought of as a measure of how the rate of rainfall (intensity) varies within a given time interval. For example, in a given duration of rainfall, a certain depth of precipitation will have been measured or obtained from records. However, the intensity throughout the entire period varies considerably and is not constant. When the intensity has not been measured or is not available from records for the precipitation period, or duration, assumptions will have to be made as to the variation in intensity. Generally, the greatest intensity is placed from early in the storm to near the center of the storm period.

The size of the storm is often described by the length of time over which precipitation occurs (the duration), the total amount of precipitation occurring (the depth) and how often this same storm might be expected to occur (the frequency or return period). Thus, a 100-year, 24-hour storm can be thought of as a storm producing the amount of rain in 24 hours with a 1% chance of occurrence in any given year.

For design and analysis purposes, a design rainfall depth, duration and frequency are selected and used in the model. The simulated hydrographs and the runoff results are generally assumed to have the same frequency and duration of the design rainfall. Different duration events will generally produce different runoff results and the modeler must assume which duration is appropriate for design or analysis. Assumptions about the time distribution of these statistical events must also be made. The COE and the NRCS have published procedures for developing synthetic time distributions and incorporating them into analyses.

Losses

Losses are that portion of the total precipitation that does not contribute to runoff. Initial losses and infiltration are principal losses subtracted from the total precipitation by typical single-event models. Initial losses include water held in the vegetation canopy, water stored in surface depressions and water lost to evapotranspiration. Infiltration includes gravity processes and capillary (suction) due to soil characteristics. Land use, soil type and the hydrologic condition of the watershed at the start of the storm are factors that impact the amount of losses. Continuous-event models tend to simulate and account for infiltration and its impact on soil moisture and groundwater as opposed to considering it a loss.

1. Soil Type

Different soil types have different infiltration characteristics. Fine-textured soils, such as clay, generally produce a higher rate of runoff than do coarse-textured soils, such as sand. In general, the higher the rate of infiltration, the lower the quantity of stormwater runoff.

Soils have been divided into groups called “hydrologic soil groups” (HSGs) to describe their potential to produce runoff. HSGs for various soils are identified in soil surveys published by the NRCS. These groups are based on infiltration and transmission rates. Soils are classified into HSGs to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The infiltration rate is the rate at which water enters the soil at the soil surface. It is controlled by surface conditions. The HSG also indicates the transmission rate — the rate at which the water moves within the soil. This rate is controlled by the soil profile. Musgrave (USDA, 1955) first published approximate numerical ranges for transmission rates shown in the HSG definitions.

The four hydrologic soil groups used in measuring runoff potential are:

Group A: Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well- to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 inch per hour).

Group B: Group B soils have moderate infiltration rates when thoroughly wetted. They consist chiefly of moderately deep to deep, moderately well- to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 inch per hour).

Group C: Group C soils have low infiltration rates when thoroughly wetted. They consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 inch per hour).

Group D: Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 inch per hour).

Disturbed soil profiles

As a result of urbanization, the soil profile may be considerably altered and the listed group classification may no longer apply. In these circumstances, use the following table to determine HSG according to the texture of the new surface soil, provided that significant compaction has not occurred (Brakensiek and Rawls, 1983):

Table 8.20-1

Hydrologic Soil Group	Soil textures
A	Sand, loamy sand or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay or clay

Drainage and Group D Soils

Some soils in the list are in group D because of a high water table that creates a drainage problem. Once these soils are effectively drained, they are placed in a different group. For example, Ackerman soil is classified as A/D. This indicates that the drained Ackerman soil is in group A and the undrained soil is in group D.

Consideration should be given to whether heavy equipment has or will compact the soil significantly more than natural conditions; whether much of the pervious area is barren with little sod established; and whether grading has mixed the surface and subsurface soils, causing a completely different hydrologic condition. Any one of the above can cause a soil normally in hydrologic group B or C to be classified in group C or D.

Partsch *et al.* (November-December 1993) found that the compaction of the soil significantly affected infiltration amounts and patterns, sometimes more than 20 years after compaction had occurred. Pitt (1994) observed significantly higher rates of runoff (sometimes as high as impervious surfaces) from lawns, playfields and other areas with compacted soil. Site-specific infiltration data or conservative estimates of infiltration rates should be used in urban areas.

Soil maps are extremely useful. However, soil types can be highly variable, especially in rapidly developing urban areas where soils may be removed or otherwise disturbed by human activity. Inspection by professionals and infiltration studies may be useful to verify the soil types related to a specific watershed. Disturbed urban areas can have highly variably runoff rates in most soil types, even after vegetation has been re-established.

2. Land Use (surface cover)

The type of cover and its condition affects runoff volume through its influence on the infiltration rate of soil. For a given soil type, disturbed land yields more runoff than forests or grassland. This is because the foliage and its litter maintain the soil's infiltration potential by preventing the sealing of the soil surface by the impact of the raindrops. Also, some of the raindrops are retained on the surface of the foliage, increasing their chance of being evaporated back to the atmosphere. Some of the intercepted moisture takes so long to drain from the plant down to the soil that it is withheld from the initial period of runoff. Foliage also transpires moisture into the atmosphere, thereby creating a moisture deficiency in the soil that must be replaced by rainfall before runoff occurs.

Vegetation, including its ground litter, forms many barriers along the path of the land, which slows the water down and reduces its peak rate of runoff. Covering areas with impervious material reduces storage and infiltration and thus increases the amount of runoff.

3. Antecedent Moisture Content

The soil moisture content also affects the runoff from a storm. Soil moisture may come from precipitation, ground water movement, or previous runoff and infiltration. The infiltration rates and runoff rates of all soils are affected by climatic conditions, such as freezing. Regardless of this hydrologic soil group, frozen soils can exhibit rapid runoff rates. Low soil temperatures typical of the colder seasons decrease rates of infiltration and thereby increase the volume of runoff. Rains on frozen ground may cause the largest runoff of the year.

4. Temporary and Depressional Storage

A considerable amount of surface runoff may be retained in temporary or depresssional storage in wetlands or on very flat areas where ponding occurs, thus reducing the rate at which runoff will occur.

Hydrograph Development

Unit hydrograph methods are generally used to transform the direct runoff volume into the direct runoff hydrograph. Unit hydrographs reflect the time-distribution characteristics of flow movement through the watershed or subwatershed. Unit hydrographs can be developed from stream gage data if these data are available for the watershed. Watershed size and shape and land and channel slope and length are characteristics that influence the size and shape of the unit hydrograph.

Time of concentration, lag time or travel time are key parameters used by these methods to shape the runoff volume into a unit hydrograph characteristic of the watershed. Synthetic unit hydrograph methods are available in most models and are commonly used in rainfall runoff modeling. SCS, Snyder and Clark are typical methods in common use.

Time of concentration is the time that it takes water to travel from the most distant part of the watershed to the point of interest. The time of concentration affects the peak rate of runoff and the shape of the hydrograph. Hydrology textbooks describe several methods to calculate time of concentration.

Base Flow

The streamflow hydrograph is usually comprised of both overland flow, represented by the direct runoff hydrograph, and subsurface flow, commonly called “base flow.” It is dependent on the hydrogeology in the vicinity of the stream and ground water levels at the time of the precipitation event. While methods exist to estimate base flow from analysis of stream gage flow records, runoff models use only very approximate methods to account for this portion of the total hydrograph. The importance of this parameter is generally less when simulating large-storm events; however, it becomes increasingly important as smaller-storm events are considered. It also can be a significant consideration when calibrating and verifying with actual streamflow events.

8.30 FLOW ROUTING

Flow routing is the technique used to simulate the changes that occur to a streamflow hydrograph as it moves through a river reach or reservoir. The effects of storage and flow resistance of the reach are reflected by changes in the shape and timing of the hydrograph as it moves from upstream to downstream. As movement proceeds downstream, the peak is attenuated and the hydrograph shape broadens. The basic premise used in any flow-routing procedure is that the total inflow is equal to the total outflow plus the change in storage.

Flow routing can be grouped into two different types: lumped flow routing and distributed flow routing. Lumped, or hydraulic routing, discretizes the system in the time domain (flow is calculated as a function of time at one location), while distributed, or hydraulic routing, discretizes the system in both the time and space domains (flow is calculated as a function of space and time throughout the system).

Chow *et al.* (1988) presents a detailed discussion on the assumptions and methodology of reservoir flow routing, which is summarized below.

For a hydrologic system, inflow, outflow, and storage are related by the continuity equation:

$$\frac{dS}{dt} = I(t) - Q(t)$$ **(Equation 8.30–1)**

where: I = Inflow, [L^3/T],
Q = Outflow, [L^3/T],
S = Storage, [L^3/T]
t = Time

For a pond, the inflow hydrograph (*I(t)*) is known, leaving two unknowns in Equation 8.30–1: outflow (*Q(t)*) and storage (*S*). Since it is not possible to solve this equation for outflow directly, a function must be developed to relate inflow, outflow, and storage.

One of the more widely used methods for routing flow through detention or sediment basins is the Level Pool Routing (also known as Modified Puls or Storage Indication Method). This flow-routing procedure is based upon solving the continuity equation for small time steps. This method is most commonly used for routing through a reservoir, lake, pond or wetland. It is less frequently used for channel routing by assuming a series of small reservoirs that comprise the river reach.

In general, storage is a function of inflow, outflow, and the time derivatives of inflow and outflow. The level pool routing method assumes that storage is a nonlinear function of outflow

(Q) only, and can be applied to basins with an invariable relationship between outflow and storage. Such basins have:

- a horizontal water surface,
- a pool that is wide and deep compared to the length of the pool in the direction of flow,
- a low flow velocity,
- an outlet with a fixed discharge for a given pool elevation, and
- an uncontrolled outlet or an outlet that is unmoveable (a weir) or held at a fixed position (dam gates).

For a pond with a horizontal water surface, the outflow is a function of the hydraulic head above the outlet, or the water elevation in the pond. Storage for such a pond is also a function of water surface elevation, or depth of water in the pond. Combining these two relationships results in an invariable function where storage is solely a nonlinear function of pond outflow, which is illustrated graphically in Figure 8.30–1 and mathematically as:

$$S = f(Q) \qquad \textbf{(Equation 8.30–2)}$$

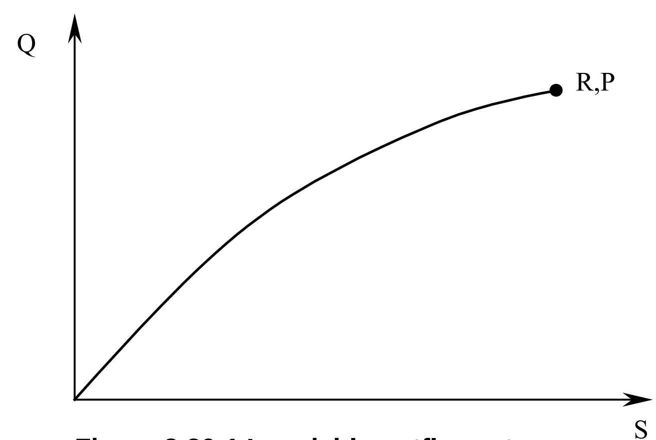

Figure 8.30-1 Invariable outflow–storage relationship (adapted from Chow *et al.,* 1988)

It follows that the peak outflow (P in Figure 8.30-2) from such a pond occurs when the inflow hydrograph intersects the outflow hydrograph, as the maximum storage occurs when the change in storage with respect to time, or the first derivative of the storage function, is zero.

$$dS / dt = I(t) - Q(t) = 0 \qquad \textbf{(Equation 8.30–2)}$$

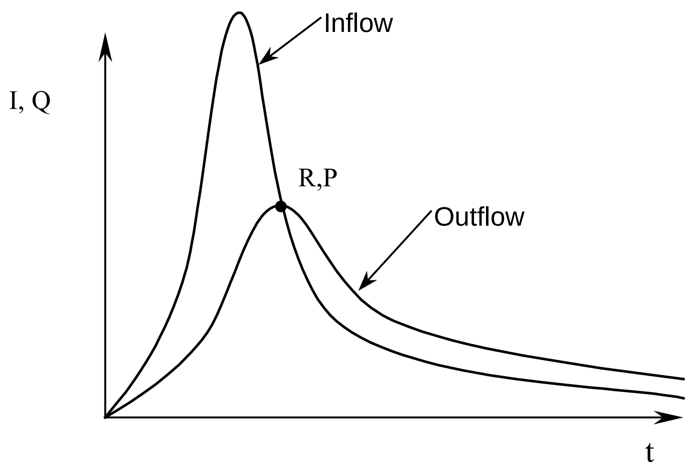

Figure 8.30-2 Hydrographs for an Invariable Storage Pond (adapted from Chow et al., 1988)

Ponds with a variable relationship between outflow and storage tend to be long and narrow — approaching the shape of a river or stream. The water surface profile of such a pond may be significantly curved due to backwater effects. The retarding of wave propagation in the reservoir from backwater causes the peak outflow of the reservoir to occur after the inflow and outflow hydrographs intersect, as shown in Figure 8.30–3. Figure 8.30–4 illustrates that the backwater effect results in a relationship between storage and outflow that is not single–valued, but exhibits a curve in the form of a single or twisted loop, depending on the storage characteristics of the system. If the backwater effect is not significant, and the graph of storage versus outflow results in a loop which is fairly narrow in width, the loop relationship may be replaced with an average curve, which is represented by the dashed line in Figure 8.30–4. This approximation will allow the use of the level pool method of flow routing through the pond.

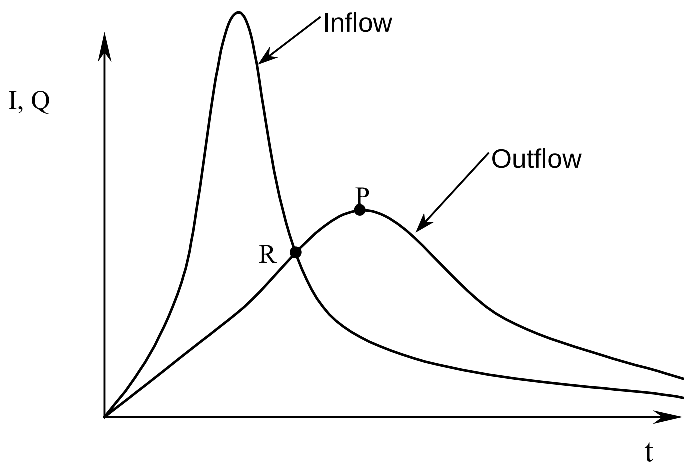

Figure 8.30-3 Hydrographs for a Variable Storage Pond (adapted from Chow et al., 1988)

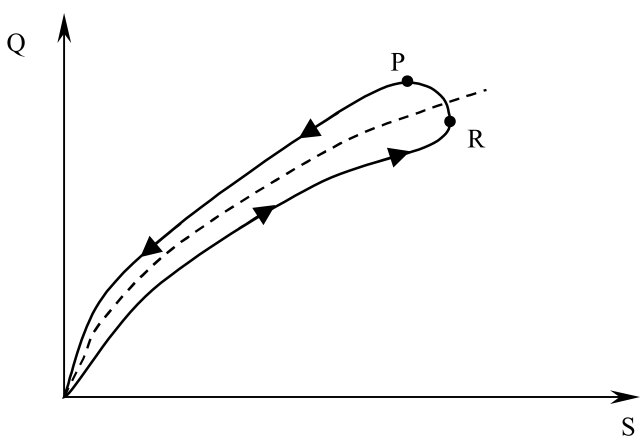

Figure 8.30-4 Variable Outflow–Storage Relationship (adapted from Chow et al., 1988)

The difference in shape of the inflow and outflow hydrographs shown in figures 8.30–2 and 8.30–3 is due to the effect of storage in the pond shifting the position of the centroid of the hydrograph. Figure 8.30–5 illustrates the time of redistribution of the hydrograph, which is the shifting in time of the centroid of the inflow hydrograph to the centroid of the outflow hydrograph from the effect of pond storage.

In a pond with a long axis in the direction of flow, the time for the flood wave to travel through the pond may be of such duration that the centroid of the hydrograph may be shifted by a time period longer than the time of redistribution. This additional time is illustrated in Figure 8.30–6 as the time of translation, which does not change the shape of the hydrograph, but does change the position. The total time of flood wave movement illustrated in Figure 8.30–7 is the sum of the time of redistribution and the time of translation.

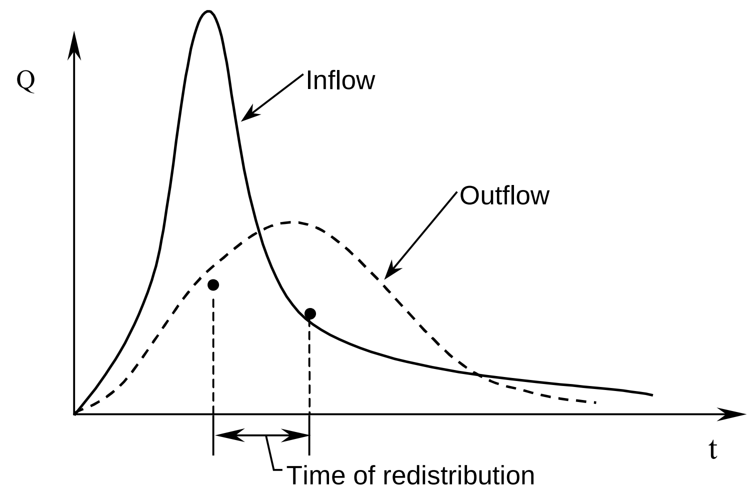

Figure 8.30-5 (adapted from Chow et al., 1988)

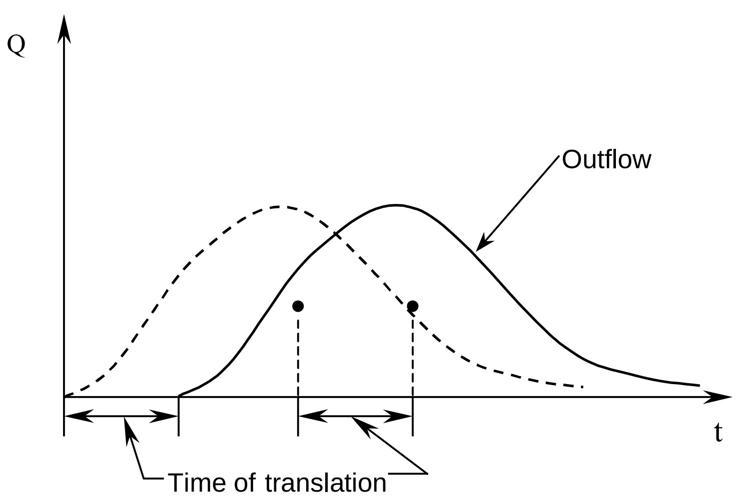

Figure 8.30-6 (adapted from Chow et al., 1988)

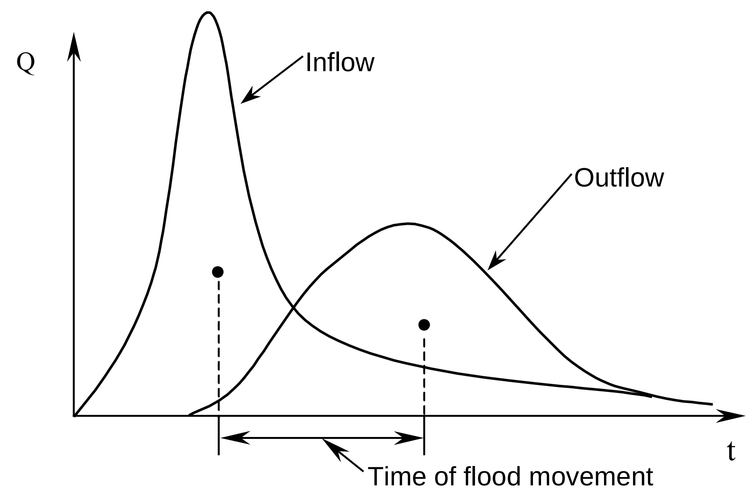

Figure 8.30-7 (adapted from Chow et al., 1988)

Level Pool Routing Methodology

The level pool routing procedures used to route an inflow hydrograph through a pond with a horizontal water surface can be divided into two categories: graphical methods and tabular methods. Graphical procedures are quicker and easier to execute by hand, while tabular methods are more complex but are conducive to computerization. With the increase in power and availability of personal computers, the tabular methods are replacing graphical methods as the commonly used method of flow routing.

The graphical level pool routing method involves breaking the time horizon of the inflow and outflow hydrographs into equal intervals of duration Δt (*i.e.,* Δt, $2\Delta t$, $3\Delta t$, …, $j\Delta t$, $(j+1)\Delta t$, as shown in Figure 8.30–8.

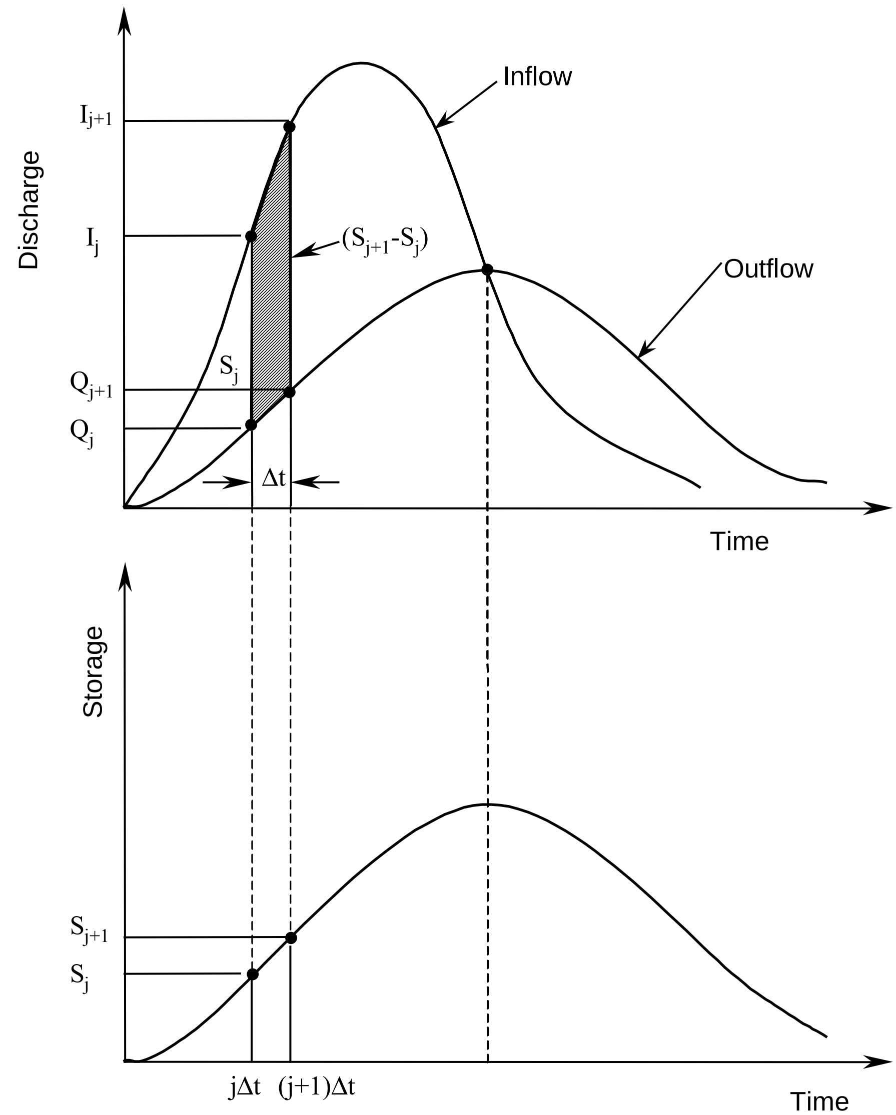

Figure 8.30-8 Change in storage during level pool routing.

The continuity equation (Equation 8.30–1) is integrated over each time interval, which for time interval j is:

$$\int_{S_j}^{S_{j+1}} dS = \int_{j\Delta t}^{(j+1)\Delta t} I(t)dt - \int_{j\Delta t}^{(j+1)\Delta t} Q(t)dt \qquad \textbf{(Equation 8.30–3)}$$

The inflow and outflow rates at the beginning of time interval *j* are I_j and Q_j, while the inflow and outflow rates at the end of time interval *j* are I_{j+1} and Q_{j+1}. By definition, the integral of a function is the area under the curve of the function. Therefore, the area under the inflow hydrograph of the slice in time from *j* to *j+1* is the volume of inflow to the pond during timestep *j*. Likewise, the area under the outflow hydrograph of the slice in time from j to $j+1$ is the volume of outflow from the pond during the timestep j. From Equation 8.30–3, it follows that the storage in the pond during timestep j is the difference in volume of the inflow and outflow hydrographs shown as the cross–hatched area in figure 8.30–8.

Assuming that the change in inflow and outflow over the timestep is linear (the cross–hatched area in Figure 8.30–8 is a trapezoid), Equation 8.30–3 can be solved for the change in storage over the time interval j by subtracting the area under the outflow curve from the area under the inflow curve:

$$S_{j+1} - S_j = \frac{I_j + I_{j+1}}{2}\Delta t - \frac{Q_j + Q_{j+1}}{2}\Delta t$$ **(Equation 8.30–4)**

Appreciable deviations from the linearity assumption require a shorter timestep.

In Equation 8.30–4, I_j and I_{j+1} are determined from the inflow hydrograph, Q_j and S_j are determined in the previous timestep, and Δt is fixed. The variables remaining as unknowns are S_{j+1} and Q_{j+1}. With one equation and two unknowns, another function must be developed to relate outflow (*Q)* to storage (*S*). By introducing a third variable — water surface elevation (*H*) — a graphical relationship between outflow and storage can be developed.

Solving 8.30–4 for storage and outflow at the j+1 time interval gives:

$$\left(\frac{2S_{j+1}}{\Delta t} + Q_{j+1}\right) = \left(I_j + I_{j+1}\right) + \left(\frac{2S_j}{\Delta t} - Q_j\right)$$ **(Equation 8.30–5)**

By developing curves or tables which relate water surface elevation to storage and to outflow rate, a subsequent curve or table can be constructed which relates outflow rate to the unknown term $2S/\Delta t + Q$. This process is illustrated graphically in Figure 8.30–9. The relationship between pond water surface elevation and pond storage can be developed by digitizing curves of constant elevation of the pond bottom from the topographic design plan for the pond. The rating curve for the pond outlet can be determined from equations for standard outlets, such as culverts and weirs, or by direct measurement. Direct measurement involves measuring the cross-sectional area of water flow and flow velocity at the outlet utilizing a current meter for incremental water elevations.

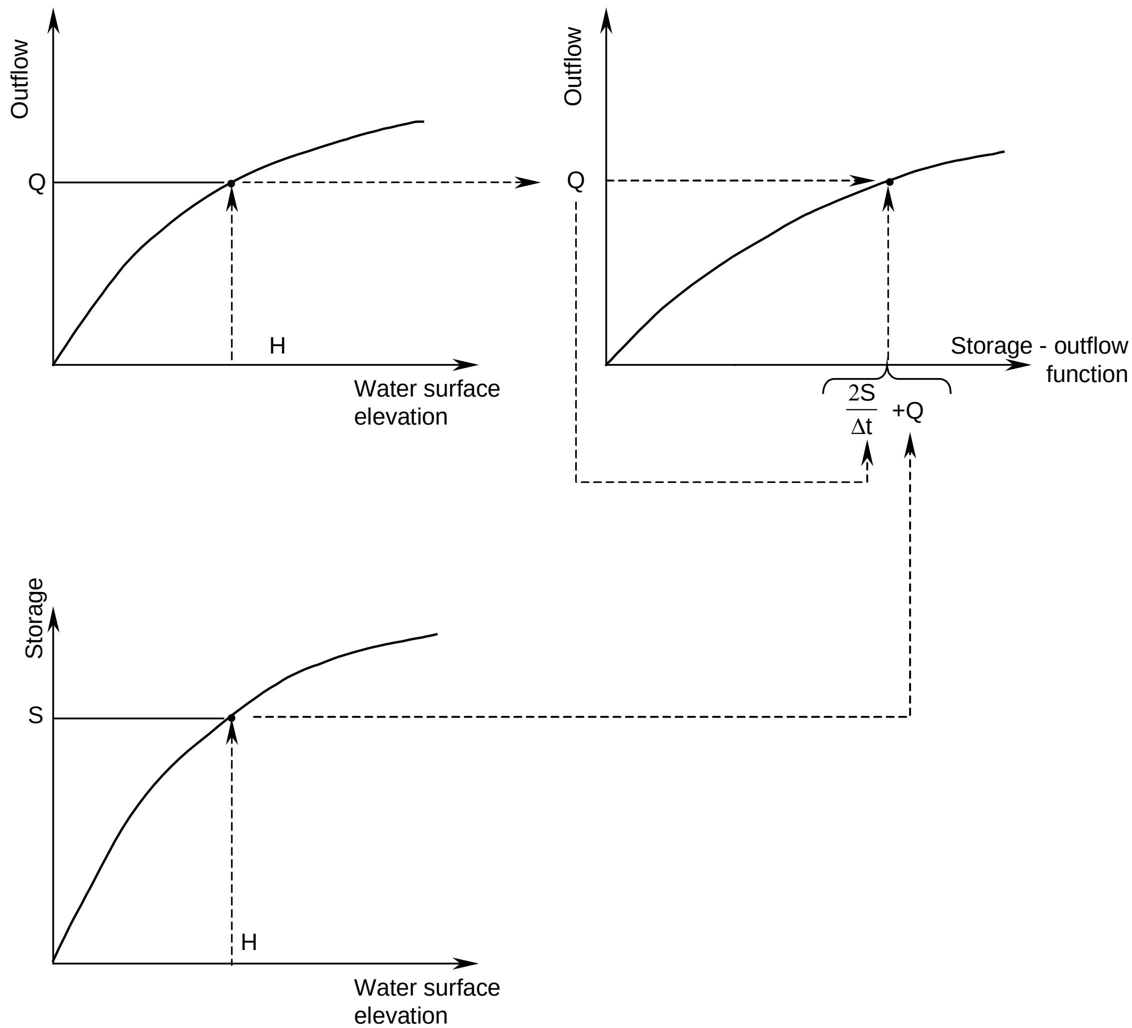

Figure 8.30-9 Development of a storage-discharge function

At time interval j, all the terms in the right–hand side of Equation 8.30–5 are known, so the value of $2S_{j+1}/\Delta t + Q_{j+1}$ can be calculated. Utilizing the preconstructed table or curve (Figure 8.30–9) of outflow (Q) versus the storage–outflow function ($2S/\Delta t + Q$), the outflow rate at timestep $j+1$ (Q_{j+1}) is determined by either reading the value directly off of the curve, or in the case of tabular values, linear interpolation. For the next time step, the unknown value $2S_{j+1}/\Delta t - Q_{j+1}$ in the right-hand side of Equation 8.30–5 is calculated by using the following equation:

$$\left(\frac{2S_{j+1}}{\Delta t} - Q_{j+1}\right) = \left(\frac{2S_{j+1}}{\Delta t} + Q_{j+1}\right) - 2Q_{j+1} \qquad \textbf{(Equation 8.30–6)}$$

This procedure is repeated for the duration of the routing period.

Models generally offer one or more channel-routing procedures. They range in complexity from the complete solution of the Saint Venant equations of motion to solutions solving only the portion(s) of the equations deemed most important and to those employing approximate methods. The TR-55 graphical method is a short-cut Storage-Indication Method of reservoir routing that is based on investigation of average storage and routing effects from many structures. Muskingum, Muskingum-Cunge and Modified ATT-KIN are some methods based on portions of the equations of motion. As computer capabilities increase, more models, such as SWMM, are including complete solution methods as data needs are often not substantially increased over some of the more rigorous partial solutions. Hydraulic routing models, such as UNET or FLOODWAV, focus only on routing, and hydrographs from recording gages or other models are a necessary input.

In routing, the shape and volume of the inflow hydrograph are as important as the peak discharge. For this reason, peak discharges derived from runoff methods intended only to predict peak discharge should be used with caution.

8.40 MODEL DESCRIPTIONS

Many methods for computing runoff, peak discharge and other information useful in designing stormwater-management systems have been developed. Table 8.40-1 shows the relative suitability of some models for various types of analysis and gives short descriptions of the major nonproprietary computer models that are available. A description of some of the more specialized water-quality-analysis models is also included later in this section.

Table 8.40-1 Relative suitability of some stormwater models

Model	Water Quality Analysis		Simulation Type[a]	Drainage Area up to 20 Acres	Drainage Area 20 to 2,000 Acres	Drainage Area 3 to 20 Square Miles	Peak Discharge and Runoff Volume	Hydrograph Produced?
	Pollutograph	Average Annual Loading						
AnnAGNPS	No	Yes	C	Yes	Yes	Yes	Yes	No
CREAMS/ GLEAMS	Yes	Yes	C	Yes	Yes	No	Yes	Yes
DETPOND	No	Yes	ME	Yes	Yes	Yes	Yes	Yes
HEC1	No	No	ME	No	Yes	Yes	Yes	Yes
HSPF[b]	Yes	Yes	C	Yes	Yes	Yes	Yes	Yes
P8[b]	Yes	Yes	ME	Yes	Yes	Yes	Yes	Yes
Rational Method	No	No	SE	Yes	No	No	No	No
SLAMM	No	No	ME	Yes	Yes	No	Yes	Yes
SWMM[b,c]	Yes	Yes	C, ME	Yes	Yes	Yes	Yes	Yes
TR20	No	No	ME	Yes	Yes	Yes	Yes	Yes
TR55-Graphical	No	No	SE	Yes	Yes	No	No	No
TR55-Tab. Method	No	No	SE	Yes	Yes	No	Yes	Yes

a SE = single event, C = continuous, ME = multievent

b It is recommended that these models be used in conjunction with a water quantity model for large-storm peak discharge designs.

c Also allows analysis of reverse flow, which can be important in two-cell stormwater-treatment systems.

AnnAGNPS (Annualized Agricultural Nonpoint Source Pollution Model)

Description

AnnAGNPS is a continuous simulation surface water pollutant transport model that estimates the amount of sediment, nutrients, and pesticides in runoff from land areas and in streams. This model was developed for agricultural watersheds in Minnesota, and has also been tested in Nebraska and Iowa. It supersedes the predecessor to AnnAGNPS – AGNPS 5.0 – a storm event version of the model that is no longer distributed or supported. AnnAGNPS is a distributed simulation model and is implemented by dividing a watershed into irregularly shaped cells. The cells can be up to 10,000 acres in area, and the watershed can be of any size. Land use, topography, and soil type are assumed to be homogeneous within each cell. AnnAGNPS gives estimates of bed–and–bank, gully, and sheet–and–rill erosion in each of the particle sizes of sand, silt, clay, small aggregates and large aggregates. AnnAGNPS is also capable of handling point-source input from feedlots, waste-water-plant discharges, and streambank and gully erosion. It also represents the effects of impoundments on water quality at the watershed outlet. Output can be obtained by storm event, monthly, or on an annual basis. The model also has a source accounting capability that quantifies the amount of pollutants contained in runoff at any point of interest in the watershed, such as the watershed outlet, from individual cells upgradient in the watershed.

Uses and Applications

- Evaluates the effect of various BMPs on the downstream sediment, nutrient, and pesticide load.
- Simulates the amount of soluble nutrients and chemical oxygen demand present in feedlot runoff.
- Predicts erosion for five particle sizes (sand, silt, clay, small aggregates and large aggregates).
- Predicts water quality and erosion on a cell, reach, and watershed basis.
- Incorporates the spatial variation of hydrologic, nutrient, and sediment processes when the watershed is divided into cells.
- Divides pollutant transport into soluble pollutants and sediment-attached pollutants.
- Source accounting feature creates the ability to rank individual cells based on impact to receiving water at watershed outlet.
- Soil erosion is determined using the Revised Universal Soil Loss Equation.
- Simulates snowmelt.
- Simulates changes in runoff pollutant concentrations due to conservation tillage, nutrient management, contour farming, and stripcropping on agricultural fields.

Input Data

Input data requirements are quite extensive for a continuous simulation. AnnAGNPS input consists of 34 categories of data for job control, landuse, topography, hydrology, soils and climate. The model can be run for a single-storm event, which reduces the required amount of input data significantly (to 24 sections). The development of topographic input data can be assisted by the use of a flownet generator which automates the task of developing stream reach and cell physical characteristics. The flownet generator, TopAGNPS, is based on the USDA–Agricultural Research Service Topographic ParameteriZation (TOPAZ) model, and allows the user to utilize existing

Digital Elevation Models (DEMs) for the development of topographic parameters. The program can also utilize a synthetic weather generator, Generation of weather Elements for Multiple applications (GEM), to develop a portion of the climatological input. Required input data can be obtained from the Minnesota Land Management Information Service (LL45 Metro Square, 7th and Robert, Saint Paul, MN 55101), Soil Survey Geographic (SSURGO) data base, USDA–NRCS soil surveys, field analysis, and United States Geographical Survey topographic maps and DEMs.

Output Available

- Runoff hydrology, sediment, nutrient, pesticide and chemical oxygen demand.
- Output available at the outlet of any cell or for any reach in the watershed.
- Daily, monthly, or yearly values are available.

Limitations

- AnnAGNPS is a comprehensive watershed model and as such the amount of input data required can become quite demanding with increasing watershed size and/or resolution.
- The development of topographic input data utilizing the flownet generator with DEMs is cumbersome.
- Wetland and lake nutrient processes are not simulated.
- Agricultural field tile drainage is not simulated.
- Documentation is not completed.

Future Modifications

- The interface of AnnAGNPS with Geographical Information Systems is being enhanced.
- Incorporation of a lake and a wetland model is under development.
- Completion of a one-dimensional, unsteady, advanced channel dynamics component that simulates streambank stability, bank erosion and channel evolution.
- Integration of Next Generation Weather Radar (NEXRAD) technology.

CREAMS (Chemicals, Runoff and Erosions from Agricultural Systems) GLEAMS (Groundwater Loading Effects of Agricultural Management Systems)

Description

Chemicals, Runoff and Erosions from Agricultural Systems (CREAMS) is a continuous field-scale model developed by the U.S. Department of Agriculture – Agricultural Research Service (USDA–ARS) that simulates surface runoff, infiltration, evapotranspiration, erosion, sediment yield, and plant nutrient and pesticide delivery (Knisel, 1980). CREAMS can simulate aerial spraying or soil incorporation of pesticides, animal waste management, and alternative agricultural practices such as minimum tillage and terracing. The parameters needed for the model are physically measurable and *there is no calibration required for individual watersheds*.

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) was developed by the USDA–ARS to analyze the effects of pesticide and nutrient infiltration into the root zone of the soil profile (Knisel, 1993; Leonard, 1987; Leonard *et al.,* 1990). GLEAMS is an extension of CREAMS in that the hydrology, plant nutrient, and pesticide components of CREAMS were modified to simulate the movement of water, nutrients and chemicals through the root zone. The representation of the various management practices presented in CREAMS were also improved.

Uses and Applications

- CREAMS and GLEAMS represent soil processes with reasonable accuracy.
- CREAMS and GLEAMS simulate on a continuous basis, and also considers event loads.
- CREAMS and GLEAMS can simulate up to 20 pesticides at one time.
- CREAMS and GLEAMS can represent various agricultural BMPs.
- CREAMS and GLEAMS are not intended for use as an absolute pollutant prediction tool — they are most effective in comparative analysis, such as comparing pollutant loads under existing conditions to pollutant loads with BMPs implemented.

Input Data

Extensive data on meteorology, hydrology, soil properties, and chemistry of pollutants are required.

Output Available

An extensive output listing for hydrology, nutrient, and pesticide simulation results is available on a storm, monthly or annual basis.

Limitations

- CREAMS and GLEAMS require extensive data inputs.
- CREAMS and GLEAMS do not simulate pollutant movement in the saturated zone.
- CREAMS and GLEAMS can only be used on field-scale plots.
- CREAMS and GLEAMS do not simulate receiving waters.
- CREAMS and GLEAMS do not simulate in-stream process.
- CREAMS and GLEAMS data-management and -handling capacity is limited.

DETPOND

Description

DETPOND is a stormwater quality model developed by Robert Pitt and John Voorhees that is used for designing of detention ponds. Its purpose is to predict how much particulate solids a wet detention pond will remove from urban runoff. It allows the user to design a detention pond as both a water-quality-control device and a water-quantity-control device. It is both user friendly and flexible, allowing either user-defined or default parameters for many input variables.

DETPOND, Version 4, routes urban runoff to a detention pond. The rain events that generate runoff are entered either individually as single events or as an inflow hydrograph, or in a series. Runoff is generated from rain events using either the SCS Curve Number method, the combined runoff method, or from runoff volumes calculated using SLAMM. The detention pond routing algorithm is based on the storage-indication reservoir routing subroutine in HEC-1 and in TR-20. Pond particulate removal is based on the particle size distribution entering the pond and the theoretical upflow velocity of the water through the pond.

Uses and Applications

DETPOND is used for stormwater and detention pond design.

Input Data and/or Model Components

- State and area information
- Rainfall
- Runoff coefficients
- Particle size distribution
- Outlet size and type

Outputs Available

Outputs available from DETPOND include outflow and inflow, evaporation, storage and stage, and particle sizes removed.

HEC-1

Description

All ordinary hydrograph computations associated with a single recorded or hypothetical storm can be accomplished with the U.S. Army Corps of Engineers' HEC-1, Flood Hydrograph Package.

Uses and Applications

Capabilities of HEC-1 include rainfall, snowfall and snowmelt determinations; computations of basin-average precipitation from gages or hypothetical storms; unit hydrographs via direct ordinates or Clark, Snyder or SCS methods, or by kinematic wave transforms; hydrograph routing by level-pool reservoir, average lag, modified Puls, Muskingum, Muskingum-Cunge, and kinematic wave methods; and complete stream system hydrograph combining and routing. Best-fit unit hydrograph, loss rate, snowmelt, base freezing temperatures and routing coefficients can be derived automatically. HEC-1 may also be used to simulate flow over and through breached dams. Expected annual flood damage can also be computed for any location in a river basin.

Input Data and/or Model Components

Batch processing is employed and the sequence of input data records prescribes how the river basin is simulated. Basin simulation data records are structured by the user to reflect the topography of the basin.

Outputs Available

Text output includes immediate simulation results, summary results and error messages. Printer plot routines are provided. HEC-1 interfaces with HEC-DSS routines for storing, retrieving, graphing and tabulating data.

Limitations

Simulations provided by HEC-1 are limited to single-storm events because no provision is made for soil moisture recovery between storms. HEC-1 does not account for backwater effects from downstream reaches or reservoirs.

HSPF (Hydrological Simulation Program – Fortran)

Description

HSPF is a comprehensive package for simulation of watershed hydrology and water quality. It is an integrated program that simulates the hydrology and the behavior of conventional and organic pollutants in surface runoff and receiving waters. The 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 PERLLND (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 structure that permits the continuous simulation of a comprehensive range of hydrologic and water-quality processes.

Use and Application

- Continuous hydrologic simulation can be done with HSPF.
- HSPF integrates the loading from nonpoint sources (including alternative control practices) and receiving water quality simulation into a single package.
- HSPF analyzes both point- and nonpoint-source loading.
- HSPF provides the option of using simplified or detailed representation of nonpoint-source runoff.
- HSPF performs risk analysis due to the exposure of aquatic organisms to the toxic chemicals present in receiving waters.
- HSPF incorporates agricultural management practices by changing parameter values.

Input Data and/or Model Components

HSPF requires extensive data along with meteorological and hydrologic data.

Outputs Available

The output of HSPF includes system 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 concentration is provided along with the link between simulated receiving water pollutant concentration and risk assessment.

Limitations

- HSPF needs calibration before it can be applied to a particular site.
- HSPF requires extensive data along with meteorological and hydrologic data.
- Two to three months are required to learn HSPF’s 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%) of total application costs, depending on the extent to which the model will be used.

MFES (Minnesota Feedlot Evaluation System)

Description

MFES is the model developed to evaluate and rate the pollution potential of feedlot operations. It 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 SCS Curve number approach. The pollutant indicators are phosphorus and chemical oxygen demand. Currently, the MPCA uses this model in its feedlot permit program.

Uses and Applications

- MFES is an excellent screening tool.
- MFES evaluates different land-management practices.
- MFES considers both surface and ground-water pollution.
- MFES is a fast and effective tool.

Input Data

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

Output Available

The pollutant delivery is present at the discharge point.

Limitations

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

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

Description

Nitrogen, Tillage, and Crop Residue Management (NTRM) is a large, broad-based computer-simulation model for tillage, crop residue and nitrogen fertilizer management. The NTRM model is designed mainly to provide management assistance at the farm management and engineering levels. This 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 equilibrium 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.

Uses and Applications

- NTRM simulates physical, chemical, and biological processes in the soil-water-crop continuum.
- NTRM predicts the effect of soil environment on crop growth.
- NTRM serves as a tool for nitrogen-fertilizer management.
- NTRM can be used for long-term agricultural planning.

Input Data

With the NTRM model, extensive data are 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 equilibrium model; solute transport model and the crop residue model.

Output Available

The outputs available from NTRM 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 homographs.

Limitations

- NTRM currently can only simulate corn growth.
- NTRM requires large data input.
- NTRM requires additional testing for many components of the model.

Pondsize

Description

Pondsize is a spreadsheet program that can be used to determine the volume and dimensions of a sedimentation basin to retain the runoff generated from a given precipitation event for a given land use. The program was written for the Lotus 1-2-3 spreadsheet program, but it can readily be imported into other spreadsheet packages. The equations presented in the report upon which the spreadsheet is based (Walker, 1987b) can also be solved manually.

Uses and Applications

The Pondsize program is used to determine the size and shape of a sedimentation basin to detain the runoff from a given precipitation event for a given land use.

Input Data and Model Components

- Twelve user inputs are required: watershed area, runoff curve number, connected impervious fraction of watershed, precipitation volume (2.5 inch recommended), antecedent moisture condition, pond maximum depth, aquatic bench width and slope, permanent pool sideslope, pond shape, length-width ratio, and pond top length.
- Pondsize uses the NRCS runoff curve number method to determine runoff from pervious areas and unconnected impervious areas (such as rooftops) for a single-precipitation event.
- The entire volume of runoff from connected impervious areas is routed directly to the pond without watershed retention.
- Pond shape can be either triangular (preferred), rectangular or elliptical.
- By varying the length-width ratio and the top length, the spreadsheet can be used iteratively to determine a pond volume that is greater than or equal to the watershed runoff volume. Alternatively, an “autofit” macro can be used which will determine a top length for the user for a given length-width ratio.

Outputs

- Pondsize calculates pond surface area, mean depth and volume.
- Pondsize determines dimensions of pond bottom, aquatic bench and pond surface.
- Pondsize produces plots of the pond in plan view and in cross section.

Limitations

- Runoff volume is determined for one homogeneous watershed. Variations in pervious landuse are lumped into one runoff curve number.
- Pondsize does not design the principal or emergency spillway.
- Pondsize does not provide for temporary flood prevention storage.

PRZM (Pesticide Root Zone Model)

Description

The PRZM model simulates the vertical movement of pesticides in the unsaturated soil, within and below the plant root zone, and extending to the water table. It uses 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.

Uses and Applications

- 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.

Input Data

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

Output Available

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

Limitations

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

P8 Urban Catchment Model (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds)

Description

The P8 Urban Catchment Model was developed by the Narragansett Bay Project (Providence, Rhode Island). It is used to predict the generation and transport of stormwater-runoff pollutants in small urban watersheds (Walker, 1990). It incorporates the algorithms of existing stormwater-runoff models, such as HSPF, SWMM, DR3M, STORM and TR20. Runoff from impervious areas is calculated directly from rainfall once depression storage is exceeded. Particle build-up and wash-off processes are obtained using equations derived primarily from the SWMM program. The SCS curve number equation is used to predict runoff from pervious areas. Water balance calculates percolation from the pervious areas. Baseflow is simulated by a linear reservoir. Without calibration, use of model results should be limited to relative comparisons. This menu-driven computer program runs on IBM-compatible personal computers, and includes extensive user interfaces, such as on-line help and look-up tables for input parameters.

Uses and Applications

The P8 Urban Catchment Model can be used for:

- selecting and sizing BMPs.
- surface water quantity routing.
- small urban area assessments.
- watershed-scale land-use planning.
- site planning and evaluation for compliance.
- simplified watershed-scale pollutant generation and transport simulations.
- routing through control structures.

Input Data and/or Model Components

The following are input data and/or components needed to run the P8 Urban Catchment Model:

- time series meteorological data
- land area
- impervious fraction
- SCS curve number
- BMP characteristics
- device (hydraulic) parameters for pond, basin, buffer, pipe, splitter and aquifer
- depressional storage

Outputs Available

Outputs available from the P8 Urban Catchment Model include:

- water and mass balances, removal efficiencies, mean inflow/outflow concentrations and statistical summaries by device and component;

- comparison of flow, loads and concentration across devices;
- peak elevation and outflow ranges for each device;
- sediment accumulation rates by device; and
- violation frequencies for event mean concentrations.

Limitations

The P8 Urban Catchment Model has some limitations:

- No snowfall, snowmelt, or erosion is calculated.
- Effects of variations in vegetation type/cover on evapotranspiration are not considered.
- Watershed lag is not simulated.
- Quantitative analysis should be checked using another method.

Rational Method

Description

Approximates the peak flow that results from a given rainfall intensity and duration. Used widely around the world on small rural and urban drainage basins.

Use and Applications

The Rational Method should generally be used for watersheds that are smaller than 200 acres.

Input data and/or model components

Input data and/or model components for the Rational Method include:

- Q_P = CiA
- Q_P = peak flow rate (cfs)
- C = runoff coefficient for drainage area
- I = rainfall intensity (inches/hour)
- A = drainage area (acres).

Outputs Available

Specific results of the Rational Method are peak flow from solving the equation, although software exists that incorporates this method with routines providing more output options.

Limitations

- In practice, runoff coefficient is only related to type of terrain; however, in reality, it is also related to storm event frequency (intensity/duration).
- Assumes no temporary storage (basin or stream) within watershed.
- Published coefficients are valid only for two- to 10-year storm events.

SLAMM (Source Loading and Management Model)

Description

The Source Loading and Management Model (SLAMM) was originally developed to better understand the relationships between sources of urban runoff pollutants and runoff quality. It has been continually expanded since the late 1970s and now includes a wide variety of source area and outfall control practices (infiltration practices, wet detention ponds, porous pavement, street cleaning, catch basin cleaning and grass swales). SLAMM is strongly based on actual field observations, with minimal reliance on theoretical processes that have not been adequately documented or confirmed in the field. SLAMM is mostly used as a planning tool to better understand sources of urban-runoff pollutants and their control.

SLAMM has been used in many areas of North America and has been shown to accurately predict stormwater flows and pollutant characteristics for a broad range of rains, development characteristics and control practices. As with all stormwater models, SLAMM needs to be accurately calibrated and then tested as part of any stormwater-management effort.

SLAMM incorporates unique process descriptions to more accurately predict the sources of runoff pollutants and flows for the storms of most interest in stormwater-quality analyses. However, SLAMM can be effectively used in conjunction with drainage design models to incorporate the mutual benefits of water-quality controls on drainage design.

Uses and Applications

SLAMM can be used for:

- water-quality planning,
- site design,
- water-loss determinations,
- predicting runoff yields, and
- checking structure effectiveness.

Input Data and/or Model Components

Input data and model components for SLAMM include:

- rainfall characteristics,
- runoff characteristics,
- land use types by percentage, and
- stormwater-control practices.

Outputs Available

The outputs available from SLAMM include:

- particulate analysis,
- runoff yields,

- percentage of contribution by land use type,
- curve number calculation, and
- comparative structure effectiveness.

SWMM (Storm Water Management Model)

Description

The USEPA's Storm Water Management Model (SWMM) is a comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. Both single-event and continuous simulation can be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations. Extran Block solves complete dynamic flow routing equations (St. Venant equations) for accurate simulation of backwater, looped connections, surcharging and pressure flow.

Uses and Applications

SWMM can be used for both planning and design. The modeler can simulate all aspects of the urban hydrologic and quality cycles, including rainfall, snowmelt, surface and subsurface runoff, flow routing through drainage network, storage and treatment.

Input Data and/or Model Components

The SWMM-Windows interface was developed to assist the user in data input and model execution to make a complex model user friendly.

Outputs Available

Basic SWMM output consists of hydrographs and pollutographs (concentration vs. time) at any desired location in the drainage system. Depths and velocities are also available, as are summary statistics on surcharging, volumes, continuity and other quantity parameters. Additional quality output includes loads, source identification, continuity, residuals (*e.g.,* sludge) and other parameters.

Limitations

Technical limitations include lack of subsurface quality routing (a constant concentration is used), no interaction of quality processes (apart from adsorption), difficulty in simulation of wetlands quality processes (except as can be represented as storage processes), and a weak scour-deposition routine in the Transport Block. The biggest impediment to model usage is the user interface, with its lack of menus and graphical output. The model is still run in a batch mode (the user constructs an input file with an editor). Third-party software that can greatly facilitate pre- and post-processing is available.

Technical Release 20 (Computer Program for Project Formulation Hydrology)

Description

This model was developed by the USDA NRCS, formerly the SCS. The Technical Release 20 (TR20) model is used to simulate the runoff process from a watershed through the generation and routing of hydrographs through stream reaches and structures. The SCS hydrology methods described in *National Engineering Handbook* section 4 (NEH-4) are used. Without calibration, use of the model results should be limited to relative comparisons. The recent addition of an input program makes the model easier to use. TR20 can be used in conjunction with a water surface profile model, for determining the flood profile of a stream.

Uses and Applications

Uses and applications for the TR20 model include:

- watershed-scale planning,
- design of water-management structures,
- surface water quantity routing,
- hydrograph development, and
- structure routing and approximate sizing.

Input Data and/or Model Components

The input data and components of the TR20 model include:

- rainfall amount and time distribution,
- land use data and soils for developing a runoff curve number (RCN) for each subarea,
- time of concentration (Tc) for each subarea,
- stream reach length and typical cross section for reach-routing applications,
- structure stage/discharge/storage tables and
- antecedent moisture condition.

Outputs Available

Outputs available from the TR20 model include:

- peak discharge,
- runoff volume,
- hydrographs,
- estimated elevations and
- results of structure and stream-reach routings.

Limitations

- The TR20 model is a single-event model.
- Snowmelt inputs cannot be entered directly.
- Using the TR20 model requires an understanding of hydrologic processes.

- Three hundred time increments for hydrographs in the 1983 version (400 points in the newer version that is being developed).
- The initial abstraction assumptions may not be valid for watersheds with a high percentage of impervious area when rainfall amounts less than 1.5 inches are used.

Technical Release 55 (Urban Hydrology for Small Watersheds - Graphical Method)

Description

The graphical method in Technical Release 55 (TR55) is used to determine the peak discharge for a single storm event on a watershed. The method applies to an urban or a rural watershed or one in transition. The method uses NRCS hydrology as described in *National Engineering Handbook* section 4, “Hydrology” (NEH-4), and was developed from hydrograph analysis using Technical Release 20: Computer Program for Project Formulation–Hydrology. The procedure calculates the runoff curve number (RCN) and time of concentration (Tc) based on measured watershed parameters.

Uses and Applications

Uses and applications for the TR55 Graphical Method model are:

- small-scale watershed planning and
- comparison of “before” and “after” conditions for installation of structures or watershed-development actions.

Input Data and/or Model Components

Data to be input into the TR55 Graphical Method include:

- rainfall amount and choice of synthetic time distribution,
- land-use data and soils for developing a runoff curve number (RCN) for the watershed, and
- time of concentration using measured parameters or the lag equation.

Outputs Available

Outputs available from the TR55 Graphical Method model include:

- peak discharge and
- runoff volume in watershed inches.

Limitations

- TR55 Graphical Method is a single-event model.
- Use of TR55 is limited to watersheds of less than 2,000 acres.
- Only a single homogeneous watershed may be simulated.
- Time of concentration must be less than 10 hours.
- The initial abstraction assumptions may not be valid for watersheds with a high percentage of impervious area when rainfall amounts less than 1.5 inches are used.

Technical Release 55 (Urban Hydrology for Small Watersheds - Tabular Method)

Description

This method was also developed by the USDA NRCS (formerly the SCS). The tabular method in Technical Release 55 (TR55) is used to determine the peak discharge and an approximate hydrograph for a single-event storm on a single watershed. The method applies to an urban or a rural watershed or one in transition. The model uses SCS hydrology as described in National Engineering Handbook section 4, "Hydrology" (NEH-4). The program will calculate the runoff curve number (RCN) and time of concentration (Tc) based on watershed parameters that are measured and entered into the program.

Uses and Applications

Uses and applications for the TR55 Tabular Method include:

- small-scale watershed planning,
- comparison of "before" and "after" conditions for installation of structures or watershed-development actions, and
- simple hydrograph development (limited detail).

Input Data and/or Model Components

Input data for the TR55 Tabular Method include:

- rainfall amount and choice of synthetic time distribution,
- land use data and soils for developing a RCN for each subarea,
- time of concentration using measured parameters or the lag equation for each subarea, and
- travel times through subareas.

Outputs Available

Outputs available from the TR55 Tabular Method include:

- peak discharge for each subarea,
- runoff volume in watershed inches, and
- simple hydrograph.

Limitations

The TR55 Tabular Method has the following limitations:

- TR55 Tabular Method is a single-event model.
- Watersheds must be less than 2,000 acres in size.
- Watershed subareas must be hydrologically homogeneous.
- Ten subacres or less
- Time of concentration less than two hours in each subarea
- Travel time of three hours or less in each subarea
- The initial abstraction assumptions may not be valid for watersheds with a high percentage of impervious area when rainfall amounts less than 1.5 inches are used.