

Modeling Nitrogen Transport with the ANSWERS Model

by

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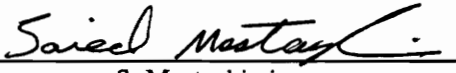
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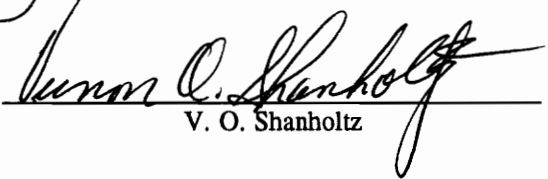
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(ABSTRACT)

Nonpoint source pollution from cropland has been identified as the primary source of nitrogen and sediment, and a significant source of phosphorus in the Chesapeake Bay. These pollutants, whether from point or nonpoint sources, have been found to be the primary cause of declining water quality in the Bay. Numerous studies have indicated that, for many watersheds, a few critical areas are responsible for a disproportionate amount of the nutrient and sediment yield. Consequently, if pollution control activities are concentrated in these critical areas, then a far greater improvement in downstream water quality can be expected with limited funds.

In this research a nitrogen transport model is incorporated into ANSWERS, a distributed parameter watershed model. The nitrogen model simulates nitrogen transformations of applied fertilizer and soil nitrogen in the soil. Dissolved nitrogen transport in surface runoff is modeled by assuming complete mixing of the soil surface layer and surface runoff. Sediment-bound nitrogen transport is modeled as a function of the clay content of transported sediment.

The extended ANSWERS model was verified using water quality data from rainfall simulator plot studies conducted on the Prices Fork Research Farm in Blacksburg, Virginia. The four plots were 5.5 m wide by 18.3 m long with average slopes ranging from 6.2 to 11 percent. Two of the plots were tilled conventionally, and two were no-till. Simulated rainfall at an intensity of 5 cm/h was applied to the plots and runoff samples were analyzed for sediment and nitrogen. The model was then verified by comparing the simulated response with the observed data. The model predicted sediment-bound nitrogen losses within a factor of two. The model tended to overpredict dissolved nitrogen losses by a factor of five. The model shows potential as a best management practice planning tool, however, further verification of model predictions versus observed data is required.

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INTRODUCTION

The growth in agriculture, industry, and population in the Chesapeake Bay drainage basin has led to a decline in the Bay's water quality. A 1983 congressionally-mandated study by the Environmental Protection Agency (EPA) identified excess nutrients, sediment, and elevated levels of toxic substances as the primary reasons for this decline (USEPA, 1983). Of particular concern are the loadings of nutrients to the Bay, which result in excess algal growth and a subsequent reduction in oxygen and sunlight reaching the water's plant and animal life. Estimates from EPA's Chesapeake Bay Model indicate that 77% of the nitrogen (N) and 66% of the phosphorus (P) entering the Bay originate from nonpoint sources (USEPA, 1992).

The diffuse nature of nonpoint source (NPS) pollution makes it difficult to control and not readily amenable to "end-of-pipe" treatment as point sources are. Typical sources of NPS pollution include: surface runoff and subsurface flow from agriculture areas, urban runoff, septic tank effluents, and runoff from forestry operations. Recent estimates of the agricultural contribution to the NPS nutrient load entering the Bay are 52% and 76% of the N and P, respectively (USEPA, 1992). Agricultural sources in general are not significant nutrient sources on a per hectre basis, but because of the large areas involved, the total loadings are highly significant. Numerous studies have shown that for many watersheds, a few critical source areas are responsible for a disproportionate amount of the nutrient and sediment yield. Given the limited resources available for pollution control activities, such as cost-sharing for Best Management Practices (BMPs), it is essential that these critical areas be targeted to obtain the maximum improvement possible in the water quality with each investment of time and money.

One manner in which to accomplish targeting is the use of comprehensive watershed models in water quality planning. Such models can be utilized in estimating reductions in nutrient loadings to receiving

waters due to changes in land management. One such model, ANSWERS, has been designed to identify and evaluate potentially critical sources of sediment and P on a watershed scale.

Objectives

The overall goal of this study was to incorporate a N transport model into the ANSWERS model. The nitrogen transport in surface runoff model presented in this research is an extension of the work of Huggins and Monke (1966), Beasley (1977), Dillaha (1981), and Storm (1987). Specific objectives of this research were to:

1. Develop a process oriented N transport model for describing N movement in surface runoff from agricultural areas. This will include a mechanism to account for N transformations in the soil prior to the storm event.
2. Validate the new model using data from experimental plot studies.
3. Test the sensitivity of the model to variations in input parameters that impact N transport processes.

LITERATURE REVIEW

Nitrogen in the Soil

Forms and Distribution of Soil Nitrogen

One of the main difficulties in working with N in the soil-water matrix is the numerous forms in which N can occur. The predominate forms of N in the environment are nitrate, nitrite, ammonium, and organic N. The occurrence of these four types of N is very interrelated and their relative distribution in the soil is dependent on a variety of factors including: temperature, moisture content, soil type, cultivation practice, and microorganism population. As these factors change with time, so does the balance that exists between the forms of N. This balance also changes with depth in the soil profile. However, since this study is concerned primarily with the surface zone, the information that follows pertains primarily to the upper few cm of the soil profile.

Nitrate and nitrite occur as dissolved forms of N in the soil water. Nitrite is generally disregarded since under most conditions it is rapidly converted to nitrate. Only in a saturated soil where anaerobic conditions exist will nitrite accumulate (Schmidt, 1982). Levels of nitrate in a soil generally cycle during the year. Quantities of nitrate in the surface layers of a typical soil in a temperate climate humid area are lowest in winter, increase in spring as mineralization of organic matter occurs, decrease slightly during summer due to plant consumption, and peak during the fall as plant residues begin to decay (Young and Aldag, 1982). The high mobility of nitrate allows its movement via overland flow and percolation. High

levels of leaching often occur during the winter months because of increased precipitation and reduced evapotranspiration and plant uptake. A study by Bandel et al. (1975) showed that most of the residual nitrate remaining at harvest in the top fifteen centimeters of the soil profile was lost before the next crop in areas with high winter rainfall.

Ammonium is found in the soil in several different configurations. It can be dissolved and found in the soil-water, adsorbed to the surface of soil particles, or held in the lattice structures of silicate minerals. Ammonium entrapped in the lattice of clay minerals is referred to as "fixed ammonium" and is nonexchangeable. This means that it resists removal from soil that is flushed with neutral salt solutions typically used for extracting exchangeable ions (Young and Aldag, 1982). Fixation of ammonium occurs when interlayer cations (sodium, calcium, magnesium) of certain clay minerals are replaced by ammonium ions (Freney, 1964). Ammonium that is fixed in this way is not available for plant uptake.

Ammonium in solution and in the adsorbed phase are available to higher plants and are very significant agronomically. A dynamic equilibrium exists between the ammonium in solution and that attached to the soil particles. Their relative concentrations are determined by chemical mass action laws. Experiments by Preul and Schroepfer (1968) have shown that the equilibrium between ammonium in solution and adsorbed ammonium is established very slowly even under conditions of vigorous agitation such as might occur during rainfall or runoff. Ammonium found in the soil in this configuration is known as exchangeable ammonium. The cationic nature of ammonium that allows it to bind to soil colloids protects it from being leached from the soil by percolating waters. Only in soils with low cation exchange capacities, such as those with high sand content, will losses of ammonium by leaching be significant (Nommik and Vahtras, 1982).

Only a very small percentage of the total N in soils exists in readily available mineral forms (nitrate and exchangeable ammonium). In most soils the amount of fixed ammonium greatly exceeds these other forms. For agricultural soils the quantity of fixed ammonium ranges loosely from three to ten percent of the total N in the plow layer (Young and Aldag, 1982). In a study by Smith and Young (1975) the proportion of nonexchangeable ammonium in surface soils was in the range 6.6 to 10.9 percent. The lower values of fixed ammonium were found in virgin soils and the higher percentages corresponded to those under cultivation. This suggests that cultivation of virgin soils can lead to changes in the distribution of

the inorganic N fraction of the soil. It is interesting to note that the percentage of total N occurring as fixed ammonium is much higher in the subsoil and can be as high as fifty percent (Nommik and Vahtras, 1982).

Organic N accounts for 90% or more of the total N found in the surface layer of most soils. The organic N is associated with the colloidal fraction of the soil which includes clay and humus (Stevenson, 1982). Climate is the most important factor in determining the total organic N content of a soil (Jenny, 1930). Type of vegetation and soil texture also directly affect organic N content. Nitrogen content will generally increase as the texture becomes finer. This is in part due to the fact that finer soils contain more clay and it has been shown that clay minerals help stabilize organic N compounds (Bremner, 1965).

Tillage method also plays a part in organic N content. Soils under conventional tillage will have lower organic N contents than those under no tillage farming. In a study by Stanford et al. (1974) over a ten year period, organic N contents increased more with mulch tillage than when the cover crop was plowed under or no cover crop was used at all. Bennett et al. (1975) found organic N contents about 40% higher on untilled grass sod plots than on plowed plots after one season.

Transformations of Soil Nitrogen

The transformations of N in the soil from one form to another occurs in a continuous cycle as shown in Figure 1. The cycle begins with the conversion of organic forms of N to ammonium, which is referred to as mineralization. The process is performed by heterotrophic organisms that utilize organic compounds as energy sources. The subsequent oxidation of ammonium to nitrate is termed nitrification. The process of converting inorganic forms of N into organic compounds is called immobilization and is basically the opposite of mineralization. This occurs as soil organisms assimilate inorganic nitrogen into their cell walls and tissues (Jansson and Persson, 1982). Both of these processes occur simultaneously in the soil and are very difficult to separate in the laboratory. Therefore, in research experiments, net mineralization, the resultant of concurrent mineralization and immobilization, is commonly measured (Stanford, 1976). Inorganic N can also be transformed into gaseous forms and lost to the atmosphere through denitrification.

This cycle is completed by N being returned to the soil through fixation of gaseous N into organic compounds and by organic and inorganic N in precipitation, commercial fertilizers, and animal wastes.

The rate of soil N mineralization is highly affected by soil temperature and water content. The optimum soil water content for nitrogen mineralization occurs in the range of 0.1 to 0.3 bar of matric suction. This range encompasses the soil water content defined as "field capacity" and corresponds to 80-90% of the total pore space being filled with water (Stanford and Epstein, 1974). Temperature is important in mineralization because chemical and biological reaction rates increase as temperature increases. Typically, biological reaction rates will double with each 10°C rise in temperature (Donigian and Davis, 1976). The rate of mineralization has considerable impact on the amount of inorganic N that is available for plant uptake or subject to leaching.

Normally about 2-3% of the total organic N in the surface layer of a soil is mineralized each year (Stanford, 1976). A study by Stanford et al. (1973) showed that under the same temperature and moisture conditions, mineralization rates did not differ significantly among most of the soils that they tested. This suggests that the forms of organic N contributing to N mineralization and the transformations that they are undergoing do not differ appreciably among soils.

The process whereby ammonium is oxidized to nitrate is referred to as nitrification. Nitrification is brought about by certain special purpose bacteria in two coordinated steps. The first step consists of ammonium being oxidized to nitrite. The nitrite is then oxidized again to form nitrate. The second oxidation is much more rapid than the first so that very little nitrite accumulates. This is fortunate since nitrite is toxic to higher plants and animals. Overall, the nitrification process is very quick. Aeration of the soil is very important in nitrification since it is an oxidation process. With good aeration and normal temperatures, almost complete conversion of ammonium to nitrate occurs. Nitrification is also dependent on temperature, with the optimum being from 25 to 32°C. Nitrification will cease below freezing or at temperatures above 45°C (Brady, 1974).

Denitrification is the microbial reduction of nitrate or nitrite to gaseous N. It is favored in wet, poorly aerated soils, with an available carbon supply. It is possible that denitrification may occur to some small degree in well aerated soils in anaerobic microsites (Broadbent and Clark, 1965). Most studies, however, record very low losses of gaseous N from unsaturated surface soils (Volz et al., 1975).

Potentially Mineralizable N

Soil contains various forms of organic N that differ in their susceptibility to mineralization. It is postulated that only a small, active fraction of soil organic N is involved in mineralization-immobilization activities. The majority of the soil N remains resistant to microbial attack. The fraction of the organic N that is subject to decomposition is referred to as the N mineralization potential, N_o , of the soil.

In a study by Stanford and Smith (1971), N_o of 39 soils were determined and compared. The fraction of total organic N comprising N_o varied widely among the soils from a low of 5% to a high of 40%. Cropping and fertilization practices seemed to have some influence on the proportion of total N available for mineralization. Several soils that had been subjected to intensive cropping with little or no fertilizer applied were among those with lower fractions of total N as N_o . Soils with corn in rotation with fescue-clover had considerably higher percentages of potentially mineralizable N than did those with continuous corn. In a related study, Bennett et al. (1975) found that values of N_o in the surface layer were considerably higher for untilled than for plowed soils. Similarly, Smith and Young (1974) found an average decrease in N_o of 43% in soils under cultivation compared to virgin soils.

Nitrogen and Nonpoint Source Pollution

Nitrogen and phosphorous have been identified as the principal pollutants in eutrophic aquatic ecosystems. Two problems associated with nutrients in the aquatic environment are: toxicity of the water to humans, animals, or fish and eutrophication (Frere, 1976). The nitrite form of N is extremely toxic and interferes with oxygen transport in the blood of mammals. Infants are especially susceptible to this illness known as methemoglobinemia. Nitrate is not toxic but can be converted to nitrite in the stomachs of young animals and infants. Eutrophication is the enrichment of waters by nutrients and the subsequent accelerated growth of plants. Excess plant growth, particularly algal blooms, increase the turbidity of water and

can cause oxygen shortages when the algae cells die and decay. Frere (1976) lists three transport processes by which nutrients from cropland reach streams and lakes: leaching, runoff, and erosion. He suggests various nutrient management practices such as eliminating excessive fertilization and timing fertilizer applications as ways to limit nutrient runoff.

Any discussion of nonpoint source pollution must include hydrology since water is its primary medium of transport. D. A. Woolhiser (1976) discusses the hydrologic aspects of NPS pollution and describes the modes of transport of nutrients by surface runoff. There are four transport mechanisms:

- 1) Turbulent transport of the dissolved chemical from the soil into the overland flow.
- 2) Desorption of the chemical from soil particles into the flow.
- 3) Dissolution of stationary particulate matter at the soil-flow boundary.
- 4) Scouring of particulate matter and its subsequent transport.

All of these result in the loss of N from cropland. Woolhiser (1976) includes a description of eighteen practices for controlling direct runoff and subsequently lessening chemical losses. These practices include no-till farming, contouring, terracing, and grassed outlets, among others.

Loss of sediment from cropland in storm runoff is important in NPS pollution because a large percentage of the nutrients is carried directly by soil particles. Erosion is a selective process in both a physical and chemical sense. The smallest and least dense particles are usually the particles most easily transported. These small fines and organic particles also carry the majority of the sediment-bound chemicals. This relationship between chemical content, small particles, and erosion often causes eroded sediment to have very different chemical characteristics relative to its parent soil (Young et al., 1984). This phenomenon is known as enrichment and becomes very important in modeling N losses from agricultural lands. An enrichment ratio is defined as the chemical content of sediment leaving an area divided by the concentration of that chemical in the original soil mass. Using simulated rainstorms, Young et al. (1984) found that enrichment ratios tend to be greatest in the North and least in the South due to soil mineralogy differences. Enrichment ratios also tend to be higher with less severe hydrologic events and move toward a value of one for severe storms. Reported values of enrichment ratios are usually in the range of two to four (Novotny and Chesters, 1981).

The timing and magnitude of individual storms has a large impact on how much they contribute to nonpoint pollution. Runoff from storms that occur directly after fertilizer application is often high in nitrate (Kissel et al., 1976). In a five year study, Owen et al. (1984) reported that seventy-five of the storms that exceeded the recommended nitrate standard of 10 mg/L occurred within thirty days of fertilizer application. Only ten events had concentrations in excess of 30 mg/L and all occurred within seventeen days of fertilizer application. These were all large storms and the first precipitation event after fertilizer application. Large events also cause more erosion and therefore more sediment-bound nutrients are lost. Especially large events, such as major floods, may also have very long-term effects because of the recycling of sediment-bound chemicals in the benthic sediments of receiving waters.

Factors Affecting Nitrogen Losses

Numerous factors influence the amount of N lost from cropland: tillage method, cover crop, and type of fertilizer used, to name a few. The following section summarizes some of the research completed in this area.

Moe et al. (1968) studied N losses in surface runoff from plots fertilized with urea and ammonium nitrate. Rainfall was simulated at intervals of one and five days after fertilizer application. For the one day interval, total N loss was twice as high for the plots treated with ammonium. The reason for this was that although ammonium losses were about equal for both types of applications, there was almost no nitrate loss from the urea plots. The results for the five day interval were similar to those for the one day interval except that nitrate losses increased on the urea plots to about one-third of the nitrate losses on the ammonium plots.

Placement of fertilizer can also effect N losses in surface runoff. Timmons et al. (1973) measured N losses in runoff on several plots with fertilizer deeply incorporated by plowing and others with the fertilizer disked in or just broadcast on a disked surface. As expected, the losses were smallest when the

fertilizer was deeply incorporated. The effect of the different applications on N losses through leaching were not reported.

Romkens et al. (1973) compared the effects of five tillage-planting systems on N losses in runoff. The five systems examined were coulters-plant, till-plant, chisel-plant, disk-plant, and conventional-plant. The losses of dissolved N from surface applied fertilizer was highest for the coulters system, with the other systems ranking in order: till > chisel > disk > conventional. As might be expected, the conventional tillage system had the highest sediment-bound N losses. Conventional till was followed in successive order by the till > disk > coulters > chisel system for sediment N. Barisas et al. (1976) did a similar study with the same five tillage systems and a ridge plant system. He found that the efficiencies of each system in terms of N loss was somewhat dependent on soil type. Chisel and coulters tillage were again found to be among the highest for dissolved N loss. However, in this study, the till system had the lowest for dissolved N loss. The results for sediment-bound N were similar.

Klausner et al. (1974) investigated the surface runoff losses of dissolved N under two systems of soil management. He found that time of N fertilization was very important in this respect. Heavy fall fertilization on a poorly managed soil led to very high nitrate and ammonium losses. In general, he suggested that excessive fertilization prior to wet seasons be avoided if possible to minimize losses.

Busch et al. (1975) studied the effects of nine factors on the loss of nitrogen from tracts of irrigated land. Nitrogen in runoff and drainage were both considered. A stepwise regression analysis was performed to select and evaluate the variables which affected the amounts of nutrients lost in the surface runoff. Nitrate losses were found to be highly correlated with three factors: amount of runoff, the amount of applied water retained on the field, and average daily air temperature. Other forms of N were correlated most highly with the amount of total solids in the runoff.

Soil cover and season also have considerable influence on nutrient losses. Burwell et al. (1975) measured runoff losses for five soil cover conditions over a two year period. Of the five cases, continuous corn was the worst with the majority of the losses occurring immediately after snow melt and for the first two months after planting. The use of corn in rotation with wheat as a soil cover cut N losses in half. In fields where hay was the cover, minimal N losses were reported.

Hoyt et al. (1977) investigated the effects of soil, cover crop, and nutrient source on the movement of N under simulated rain conditions. They found an inverse relationship between runoff and leachate. Their study also showed that crop type had little effect on nitrate lost in runoff and leachate.

Neilson and MacKenzie (1977) monitored seven watersheds in Eastern Canada for dissolved and sediment-bound N losses. They found a high correlation between high dissolved N losses and the percentage of watershed occupied by corn and hydrologic C soils. Since the areas in corn and that consisting of class C soils were not independent, it could not be determined if the crop or the soil type had the greater effect. Their study showed that 56 to 100% of the annual dissolved N losses occurred during spring runoff. Their data also showed that dissolved inorganic N concentrations were above potential eutrophication levels for most sites.

Some studies on N losses have shown that the dissolved nutrient concentrations in runoff are higher for conservation tillage systems. Baker and Laflen (1979) investigated this effect by varying the amounts of corn residue on the soil surface of twenty-four runoff plots. Their results showed that the amount of residue had very little effect on increasing the nutrient concentrations in the runoff and was therefore not responsible for the higher concentrations of dissolved N leaving conservation tillage areas. They concluded that the increase was instead the result of reduced incorporation of fertilizer with conservation practices.

Johnson et al. (1979) studied six small watersheds to compare the effects of tillage on sediment and nutrients in runoff. Two conservation tillage systems, ridge-planting and till-planting, were compared with a conventional tillage system. As expected the conventional tillage system had much higher N losses. In the conventional tillage system 99% of the N lost was associated with the sediment as compared to 75% with the conservation till systems. In this study, conservation tillage did not affect nitrate concentrations in the runoff water. Angle et al. (1984) obtained similar results on no-till and conventional till watersheds over a three year period. Total N losses were generally very low in their study. For the year 1982, the total N losses for the conventional till area were twenty-nine times those on the no-till watershed.

Beaulac and Reckhow (1982) examined nutrient export relationships according to land use. They concluded that nutrient loading from forest land was low and relatively homostatic. Nutrient export for pastures was not significantly different from undisturbed forest especially if rotational grazing was used.

On the other hand, agricultural and urban watersheds were found to have high nutrient losses with a high range of variability, which makes prediction of nutrient loading factors more difficult.

Lafren and Tabatabai (1984) found that incorporation of fertilizer played a major role in dissolved N losses in a study comparing three tillage practices. Their results showed that when nutrients were not incorporated, the nutrient concentrations in runoff are increased substantially. This is a probable explanation for the higher observed dissolved N concentrations in runoff from conservation tillage watersheds.

McLeod and Hegg (1984) studied the environmental impact of the land application of organic wastes as compared to commercial fertilizer. Their results showed that the levels of ammonium and nitrate lost in the surface runoff were much higher for plots where commercial fertilizer was applied. This effect lasted for about seven days after fertilizer application at which point the losses became about equal. The overall losses of N for this study were low in all cases.

Depth of Rainfall-Soil Interaction

The transport of agricultural chemicals with storm runoff is a complicated process. It is recognized that a thin zone of soil at the surface interacts with rainfall and overland flow, however, there is a lack of knowledge as to the depth and dynamics of this zone. In the chemical transport model ARM, Donigian et al. (1977) determined the depth of interaction by model calibration with experimental data and found values ranging from 0.2-0.6 cm. Frere et al. (1980) set the depth as 1.0 cm.

The concept of a certain thickness of soil having a uniform interaction with the overland flow is technically not accurate. The degree of interaction is at a maximum right at the soil surface and decreases with depth. Ahuja et al. (1981) found in experiments using phosphorous that the amount of interaction decreased exponentially with depth and was negligible below 1.5 cm. The assumption of an effective depth of interaction, EDI, such that all of the soil above an assumed depth has the same degree of interaction with rainfall and runoff as does the soil surface is necessary for practical purposes. An EDI is

chosen so that the total interaction is the same for the real case. In his study, Ahuja et al. (1981) found that the EDI ranged from 0.2 to 0.3 cm and depended very little on soil type.

In a further study, Ahuja and Lehman (1983) investigated effective depth of interaction using a nonadsorbed chemical, bromide. They found that with a soluble chemical, the depth of interaction changed not only with depth but also very quickly with time and that bromide from as deep as 2.0 centimeters was lost to runoff. They suggested that soluble chemicals were transferred to the soil surface by a pumping action due to rainfall impact in an accelerated-diffusion process. This pumping action was postulated to be especially important under restricted infiltration conditions such as in clay-pan soils or wet areas in a watershed. In the same study, a direct correlation between the release of the chemical to runoff and hydraulic conductivity was noted. Release increased with infiltration rate indicating an expanded depth of mixing due to greater hydraulic conductivity. It should be noted that although EDI varies with time, the initial high concentrations in runoff will be predicted with less relative error than the low concentrations later in a storm event. This is important from a modeling perspective.

A study by Sharpley (1985) compared EDI under different rainfall intensities, soil slopes and crop managements. Using phosphorous he found that EDI increased with increasing rainfall intensity and slope because of more turbulent mixing in the zone of interaction. The effective depth of interaction decreased with increased crop residue and soil cover because of reduced raindrop impact and a lowering of runoff energy. Sharpley (1985) also found that EDI was a function of soil aggregation. The greater stability of soil structure in well aggregated soils led to a greater EDI. The likelihood of surface sealing due to raindrop impact and a corresponding reduction in EDI is greater in poorly aggregated soils. He used this data to develop an equation for determining EDI from the degree of soil aggregation and soil loss, which also correlated well with depth of interaction. It is given as:

$$\ln \text{EDI} = -3.130 + 0.071 (\text{soil aggregation}) + 0.576 \ln(\text{soil loss}) \quad [1]$$

where EDI is in millimeters, soil loss is in kg/ha, and the degree of soil aggregation is unitless. In this equation, soil loss establishes the slope of a logarithmic relationship with EDI and the degree of soil aggregation establishes the intercept. Sharpley (1985) points out that under normal conditions EDI will vary over a watershed.

Review of Selected Nutrient Models

ACTMO

One of the first models to predict nutrient movement in surface runoff was the Agricultural Chemical Transport Model (ACTMO) (Frere et al., 1973). It was designed to trace a single application of one chemical over a watershed. The hydrologic components of the model were based on the USDA Hydrograph Lab model. Erosion and sediment transport processes were modeled using a modification of the USLE. The concentration of dissolved nutrients in runoff was calculated using simple chromatographic theory. Sediment-bound nutrient loss was estimated using enrichment ratios. Overall the model was very basic and much less sophisticated than later models.

ARM

The Agricultural Runoff Management (ARM) model (Davis and Donigian, 1979; Donigian and Davis, 1978; Donigian et al., 1977; Donigian, 1976) simulates runoff, sediment, pesticides, and nutrient loadings into stream channels from surface and subsurface sources. The model simulates surface runoff, interflow, and groundwater flow using a modified version of the Stanford Watershed Model (Crawford and Linsley, 1966) and can be driven by either rainfall or snow melt. The erosion processes of particle detachment and transport in overland flow are simulated using equations based on research by Negev (1967). The model is applicable only to watersheds with uniform cropping and management practices. Watershed size is also limited to areas where channel erosion processes are negligible since no channel routing procedures are included. Donigian and Davis (1978) suggest that watersheds greater than 200 to 500 hectare are approaching the upper limit of applicability of the ARM model. Calibration of the model using three to five years of historical records is also suggested as a means for making accurate simulations.

Nitrogen transformations in the ARM model include immobilization, mineralization, nitrification, and adsorption-desorption. These processes are simulated by assuming first-order reactions. The model simulates nutrient transport using the concept of potency factors which are similar to enrichment ratios. Donigian et al. (1977) acknowledge that sediment-associated forms of nutrients are better simulated with the ARM model than are dissolved forms. It was also found that monthly predictions of losses of nitrogen in runoff were much more satisfactory than single storm event simulations.

CREAMS

The Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980) is a daily simulation model that estimates runoff, sediment transport, nitrogen and phosphorous losses, and pesticide yield from field-sized areas. A field is defined as a management unit having a single land use, homogeneous soils, and a single management practice. CREAMS cannot therefore be applied to larger nonhomogeneous areas, such as watersheds. The model has two hydrologic options whose use depends on the availability of input data. If hourly rainfall is available, an infiltration-based model is used to simulate runoff, but if only daily rainfall data is available, an SCS curve number model is used. Erosion is modeled using elements of the USLE and includes sediment transport capacity for overland flow.

CREAMS considers both sediment-bound and dissolved N in runoff. The amount of dissolved N in runoff is calculated by assuming complete mixing in the top centimeter of the soil profile and using empirical extraction coefficients to determine how much N moves into overland flow and infiltrating waters. The amount of sediment-bound N lost is estimated using an enrichment ratio. The N component of the model also considers mineralization, nitrification, and denitrification that occurs before and after the rainfall event.

GLEAMS

The Groundwater Loading Effects of Agricultural Management Systems Model (GLEAMS) (Leonard, et al., 1987) was developed to consider the vertical movement of pesticides in and through the root zone on a field scale. Its basic hydrology and erosion components are the same as those used in CREAMS (Knisel, 1980). Components have been added in GLEAMS to better represent important management systems, such as legumes in rotation and land application of animal waste. The GLEAMS model uses a layered soil structure for better simulation of pesticide and plant nutrient cycling and transformation. Nitrogen mineralization is considered a two-stage process in GLEAMS for improved prediction of ammonia volatilization in surface applied waste. Nitrogen uptake in plants is patterned after that in the EPIC model (Sharpley and Williams, 1990).

AGNPS

The Agricultural Non-Point Source Pollution Model (AGNPS) was developed by USDA-ARS to simulate sediment and nutrient export from agricultural watersheds (Young et al., 1989). AGNPS is a distributed parameter, single event-based model that can be applied to watersheds up to 10,000 ha in size.

The basic components of the AGNPS model are: hydrology, erosion, sediment transport, nitrogen and phosphorous transport, and chemical oxygen demand. Runoff volume from each cell in the model is estimated using the Soil Conservation Service curve number technique, and peak runoff is determined using a procedure developed by Smith and Williams for the CREAMS model. Total upland erosion is calculated in the model using the modified universal soil loss equation (USLE). Sediment routing in the model occurs in five particle size classes and includes mechanisms for channel erosion. In the AGNPS model both dissolved and sediment-bound forms of N and P are predicted using procedures found in the CREAMS model (Frere et al., 1982).

The flexibility of the AGNPS model allows estimation of pollutant loads from feedlots, analysis of the effects of implementing various conservation practices, and the ability to output water-quality characteristics at several points in the watershed including the outlet (Young et al., 1987).

HSPF

The Hydrologic Simulation Program Fortran (HSPF) is a continuous simulation model developed for the U.S. Environmental Protection Agency by Hydrocomp Inc., (Johanson et al., 1981; Decoursey, 1985). It is a modification of the Stanford Watershed Model (Crawford and Linsley, 1966) and uses many of the same nutrient transport algorithms developed for ARM (Davis and Donigian, 1979; Donigian and Davis, 1978; Donigian et al., 1977; Donigian, 1976). The model simulates hydrology, erosion, nutrient, pesticide, pH, dissolved oxygen, organic matter, temperature, salt, bacteria, and plankton movement in the surface and groundwater. Routing and in-stream transformation processes are included in the model. HSPF also provides a flexible means of estimating the impacts of a wide range of nonpoint source BMPs.

HSPF is a very complex model and requires substantial calibration. Many of its hydrologic components are empirically based and several years of recored data are required to establish values for the input parameters. Calibration of the HSPF model is time consuming and formal training with the model is recommended before use. The detailed nature of the HSPF model allowed it to be used as the basis for the Chesapeake Bay Watershed Model (USEPA, 1989).

The ANSWERS Model

Model Description

ANSWERS (Areal Nonpoint Source Watershed Environmental Response Simulation) is a distributed parameter, deterministic, watershed model developed by Purdue University (Beasley, 1977) to simulate the hydrologic and erosion response of watersheds having agriculture as their primary land use. The basic hydrologic model was developed by Huggins and Monke (1966) and includes interception, infiltration, surface storage, interflow, and surface runoff. The model was expanded by Beasley (1977) to include erosion, sediment transport, tile drainage, and channel flow. Dillaha (1981) expanded the sediment transport processes in ANSWERS to simulate the transport of individual particle classes in a sediment mixture during surface runoff. A phosphorous transport component was incorporated into the model by Storm (1987).

ANSWERS can be used as a planning tool for evaluating the benefits of various BMP scenarios for reducing the loss of sediment and nutrients from agricultural lands. Structural BMPs that can be modeled in ANSWERS include ponds, grass waterways, and tile-outlet terraces. Like many distributed parameter watershed models, ANSWERS can be used to identify critical areas that contribute a disproportionate amount of the nonpoint source pollution from a watershed. Various management scenarios can then be simulated to analyze their impact and cost effectiveness.

A watershed being modeled with ANSWERS is assumed to be composed of a grid of square elements. An element is defined as an area within which all hydrologically significant parameters are uniform. The component processes within the model therefore need only to simulate water and pollutant production for small, uniform elements. The output from each element in surface flow, flow in tile drains, and interflow is then routed to its downslope, adjacent elements and eventually to the watershed outlet.

The distributed nature of the ANSWERS model is both its strength and its limiting factor. The time required for preparation of input files increases with the number of elements in a simulated watershed.

In modeling large watersheds a balance must be achieved between time constraints and maintaining an element size such that elemental areas are hydrologically homogeneous. The use of larger elements often results in a decrease in the quality of the simulation. Additional detail concerning the use of the ANSWERS model and its component processes is given by Beasley (1977), Beasley et al. (1980), and Beasley and Huggins (1980).

Modeling Nitrogen Transport

Nitrogen Transformations

There is a great deal of literature concerning mathematical equations and models that deal with nitrogen transformations in the soil. Many of these equations describe a single process, such as mineralization, while others link together several processes and consider them simultaneously. Some of these equations are used as subroutines in larger more comprehensive simulation models.

One of the earliest models of soil N transformations was reported by Dutt et al. (1970). The N transformations considered were urea hydrolysis, nitrification, net mineralization, and immobilization of nitrate. These coupled equations were the result of carrying out multiple regressions on experimental data from incubation studies and are included in Table 1. The assumptions upon which the model was built include a soil pH in the range of 7.0 to 8.5, no fixation of ammonium to clay particles in the soil, and minimal denitrification losses.

Mehran and Tanji (1974) assumed first-order kinetics for all nitrogen transformations in their model. A diagram of the pathways of N transformations considered in the model is shown in Figure 2. The coupled mathematical equations for all of the N species are given in Table 2. The model includes equations to account for plant uptake of the available N forms and also ammonium exchange.

Table 1. Model for soil-N transformations given by Dutt et al. (1970).

$$\text{Urea hydrolysis rate} = 413 - \log_{10}T - 153 \log_{10}(\text{Urea} - \text{N}) \quad [3]$$

$$\begin{aligned} \text{Mineralization - immobilization rate} = & 0.892 + 0.00216T + 0.027(\text{Org} - \text{N}) \\ & + 0.392 \log_{10}(\text{NH}_4^+) \end{aligned} \quad [4]$$

$$\text{Nitrification rate} = 4.64 + 0.00162T(\text{NH}_4^+) + 0.00162 \log_{10}(\text{NH}_4^+) - 2.51 \log_{10}(\text{NO}_3^-) \quad [5]$$

$$\begin{aligned} \text{Nitrate immobilization rate} = & 0.049 + (1.52T)/(\text{Org} - \text{N})^2 + 3.23 \times 10^{-15} \exp(T) \\ & - [0.0049T(\text{Org} - \text{N}) - (\text{NO}_3^-)]/(\text{Org} - \text{N}) \end{aligned} \quad [6]$$

Rates are in units of ppm/day for the N species involved, concentrations of N species on the right hand side of the equations are in $\mu\text{g/g}$ soil, and T is in $^{\circ}\text{C}$.

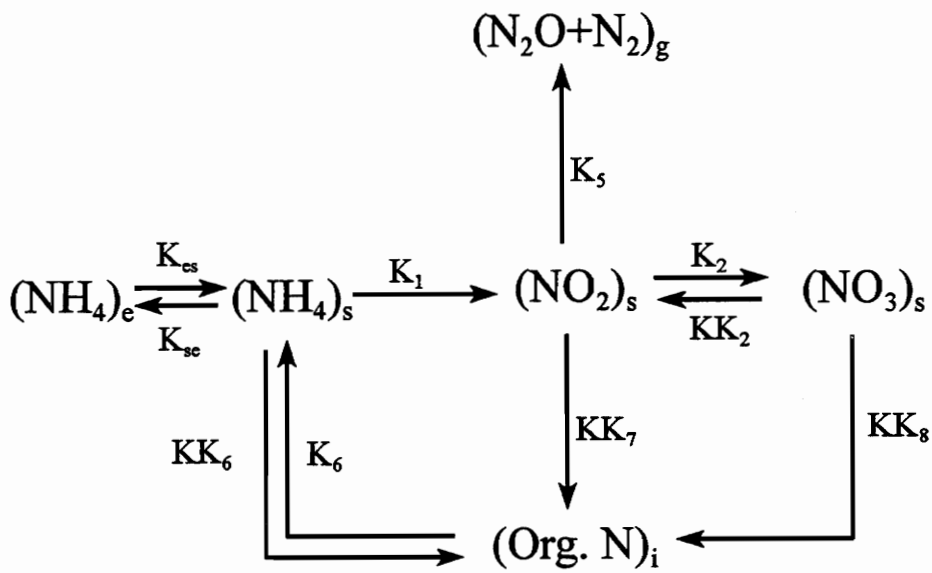


Figure 2. Transformations of soil nitrogen: Subscripts K and KK denote rate constants, while subscripts, e, s, i, and g, respectively refer to exchangeable, solution, immobilized, and gaseous phases.

Table 2. Mathematical model in the coupled form for N transformations (Mehran and Tanji, 1974).

$$\text{Exchangeable NH}_4: \frac{d[\text{NH}_4]_e}{dt} = -K_{es}[\text{NH}_4]_e + K_{se}[\text{NH}_4]_s \quad [7]$$

$$\text{Solution NH}_4: \frac{d[\text{NH}_4]_s}{dt} = - (K_1 + K_{se} + KK_6)[\text{NH}_4]_s + K_{es}[\text{NH}_4]_e + K_6[\text{OrgN}]_i \quad [8]$$

$$\text{Solution NO}_2: \frac{d[\text{NO}_2]_s}{dt} = - (K_2 + K_5 + KK_7)[\text{NO}_2]_s + K_1[\text{NH}_4]_s + KK_2[\text{NO}_3]_s \quad [9]$$

$$\text{Solution NO}_3: \frac{d[\text{NO}_3]_s}{dt} = - (KK_2 + KK_8)[\text{NO}_3]_s + K_2[\text{NO}_2]_s \quad [10]$$

$$\text{Organic N: } \frac{d[\text{OrgN}]_i}{dt} = -K_6[\text{OrgN}]_i + KK_6[\text{NH}_4]_s + KK_7[\text{NO}_2]_s + KK_8[\text{NO}_3]_s \quad [11]$$

$$\text{Gaseous N: } \frac{d[\text{N}_2\text{O} + \text{N}_2]_g}{dt} = K_5[\text{NO}_2]_s \quad [12]$$

Ardakani et al. (1975) proposed a model based on the theory that the biochemical conversion of inorganic N follows Michaelis-Menten kinetics:

$$-\frac{dN_{io}}{dt} = \frac{K \times N_{io}}{K_m + N_{io}} \quad [2]$$

where:

N_{io} = concentration of inorganic N substrate,

K = rate constant,

K_m = saturation constant, and

t = time

This equation reduces to first order kinetics in the case of $N_{io} \ll K_m$. This means that the rate of disappearance of N_{io} is directly proportional to its concentration. If $N_{io} \gg K_m$ then, it becomes a zero order reaction and the rate of disappearance is equal to K and is independent of concentration.

A simple model was developed by Cameron and Kowelenko (1976) to simulate the major nitrogen flow pathways in an unsaturated soil. Mineralization and nitrification were assumed to follow first-order, time dependent equations similar to those used by Mehran and Tanji (1974). The equilibrium relationship between soluble ammonium ($NH_4^+_s$) and exchangeable ammonium ($NH_4^+_e$) and was assumed to follow a nonlinear Freundlich equilibrium given as:

$$(NH_4^+_e) = 3.54[(NH_4^+_s)]^{.78} \quad [13]$$

This equation is independent of time and assumes that the equilibrium is reached instantaneously.

The N transformations that occur when animal waste is applied to agricultural lands depend heavily on the carbon-nitrogen (C/N) ratio in the manure. Reddy et al. (1977) describes the transformation of organic N to inorganic N in the form of nitrate for two C/N ratios. For a C/N ratio in the original manure of less than 10, the transformation is given by:

$$N_i = \{N_m - 0.4348 \times N_m \times (C/N)\} \times \{1 - \exp(-kt)\} \quad [14]$$

where:

N_i = amount of inorganic N mineralized,
 N_m = amount of N applied in the manure,
C/N= carbon-nitrogen ratio of the manure, and
 k = rate constant

For C/N greater than 10:

$$N_i = \{N_m - 0.04348 \times N_m \times (C/N) \times \exp(-At)\} \times \{1 - \exp(-kt)\} \quad [15]$$

where A is an empirical coefficient. The nitrate thus transformed is then available for leaching or transport in overland flow.

Using coupled transformations nearly identical to those of Mehran and Tanji (1974), Donigian and Crawford (1976) incorporated temperature effects directly into their transformation equations. The equation for mineralization is given as:

$$-\frac{d[N_{org}]}{dt} = KM_{35}[Org - N]\theta^{T-35} \quad [16]$$

where:

Org-N= organic N mass, kg/ha
 KM_{35} = mineralization rate constant at 35 °C
 θ_{KAM} = temperature correction coefficient for mineralization
T= soil temperature, °C

Donigian et al. (1977) later simplified the transformation submodel in ARM by eliminating N pathways that had little effect on the model and by combining nitrate and nitrite into one N form in the model.

A model developed by Watts and Hanks (1978) uses the concept of potentially mineralizable N and a first-order rate equation derived from equations presented by Stanford and Smith (1972) to describe the mineralization of organic matter to ammonium.

$$N_{t_o} = N_o[1 - \exp(-K_o\Delta t)] \quad [17]$$

where:

N_{to} = N mineralized in time Δt at optimum soil moisture content,

N_o = potentially mineralizable N in the soil depth increment,

Δt = time interval (hours), and

K_o = mineralization rate coefficient.

The mineralization rate coefficient, K_o , is calculated as a function of absolute soil temperature, T_a , by the equation:

$$K_o = \exp(17.753 - 6350.5/T_a)/168.0 \quad [18]$$

These are the same equations that are used to represent the mineralization process in both the ACTMO and CREAMS models.

Based on research by Stanford and Epstein (1974), the amount of N mineralized, N_{to} , in Equation 17 must be adjusted for the effect of soil water content. The equation is given as:

$$N_t = R_m \times N_{to} \quad [19]$$

where:

$R_m = 1.111f_{ps}$ for $0.0 \leq f_{ps} < 0.9$ and $R_m = 10.0 - 10.0f_{ps}$ for $0.9 \leq f_{ps} < 1.0$,

R_m = reduction coefficient for soil water content,

f_{ps} = fraction of fillable pore space, and

N_t = actual amount of N mineralized.

In the model of Watts and Hanks (1978), the nitrification of ammonium to nitrate is described by the equation:

$$N_{no} = N_a [1 - \exp(-K_a \Delta t)] \quad [20]$$

where:

N_{no} = amount of ammonium converted to nitrate in time Δt at optimum water content,

N_a = amount of soluble ammonium subject to conversion, and

K_a = nitrification rate coefficient (1/hour).

The rate coefficient K_a can be calculated as a function of temperature using the equation:

$$K_a = (0.032T_c - 0.12)KN_{35} \quad [21]$$

In the above, K_a = nitrification rate coefficient, KN_{35} = nitrification rate coefficient at 35 °C, and T_c = soil temperature (°C). This equation is only valid for temperatures between 10 and 35°C. The nitrification equation must also be modified for soil water content using Equation 19.

Soil temperature is extremely important in determining rate coefficients for N transformations as can be seen in Equations 18 and 21. Watts and Hanks (1978) developed an equation to relate air temperature to soil temperature with provisions for the effects of an emerging ground cover:

$$T_{ms} = T_{ma} \times (C_t - [(C_t - 1) / \{1 + \exp(6.0 - 12.0t_{ae}/t_{fc})\}]) \quad [22]$$

where:

T_{ms} = maximum soil temperature,

T_{ma} = maximum air temperature,

C_t = ratio of T_{ms} to T_{ma} at the time of emergence,

t_{fc} = time in days between emergence and full cover, and

t_{ae} = elapsed time in days since emergence.

The equation was designed so that before emergence, the expression inside the parenthesis is approximately equal to C_t . This relates to the surface soil temperature often being higher than the air temperature because of the effect of direct sunshine.

Wagenet (1980) developed a model known as NFLUX for modeling upward and downward fluxes of N within the soil profile. Horizontal fluxes are not considered. The processes of urea hydrolysis, nitrification, denitrification, and ammonia volatilization are considered. The model uses finite difference methods to solve the equations for these transformations. Some equations for plant N uptake are also included. A model developed by Kruh and Segall (1980) and known as NDS performs the same simulations as NFLUX but integrates the equations representing the different processes simultaneously. Oxygen movement is also included in the NDS model. A fertilization management model was developed by Veen and Frissel (1980) that also simulates N transformations in the soil. This model, known as M3, is primarily for long-term simulations.

Sediment-bound Nitrogen

The modeling of sediment-bound N is extremely important since over 90% of the total N in the soil is associated with soil particles. This includes organic N, and fixed and adsorbed ammonium. All of the nutrient models rely very heavily on the erosion submodels to simulate loss of sediment-bound N.

Donigian and Crawford (1976) presented one method to estimate nutrient losses due to adsorbed chemicals on eroded sediment. The Langmuir equation relates the adsorbed concentration on a soil particle to the dissolved concentration in the soil-water.

$$\frac{X}{M} = \frac{aC}{1/b + C} \quad [23]$$

where:

$\frac{X}{M}$ = amount of adsorbed chemical per unit weight of the adsorbent

C = equilibrium concentration of adsorbate

a, b = empirical constants

The ratio X/M could then be multiplied by the amount of sediment lost due to erosion in conjunction with an enrichment ratio to determine the total amount of chemical loss.

In a very simple model designed for use as a planning tool, Frere (1978) relates the amount of chemical transported to the loading function:

$$C_T = C_s \times E \times E_R \quad [24]$$

where: C_T is the amount of chemical loss per unit area, C_s is the chemical content of the watershed soil, E is soil loss and, E_R is the relative enrichment of the sediment as compared to the soil which is given as:

$$E_R = \frac{\eta}{E} + 1 \quad [25]$$

In the above equation η is a fitted coefficient.

Donigian and Crawford (1979) use the concept of a potency factor to calculate the pollutant content of overland flow in their Nonpoint Source Model (NPS). The same method of calculation is used in the ARM model. A potency factor indicates the pollutant strength of the sediment for each pollutant simulated. It is equal to pollutant mass per sediment mass in percent. Potency factors can be used in the following manner to calculate the total amount of a pollutant reaching a stream:

$$\text{POLP} = E \times \text{PMP} \quad [26]$$

where:

POLP= mass of pollutant to reach the stream

E= sediment loss to the stream

PMP= potency factor

The potency factor for a chemical in a particular watershed is found by calibration.

Williams (1979) uses an enrichment ratio in his organic N loading function for individual storms.

The function is given as:

$$Y_{\text{ON}} = 0.001 \times Y \times N_{\text{org}} \times E_{\text{R}} \quad [27]$$

where:

Y_{ON} = organic N yield, kg

Y= sediment yield, t

N_{org} = soil organic N concentration, ppm

E_{R} = N enrichment ratio

The enrichment ratio is determined by considering the clay fraction in the sediment as compared to the soil. It is computed as:

$$E_{\text{R}} = \frac{\zeta_{\text{y}}}{\zeta_{\text{s}}} \quad [28]$$

where:

ζ_y = percent of sediment with size of less than 1μ

ζ_s = percent of soil with size of less than 1μ

The nutrient submodel for the CREAMS model is similar to several others previously presented. The equation used for N transported by sediment in CREAMS is the same as Equation 27. A new equation for enrichment ratio is presented and is given as (Frere et al.,1980):

$$E_R = a \times E^b \quad [29]$$

where:

E_R = enrichment ratio

E = eroded sediment

a and b = calibration coefficients for N

Values for a and b for a watershed in Georgia were given as 16.8 and -.16 respectively.

Delwiche and Haith (1983) presented loading functions for the loss of sediment-bound N on sediment for cropland, forests, barnyards, and urban areas. The loading functions for the four land areas were proposed for use primarily as planning tools. The nutrient export from cropland was given as:

$$L_S = 0.001 \times N_x \times E \times T_S \times A \quad [30]$$

where:

L_S = solid phase nutrient export, kg

N_x = nutrient concentration in sediment, mg/kg

E = soil loss, kg/ha

A = area, ha

T_S = solid phase transport factor

The transport factor is the fraction of the soil lost that is delivered to the watershed outlet and is given by the sediment delivery ratio:

$$T_S = 0.047 \times A^{-.125} \quad [31]$$

The nutrient concentration in sediment, N_x , used in Equation 30 is assumed to be twice that of the soil concentration.

Dissolved Nitrogen Transport

The transport of dissolved chemicals from agricultural lands by runoff is greatly simplified in most models. The primary reason for this is that the movement of solutes in soils is an extremely complicated process. Not only does nitrate move both vertically and horizontally in the soil profile but dispersion and diffusion effects must be considered. Further complications arise because of the various sized pore spaces found in individual soils and between different soils.

Neilsen and Biggar (1962) discuss various equations that are used to describe the miscible displacement of chemicals in porous materials. One such equation is given as:

$$\frac{C}{C_o} = 1/2 \operatorname{erfc} \left[\frac{x - v \times t}{\sqrt{4 \times D \times t}} \right] \quad [32]$$

where:

x = distance,

v = average velocity (flux divided by pore space volume),

D = factor of dispersion,

t = time,

C = solution concentration at t and x , and

C_o = original solution concentration.

Due to the assumptions upon which it is based, Equation 32 has very limited use.

A more flexible equation is given by Lapidus and Amundson (1952):

$$\frac{C}{C_o} = 1/2 \left[\operatorname{erfc} \left(\frac{x - v \times t}{\sqrt{4 \times D \times t}} \right) + \exp \frac{V \times x}{D} \operatorname{erfc} \left(\frac{x - v \times t}{\sqrt{4 \times D \times t}} \right) \right] \quad [33]$$

This equation has proved accurate in saturated soils although it is much less reliable under unsaturated conditions. One of the most difficult variables to determine in Equation 33 is the factor of dispersion (D). Frissel et al. (1970) used a computer model fitted against test data to determine dispersion coefficients for three soils. They found that D varied with depth, soil moisture, and soil type.

Frere et al. (1973) used an equation similar to Equation 33 in the ACTMO model to calculate the solution concentration of nitrate at any depth at a specific time:

$$C(x) = \frac{A \times U}{\sqrt{4\pi \times D \times d}} \exp - \left(\frac{d - X}{\sqrt{4 \times D \times d}} \right)^2 \quad [34]$$

where:

C= solution concentration, ppm,

A= amount of chemical, M/L²

U= conversion factor,

X= depth of concentration,

d= average depth of chemical movement, and

D= dispersion coefficient.

The average depth of chemical movement (d) depends on the amount of infiltration and the properties of the soil in question. These factors can be combined into the following equation:

$$d = \frac{IN}{FC} \times \frac{FC}{AM + BD \times AC} \quad [35]$$

where:

d= average depth of movement,

IN= infiltration depth,

FC= volumetric moisture content at field capacity,

AM= initial volumetric moisture content,

BD= bulk density of the soil, and

AC= adsorption coefficient.

In calculating the concentration of chemicals in the runoff, the assumption is made that the extraction efficiency is the same at the surface for infiltration and runoff at the surface. The runoff concentration can then be calculated using Equation 34 with $X=0$.

The CREAMS model simulates nitrate removal in a very different manner, that is less theoretical and more empirical in nature. Nitrate loss is a function of the difference between nitrate concentrations at the beginning and end of runoff. The concentration at the start of runoff is given as:

$$N_1 = (NO_3 - N_R) \times \exp(-K_1 \times F) + N_R \quad [36]$$

where:

NO_3 = initial nitrate concentration at the surface,

N_R = concentration of nitrate in the rain,

K_1 = rate constant for the downward movement of nitrate, and

F = total infiltration for the storm.

The final concentration after runoff is:

$$N_2 = (N_1 - N_R) \times \exp(-K_2 \times Q) + N_R \quad [37]$$

and the mean concentration during runoff is:

$$\bar{N}_2 = ((N_1 - N_R)/K_2 \times Q)(1 - \exp(-K_2 \times Q)) + N_R \quad [38]$$

where:

K_2 = rate constant for movement into runoff

Q = total runoff

The amount of total dissolved N in runoff, YNO_3 , is calculated as:

$$YNO_3 = \bar{N}_2 \times EXKN_2 \times Q \times 0.01 \quad [39]$$

In this equation $EXKN_2$ is an extraction coefficient related to K_2 and can be found from the equation:

$$EXKN_2 = d \times POR \times K_2 \quad [40]$$

In the above, d = the effective depth of interaction and POR = porosity.

The yield of nitrate in runoff water is also predicted in the model developed by Williams (1979). It is based on the assumption that the concentration in the runoff is the same as that of the top soil storage. The equation for total nitrate yield is given by:

$$YNO_3 = P_s \times NO_3 \times (1 - \exp(-Q \times P_w / P_s)) + RNO_3 \times Q \quad [41]$$

where:

YNO_3 = nitrate yield

P_s = specific weight of a particular soil, kg/ha

NO_3 = nitrate concentration in the soil

Q = runoff

P_w = weight of water, kg/ha

RNO_3 = concentration of nitrate in rainfall

The literature contains an extensive amount of material on modeling nitrogen losses on a field-scale. The inclusion of these processes into watershed-scale models is less prevalent and would be useful as a planning tool for identifying critical areas and for evaluating best management practice implementation scenarios.

SURFACE TRANSPORT MODEL

DEVELOPMENT

The comprehensive watershed model, ANSWERS, was chosen to serve as the basis for the N transport submodel. The arrangement of the hydrologic and sediment transport components in the ANSWERS model made it possible to add several subroutines to simulate N losses during runoff from cropland relatively straight forward. A block diagram of the submodel is shown in Figure 3. The submodel consists of three basic subroutines. The N transformation subroutine allows the submodel to transform N in the soil and that applied as fertilizer into its various forms between the time of fertilizer application and the modeled storm. A second subroutine in the submodel simulates sediment-bound N transport. The last subroutine simulates dissolved N loss in surface runoff. The model is written in FORTRAN 77. A computer program listing and a list of variables used in the subroutines are included in the appendices.

Nitrogen Transformation Subroutine

The arrangement of the transformation subroutine is similar to that in the ARM model (Donigian and Davis, 1978). Coupled, first-order rate reactions are utilized to simulate mineralization, nitrification, and the adsorption of NH_4 .

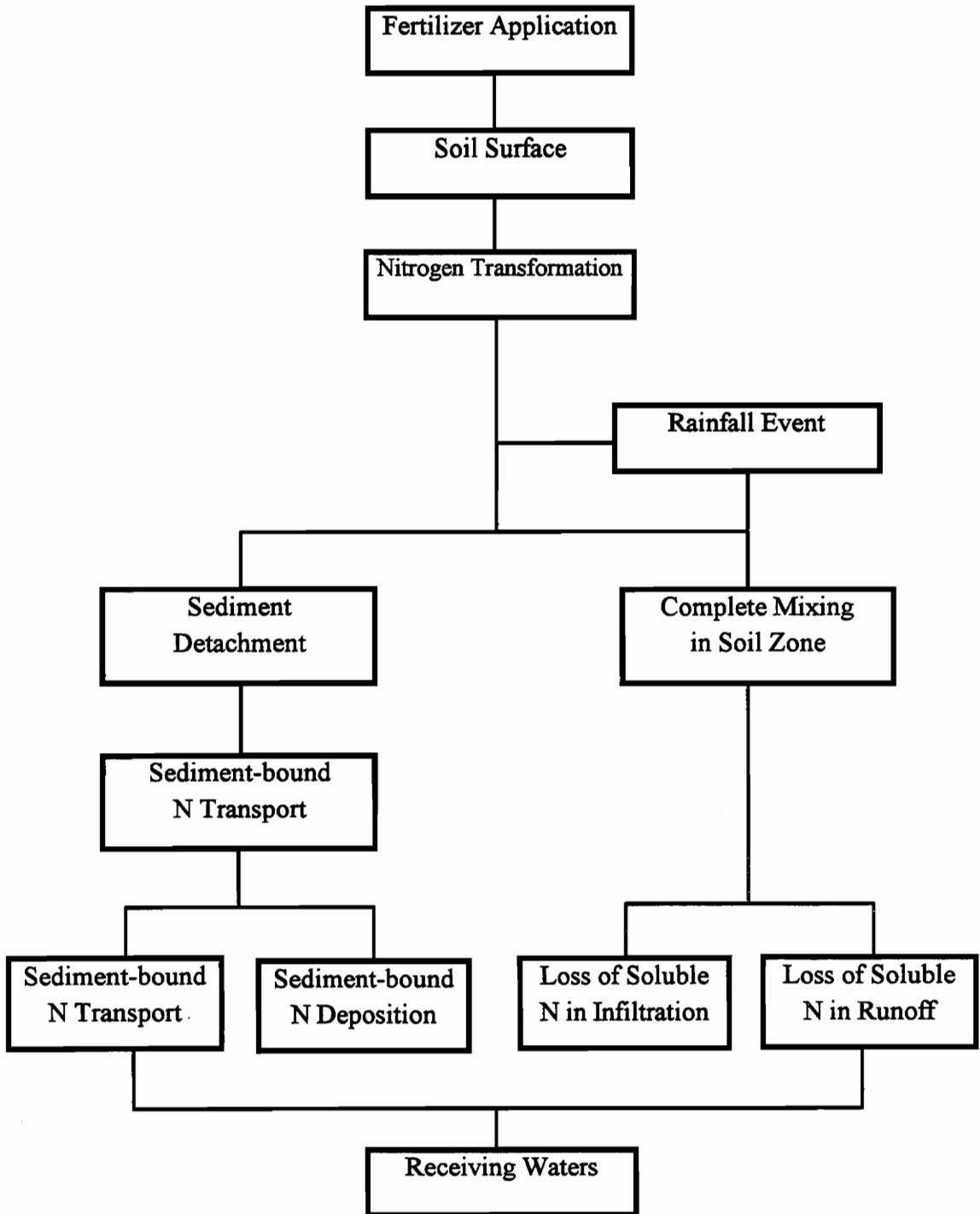


Figure 3. Block diagram of nitrogen model

The mineralization of organic matter to ammonia is described using Equation 17 (Stanford and Smith, 1972):

$$DPOTN = POTMIN * (1 - \exp(-XKO * DELTH)) * WCCOEF \quad [42]$$

Where DPOTN is the N mineralized in time, DELTH; POTMIN is the potentially mineralizable N in the soil depth increment; XKO is the rate coefficient, and WCCOEF is the soil water content correction factor developed by Stanford and Epstein (1974), as given in Equations 19 and 20.

The amount of NH_4^+ transformed into NO_3^- through nitrification in time, DELTD, is given in the submodel as:

$$DSNO_3 = SNH_4 * XKAN * DELTD * WCCOEF \quad [43]$$

In this equation, SNH4 is the amount of dissolved ammonium that exists in the soil zone and XKAN is the nitrification rate coefficient. The assumption that ammonia is transformed directly to nitrate is made here to simplify the N pathway. This assumption is reasonable since in all but saturated soils, nitrite rapidly mineralizes to nitrate.

The change in the amount of adsorbed ammonium, DANH4, is given as:

$$DANH_4 = (SNH_4 * XKSA - ANH_4 * XKAS) * DELTD \quad [44]$$

where SNH4 and ANH4 are the dissolved and adsorbed NH_4^+ in the soil zone, respectively; XKSA is the rate of adsorption of ammonium by soil particles; and XKAS is the rate at which adsorbed molecules move back into the soil water.

The last of the coupled mathematical equations is the change in the amount of dissolved NH_4^+ in the soil zone. It is a combination of Equations 42, 43, and 44 and is given as:

$$DSNH_4 = DPOTN - DSNO_3 - DANH_4 \quad [45]$$

The rate coefficients; XKAN, XKSA, and XKAS are based on a soil temperature of 35°C. For temperatures lower than this, they are adjusted by dividing by a factor, ADIK, given in the subroutine as:

$$\text{ADJK} = \frac{(35 - \text{TEMP})}{10} \quad \text{for } 35 \geq \text{TEMP} \geq 25 \quad [46]$$

$$\text{ADJK} = 2^{(35 - \text{TEMP})/10} \quad \text{for } \text{TEMP} < 25 \quad [47]$$

The use of the variable ADJK is necessary because reaction rates decrease by half with every 10°C drop in temperature.

Additional assumptions upon which the transformation subroutine is based are:

1. Only a small active fraction of soil organic N, known as the potentially mineralizable N, is available for mineralization.
2. No denitrification or volatilization takes place in the surface soil zone.
3. At temperatures greater than 35°C transformation reaction rates are assumed to be constant.
4. Soil pH ranges from 7.0 to 8.5.
5. There is no plant uptake of N.
6. The transformations stop when rainfall begins.

Sediment-Bound Nitrogen Transport Subroutine

The purpose of the sediment-bound N transport model is to estimate the loss of fixed soil N and adsorbed ammonium in connection with simulated soil loss by the ANSWERS model. The sediment-bound N transport model relies heavily on the extended sediment transport model developed for ANSWERS by Dillaha (1981), which simulates the transport of sediment by individual particles size classes. The N transport model is based on the assumption that the fraction of the total N in the soil found in each particle class is equivalent to the fraction of the total clay in the soil in each particle class. This assumption is based on soil-bound N being primarily associated with that portion of the soil known as

colloids, of which the clay fraction of the soil is a major part. The sediment-bound N transport model can be found in SUBROUTINE SEDNIT.

The initial N in storage on an element for particle class i at the beginning of a time interval is calculated as:

$$TKNSTR_i = STOTKN_i * STOLD_i \quad [48]$$

$$ANHSTR_i = STOANH_i * STOLD_i \quad [49]$$

where for particle size i, TKNSTR is the fixed soil nitrogen in storage (mg-N/sec), ANHSTR is the adsorbed ammonium in storage (mg-N/sec), STOTKN is the concentration of fixed soil N in storage (mg-N/kg soil), STOANH is the concentration of adsorbed ammonium in storage (mg-N/kg soil), and STOLD is the sediment in storage (kg-soil/sec).

The rate of soil N being newly eroded in a cell is similarly calculated as:

$$TKNNEW_i = CELTKN_i * SEDNEW_i \quad [50]$$

$$ANHNEW_i = CELANH_i * SEDNEW_i \quad [51]$$

where TKNNEW and ANHNEW are in mg-N/sec, and SEDNEW is the rate of new erosion in kg-soil/sec for particle class i. CELTKN and CELANH are the fixed N and adsorbed ammonium concentrations in the soil of the cell for each particle class in mg – NH₄/kg – soil, and are determined as:

$$CELTKN_i = TKN * \frac{PERCLA_i}{F_i} \quad [52]$$

$$CELANH_i = ANH4 * \frac{PERCLA_i}{F_i} \quad [53]$$

In these equations PERCLA is the percentage of the total soil clay found in particle class i, F is the weight fraction of the soil in particle class i, and TKN and ANH4 are the initial concentrations of fixed N and

adsorbed ammonium in the soil for the element in kg-N/ha. TKN and ANH4 are input variables for each element.

A test is now made to see if there is any outflow from the cell at the end of the time interval. If there is no outflow from the cell, the concentration of fixed N in the depositing sediment, TKNCON, and the concentration of adsorbed ammonium, ANHCON, are calculated as:

$$\text{TKNCON} = \frac{\text{TKNIN} + \text{TKNSTR}}{\text{SI} + \text{STOLD}} \quad [54]$$

$$\text{ANHCON} = \frac{\text{ANHIN} + \text{ANHSTR}}{\text{SI} + \text{STOLD}} \quad [55]$$

where TKNIN, ANHIN, and SI are the rates of fixed N, adsorbed N, and sediment coming into the cell, respectively. TKNCON and ANHCON are then multiplied by SEDSEL, the deposition rate for the cell, and added to the aggradation values, TKNSEL (mg-N/sec) and ANHSEL (mg-N/sec), for that cell.

If outflow from the cell is not zero then additional erosion may occur and the equations for TKNCON and ANHCON change to account for the newly eroded sediment, SEDNEW. Equations 54 and 55 become:

$$\text{TKNCON} = \frac{\text{TKNIN} + \text{TKNSTR} + \text{TKNNEW}}{\text{SI} + \text{STOLD} + \text{SEDNEW}} \quad [56]$$

$$\text{ANHCON} = \frac{\text{ANHIN} + \text{ANHSTR} + \text{ANHNEW}}{\text{SI} + \text{STOLD} + \text{SEDNEW}} \quad [57]$$

The aggradation values for the cell are then calculated as:

$$\text{TKNSEL} = \text{TKNSEL} - \text{TKNNEW} + \text{SEDSSEL} * \text{TKNCON} \quad [58]$$

$$\text{ANHSEL} = \text{ANHSEL} - \text{ANHNEW} + \text{SEDSSEL} * \text{ANHCON} \quad [59]$$

TKNCON and ANHCON are then multiplied by SE, the rate of sediment leaving a cell, to determine TKNIN and ANHIN for the cell or cells into which the outflow is apportioned.

Dissolved Nitrogen Transport Subroutine

The dissolved nitrogen transport subroutine is based on mass balance theory in a soil surface zone equal to the effective depth of interaction. The subroutine deals with dissolved nitrate and dissolved ammonium and the two are handled identically. In this description only nitrate will be dealt with for simplification purposes. The model accounts for the mass of water and N entering a cell from adjoining cells and in rainfall, the mass of water and N leaving a cell through infiltration and runoff, and the mass of water and N originally in the soil surface zone. The assumption is made that complete mixing of water entering a cell and of water originally in storage in a cell occurs. A mass balance diagram which illustrates the principle upon which the subroutine is based is shown in Figure 4. The mass of dissolved nitrate entering a cell, $AINNO3$ (kg), in time step, DT , is calculated as:

$$AINNO3 = (RN03 \times R + Q1N03) \times DT \quad [60]$$

where R is rainfall rate, $RNO3$ is the N concentration of the rainfall and $Q1N03$ is the rate of N entering the cell from adjoining cells.

Added to the $AINNO3$ to get the total amount of N in the cell available for loss during the time step, $TNO3$, is the N already in storage in the cell, $STORNO$, and a portion of the N in the soil storage zone, $SZNO3$.

$$TNO3 = AINO3 + STORNO + SZNO3 \times EXTFAC \quad [61]$$

Dissolved N in storage in the soil, $SZNO3$, is made up of the dissolved nitrate in the soil surface zone at the beginning of the time step and includes the N which existed in the soil at the beginning of the model run in addition to that added in fertilizer. The term $EXTFAC$, which is multiplied by $SZNO3$, is an extraction factor, the purpose of which is to account for the fact that dissolved N contained in the soil surface

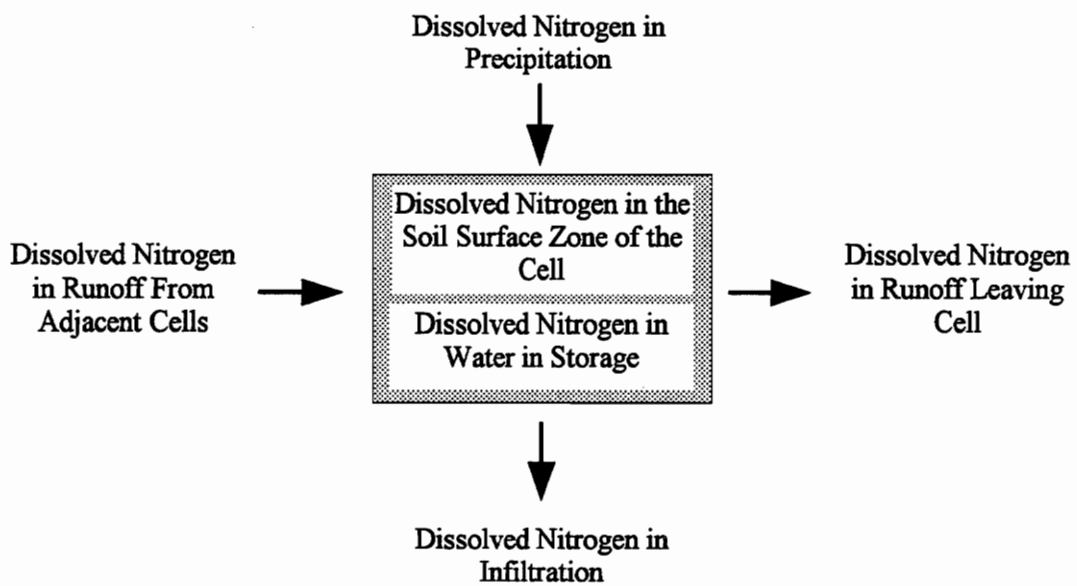


Figure 4. Mass balance diagram of soluble nitrogen transport subroutine.

zone is not equally available for removal due to the large variation in size of the pores in the soil (Knisel, 1980). Nitrogen contained in larger soil pores is more available, as water moves easily through large pores, while the dissolved nitrate in the micropores becomes available only as rainfall continues.

This concept is in line with studies on effective depth of interaction by Ahuja and Lehman (1983), who found that raindrop impact surface results in a pumping action which would tend to flush the larger pores first. The result of using an extraction factor is that the soil surface zone acts as a source of N during the model run in terms of mass balance theory. The value of EXTFAC is tied to the total amount of water passing through the cell during that time step as compared to the total amount of water in the soil surface zone.

Using TN03, N is proportioned to outflow, and storage in three coupled equations.

$$\text{OUTN03} = \frac{\text{Q2}}{\text{DENOM}} * \text{TN03} \quad [62]$$

$$\text{FILN03} = \text{FILN03} + \frac{\text{FIL}}{\text{DENOM}} * \text{TNO3} \quad [63]$$

$$\text{STORNO} = \frac{\text{SSTOR}}{\text{DENOM}} * \text{TNO3} \quad [64]$$

In these equations, OUTN03 and FILN03 are the N in surface outflow, Q2, and infiltration, FIL, respectively. DENOM is the sum of Q2, FIL, and SSTOR, the water in storage in the cell. These equations are based on the assumption mentioned earlier that complete mixing in the soil zone occurs. This results in the concentration of N in the outflow from the cell, infiltrating water, and that remaining in storage on the surface being the same.

The STORNO that is calculated is then the new value for the amount of nitrate stored on the surface for the cell and is used to calculate TNO3 for the next time step. OUTN03 becomes AINN03 for the adjoining receiving cells and is proportioned to the adjoining cells in the same manner as Q2.

The subroutine calculates the amount of nitrate and dissolved ammonium being lost from the soil surface zone of each cell in addition to the total amount lost from the watershed in surface runoff. The loss of dissolved N from the surface zone in infiltration is also tabulated.

SURFACE TRANSPORT MODEL

VALIDATION

The ultimate test of a mathematical model is a comparison of the simulated and observed responses of the physical system to a variety of input conditions. To evaluate the effectiveness of the model developed in this research, the model's predictions were compared with observed sediment, dissolved nitrogen, and sediment-bound nitrogen yields from rainfall simulator plot studies.

Plot Descriptions and Data Collection

Data collected during field plot experiments in 1985 at the Prices Fork Research Farm in Blacksburg, Virginia, was utilized to assess the predictive capabilities of the nitrogen transport model. A total of four plots were used in the validation analysis: two replications of conventional disk plowed plots, tilled to a depth of 20 - 30 cm and two replicate no-till plots planted in winter rye. The use of conventional till and no-till plots in the verification process served to simulate the range of conditions expected in future model applications.

The plots were located on Groseclose silt loam, a clayey, mesic Typic Hapludult soil common to the region. Each plot had a surface area of 0.01 ha (5.5 m wide by 18.3 m long). Plots 4 and 6, the no-till plots, had average slopes of 14.1 and 14.0 percent respectively. The conventional tillage plots, C and F, had average slopes of 9.1 and 8.3 percent, respectively. Ammonium nitrate fertilizer (50% NO₃ and 50%

NH₄) was surface applied by hand to plots 4, C, and F at a rate of 50 kg-N/ha one hour prior to the first simulation. No fertilizer was applied to plot 6.

A rainfall simulator (Shanholtz et al., 1981; Neff, 1979; Dillaha et al., 1987) was used in the field experiments to produce runoff, which in turn transported sediment and nutrients from the plots. A total of 100 mm of rainfall was applied to each plot in three simulator runs over a two day period. The first run was 60 minutes, followed 24 hours later by two 30 minute runs half an hour apart. The sequencing of the rainfall runs was designed to simulate a range of soil moisture conditions from dry to very wet and is typical for plot studies. For each plot, rainfall simulator application rates and uniformity was measured using 12 volumetric rain gauges. A summary of rainfall simulator average intensities, rainfall volumes, and uniformity coefficients is given in Table 3.

Runoff from each plot was measured with a 15 cm (6 inch) H-flume and stage recorder. Runoff rates were also verified periodically during each simulation by making time-volume measurements. Runoff water samples were collected at predetermined intervals from each flume after the start of runoff for each simulation run. All runoff samples were refrigerated immediately after collection and stored for subsequent water quality analysis.

The plant residue for both no-till plots was measured at approximately 1900 kg/ha at the time of the runs. The winter rye in these plots had been previously killed with paraquat. Soil samples used for measuring moisture content and nutrient levels were taken before and after each run to a depth of 30 cm at 5 cm intervals. Soil N levels in the top 5 cm before and after the rainfall simulations are presented in Table 4 for each plot. A detailed summary of the plot data and experimental procedures employed in data collection is given by Dillaha et al. (1987) and Mostaghimi et al. (1987).

Plot Simulations

In order to perform computer simulations of the Prices Fork field plots with the ANSWERS model, it was first necessary to divide the plots into a grid with uniform square elements. Due to the elongated

Table 3. Rainfall simulator summary statistics (Mostaghimi et al. 1987).

| Plot | Run Number | Average Intensity (mm/hr) | Average Rainfall (mm) | Uniformity Coefficient (%) |
|------|------------|---------------------------|-----------------------|----------------------------|
| 4 | 1 | 48.7 | 48.7 | 94.3 |
| | 2 | 52.6 | 26.3 | 92.1 |
| | 3 | 53.4 | 26.7 | 88.0 |
| 6 | 1 | 50.7 | 50.7 | 96.1 |
| | 2 | 53.0 | 26.5 | 93.2 |
| | 3 | 54.4 | 27.2 | 89.7 |
| C | 1 | 50.8 | 50.8 | 92.5 |
| | 2 | 46.8 | 23.4 | 95.1 |
| | 3 | 47.2 | 23.6 | 94.7 |
| F | 1 | 51.2 | 51.2 | 92.3 |
| | 2 | 52.8 | 26.4 | 94.7 |
| | 3 | 53.6 | 26.8 | 83.8 |

Plot QF4: no-till; fertilizer applied

Plot QF6: no-till; no fertilizer applied

Plot QFC: conventional tillage; fertilizer applied

Plot QFF: conventional tillage; fertilizer applied

Table 4. Soil nutrient summary for Prices Fork Farm plot soil samples.

| Plot | Initial Soil Nitrogen | | | |
|------|-----------------------|---------------------------------|--------------------|----------------------------------|
| | Organic-N (mg/kg) | Adsorbed Ammonium (mg/kg) | Nitrate (mg/kg) | Dissolved Ammonium (mg/kg) |
| 4 | 1755.0 | 197.0 | 4.77 | 0.049 |
| 6 | 1231.0 | 147.0 | 2.57 | 0.054 |
| C | 629.0 | 73.5 | 0.11 | 0.016 |
| F | 922.0 | 11.9 | 3.75 | 0.035 |

Plot QF4: no-till; fertilizer applied

Plot QF6: no-till; no fertilizer applied

Plot QFC: conventional tillage; fertilizer applied

Plot QFF: conventional tillage; fertilizer applied

shape of the plots, five square elements with 3.66 m (12 feet) sides were chosen. This resulted in only 66.6% of each plot being covered by the grid. To remedy this difference and make it possible to directly compare the simulation results with observed data, all field observed nutrient loads, runoff volume, and sediment yields were reduced by 33%.

Input parameters to the model were obtained from a variety of sources including field measurements. Surface roughness, crop constants, and drainage and infiltration parameters were initially estimated with data from the Soil Survey of Montgomery County, Virginia (USDA, 1985) using procedures recommended by Beasley and Huggins (1981). Field capacity estimates for Groseclose silt loam were obtained from Shanholtz and Lillard (1968). Additional details on parameter estimation procedures are given by Dillaha et al. (1987).

Calibration of the model to observed runoff and erosion data was conducted to provide a more accurate evaluation of the N transport submodel by reducing the effects of model components (hydrology and erosion) on which the N model is dependent. Calibration was performed on each of the four plots with the intent of improving predictions of runoff and erosion. All calibrated parameters were kept within suggested model parameter ranges. Parameters in the N transport models were not calibrated.

The model parameters that were calibrated to improve predicted runoff and erosion included: FC, steady state infiltration rate; A, the maximum infiltration rate in excess of FC; DF, depth of the infiltration control zone; c, crop management factor; and K, soil-erodibility factor. Table 5 shows the initial estimates for each of these parameters along with the calibrated results. From Table 5 it can be seen that the initial estimates for A, K, and conventional till C were close to the calibrated values. The estimate for no-till C is also reasonably good considering the sensitivity of such a low crop management factor. The calibrated results for FC were much lower than the initial estimates for both the conventional and no-till plots. The calibrated FC values for no-till and conventional till are closer in value than would be expected given the higher organic matter content of the no-till plots, but are reasonable since this was the first year of no-till and significant changes in soil properties take years to develop. This in part is offset by calibrated DF factors higher than suggested for the no-till plots and lower for the conventional till plots. Variations in the FC and DF parameters from recommended values could in part be the result of a phenomena such as surface-sealing occurring on the unprotected conventional till plots.

Table 5. Suggested and calibrated parameters for plot simulations.

| Plot | | FC (mm/hr) | A (mm/hr) | DF (mm) | K | C |
|-----------|------------|---------------|--------------|------------|------|------|
| QF4 & QF6 | Suggested | 47.63 | 114.30 | 150.00 | 0.43 | 0.03 |
| | Calibrated | 18.67 | 101.70 | 415.00 | 0.29 | 0.05 |
| QFC & QFF | Suggested | 38.10 | 91.44 | 150.00 | 0.28 | 0.50 |
| | Calibrated | 17.00 | 86.67 | 90.00 | 0.30 | 0.43 |

FC - steady state infiltration rate

A - maximum infiltration rate in excess of FC

DF - depth of the infiltration zone

K - soil-erodibility factor

C - crop management factor

Plot QF4: no-till; fertilizer applied

Plot QF6: no-till; no fertilizer applied

Plot QFC: conventional tillage; fertilizer applied

Plot QFF: conventional tillage; fertilizer applied

Modification of field measured antecedent soil moisture content for each plot was necessary for runoff hydrograph calibration. Downhill grid elements were assigned higher moisture content than uphill elements, however, the average moisture content over the entire plot was maintained equal to the field measurement.

Representative soil particle classes were an additional model input that required modification of field measured data for use in the N transport submodel. Soil particle size analysis was conducted on the plot soils (upper 5 cm of the soil profile) to estimate the particle size distribution of detached sediment. Particle size analysis results are presented in Table 6. The particle size distribution was modified somewhat to correspond to the five representative particle size classes used in the CREAMS model (Foster et al., 1985). The modified particle class distributions used as model input are presented in Table 7.

An adjustment was also necessary in the rainfall detachment equation used in ANSWERS to account for the lower kinetic energy of raindrops produced by the rainfall simulator as compared to the energy of natural rainfall at the same intensity which is used in the model. It was estimated that the kinetic energy in raindrops from the rainfall simulator was 60% less than that of natural rainfall (Neff, 1979). Therefore, rainfall detachment in the model was reduced 60%.

In the computer simulation of the plot runs, only one hour was allotted between the first and second runs as opposed to the 24 hours that occurred in the field. This was necessary because ANSWERS is an event oriented model and simulation of periods longer than 24 hours is not practical. The one hour period between the first and second runs allowed enough simulation time for surface storage to infiltrate. However, soil moisture levels may have been high at the start of the second and third runs because more drainage may have occurred from the infiltration control zone than predicted by the model. In the case of runs 2 and 3, the actual 30 minute period between plot runs was used in the simulation. The observed and calibrated hydrographs for plots 4, 6, C, and F are shown in Figures 5 through 8.

Table 6. Particle size distribution for 0-5 cm soil samples from selected field plots at Prices Fork Farm.

| Particle Size | | Percent of Soil Mass | | | |
|---------------|-------------|----------------------|------|------|------|
| | | QF4 | QF6 | QFD | QFF |
| < 0.002mm | Dispersed | 16.4 | 22.7 | 16.8 | 20.0 |
| | Undispersed | 3.5 | 3.5 | 3.0 | 3.8 |
| 0.002-0.05mm | Dispersed | 61.1 | 38.6 | 66.5 | 69.0 |
| | Undispersed | 28.3 | 24.5 | 30.1 | 32.3 |
| > 0.05mm | Dispersed | 22.5 | 38.7 | 16.7 | 11.0 |
| | Undispersed | 68.2 | 72.0 | 66.9 | 63.9 |

Plot QF4: no-till; fertilizer applied

Plot QF6: no-till; no fertilizer applied

Plot QFC: conventional tillage; fertilizer applied

Plot QFF: conventional tillage; fertilizer applied

Table 7. Representative particle classes and clay content for 0-5 cm soil samples from selected plots at Prices Fork Farm.

| Plot | Particle Class | Diameter (mm) | Soil Fraction (%) | Clay Content | |
|------|----------------|---------------|-------------------|------------------|------------------|
| | | | | Percent of Class | Percent of Total |
| QF4 | Primary Clay | 0.002 | 3.5 | 100.0 | 21.3 |
| | Primary Silt | 0.010 | 0.0 | 0.0 | 0.0 |
| | Primary Sand | 0.200 | 9.2 | 0.0 | 0.0 |
| | Small Agregate | 0.030 | 28.3 | 21.2 | 36.5 |
| | Large Aggregat | 0.328 | 59.0 | 11.7 | 42.2 |
| QF6 | Primary Clay | 0.002 | 3.5 | 100.0 | 15.4 |
| | Primary Silt | 0.010 | 0.0 | 0.0 | 0.0 |
| | Primary Sand | 0.200 | 10.7 | 0.0 | 0.0 |
| | Small Agregate | 0.030 | 24.5 | 37.0 | 40.0 |
| | Large Aggregat | 0.454 | 61.3 | 16.5 | 44.6 |
| QFC | Primary Clay | 0.002 | 2.9 | 100.0 | 12.7 |
| | Primary Silt | 0.010 | 0.0 | 0.0 | 0.0 |
| | Primary Sand | 0.200 | 3.3 | 0.0 | 0.0 |
| | Small Agregate | 0.030 | 31.7 | 26.1 | 36.1 |
| | Large Aggregat | 0.400 | 62.1 | 18.8 | 51.1 |
| QFF | Primary Clay | 0.002 | 3.8 | 100.0 | 19.1 |
| | Primary Silt | 0.010 | 0.0 | 0.0 | 0.0 |
| | Primary Sand | 0.200 | 3.6 | 0.0 | 0.0 |
| | Small Agregate | 0.030 | 32.3 | 22.5 | 36.4 |
| | Large Aggregat | 0.400 | 60.3 | 14.6 | 44.5 |

Plot QF4: no-till; fertilizer applied

Plot QF6: no-till; no fertilizer applied

Plot QFC: conventional tillage; fertilizer applied

Plot QFF: conventional tillage; fertilizer applied

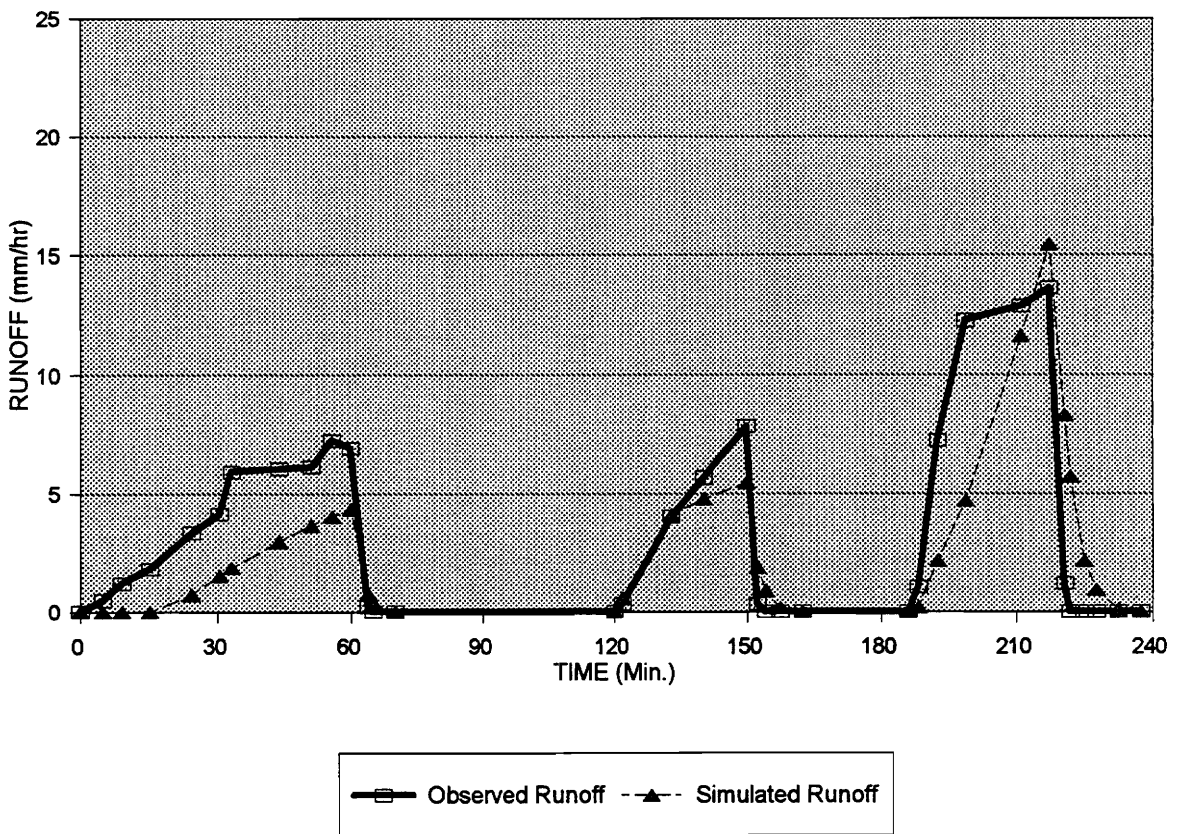


Figure 5. Observed and calibrated hydrographs for fertilized, no-till plot QF4.

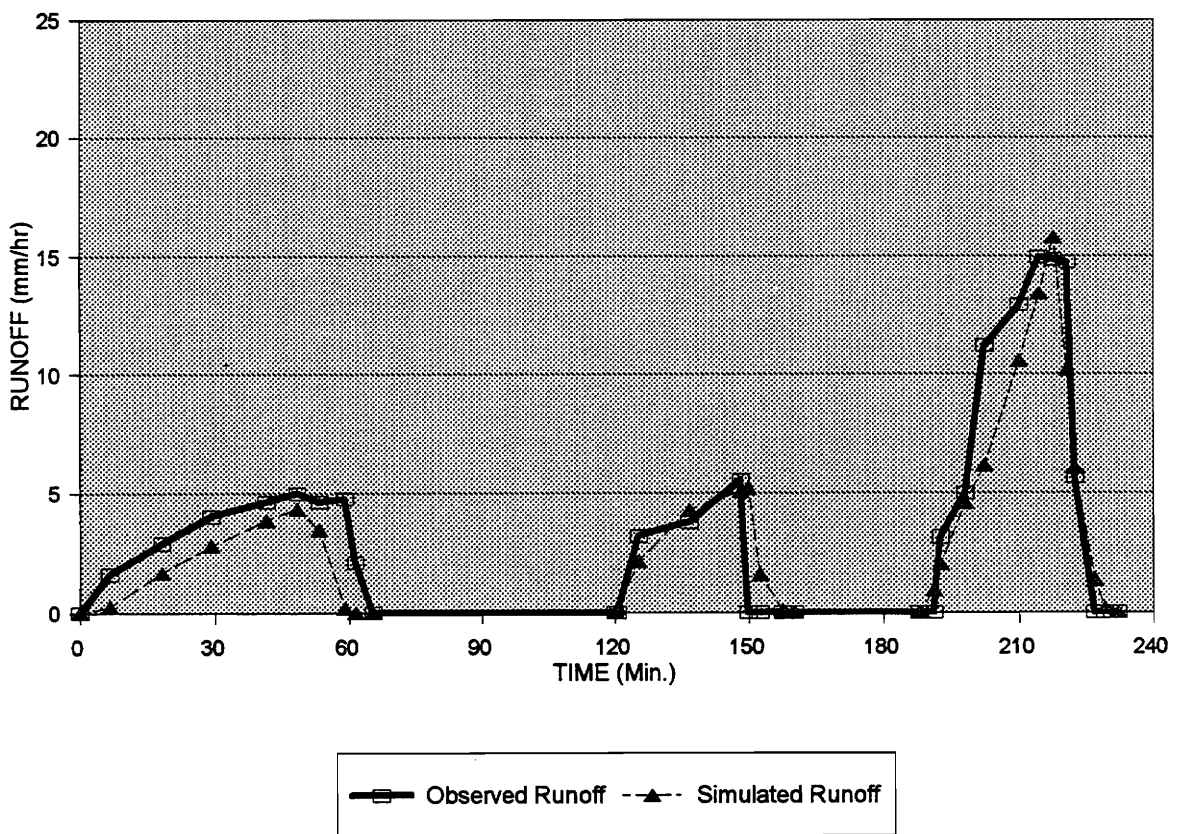


Figure 6. Observed and calibrated hydrographs for unfertilized, no-till plot QF6.

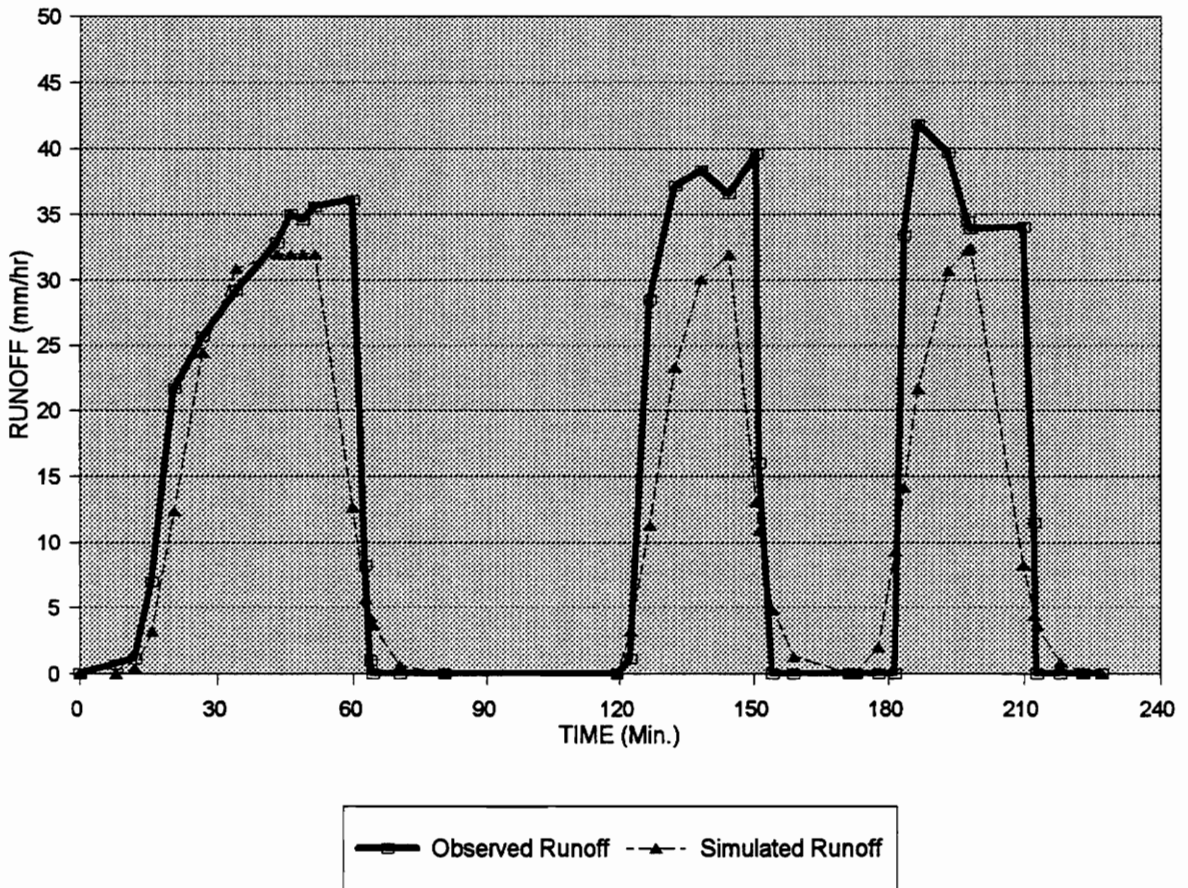


Figure 7. Observed and calibrated hydrographs for fertilized, conventional tillage plot QFC.

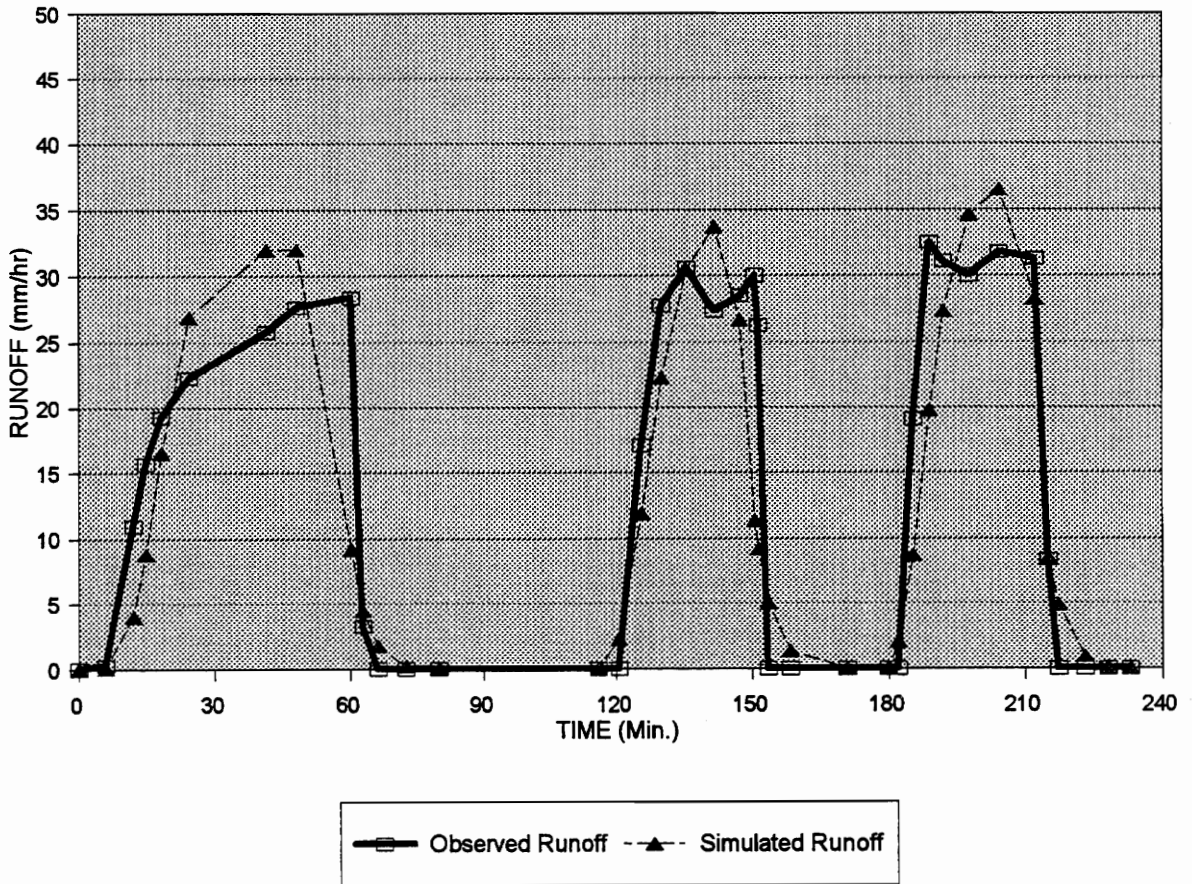


Figure 8. Observed and calibrated hydrographs for fertilized, conventional tillage plot QFF.

Results and Discussion

The results of the model simulations and the corresponding observed yields from the plots are given in Table 8. The results show the total of loadings from all three simulated storms. The relative error is calculated by:

$$\text{Relative error \%} = \frac{\text{Simulated} - \text{Observed}}{\text{Observed}} \times 100 \quad [65]$$

McKeon and Segna (1987) investigated the selection criterion for hydrologic models used in exposure assessment. Screening level models, where validation and calibration is limited, should yield predictions within an order of magnitude of observed values. Hydrologic assessment models that have on-site measured parameters or that have been calibrated should yield results with less uncertainty. Heatwole et al. (1991) suggests that the predictions of good hydrologic assessment models should be within a factor of two when these conditions exist. For the purposes of this validation study, the nitrogen model will be considered adequate if model results are within a factor of two of observed values.

The results of the validation study show that the predictions for runoff, sediment, and sediment-bound TKN are within a factor of two. This is not the case for exchangeable ammonium and nitrate, which were generally overpredicted by a factor of five. This would be adequate for a screening level model, but is not for a calibrated hydrologic assessment model.

The predictions of nitrate by the model were high on each plot except plot QF6. The possible explanation for this is that plot QF6 was the only plot that was not fertilized. The model assumes that all fertilizer applied as nitrate is immediately available for movement with infiltration and runoff. The lower observed nitrate values indicate that this assumption may be a source of error in the model. Surface applied fertilizer in the solid form must have time to dissolve before it is transported in runoff, infiltration, and soil water as a result of moisture contact. The model as it is currently configured does not account for this process. The fact that plot QF6, with no fertilizer application, yields a satisfactory prediction suggests that the over prediction of nitrate loss is due to poor simulation in regards to the applied fertilizer and

Table 8. Simulated total loadings from storms R1, R2, and R3.

| Plot | Quantity | Simulated | Observed | Relative Error, % |
|------|------------------------|-----------|----------|-------------------|
| 4 | Runoff (mm) | 8.53 | 11.82 | -27.8 |
| | Sediment (kg) | 1.47 | 1.77 | -16.9 |
| | Sediment-bound TKN (g) | 2.62 | 4.44 | -41.0 |
| | Ammonium (g) | 10.69 | 1.85 | 477.8 |
| | Nitrate (g) | 12.35 | 2.12 | 482.5 |
| 6 | Runoff (mm) | 8.92 | 10.53 | -15.3 |
| | Sediment (kg) | 1.52 | 4.54 | -66.5 |
| | Sediment-bound TKN (g) | 1.91 | 4.50 | -57.6 |
| | Ammonium (g) | 0.25 | 0.20 | 25.0 |
| | Nitrate (g) | 1.07 | 1.80 | -40.6 |
| C | Runoff (mm) | 43.97 | 57.06 | -22.9 |
| | Sediment (kg) | 37.47 | 69.90 | -46.4 |
| | Sediment-bound TKN (g) | 23.65 | 98.48 | -76.0 |
| | Ammonium (g) | 59.99 | 27.11 | 121.2 |
| | Nitrate (g) | 57.44 | 8.44 | 580.6 |
| F | Runoff (mm) | 48.93 | 48.30 | 1.3 |
| | Sediment (kg) | 42.37 | 35.47 | 19.5 |
| | Sediment-bound TKN (g) | 39.24 | 48.72 | -19.5 |
| | Ammonium (g) | 58.76 | 10.47 | 461.2 |
| | Nitrate (g) | 66.90 | 11.06 | 504.9 |

Plot QF4: no-till; fertilizer applied

Plot QF6: no-till; no fertilizer applied

Plot QFC: conventional tillage; fertilizer applied

Plot QFF: conventional tillage; fertilizer applied

may not be due to the component processes of the dissolved nitrogen submodel that deal with the release of nitrate from the soil water to runoff. It is interesting to note that the observed nitrate losses on Plots 4 and 6 are similar despite fertilizer being added to one and not the other. This also suggests that a significant portion of the applied nitrogen was not immediately available for removal in runoff.

Figures 9, 10, and 11 show the observed and predicted concentrations of nitrate in the runoff from several of the experimental plots, over the course of the three simulated rainfall events. It is interesting to note that for each plot, the predicted concentrations of nitrate in runoff for simulation event R2 is far below the levels for events R1 and R3. This trend is not seen as dramatically with the observed nitrate concentrations for R2. Storm event R2 typically is the simulated rainfall event which shows the lowest total volume of runoff. This suggests that the extraction of nitrate from the soil water into runoff and infiltration is not strictly proportional to the ratio of water in surface storage and in the soil surface zone as is assumed in the model. It may be that extraction is a nonlinear relationship that calls for a variation in the extraction factor used in the dissolved nitrogen transport submodel for low runoff events. The model overpredicted nitrate loss by a factor of approximately five on plots that were fertilized, but accurately predicted nitrate loss from the unfertilized plot.

It is difficult to analyze separately the predictive capabilities of the model concerning adsorbed ammonium and dissolved ammonium. No differentiation was made between the two forms in the analysis of plot runoff and therefore in the results they are treated together. The shortcomings of the model in dealing with nitrate fertilizer applications are also evident for dissolved ammonium. The simulation for plot QF6, where no fertilizer was applied, is the only one which yields predictions within a factor of two to the ammonium levels observed in plot runoff.

It is obvious that to be more effective as a planning tool, revisions and further testing of certain model components are necessary. The sediment-bound N subroutine seems to yield adequate results; the dissolved N subroutine, however, appears to overestimate fertilizer availability. The model should be revised to better predict N transformations prior to the storm event and/or in the dissolved N subroutine during the event. No independent verification of the transformation subroutine is included here, however, the subroutine borrows heavily from other models that have been field tested (Donigian and Davis, 1978) and should be adequate.

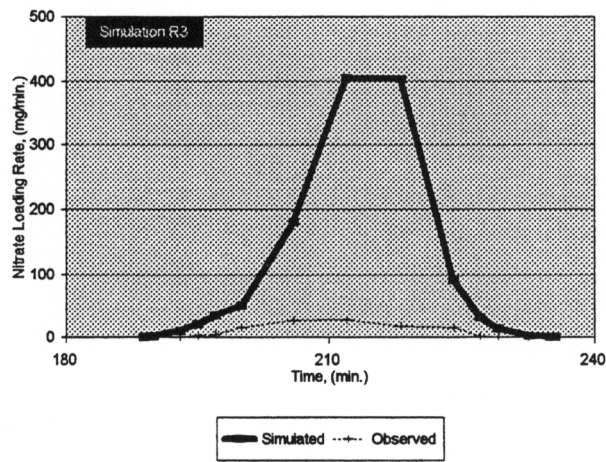
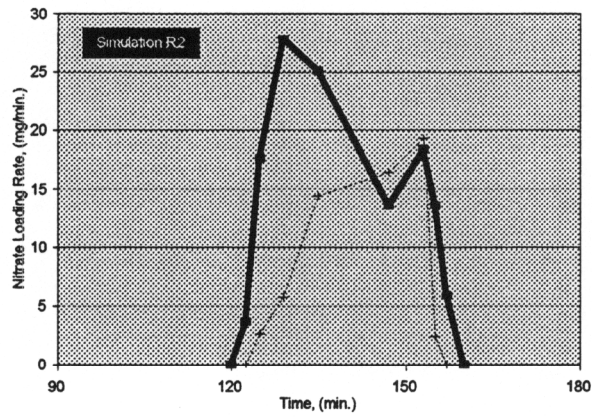
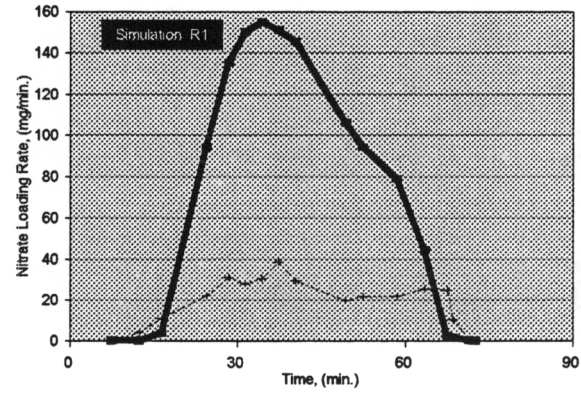


Figure 9. Observed and simulated nitrate loading rates for the fertilized, no-till plot QF4.

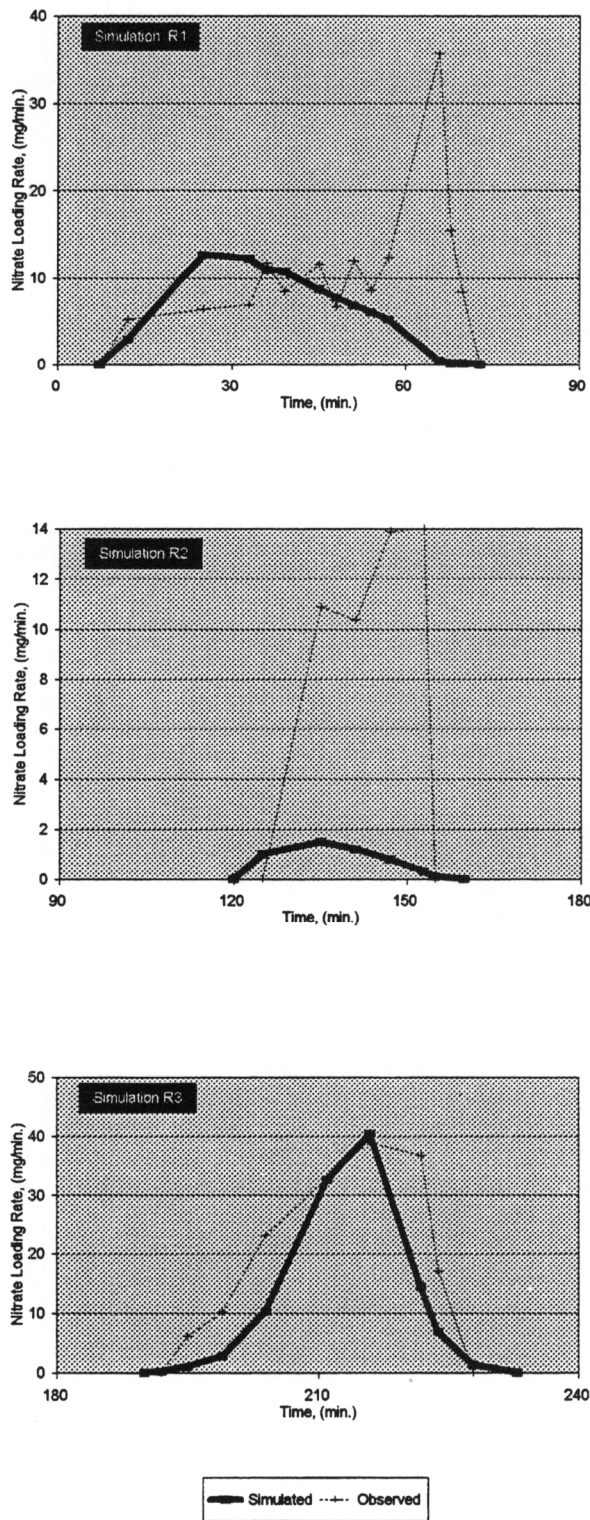


Figure 11. Observed and simulated nitrate loading rates for fertilized, conventional tillage plot QFF.

SENSITIVITY ANALYSIS

A sensitivity analysis was performed on the N component of the ANSWERS model to evaluate the effect of varying individual input parameters on model predictions. Such an analysis aids in identifying model components and parameters which have the greatest impact on model predictions. This allows additional research to improve model accuracy to be focused on those parameters which are most significant.

The sensitivity analysis was performed on the input parameters for Plot QFF and are summarized in Tables 9 and 10. The selected input parameters were varied by a percentage based on their probable range of variability. Table 9 shows the sediment and N yields predicted in the sensitivity analysis model runs. Table 10 gives the resulting percent deviation in the model predictions for each selected input parameter. The reported percent deviations are calculated by the formula:

$$D = \frac{R_v - R_o}{R_o} \times 100 \quad [66]$$

where D is percent deviation, R_o is the resulting model prediction from the original input parameters, and R_v is the resulting prediction from the varied parameter.

The results of the sensitivity analysis show that the dissolved N component of the model is most impacted by EDI (effective depth of interaction) and EXT (nitrogen extraction coefficient). Of these parameters, the model is most sensitive to EDI. EXT is interactive within the model with DF (infiltration control zone). EXT establishes the rate at which dissolved N moves to runoff and infiltrating waters, and DF impacts how much infiltration and runoff will occur. It should be noted that, since the parameter DF is also related to the output hydrograph for the model, attempts to improve dissolved nitrogen model predictions should be focused on EDI and EXT so as not to impact other model components.

Table 9. Absolute change in N submodel predictions due to variations in input parameters.

| Variable | Variation (%) | Sediment Sediment (kg) | Bound N (mg) | Adsorbed Ammonium (mg) | Soluble Nitrogen (mg) | Soluble Ammonium (mg) |
|------------------|---------------|------------------------|--------------|------------------------|-----------------------|-----------------------|
| EDI (10.0 mm) | +50% | 0.0 | 0.0 | 0.0 | 79.6 | 79.6 |
| | -50% | 0.0 | 0.0 | 0.0 | -70.0 | -70.0 |
| n (0.20) | +50% | -2.3 | -2.3 | -2.0 | -3.5 | -3.5 |
| | -50% | 2.5 | 2.5 | 2.0 | 4.8 | 4.8 |
| C (0.433) | +25% | 42.0 | 42.0 | 41.2 | 0.0 | 0.0 |
| | -25% | -42.0 | -42.0 | -41.2 | 0.0 | 0.0 |
| K (0.30) | +25% | 26.7 | 26.6 | 25.5 | 0.0 | 0.0 |
| | -25% | -26.7 | -26.7 | -27.5 | 0.0 | 0.0 |
| TP (48.0%) | +25% | -4.5 | -4.6 | -3.9 | -2.3 | -2.3 |
| | -25% | 4.6 | 4.6 | 3.9 | -1.1 | -1.1 |
| ASM (58.0%) | +25% | 8.5 | 8.5 | 7.8 | 0.0 | 0.0 |
| | -25% | -1.7 | -1.7 | -2.0 | -0.6 | -0.6 |
| DT (30 sec) | +100% | -0.3 | -0.5 | 0.0 | 1.6 | 1.6 |
| | -100% | 0.0 | 0.2 | 0.0 | -1.3 | -1.3 |
| DF (90.0 mm) | +50% | -9.2 | -9.1 | -9.8 | -25.1 | -25.1 |
| | -50% | 9.2 | 9.1 | 9.8 | 35.6 | 35.6 |
| EXT (0.35) | +25% | 0.0 | 0.0 | 0.0 | -12.8 | -12.8 |
| | -25% | 0.0 | 0.0 | 0.0 | 15.2 | 15.2 |

Initial value for each variable is found in parenthesis under variable name.

EDI - effective depth of interaction

n - Manning's n

C - crop management factor

K - soil-erodibility factor

TP - total soil porosity

ASM - antecedent moisture content

DT - simulation time increment

DF - infiltration control zone depth

EXT - soluble nitrogen extraction factor

Table 10. Percent deviation of N predictions due to variation of input parameters.

| Variable | Variation | Sediment Sediment | Adsorbed Bound N | Soluble Ammonium | Soluble Nitrogen | Soluble Ammonium |
|------------------|-----------|----------------------|---------------------|---------------------|---------------------|---------------------|
| EDI (10.0 mm) | +50% | 42.4 | 39.3 | 0.5 | 120.2 | 104.6 |
| | -50% | 42.4 | 39.3 | 0.5 | 20.1 | 17.5 |
| n (0.20) | +50% | 41.4 | 38.3 | 0.5 | 64.6 | 56.2 |
| | -50% | 43.5 | 40.3 | 0.5 | 70.1 | 61.1 |
| C (0.433) | +25% | 60.2 | 55.7 | 0.7 | 66.9 | 58.3 |
| | -25% | 24.6 | 22.8 | 0.3 | 66.9 | 58.3 |
| K (0.30) | +25% | 53.7 | 49.7 | 0.6 | 66.9 | 58.3 |
| | -25% | 31.1 | 28.8 | 0.4 | 66.9 | 58.3 |
| TP (48.0%) | +25% | 40.4 | 37.5 | 0.5 | 65.4 | 56.9 |
| | -25% | 44.3 | 41.1 | 0.5 | 66.2 | 57.6 |
| ASM (58.0%) | +25% | 46.0 | 42.6 | 0.6 | 67.0 | 58.3 |
| | -25% | 41.6 | 38.6 | 0.5 | 66.5 | 57.9 |
| DT (30 sec) | +100% | 42.2 | 39.0 | 0.5 | 68.0 | 59.2 |
| | -100% | 42.4 | 39.3 | 0.5 | 66.0 | 57.5 |
| DF (90.0 mm) | +50% | 38.5 | 35.7 | 0.5 | 50.1 | 43.7 |
| | -50% | 46.3 | 42.8 | 0.6 | 90.7 | 79.0 |
| EXT (0.35) | +25% | 42.4 | 39.3 | 0.5 | 58.3 | 50.8 |
| | -25% | 42.4 | 39.3 | 0.5 | 77.0 | 67.1 |

Initial value for each variable is found in parenthesis under variable name.

EDI - effective depth of interaction

n - Manning's n

C - crop management factor

K - soil-erodibility factor

TP - total soil porosity

ASM - antecedent moisture content

DT - simulation time increment

DF - infiltration control zone depth

EXT - soluble nitrogen extraction factor

The parameters to which the sediment-bound N predictions show the most sensitivity, C (cropping factor) and K (soil erodibility factor), are those which also impact soil erosion predictions to the greatest extent. In all cases, the percent deviations of the sediment-bound N and ammonium mirror the percent deviations for sediment. Therefore, in terms of the parameters included in the sensitivity analysis, improvements to the sediment-bound N submodel predictions cannot be made independently of basic model components such as sediment transport and enrichment. If improvement of the model's ability to predict sediment-bound N loss is necessary, it will have to occur within the component processes of the sediment-bound N submodel.

Tables 11 and 12 are included as a sensitivity analysis of parameters which specifically effect the N transformation subroutine. It can be seen in those tables that the transformation submodel predictions of the forms of nitrogen are only slightly sensitive to variation in the N transformation coefficients, XKAN, XKSA, and XKAS, and are insensitive to time step, NDELTA. This reflects the small amounts of nitrogen being transformed in the model relative to the input values for each form of nitrogen.

Table 11. Absolute changes in transformation submodel predictions due to variations in parameters.

| Variable | Variation (%) | Adsorbed Soluble Soluble | | | |
|----------------|---------------|--------------------------|----------|----------|----------|
| | | Org-N (kg) | NH4 (kg) | NO3 (kg) | NH4 (kg) |
| NDELTA | +100% | 0.0 | 0.0 | 0.0 | 0.0 |
| (60 min) | +100% | 0.0 | 0.0 | 0.0 | 0.0 |
| XKAN (3.00) | +25% | 0.0 | -0.8 | 1.0 | -0.2 |
| | -25% | 0.0 | 1.0 | -1.2 | 0.2 |
| XKSA (5.00) | +25% | 0.0 | 1.0 | -0.8 | -0.2 |
| | -25% | 0.0 | -1.3 | 1.0 | 0.2 |
| XKAS (0.75) | +25% | 0.0 | -1.3 | 1.1 | 0.2 |
| | -25% | 0.0 | 1.6 | -1.3 | -0.3 |

Initial value for each variable is found in parenthesis under variable name.

NDELTA - time step for transformations

XKAN - transformation rate coefficient for ammonium to nitrate

XKSA - adsorption rate coefficient

XKAS - desorption rate coefficient

Table 12. Percent deviation in transformation submodel predictions due to variations in parameters.

| Variable | Variation (%) | Org-N (%) | Adsorbed | Soluble | Soluble |
|----------|---------------|-----------|----------|---------|---------|
| | | | NH4 (%) | NO3 (%) | NH4 (%) |
| NDELTA | +100% | 0.0 | 0.0 | 0.0 | 0.0 |
| (60 min) | +100% | 0.0 | 0.0 | 0.0 | 0.0 |
| XKAN | +25% | 0.0 | -6.3 | 11.3 | -10.6 |
| (3.00) | -25% | 0.0 | 7.3 | -13.3 | 13.1 |
| XKSA | +25% | 0.0 | 7.2 | -8.8 | -10.6 |
| (5.00) | -25% | 0.0 | -9.5 | 11.9 | 14.4 |
| XKAS | +25% | 0.0 | -10.0 | 12.8 | 13.1 |
| (0.75) | -25% | 0.0 | 11.7 | -14.4 | -16.9 |

Initial value for each variable is found in parenthesis under variable name.

NDELTA - time step for transformations

XKAN - transformation rate coefficient for ammonium to nitrate

XKSA - adsorption rate coefficient

XKAS - desorption rate coefficient

USING THE NITROGEN SUBMODEL

The use of the N submodel requires input of numerous variables. In order for the model to run effectively on a watershed scale, the variables must be chosen based on the soil and landuse characteristics in the region in question, often without the benefit of soils testing. The following is meant to be used as a guide in choosing model variables. Familiarity and/or specific knowledge concerning the input variables in a region in which the N submodel is being utilized should be used to supplement or supersede the general guidelines given here. Table 13 is a summary of the nitrogen model input variables.

Number of Particle Size Classes (NPART)

The extended sediment transport model in ANSWERS, developed by Dillaha (1981) and used by the sediment-bound nitrogen subroutine, requires that representative particle classes be defined. A maximum of five particle classes may be input. One suggested method of classification that can be utilized without soil testing is a set of equations developed by Foster et al. (1985). These equations break the sediment composition into five particle classes: primary clay, primary silt, small aggregate, large aggregate, and primary sand. The composition of the aggregate classes in terms of the primary particles is also determined. The equations are functions of the percentage of the primary clay, silt, and sand in the matrix soil in question. These percentages can be estimated for any soil using its textural class and the diagram shown in Figure 12.

Number of Wash Load Classes (NWASH)

This parameter is also for use in the extended sediment transport model. It designates how many of the soil particle classes will be considered wash load in the erosion model. The number of wash load

Table 13. Summary of input variables and formats for the N submodel.

| Variable Name | Variable Type | Format | Column Input | Description |
|----------------------------|---------------|--------|--------------|---|
| NPART | Integer | I2 | 37-38 | Number of soil particle size classes |
| NWASH | Integer | I2 | 37-38 | Number of wash load classes |
| DIAMM | Real Array | F15.8 | 2-16 | Diameter of soil particle class i, mm |
| SG | Real Array | F15.3 | 17-31 | Specific gravity of soil particle class i, kg/cu m |
| FV | Real Array | F15.7 | 32-46 | Fall velocity of soil particle class i, m/s |
| F | Real Array | 8F6.3 | 2-49 | Fraction of particle class i in soil type k |
| PERCLA | Real Array | 8F7.3 | 6-61 | Percentage of total clay in particle class i |
| NDUR | Integer | I6 | 32-37 | Duration of N transformations, min |
| NDELTA | Integer | I5 | 39-44 | Time increment for N transformations, min |
| TEMP | Real | F5.1 | 44-48 | Mean temperature during N transformations, degree C |
| NIT | Integer | I2 | 43-44 | Number of initial N soil categories |
| TKN | Real | F5.1 | 16-20 | Organic N content of soil type k, mg-N/kg |
| ANH4 | Real | F5.1 | 33-37 | Sediment bound ammonium content of soil type k, mg-N/kg |
| SNO3 | Real | F5.2 | 50-54 | Dissolved nitrate in surface zone of soil type k, mg-N/ha |
| SNH4 | Real | F5.2 | 67-71 | Dissolved ammonium in surface zone of soil type k, mg-N/ha |
| FERT | Integer | I2 | 45-46 | Number of fertilizer management practices |
| FERTNO | Real | F6.2 | 20-25 | Nitrate applied in fertilizer for management practice j, kg-N/ha |
| FERTNH | Real | F6.2 | 42-47 | Ammonium applied in fertilizer for management practice j, kg-N/ha |
| ----- Elemental Data ----- | | | | |
| NIT | Integer Array | I8 | 49-56 | Assigns initial N category to element |
| MAN | Integer Array | I4 | 57-60 | Assigns fertilizer management practice |
| PERPOT | Real Array | I7 | 61-67 | Percentage of potentially mineralizable N |
| EDI | Real Array | I4 | 68-71 | Effective depth of interaction |

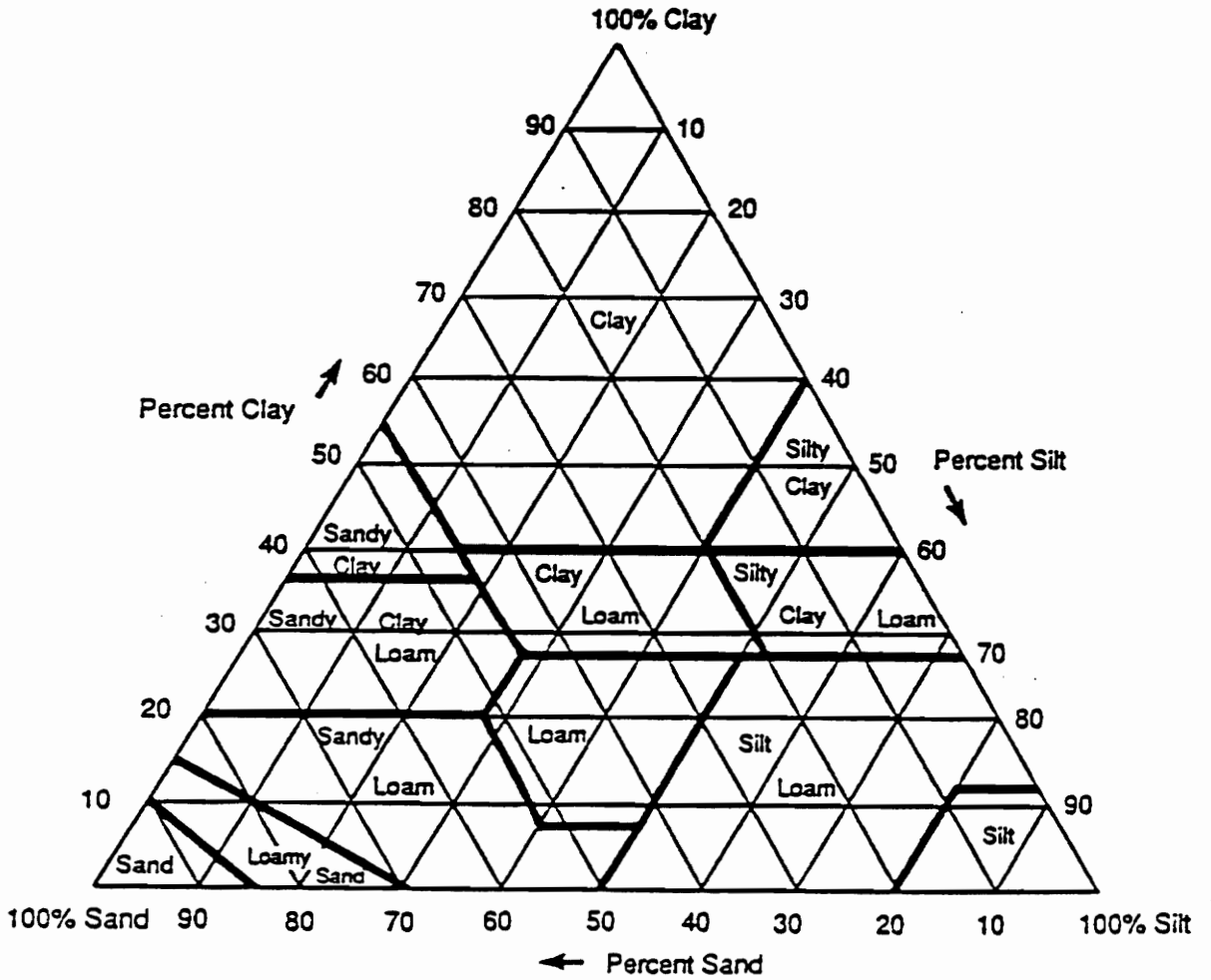


Figure 12. USDA Soil Texture Triangle.

classes cannot exceed the number of particle size classes. The inclusion of one wash load class, primary clay is typical in running the model.

Size (DIAMM), Specific Gravity (SG), Fall Velocity (FV)

The size, specific gravity, and fall velocity for each soil particle class are for use in the sediment transport model. Representative size and specific gravities for the five particle size classes designated by Foster et al. (1985) are as follows:

| <i>Particle Class</i> | <i>Diameter</i> | <i>Specific Gravity</i> |
|-----------------------|-----------------|-------------------------|
| Primary clay | 0.002 mm | 2.65 |
| Primary silt | 0.010 mm | 2.65 |
| Primary sand | 0.200 mm | 2.65 |
| Small aggregates | 0.030 mm | 1.80 |
| Large aggregates | 0.400 mm | 1.60 |

In lieu of testing or specific knowledge concerning particle fall velocities, the model will calculate an estimated fall velocity for each particle class using Stokes Law. This component of the model is only utilized in the absence of input fall velocities.

Particle Size Fractions (F)

The fraction of the matrix soil made up by each of the designated soil particle classes for use in the sediment transport model. Particle size fractions are input for each soil which exists in the modeled area. The following equations from Foster et al. (1985) can be used to determine particle size fractions for a soil from the percentage of primary clay, silt, and sand in the matrix soil:

Primary clay

$$F_{cl} = 0.25 O_{cl} \tag{67}$$

where Fcl is the fraction of the sediment composed of the primary clay class and Ocl is the clay fraction in the matrix soil.

Small aggregate

$$F_{sg} = 1.8 O_{cl} \quad O_{cl} > 0.25 \quad [68]$$

$$F_{sg} = 0.45 - 0.6 (O_{cl} - 0.25) \quad 0.25 \leq O_{cl} \leq 0.50 \quad [69]$$

$$F_{sg} = 0.6 O_{cl} \quad O_{cl} > 0.50 \quad [70]$$

where Fsg is the fraction of the sediment composed of the small aggregate class.

Primary silt

$$F_{si} = O_{si} - F_{sg} \quad [71]$$

In this equation, Fsi is equal to the fraction of the primary silt class in the sediment and Osi is the fraction of silt in the matrix soil. If Fsi results in a negative number from equation [71], then Fsi is set equal to zero and Fsg is set equal to Osi.

Primary sand

$$F_{sa} = O_{sa} (1 - O_{cl})^5 \quad [72]$$

where Fsa is the primary sand class in the sediment and Osa is the sand fraction in the matrix soil.

Large aggregate

$$F_{lg} = 1 - F_{cl} - F_{si} - F_{sg} - F_{sa} \quad [73]$$

The calculation of F_{lg} , the fraction of large aggregate in the sediment, by equation [73] assures that the sum of all the particle classes equals one.

It should be noted that in using Foster's equations to determine particle size fractions, most of the primary clay and possibly all of the primary silt will be contained in the small and large aggregates. For this reason, F_{cl} and F_{si} are typically very small.

Fraction of Clay in Particle Classes (PERCLA)

The fraction of the total clay which exists in each soil particle class is used in the sediment-bound nitrogen transport subroutine. The primary particle composition of the sediment classes are also given by Foster et al. (1985). The equations for the fraction of clay, f_{cl} , in each particle class are as follows:

Primary clay

$$f_{cl}(sl) = 1.0 \quad [74]$$

Primary silt

$$f_{cl}(si) = 0.0 \quad [75]$$

Small aggregate

$$f_{cl}(sg) = O_{cl} / (O_{cl} + O_{si}) \quad [76]$$

Primary sand

$$f_{cl}(sa) = 0.0 \quad [77]$$

Large aggregate

$$f_{cl}(lg) = [O_{cl} - F_{cl} - (F_{sg} \times f_{cl}(sg))] / F_{lg} \quad [78]$$

To assure large aggregate stability, the assumption was made that the clay content of the large aggregates is a minimum of one-half that of the matrix soil (Foster et al., 1985). If the clay content computed in equation [78] is less than one-half the clay content of the matrix soil, the fraction of sediment in the small aggregate class is recalculated as:

$$F_{sg} = (0.3 + 0.5S)(O_{cl} + O_{si}) / [1 - 0.5(O_{sl} + O_{si})] \quad [79]$$

where: $S = F_{cl} + F_{si} + F_{sa}$. This ensures that f, cl, lg will meet the required minimum of one-half of O_{cl} .

Duration of Transformations (NDUR)

NDUR is the period of time (minutes) between fertilizer application and the simulated storm. The length of this period should be chosen to meet the simulation purposes of the user.

Time Increment for Transformations (NDELTA)

The time step used in the nitrogen transformation submodel in the equations for mineralization, nitrification, and adsorption/desorption. A time step of 60 minutes is recommended.

Mean Temperature During Transformations (TEMP)

The average daily temperature over which the model simulation is run in degrees Celsius. This parameter is used as an approximation of the soil temperature for use in the nitrogen transformation subroutine.

Number of Initial Nitrogen Soil Categories (NIT)

The number of initial nitrogen soil categories that are to be used in a model simulation. The N category for each cell in a simulated watershed consists of the initial concentrations of: total organic N, adsorbed NH_4^+ , soluble NH_4^+ , and NO_3^- . Each cell in the watershed being modeled is assigned an N soil category based on soil type and landuse. The number of soil categories for any watershed will depend

on the variety and combination of soil types and land uses within it. A maximum of forty nitrogen soil categories may be input to the model

ORG-N (TKN)

The total organic nitrogen content for an individual soil makeup in mg-N/kg-soil. This parameter is important in the nitrogen transport model as it directly relates to the loss of nitrogen with eroded sediment and is the major soil nitrogen pool involved in N transformations in the soil. However, it is also one of the most difficult parameters to quantify accurately. The dependence of soil organic N content on soil texture, prior landuse, and climate make it variable and hard to quantify.

Using a reported range of soil N content from .0005 to .003 kg-N/kg-soil (CREAMS, 1980) and a soil clay content from 5 to 80% based on soil surveys in Virginia, Yagow et al. (1990) established a linear relationship between organic soil nitrogen and clay content of the form:

$$\text{NORG} = (3.35 + 0.33 \times \text{CLAY}) \times 0.0001 \quad [80]$$

where:

NORG = soil N content, kg-N/kg-soil

CLAY = clay content, percent

Equation [80] can be converted to mg-N/kg-soil as required for model input by multiplying by 10^6 .

As shown in a study by Smith and Young (1975), substantial variations in the nitrogen content of soils may occur as the result of climate. In general, northern soils have higher nitrogen content than do southern soils. Since equation [80] was developed based on nitrogen contents from soils all over the United States, modification may be in order to better reflect conditions in a study area. Nitrogen content ranges for a specific region may be obtained from state or commercial soil testing laboratories. Data from soil test laboratories or Soil Conservation Service (SCS) publications can also help account for variations in organic N content due to landuse.

ADS-NH4 (ANH4)

The total of sediment bound ammonium for a soil nitrogen category, includes both the nonexchangeable ammonium and the adsorbed ammonium, in mg-N/kg-soil. Bremner (1965) states that the ratio of nonexchangeable ammonium to total N rarely exceeds eight percent in surface soils. A study by Smith and Young (1975) for eight agricultural soils found average values for nonexchangeable ammonium in the range 6.6 to 10.9 percent. The lower values in the Smith and Young (1975) study were generally for virgin soils. The possibility of the reported values being high due to problems with the extraction procedure was also raised. The same study showed that the adsorbed ammonium generally constituted approximately two percent of the total sediment bound ammonium. It is clear that the nonexchangeable ammonium is by far the dominant fraction of the sediment bound ammonium. Therefore, the use of eight percent of the total N content as the sediment bound ammonium model input is suggested. This percentage is close to the values found in soils testing performed on the study plots used for model verification.

SOL-NO3 (SNO3)

The concentration of soluble nitrate in the upper centimeter of a soil category in mg-N/ha. An observed range of 2 ppm to 5 ppm for nitrate in the surface zone has been reported by Frere et al. (1980). Parts per million are easily converted to the correct units for model input utilizing the following equation:

$$\text{SOLNO3} = \frac{\text{PPM} \times \text{TP}}{10} \quad [81]$$

where: SOLNO3 is in mg-N/ha, PPM is nitrate in parts per million, TP is total porosity, and 10 is a unit conversion factor. Smith and Young (1975) reported that the NO₃ in the surface zone is typically about 1% of the total N, reflects the range given by Frere et al. (1980). At a minimum, the value for nitrate in the soil zone should be higher than that in rainfall. Generally speaking, fertilizer application will overshadow the estimate of the initial soluble nitrate concentration of the soil in terms of what is reflected in the simulated runoff.

SOL-NH4 (SNH4)

The amount of soluble ammonium in a surface soil category is input in mg-N/ha. Soluble NH_4^+ is generally found in only minute amounts in the soil. This is due to the dynamic nature of soluble ammonium which is subject to plant uptake, nitrification and adsorption, and is continually added to the soil in the mineralization process. The transformation subroutine automatically establishes a concentration for soluble NH_4^+ balanced between mineralization, nitrification, and adsorption/desorption. In addition, any fertilizer input will typically be several orders of magnitude greater than the initial soluble ammonium concentration. Therefore, the assumption that the initial soluble ammonium concentrations in each soil category is zero is acceptable and will have little effect on the modeling results.

Number of Fertilizer Management Practices (FERT)

Each cell in the watershed being modeled is assigned a fertilizer practice. The fertilizer management practice for each cell consists of the amount of nitrate and ammonium that are applied to the soil surface for a particular crop and tillage practice. In a management practice where fertilizer is incorporated, only the portion of the nitrate and ammonium remaining in the upper centimeter of the soil is considered. Estimates of soil fertilizer availability as related to tillage practice can be found in Williams (1983). A maximum of ten fertilizer management practices can be input to the model.

Nitrate (FERTNO) and Ammonium (FERTNH)

Represents the nitrate and ammonium fertilizer (kg-N/ha) applied in one fertilizer application for an individual management practice. Nutrient management guides which contain fertilization levels for crop type and management practice are typically available from state agencies.

The following are elemental variables entered for each cell:

NIT (NIT)

Assigns an initial nitrogen soil category for that cell by referring to a previously input table containing concentrations of organic N, sediment bound ammonium, soluble ammonium, and solute nitrate in the soil.

MAN (MAN)

Assigns a fertilizer management practice for that cell by referring to a previously input table containing nitrate and ammonium fertilizer application rates.

PERPOT (PERPOT)

The percentage of total N which is available for mineralization in each cell. This percentage is multiplied by total N to yield POTMIN, potentially mineralizable N, for use in equation [42] in the transformation subroutine. A study by Stanford and Smith (1972) determined the mineralization potential for various soils. Partial results of that study are shown in Table 14. In the study, mineralization potentials were found to range from 5 to 41 percent of total N. Cropping and fertilization practices appear to have significant impact on the percentage of total N in mineralizable forms. Corn in rotation showed higher mineralization potentials than did continuous corn, as did soils where manure had been applied in combination with nitrogen fertilizer. It is worth noting that in soils with lower levels of total N, less than 1000 mg/kg, the variation in the proportion of mineralizable nitrogen was greatest, from 5 to 41 percent. This is in contrast with soils having nitrogen levels greater than 1000 mg/kg, where the potentially mineralizable N varied from 10 to 25 percent. It is therefore necessary to take management practice, soil type, and total nitrogen content into consideration when estimating mineralization potentials.

EDI (EDI)

The effective depth of interaction of the surface soil in each cell is input in millimeters. Effective depth of interaction is dependent on numerous factors including: hydraulic conductivity, soil aggregation, slope, rainfall intensity, and plant residue. A study by Sharply (1985) found EDI's ranging from 1.5 mm to 37.43 mm corresponding to soils with low to high aggregation. The same study showed an 86 to 41 percent reduction in EDI due to surface residue. Similar values were reported by Ahuja (1982). An EDI of 10 millimeters is suggested for running the model. This value is used in the CREAMS (Knisel, 1980),

Table 14. Mineralization potential for 31 soils (Stanford and Smith, 1972).

| Soil Designation | Location | Classification | Organic C (%) | Total N (%) | N Mineralization Potential (%) |
|------------------|----------|-------------------------|---------------|-------------|--------------------------------|
| Amarillo fsl | Tex. | Aridic Paleustalf | 0.53 | 0.053 | 17.4 |
| Hagerstown sil | Pa. | Typic Hapludalf | 1.64 | 0.144 | 15.2 |
| Grenada fsl | Miss. | Glossic Fragiudalf | 1.28 | 0.132 | 27.0 |
| Corfu fsl | Wash. | Xerollic Camborthid | 0.29 | 0.043 | 9.1 |
| Minidoka sil | Ida. | Xerollic Durothid | 1.00 | 0.128 | 23.1 |
| Portneuf sil | Ida. | Xerollic Calciothid | 0.67 | 0.104 | 19.7 |
| Shano sil | | Xerollic Camborthid | 0.23 | 0.039 | 4.6 |
| Warden fsl | Wash. | Xerollic Camborthid | 0.28 | 0.040 | 16.0 |
| Colby sil | Cal. | Ustic Torriorthent | 0.78 | 0.096 | 15.4 |
| Holtville scl | | Typic Torriorthent | 0.95 | 0.127 | 24.0 |
| Lakeland ls | S.C. | Typic Quartzipsamment | 0.26 | 0.031 | 10.0 |
| Quincy ls | Ore. | Typic Torripsamment | 0.35 | 0.039 | 29.2 |
| Aastad cl | Minn. | Pachic Udic Haploboroll | 3.02 | 0.291 | 10.9 |
| Barnes l | Minn. | Udic Haploboroll | 2.43 | 0.234 | 13.6 |
| Bearden sil | Minn. | Aeric Calciaquoll | 2.19 | 0.190 | 11.9 |
| Kranzburg sil | S. Dak. | Udic Haploboroll | 2.38 | 0.231 | 13.5 |
| Parshall fsl | N. Dak. | Udic Haploboroll | 1.32 | 0.112 | 12.5 |
| Palouse sil | Wash. | Pachic Udic Haploboroll | 1.82 | 0.135 | 11.5 |
| Pullman sicl | Tex. | Pachic Paleustoll | 1.06 | 0.110 | 25.7 |
| Rago sil | | Pachic Argiustoll | 1.01 | 0.110 | 15.4 |
| Regent sicl | N. Dak. | Typic Argiboroll | 2.46 | 0.222 | 10.4 |
| Ritzville sil | Wash. | Calciothidic Haploxerol | 0.72 | 0.068 | 10.0 |
| Sprolesil | Mont. | Typic Argiboroll | 1.40 | 0.145 | 19.8 |
| Temvik sil | N. Dak. | Typic Haploborroll | 2.40 | 0.205 | 11.7 |
| Walla Walla sil | Wash. | Typic Haploxeroll | 1.00 | 0.085 | 12.1 |
| Weld sil | | Aridic Paleudult | 0.53 | 0.065 | 21.5 |
| Cecil sl | Ga. | Typic Hapludult | 0.34 | 0.021 | 23.8 |
| Goldsboro sl | S.C. | Aquic Paleudult | 0.66 | 0.039 | 11.0 |
| Greenville fsl | Ala. | Rhodic Paleudult | 0.92 | 0.048 | 21.0 |
| Leck Kill sil | Pa. | Typic Hapludult | 1.51 | 0.115 | 25.7 |
| Norfolk fsl | S.C. | Typic Paleudult | 0.45 | 0.030 | 13.3 |

Note: Information as to past management practice for each soil is included in Stanford and Smith (1972).

GLEAMS (Leonard, et al., 1987), EPIC (Sharpley and Williams, 1990), and AGNPS (Young et al., 1987) models. A reduction of EDI to 6 millimeters might be considered with a land use such as no-till.

RNO3 and RNH4

Respectively, the nitrate and ammonium concentration of the simulated rainfall. RNO3 and RNH4 are not inputs to the model. However, they are initialized in the soluble subroutine (SOLNIT) and since nitrogen concentrations in rainfall vary with geographic location, it may be necessary to edit the initialized values in the program to better reflect conditions in the geographic area in which the model is being run. A study by Buikema et al. (1986) estimated nitrogen in precipitation to be in the range 0.27 to 0.45 ppm for NO_3^- and 0.16 to 0.27 for NH_4^+ . These values are multiplied by 10^{-3} to be converted to kg/m^3 for use in the model. Frere et al. (1980) reported that the total concentration of nitrogen in rainfall is approximately 1 ppm. For this reason, the model uses the upper range of numbers given by Buikema et al. (1986). Specific information as to the nitrogen concentrations in rainfall in which a watershed is being modeled may predicate changes to the values of RNO3 and RNH4 currently used in the model.

SUMMARY AND CONCLUSIONS

Summary

Nitrogen dynamics and transport submodels were developed to simulate the transport of soluble and sediment-bound nitrogen in surface runoff from agricultural land. The subroutines were incorporated into the distributed parameter watershed model, ANSWERS. The nitrogen submodel includes a component whereby residual soil nitrogen and that applied in fertilizer are transformed into various forms prior to a simulated rainfall event. Mass balance equations are used to account for the movement of soluble forms of nitrogen from the soil surface zone to infiltrating waters and surface runoff. Sediment-bound nitrogen loss is modeled as a function of the clay content of the original soil matrix and the transported sediment. The nitrogen submodel relies heavily on an extended sediment transport model in the version of ANSWERS being utilized which simulates the transport of sediment by individual particle size classes. The nitrogen submodel is designed for use with no calibration and a simple knowledge of watershed landuse practices and soil characteristics for input parameter selection. Documentation is included to simplify model input.

To validate the effectiveness of the model developed in this research, results from plot studies performed at the Prices Fork Research Farm in Blacksburg, Virginia, were used. The comparison of data from the plot studies to simulated nitrogen losses from model runs yielded mixed results. Estimated sediment-bound nitrogen losses were within a factor of two to field observed values. However, predicted soluble nitrogen losses were overestimated by the model by a factor of five. The exception to this was one plot where no fertilizer was applied, and model results compared favorably to plot data. This indicates that the model may not adequately simulate the availability of recently applied fertilizer to surface runoff.

Conclusion

To be more effective as a planning tool, revisions and further validation of certain model components are necessary. The sediment-bound N subroutine seems to yield adequate results, however, further validation under varying field and cropping conditions at the plot and watershed level are needed. The model overestimates dissolved nitrogen losses in runoff in situations where fertilizer has been applied just prior to the rainfall event. A revision to the model is needed to account for the availability for loss in runoff of fertilizer applied in the solid form or in how this information is input into the model. Again, additional validation of the model is needed to further assess its potential for estimating dissolved nitrogen losses in runoff.

The processes by which soluble and sediment-bound nitrogen are removed from the soil surface zone and transported in overland runoff are very complex. An impediment to developing the nitrogen transport model presented here is the lack of good quantitative understanding of these processes. This was true particularly in the area of soluble nitrogen transport. In order to improve the predictive capabilities of the nitrogen transport model, the following recommendations are made as possibilities for future research:

1. Development of improved physically-based relationships to more accurately describe nitrogen fertilizer application and transformations. This appears to be the greatest shortcoming of the model and could possibly be accomplished through additional field plot studies with careful monitoring of soil nitrogen levels and loss in runoff and percolating water.
2. Validation through additional field testing of the current model's sediment-bound and soluble ammonium submodel. Losses of ammonium attached to sediment in its individual constituents could not be investigated here due to a lack of field data. Should it prove necessary, algorithms can be added to the model to account for the adsorption/desorption of ammonium during the rainfall event. Adsorption/desorption of ammonium is currently only considered in the model prior to rainfall.

3. Investigation of the extraction factor used in the soluble nitrogen subroutine to verify its value under varying cropping systems and field conditions. The accuracy of the soluble nitrogen transport model is largely dependent on the interplay between the extraction factor and a soil's effective depth of interaction. Further testing of this interaction is needed to solidify the model's predictive capability.
4. Addition of a groundwater component to the model to enable the tracking of nitrogen in the soil profile once it leaves the surface zone. The model currently has the capability to predict the loss of nitrogen in infiltrating waters from the soil surface zone only. Although groundwater processes are extremely complex, the development of even a very simplified groundwater component would greatly expand the model's usefulness by enabling the user to examine the impact of BMPs designed to reduce surface losses on groundwater loading.
5. Estimation of characteristic base soil N levels for surface soils for various crop types, farm practices, and climatic zones through soil testing and the review of existing literature. The nitrogen model is extremely dependent on initial soil nitrogen levels and the establishment of such a database would greatly facilitate model use and enhance its predictive capabilities.

The new model does show potential for predicting nitrogen losses in runoff and erosion. Additional research is needed to increase its usefulness as a planning tool for evaluating the effect of alternative best management practices on nitrogen loss from agricultural areas.

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APPENDICES

APPENDIX A: Variable Glossary

| NAME | TYPE | MAIN USE | DEFINITION |
|--------------------|------|-----------|--|
| A | R | ARRAY | Infiltration coefficient in Holtan's equations for element i |
| ADIR | R | VARIABLE | Retention depth on volume per unit area, m |
| AGRAV | R | VARIABLE | Acceleration of gravity is m/s ² |
| A _{INNH4} | R | VARIABLE | Mass of soluble NH ₄ entering a cell in inflow and rainfall, kg |
| A _{INNO3} | R | VARIABLE | Mass of soluble nitrate entering a cell in inflow and rainfall, kg |
| AKNSTR | R | VARIABLE | Adsorbed nitrogen in storage for particle class i, mg-N/sec |
| ANG | R | VARIABLE | Slope direction of element in degrees counter-clockwise from positive row axis |
| ANHCON | R | VARIABLE | Concentration of adsorbed N on sediment of particle class i, leaving a cell or being deposited, mg-N/kg-soil |
| ANHIN | R | ARRAY | Rate of adsorbed nitrogen coming into a cell from adjacent elements for particle class i, mg-N/sec |
| ANHNEW | R | ARRAY | Rate of adsorbed nitrogen being newly eroded in a cell for particle class i, mg-N/sec |
| ANHOUT | R | ARRAY | Rate of adsorbed nitrogen leaving a cell for particle class i, mg-N/sec |
| ANHSEL | R | VARIABLE | Aggradation value for adsorbed nitrogen in a cell, mg-N/sec |
| ANH4 | R | VARIABLE | Beginning concentration of adsorbed NH ₄ , kg-N/ha |
| AREA | R | VARIABLE | Catchment area as sum of element areas, ha |
| AREA2 | R | VARIABLE | Element or channel area, m ² |
| ASM | R | EQV ARRAY | Antecedent soil moisture as a fraction of pore space for soil i |
| ASMBAR | R | VARIABLE | Average ASM |
| B | R | ARRAY | Conveyance in Manning's equation |

| | | | |
|--------|---|-----------|--|
| BD | R | ARRAY | Soil bulk density, g/cm ³ |
| B0 | R | VARIABLE | Coefficient related to the binding strength of |
| CBAR | R | EQV ARRAY | Percent of watershed in crop i |
| CD | R | VARIABLE | Drag coefficient used in determining particle fall velocity |
| CDR | R | ARRAY | Erosion parameter for crop management practice i |
| CELANH | R | ARRAY | Concentration of adsorbed nitrogen in the soil of a cell for particle class i. mg-N/kg-soil |
| CELTKN | R | ARRAY | Concentration of fixed nitrogen in the soil of a cell for particle class i, mg-N/kg-soil |
| CE3-6 | R | VARIABLE | Constants in erosion equations |
| CHAN | I | EQV ARRAY | Constant indicating presence of absence of channel in an element |
| CHDR | R | VARIABLE | Groundwater discharge into a channel segment |
| CHN | R | VARIABLE | Number of channel segments |
| CINNH4 | R | VARIABLE | Concentration of ammonium in the inflow to an element, kg/m ³ |
| CINNO3 | R | VARIABLE | Concentration of nitrate in the inflow to an element, kg/m ³ |
| CN | R | EQV ARRAY | Manning's "n" for channel type i |
| CONST | R | VARIABLE | Flow depth units conversion factor |
| CONV | R | VARIABLE | Catchment conversion constant for mm/h to m ³ /s |
| CROP | R | EQV ARRAY | Alphanumeric name of crop i |
| CU | R | VARIABLE | Element conversions constant for mm/h to m ³ /s |
| CU1 | R | VARIABLE | Element conversion constant for mm to m ³ |
| CU2 | R | VARIABLE | Element conversion constant for twice m ³ |
| CWID | R | EQV ARRAY | Width of channel segment i |
| CY1-5 | R | ARRAY | Simplifying constants used in transport equation |
| C1-6 | R | VARIABLE | Product of CDR and SKDR for element |
| D | R | VARIABLE | Depth increment in segmented depth curve |
| DATE | R | EQV ARRAY | Date of event being simulated |
| DC | R | VARIABLE | Tile drainage coefficient |
| DD | R | VARIABLE | Portion of tile drainage flowing in a row direction |
| DELTA | R | ARRAY | Variable in transport equation |
| DENOM | R | VARIABLE | Denominator used in proportioning soluble nutrients to outflow and storage in mass balance procedure (m ³ & sec or m ³) |
| DEP | R | VARIABLE | Storage depth on element in volume per unit area, m |
| DETF | R | VARIABLE | Rainfall detachment, kg/s |
| DETR | R | VARIABLE | Rainfall detachment, kg/s |
| DF | R | EQV ARRAY | Infiltration control zone depth for soil i, mm |
| DI | R | VARIABLE | Simulation time minus rainfall histogram change time, s |

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|--------|---|-----------|---|
| DIA | R | ARRAY | Particle diameter, m |
| DIAMM | R | EQV ARRAY | Particle diameter, mm |
| DIN | R | EQV ARRAY | Accumulated tile drainage rate in element i, m |
| DIR | R | EQV ARRAY | Retention depth for cropping practice i, m ³ /s |
| DIRM | R | EQV ARRAY | Maximum physical retention depth for cropping practice i, mm |
| DP | R | VARIABLE | Deposition rate kg/s |
| DR | R | ARRAY | Vertical drainage loss from control zone of element i, m ³ /s |
| DRA | R | VARIABLE | Incremental increase in outflow from element in row direction, m ³ /s |
| DRANE | R | VARIABLE | Rate of tile drainage in element, m ³ /s |
| DRFT | R | VARIABLE | Sum of rainfall and flow detachment, kg/s |
| DS | R | VARIABLE | Maximum rate of sediment inflow and erosion in element, kg/s |
| DS1 | R | ARRAY | DS with only rainfall detachment, kg/s |
| DS2 | R | ARRAY | DS with rainfall and flow detachment, kg/s |
| DT | R | VARIABLE | Simulation time increment in seconds |
| DTM | R | VARIABLE | Simulation time increment in minutes |
| DTMIN | R | VARIABLE | Minimum time increment in any hyetograph |
| DX | R | VARIABLE | Length of side of square element, m |
| DX2 | R | VARIABLE | Area of element, m ² |
| EDMM | R | ARRAY | Equivalent sand diameter of particle i, mm |
| EQSDIA | R | ARRAY | Equivalent sand diameter of particle i, m |
| ER | R | ARRAY | Amount of particle type i leaving watershed, kg/s |
| ERG | R | VARIABLE | Sum of ER for all particle classes, kg/s |
| EXT | R | VARIABLE | Extraction coefficient in soluble nutrients submodel |
| EXTFAC | R | VARIABLE | Extraction factor used in the soluble nutrient submodel |
| F | R | ARRAY | Fraction of particles of type i in original soil |
| FC | R | ARRAY | Minimum, supply unlimited infiltration capacity for soil i, m ³ /s (input as mm/h) |
| FCAP | R | EQV ARRAY | Field capacity for soil i as a fraction of pore space |
| FERTNO | R | VARIABLE | NO ₃ applied in fertilizer, kg-N/ha |
| FERTNH | R | VARIABLE | NH ₄ applied in fertilizer, kg-N/ha |
| FH | R | VARIABLE | Maximum physical water depth in element, m |
| FHS | R | VARIABLE | FLINS plus FLIN |
| FIL | R | VARIABLE | Infiltration into element during time increment, m ³ /s. |
| FILNH4 | R | ARRAY | Mass of ammonium carried out of an element in infiltrating waters, kg |
| FILNO3 | R | ARRAY | Mass of nitrate carried out of an element in infiltrating waters, kg |
| FILTS | R | EQV ARRAY | Infiltration capacity for element i, m ³ /s |

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|--------|---|-----------|---|
| FLIN | R | VARIABLE | Net rate of flow into an element less losses, m ³ /s |
| FLINS | R | ARRAY | Storage, inflow and outflow for element i at start of time increment, m ³ /s |
| FLODEP | R | VARIABLE | Depth of flow in element or channel, m |
| FMAX | R | VARIABLE | Maximum infiltration capacity, surface inundated, m ³ /s (input as mm/h) |
| FPBAR | R | VARIABLE | P in Holtans equation |
| FRA | R | ARRAY | Fraction of catchment area covered by rain gauge i |
| FV | R | ARRAY | Fall velocity of particle type i, m/s |
| FWA | R | VARIABLE | Fraction of surface area of element covered by water |
| GRF | R | VARIABLE | Fractional rate of baseflow release |
| GWC | R | ARRAY | Volume of air filled pore space at field capacity for soil i, m |
| HU | R | ARRAY | Maximum height differential on soil surface, mm |
| ICR | I | VARIABLE | Number of cropping practices |
| IEL | I | EQV ARRAY | Array for data manipulation |
| IG | I | EQV ARRAY | Alphanumeric number for rain gauge |
| II | I | VARIABLE | Number of channel segments |
| IRR | I | EQV ARRAY | Number of rainfall intensity readings for rain gauge i |
| IS | I | VARIABLE | Soil type for current element |
| ISR | I | VARIABLE | Number of soil types |
| ISTL | I | VARIABLE | Comparator for sensing presence of drain tile in element |
| ISTRUC | I | VARIABLE | Counter for structural practices |
| ITEMP | I | EQV ARRAY | Array for input data manipulation |
| ITR | I | VARIABLE | Rainfall histogram counter |
| IX | I | VARIABLE | Constant to indicate presence of a channel in an element |
| IY | I | VARIABLE | Segment number on segmented discharge curve |
| I1-3 | I | VARIABLE | Counter |
| JJ, JK | I | VARIABLE | Counters |
| JMAX | I | VARIABLE | Dimension in IEL |
| JS | I | VARIABLE | Column number for last column on current element row, plus 1 |
| JTR | I | ARRAY | Current rainfall intensity histogram period for rain gauge i |
| J1-3 | I | VARIABLE | Counters |
| K | I | VARIABLE | Number of values in rainfall hyetograph and surface type of current element |
| KK | I | VARIABLE | Soil type for current element |
| KPR | I | VARIABLE | Number of time increment routings between print lines |
| K1 | I | VARIABLE | Counter |

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|--------|---|-----------|---|
| L | I | VARIABLE | Number of last element in row and a counter |
| M | I | VARIABLE | Element number counter and slope direction quadrant |
| MAN | R | VARIABLE | Integer in elemental data file referring to the fertilizer management practice in that cell |
| MOUT | I | VARIABLE | Catchment outflow overland flow element number |
| N | I | VARIABLE | Number of overland flow elements |
| NC | I | ARRAY | Number of element receiving outflow from element i in a column direction |
| NDOR | R | VARIABLE | Number of days for transformation to occur before storm |
| NDT | I | VARIABLE | Number of lines of hydrograph print |
| NEXP | I | VARIABLE | Exponent in equation controlling drainage rate from infiltration control zone |
| NF | I | ARRAY | Down-Counter from NF1 |
| NFI | I | VARIABLE | Maximum number of time increments between infiltration recalculations |
| NIOUT | I | VARIABLE | Row number of catchment outflow element |
| NIT | R | VARIABLE | Integer in elemental file referring to the nitrogen concentrations in that cell |
| NJOUT | I | VARIABLE | Column number of catchment outflow element |
| NMAX | I | VARIABLE | Maximum number of elements |
| NN | I | VARIABLE | $N2 + 1$ |
| NPAR | I | VARIABLE | Dimension of IEL and ITEMP |
| NPART | I | VARIABLE | Number of particle size classes |
| NPM | I | VARIABLE | $NPART - NWASH1$ |
| NR | I | ARRAY | Number of element receiving outflow from element i in a row direction |
| NRG | I | VARIABLE | Number of rain gauges |
| NSTRUC | I | EQV ARRAY | Type of structural practice |
| NWASH1 | I | VARIABLE | $NWASH + 1$ |
| N1 | I | VARIABLE | $N + 1$ |
| N2 | I | VARIABLE | Number of overland flow plus channel elements |
| OLDSED | R | VARIABLE | Previous transported sediment after time step for particle class i, kg/sec |
| OUTNH4 | R | VARIABLE | Mass of ammonium being carried in the outflow from an element, kg |
| OUTNO3 | R | VARIABLE | Mass of nitrate being carried in the outflow from an element, kg |
| OUTSID | R | VARIABLE | Area of watershed border elements which drain outside of watershed |
| P | R | ARRAY | Parameter in Holtan's equation for surface condition i |
| PER | R | ARRAY | Fraction of element area covered by foliage for surface type i |
| PERCLA | R | ARRAY | Percentage of the total amount of clay in the soil in particle class i |

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|--------|---|-----------|--|
| PERPOT | R | VARIABLE | Percent of potentially mineralizable N |
| PIT | R | ARRAY | Interception storage for cover for surface type i, mm |
| PIV | R | ARRAY | Volume of air filled pore space in control zone in element i |
| PIV2 | R | VARIABLE | Same as PIV |
| POTMIN | R | VARIABLE | Potentially mineralizable N, kg-N/ha |
| PP | R | ARRAY | Alphanumeric unit description |
| PRACT | I | VARIABLE | Counter for structural practices |
| PREC | R | VARIABLE | Accumulated depth of precipitation, mm |
| PRI | R | VARIABLE | PR comparator for print of hyetograph(s) |
| PS | R | ARRAY | Variable in transport equation |
| PSTOLD | R | ARRAY | Specific surface area of sediment leaving watershed, kg/s |
| Q | R | ARRAY | Outflow from element i at start of time increments, m ³ /s |
| QA | R | ARRAY | Incremental depth power values for segmented curve |
| QD | R | VARIABLE | Differential in discharge on curve segment |
| QENH4 | R | VARIABLE | Rate of ammonium leaving an element for adjacent elements, kg/sec |
| QENO3 | R | VARIABLE | Rate of nitrate leaving an element for adjacent elements, kg/sec |
| QI | R | ARRAY | Inflow to element i from adjacent elements m ³ /s |
| QINH4 | R | ARRAY | Rate of ammonium moving into an element from adjacent elements, kg/sec |
| QINO3 | R | ARRAY | Rate of nitrate moving into an element from adjacent elements, kg/sec |
| QL | R | VARIABLE | Discharge at lower end of segment IY on discharge curve |
| Q1 | R | VARIABLE | Discharge from catchment at i th hydrograph line, mm/h |
| Q1M1 | R | VARIABLE | Q1(i-1) |
| Q2 | R | VARIABLE | Outflow from element at end of time increment, m ³ /s |
| R | R | ARRAY | Net rainfall rate for rain gauge i on surface type j m ³ /s |
| R | R | VARIABLE | Ratio of VOLOUT to VOLSZ |
| RAIN | R | VARIABLE | Effective rainfall rate, m ³ /s |
| RANE | I | EQV ARRAY | Number of rain gauge applicable to element i |
| RATE | R | ARRAY | Gauge rainfall rate at rainfall gauge i, m ³ /s |
| RC | R | ARRAY | Rainfall intensity for gauge i, histogram period j, m ³ /s |
| RE | R | VARIABLE | Particle removal efficiency during deposition |
| REYN | R | VARIABLE | Particle Reynolds number |
| RFL | R | ARRAY | Fraction of discharge from element flowing in a row direction |
| RIT | R | VARIABLE | Interception during time increment, m ³ /s |
| RN | R | ARRAY | Manning's "n" for surface type 1 |
| RNH4 | R | VARIABLE | Concentration of ammonium in rainfall, kg/m ³ |
| RNO3 | R | VARIABLE | Concentration of nitrate in rainfall, kg/m ³ |

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|--------|---|-----------|---|
| ROUGH | R | ARRAY | Surface depth-storage parameter for surface i |
| RW | R | VARIABLE | Average rainfall intensity over catchment at i th hydrograph print time |
| S | R | ARRAY | Storage at start of time increment for element i, m ³ /s |
| SAI | R | ARRAY | Sediment surface area inflow from adjacent elements, m ² |
| SAIG | R | VARIABLE | Sum of SAI values for previous interval, m ² |
| SAO2 | R | VARIABLE | Sediment surface area leaving element after time step, m ² /s |
| SAPT | R | VARIABLE | Accumulated sediment surface area loss from catchment at previous time interval, m ² |
| SAT | R | ARRAY | Sum of the initial values for the sediment surface area continuity equation |
| SB | R | VARIABLE | Average overland flow conveyance coefficient |
| SBAR | R | VARIABLE | Average catchment slope |
| SC | R | VARIABLE | Depth increment for segmented curve |
| SCBAR | R | VARIABLE | Variable used for determining mean value of SS and SSI |
| SCMAX | R | VARIABLE | Maximum value of SS and SSI |
| SCMIN | R | VARIABLE | Minimum value of SS and SSI |
| SDEL | R | VARIABLE | Summation of DELTA |
| SDR | R | VARIABLE | Accumulated groundwater storage, m ³ /s |
| SE | R | ARRAY | Rate of sediment movement from element, kg/s |
| SEDNEW | R | ARRAY | Newly transported sediment after time step for particle class i, kg/sec |
| SEDNEW | R | ARRAY | Rate of new erosion occurring in a cell for particle class i, kg-soil/sec |
| SESEL | R | ARRAY | Rate of deposition or erosion occurring in a cell for particle class i, kg-soil/sec |
| SEL | R | EQV ARRAY | Accumulated sediment aggradation in element i kg/s |
| SE1-2 | R | ARRAY | Rate of sediment movement from element with and without flow detachment, kg/s |
| SF | R | VARIABLE | Segment factor. Maximum projected catchment discharge |
| SG | R | ARRAY | Specific gravity of particle type i |
| SGD2 | R | VARIABLE | SQRT (AGRAV/2) |
| SI | R | EQV ARRAY | Rate of sediment inflow into element i from adjacent elements, kg/s |
| SIG | R | VARIABLE | Sum of SI values for all particle classes, kg/s |
| SIGMA | R | VARIABLE | Coefficient in transport equation |
| SKDR | R | ARRAY | Erosion parameter for soil type i |
| SL | R | ARRAY | Slope of overland flow element or channel segment i |
| SMAX | R | VARIABLE | Final accumulated sediment loss from catchment, kg |
| SMDIR | R | VARIABLE | S-DIR |
| SMIN | R | VARIABLE | Minimum elemental and channel slope in watershed |

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|--------|---|-----------|---|
| SNH4 | R | VARIABLE | Concentration of soluble NH_4^+ , kg-N/ha |
| SNO3 | R | VARIABLE | Beginning concentration of soluble NO_3^- , kg-N/ha |
| SOIL | I | EQV ARRAY | Soil type for element i |
| SPADEP | R | VARIABLE | Maximum elemental aggradation value, kg/ha |
| SPAERO | R | VARIABLE | Minimum elemental aggradation value, kg/ha |
| SPASD | R | VARIABLE | Standard deviation of SEL |
| SPASS | R | VARIABLE | Variable used in determining SPASD |
| SPASUM | R | VARIABLE | Sum of SEL values used to calculate SPASD |
| SPER | R | EQV ARRAY | Steady state infiltration rate, mm/h |
| SPT | R | VARIABLE | Accumulated sediment loss from catchment at previous time, kg |
| SR | R | ARRAY | Rainfall rate from previous calculation, m^3/s |
| SRA | R | VARIABLE | Portion of sediment leaving element and flowing in a row direction |
| SS | R | ARRAY | Incremental increase in storage on element i |
| SSA | R | ARRAY | Total specific surface area for element m, for particle class i, m^2/kg (input/output in m^2/g) |
| SSASED | R | VARIABLE | Specific surface area of sediment leaving watershed, m^2/kg |
| SSAT | R | ARRAY | Total specific surface area for soil type i, m^2/g |
| SSCON | R | VARIABLE | Sediment concentration at print line i, mg/l |
| SSI | R | VARIABLE | Accumulated sediment loss from catchment at print line i |
| SSII | R | VARIABLE | Same as SSI |
| SST | R | EQV ARRAY | Sum of initial values in sediment continuity equation, kg/s |
| SSTOR | R | ARRAY | Storage on element at end of time increment, m^3/s |
| SS1M1 | R | VARIABLE | SSI at previous time step |
| STD | R | VARIABLE | Total inflow into tile lines during DT |
| STNEW | R | ARRAY | Sediment in particle class i in storage at the end of the time step, to be saved for next time step, kg/sec |
| STOANH | R | ARRAY | Concentration of adsorbed nitrogen in storage for particle class i, $\text{mg}-\text{N}/\text{kg}-\text{soil}$ |
| STOLD | R | ARRAY | Sediment in particle class i in storage at the beginning of the time step, kg/sec |
| STORNO | R | ARRAY | Mass of nitrate in storage on an element, kg |
| STORNH | R | ARRAY | Mass of ammonium in storage on an element, kg |
| STOTKN | R | ARRAY | Concentration of fixed nitrogen in storage for particle class i, $\text{mg}-\text{N}/\text{kg}-\text{soil}$ |
| STRNAM | R | ARRAY | Name of structure |
| STRUC | R | VARIABLE | Flag for existence of structure |
| SUPP | R | VARIABLE | Available supply for infiltration during time increment |

| | | | |
|--------|---|-----------|---|
| SUR | R | EQV ARRAY | Surface type on element i |
| SWH20 | R | VARIABLE | Specific weight water, kg/m ³ |
| SZNH4 | R | ARRAY | Mass of ammonium in the surface zone, kg |
| SZNO3 | R | ARRAY | Mass of nitrate in the surface zone, kg |
| S2 | R | VARIABLE | Variable in sediment continuity equation |
| S22 | R | ARRAY | Variable in sediment continuity equation |
| T | R | ARRAY | Real time |
| TBAR | R | VARIABLE | Percent of elements tiled |
| TC | R | ARRAY | Time of j th histogram period for rain gauge i |
| TEST | R | VARIABLE | Comparison for correct data input check |
| TF | R | ARRAY | Sediment transport capacity, kg/s |
| TFMSE2 | R | ARRAY | TF-SE2 |
| TFXCES | R | VARIABLE | Transport capacity excess, kg/s |
| TIAL | I | EQV ARRAY | Value of 1 denotes element is tile drained |
| TINT | R | VARIABLE | Time interval in hyetograph |
| TITLE | R | EQV ARRAY | Simulation title |
| TKN | R | VARIABLE | Beginning concentration of fixed nitrogen, kg-N/ha |
| TKNCON | R | VARIABLE | Concentration of fixed N on sediment of particle class i, leaving a cell or being deposited, mg-N/kg-soil |
| TKNIN | R | ARRAY | Rate of nitrogen coming into a cell from adjacent elements for particle class i, mg-N/sec |
| TKNNEW | R | ARRAY | Rate of fixed nitrogen being newly eroded in a cell for particle class i, mg-N/sec |
| TKNOUT | R | ARRAY | Rate of fixed nitrogen leaving a cell for particle class i, mg-N/sec |
| TKNSEL | R | VARIABLE | Aggradation value for fixed nitrogen in a cell, mg-N/sec |
| TKNSTR | R | VARIABLE | Fixed nitrogen in storage for particle class i, mg-N/sec |
| TMAX | R | VARIABLE | Maximum time value given in any hyetograph |
| TMIN | R | VARIABLE | Minimum time value given in any hyetograph |
| TNH4 | R | VARIABLE | Total mass of ammonium in the inflow and storage of an element to be proportioned to the outflow, kg |
| TNO3 | R | VARIABLE | Total mass of nitrate in the inflow and storage of an element to be proportioned to the outflow, kg |
| TP | R | EQV ARRAY | Porosity for soil type i |
| TRAP | R | VARIABLE | Trap efficiency of ponds |
| UN | R | VARIABLE | Comparison for units |
| UNITS | R | VARIABLE | Type of input-output units |
| VISCOS | R | VARIABLE | Kinematic viscosity of water, m ² /s |

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|--------|---|----------|---|
| VOL | R | VARIABLE | Accumulated runoff depth from catchment |
| VOLOUT | R | VARIABLE | Volume of water leaving an element in runoff and infiltration (m ³) |
| VOLSZ | R | ARRAY | Volume of water in the surface zone, mg |
| VS | R | ARRAY | Simplification variable used in transport equation |
| VSTAR | R | VARIABLE | Shear velocity, m/s |
| WDELTA | R | VARIABLE | Time increment to calculate transformations (must divide evenly into NDOR) |
| WID | R | ARRAY | Width of type 1 channel, m |
| WS | R | ARRAY | Water to soil ratio, l/kg |
| X | R | VARIABLE | Overland flow width across overland flow element, m |
| XDIR | R | VARIABLE | Same of DIR |
| XKAN | R | VARIABLE | Transformation rate coefficient for the conversion of ammonium to nitrate |
| XKAS | R | VARIABLE | Desorption rate coefficient |
| XKO | R | VARIABLE | Mineralization rate coefficient , 1/hour |
| XKSA | R | VARIABLE | Adsorption rate coefficient |
| XPR | R | VARIABLE | Real value of KPR |
| XR | R | VARIABLE | Same as R |
| XZW | R | VARIABLE | Element or channel width, m |
| X1-4 | R | VARIABLE | Simplifying variables used in SUBROUTINE SED |
| Y | R | VARIABLE | Number of appropriate increment on segmented discharge curve. Depth at initial value of this curve segment |
| YALCON | R | VARIABLE | Yalin's Constant |
| YCR | R | VARIABLE | Dimensionless critical shear stress from Shield's diagram |
| Z12 | R | VARIABLE | Rate of sediment inflow plus erosion at end of time increment |


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C***** THOROUGHLY TESTED USING OBSERVED INFORMATION FROM *****
C***** BOTH PLOT AND WATERSHED RESEARCH AREAS. SINCE THE *****
C***** MODEL IS STILL UNDERGOING DEVELOPMENT, THE ADDITION *****
C***** OR MODIFICATION OF COMPONENT RELATIONSHIPS SHOULD *****
C***** BE EXPECTED FROM ONE RELEASE TO ANOTHER. BECAUSE OF *****
C***** THIS, SLIGHTLY DIFFERENT SIMULATION RESULTS MAY BE *****
C***** OBTAINED. ALWAYS USE THE MOST CURRENT RELEASE!! *****
C***** *****

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C***** *****
C***** THIS VERSION OF ANSWERS CONTAINS: *****
C***** *****
C***** 1) MEMORY CONSERVATION EQUIVALENCING *****
C***** 2) 3-PER-PASS ALGORITHM *****
C***** 3) IMPROVED DATA VERIFICATION DIAGNOSTICS *****
C***** 4) STRUCTURAL PRACTICES *****
C***** 5) MODIFIED INPUT FORMATS (SEE USER'S MANUAL) *****
C***** 6) MODIFIED DETACHMENT RELATIONSHIPS *****
C***** 7) MODIFIED OUTPUT FORMATS *****
C***** 8) ENHANCED SEDIMENT TRANSPORT MODEL *****
C***** 9) NITROGEN TRANSPORT MODEL *****
C***** *****

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C***** THE FOLLOWING ARE NEW WITH THIS RELEASE: *****
C***** *****
C***** 8) 1977 ANSI STANDARD FORTRAN CODING *****
C***** (SHOULD YOUR PARTICULAR COMPILER NOT BE ANSI- *****
C***** 1977 COMPATIBLE, SIMPLY REMOVE THE CHARACTER *****
C***** DEFINITION STATEMENTS AT THE BEGINNING OF THE *****
C***** MAIN PROGRAM AND ALL SUBROUTINES) *****
C***** *****

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C*****
C***** *****
C***** TO CHANGE FROM DOUBLE TO SINGLE PRECISION ON IBM SYSTEM: *****
C***** *****
C***** 1. COMMENT OUT ALL IMPLICIT REAL*8 STATEMENTS. *****
C***** 2. CHANGE: DLOG TO ALOG; DEXP TO EXP; DSQRT TO SQRT. *****
C***** 3. CHANGE: IFIX(SNGL(DT)) TO IFIX(DT). *****
C***** *****

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C*****
C*****

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C ***** DISTRIBUTED PARAMETER MATHEMATICAL MODEL OF A RAINFALL
C ***** EVENT ON A CATCHMENT, WITH EROSION AND DEPOSITION.

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C IMPLICIT REAL*8 (A-H,O-Z)

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C ***** MAXIMUM NUMBER OF SOIL TYPES IS 20.

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C COMMON /CSOIL/ A(20),P(20),FC(20),GWC(20),SKDR(20)

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C ***** MAXIMUM NUMBER OF SURFACE AND CROP TYPES IS 20.

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C

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COMMON /CROUGH/ ROUGH(20),HU(20),DIR(21),PIT(5,20),PER(20),CDR(20)
C
C **** MAXIMUM NUMBER OF RAINGAGES IS 8 WITH 35 VALUES PER GAGE.
C
COMMON /CRGAGE/ RC(8,35),TC(8,35),R(8,20),FRA(8),JTR(8),RATE(8),SR
1(8),NF(8)
C
C ... PARAMETERS USED IN THE EXTENDED SED SUBROUTINE
C
COMMON /ZSEDI/ NPART,NWASH,NWASH1
COMMON /ZSEDR/ VISCOS,AGRAV,SWH2O,YALCON,SE(5),VS(2000),DIA(5),SG
1(5),FV(5),CY1(5),CY2(5),CY4(5),DIAMM(5),EQSDIA(5),EDMM(5),F(20,5)
2,PERCLA(20,5),CE1,CE2,CE3,CE4,CE5,CE6
C
C***** PARAMETERS FOR THE NITROGEN TRANSPORT MODELS *****
C
COMMON /CINPUT/ CNIT(4,40),FERT(2,10),TEMP
C
COMMON /NTRANS/ NIT(2000),MAN(2000)
C
COMMON /ELEM/ PERPOT(2000),EDI(2000),TPOR(20),SM(20)
C
COMMON /SEDSOL/ CELNO3(2000),CELSNH(2000),XNO3(2000),XNH4(2000),FI
2LNO3(2000),FILNH4(2000),SZNO3(2000),SZNH4(2000),VOLSZ(2000),STOTKN
3(2000,5),STOLD(2000,5),STOANH(2000,5),SEDNEW(5),TKNIN(2010,5),ANH
4N(2010,5),TKNSEL(2000),ANHSEL(2000),SESEL(5),TKNOUT(5),ANHOUT(5),
5STNEW(5),QINO3(2010),QINH4(2010),STORNO(2000),STORNH(2000),CELTKN(
62000,5),CELANH(2000,5)
C
C **** MAXIMUM NUMBER OF OVERLAND ELEMENTS PLUS CHANNEL ELEMENTS
C **** IS 2000 = NMAX.
C
C ***** IT IS EXPECTED THAT ARRAY "IEL" (IN SUBROUTINE DATA) WILL
C ***** BE OF SUCH A SIZE THAT IT WILL OVERLAY (BE EQUIVALENCED TO)
C ***** THE SPACE IN ARRAYS SI AND QI TOGETHER. THEREFORE IT IS
C ***** NECESSARY THAT THESE TWO ARRAYS BE KEPT ADJACENT IN THEIR
C ***** COMMON BLOCK. NOTE: THE ACTUAL NUMBER OF ELEMENTS THAT
C ***** CAN BE DIMENSIONED IN IEL WILL DEPEND ON THE WORD LENGTH
C ***** OF THE MACHINE BEING USED, E.G. ON A MACHINE WHICH USES
C ***** A SINGLE WORD INTEGER AND A DOUBLE WORD REAL, THE NUMBER
C ***** OF ELEMENTS IN IEL CAN BE FOUR TIMES THE NUMBER OF ELEMENTS
C ***** IN ARRAY SI.
C
COMMON /CFLOW/ Q(2000),RFL(2000),FLINS(2000),SS(2000),PIV(2000),B(
12000),NR(2000),NC(2000),DR(2000),S(2000),SL(2000),SEL(2000),SI(201
20,5),QI(2010),DIN(2000),SST(2000,5)
C
C ***** ARRAYS SI AND QI MUST BE DIMENSIONED TO A SIZE = NMAX+ISTRUC+2
C ***** TO HOLD, IN ORDER, SEDIMENT AND FLOW FROM THE WATERSHED
OUTLET
C ***** ELEMENT, STRUCTURAL PRACTICES AND ANY "LEAKY" ELEMENTS.
C
EQUIVALENCE (FILTS(1),CWID(1))
DIMENSION CWID(2000), FILTS(2000)
EQUIVALENCE (TIAL(1),RANE(1)), (SUR(1),SOIL(1))

```

COMMON /CSURF/ SUR(2000),RANE(2000)
INTEGER SUR,SOIL(2000),TIAL(2000),RANE

C

C **** NUMBER OF PRINT AND PLOT POINTS IS 101 MAXIMUM.

C

DIMENSION T(101), Q1(101), RW(101), SSI(101), SCON(101) , ER(8)
DIMENSION PP(14), QA(300), TT(20)
DIMENSION HYDTKN(101), HYDANH(101), HYDNO3(101), HYDSNH(101)
CHARACTER*4 PP, TT
DATA PP(1),PP(2),PP(3),PP(4),PP(5),PP(6),PP(7),PP(8),PP(9),PP(10),
1PP(11),PP(12),PP(13),PP(14) ' IN.', 'HR.', ' AC.', ' FT.', ' LB.',
2' PPM', 'AC ' , ' MM', 'H ' , ' HA ' , ' M ' , ' KG', 'MG/L', 'HA ' /

C **** NEW TRANSPORT AND DETACHMENT CONSTANTS.

C

C **** DETACHMENT COEFFICIENT CE3 (RAINFALL) WAS INCREASED BY A
FACTOR

C **** OF 4 IN THE MARCH 15, 1982 VERSION OF ANSWERS. THE REASON FOR

C **** THIS LARGE INCREASE WAS THAT A NUMBER OF THE RAINFALL
SIMULATOR

C **** PLOTS THAT WERE USED IN COEFFICIENT CALCULATION HAD DEPOSITION
C **** AREAS. HOWEVER, AFTER CLOSER EXAMINATION OF PHOTOGRAPHS AND
C **** SURVEY INFORMATION, THE DETACHMENT COEFFICIENT WAS DEEMED TO
C **** BE TOO HIGH. THUS, THE CURRENT ACCEPTED VALUE OF CE3 IS TWICE
C **** THE ORIGINAL VALUE (GASP-IV VERSION OF ANSWERS).

C

C **** DETACHMENT COEFFICIENT CE4 (FLOW) WAS INCREASED BY A FACTOR
OF

C **** 50 IN THE MARCH 15, 1982 VERSION OF ANSWERS. THE REASON FOR

C **** THIS DRAMATIC INCREASE WAS SOME RAINFALL SIMULATOR DATA THAT

C **** SHOWED THE DIFFERENCE BETWEEN RAINFALL-ONLY AND RAINFALL
PLUS

C **** UPSLOPE FLOW SEDIMENT YIELDS. WHILE THE YIELDS INCREASED
C **** SUBSTANTIALLY WITH THE INCREASED FLOW, IT APPEARS THAT THE
C **** MAJOR SOURCE OF SEDIMENT WAS WASHOFF OF UNATTACHED
PARTICLES,

C **** NOT DETACHMENT OF COHESIVE PARTICLES. A RE-EXAMINATION OF THE

C **** FLOW DETACHMENT EQUATION HAS LED TO THE CONCLUSION THAT THE

C **** FLOW DETACHMENT COEFFICIENT SHOULD BE APPROXIMATELY 5 TIMES

C **** GREATER THAN THE ORIGINAL VALUE (NOT 50 TIMES).

C

C **** WHILE THE C AND K FACTORS IN THE USLE ARE USED TO DESCRIBE

C **** THE RELATIVE DEGREE OF ERODIBILITY OF A PARTICULAR SOIL IN

C **** THIS MODEL, THE IMPACTS OF SURFACE COMPACTION, ROUGHNESS,

C **** TEMPERATURE, ETC. ARE NOT TAKEN INTO ACCOUNT. THUS, WHILE

C **** THE EROSION EQUATIONS WORK FOR THOSE SOIL SERIES FOR WHICH

C **** WE HAVE RAINFALL SIMULATOR AND WATERSHED DATA, THEY MAY NOT

C **** DO AN ADEQUATE JOB ON OTHER TYPES OF TOPOGRAPHY, SOIL

TEXTURE,

C **** SURFACE CONDITION, ETC. FOR THESE REASONS, CE3 AND CE4
SHOULD

C **** BE CONSIDERED AS POTENTIAL VARIABLES. RESEARCH NOW BEING

C **** CONDUCTED SHOULD YIELD BETTER DESCRIPTIONS OF THE
DETACHMENT

C **** PROCESS AND THE COEFFICIENTS ASSOCIATED WITH IT. WHILE IT

C **** IS NOT POSSIBLE TO GIVE EXACT INSTRUCTIONS ON MODIFICATIONS

```

C **** THAT SHOULD BE MADE TO COEFFICIENTS WHEN SIMULATED AND
OBSERVED
C **** RESULTS DON'T AGREE, WE WILL CERTAINLY BE WILLING TO DISCUSS
C **** THE PROBLEM AND MAKE SUGGESTIONS FOR LOGICAL MODEL
MODIFICATIONS.
C
C **** TO EITHER MAKE SUGGESTIONS OR RECEIVE FURTHER INFORMATION,
CONTACT:
C
C **** DAVID B. BEASLEY, PH.D., P.E.
C **** AGRICULTURAL ENGINEERING DEPARTMENT
C **** PURDUE UNIVERSITY
C **** WEST LAFAYETTE, IN 47907
C **** PHONE: (317) 494-1198
C
C **** ENGLISH UNITS.
C
CE1=5603.
CE2=4.26
CE3=62208.0
CE4=0.1
CE5=.00833333
CE6=62.3174
READ (1,280) (TT(I),I=1,19)
WRITE (2,290) (TT(I),I=1,19)
C
C **** READ, TRANSFORM AND RETURN INPUT INFORMATION.
C
CALL DATA (NDT,KPR,N,CONV,CU,SF,IT,NN,ICR,NFI,CU2,ISTRUC,SB,TMIN,T
1MAX,NRG,DX,GRF,NEXP,DC,PP,FILTS,CWID,AREA,DT,NMAX,NDUR,NDELTA)
C
C **** COMPUTE THE PIECE-WISE LINEAR SEGMENTS FOR USE IN MANNING'S
C **** EQUATION.
C
SC=((SF*CONV/SB)**.6)/300.
D=0.
DO 10 I=1,300
QA(I)=D**1.66667
10 D=D+SC
SC=1./SC
C
C **** INITIALIZE VARIABLES.
C **** SET RAINFALL INITIAL VALUES.
C
DO 20 I=1,NRG
JTR(I)=1
IF (TC(I,2).EQ.TMIN) JTR(I)=2
SR(I)=0.
20 NF(I)=NFI
N1=N+1
N2=NN-1
CHN=N2-N
C
C **** EROSION CONSTANTS.
C

```

```

IF (IT.LE.0) GO TO 30
C
C **** METRIC UNITS.
C
CE1=9.66155E+5
CE2=2.0847E+1
CE3=6.53864E+6
CE4=5.25545E+1
CE5=7.7419E-4
CE6=1.E+3
C
C **** INITIALIZE VALUES.
C
30 VOL=0.
SSI(1)=0.
SDR=0.
CHDR=0.
SSCON(1)=0.
RW(1)=0.
Q1(1)=0.
RMAX=0.
QMAX=0.
CMAX=0.
PREC=0.
DTM=DT/60.
T(1)=TMIN
C
C .... INITIALIZATION OF DATA EXTENDED SED SUBROUTINE
C
ERG=0.
DO 31 I1=1,8
31 ER(I1)=0.
YALCON=0.635
C
C***** INITIALIZE PARAMETERS FOR THE NITROGEN TRANSPORT *****
C***** MODELS *****
C
HYDTKN(1)=0.0
HYDANH(1)=0.0
HYDNO3(1)=0.0
HYDSNH(1)=0.0
RNO3=0.0
RNH4=0.0
SUMNO3=0.0
SUMNH4=0.0
J=NMAX+ISTRUC+2
DO 32 I=1,J
QINO3(I)=0.0
QINH4(I)=0.0
STORNO(I)=0.0
STORNH(I)=0.0
DO 32 IC=1,NPART
STOLD(I,IC)=0.0
STNEW(IC)=0.0
TKNIN(I,IC)=0.0

```

```

    ANHIN(I,IC)=0.0
    STOTKN(I,IC)=0.0
    STOANH(I,IC)=0.0
32 CONTINUE
C
C
C **** WRITE HYDROGRAPH HEADING AND INITIAL VALUES.
C
    WRITE (2,300)
    WRITE (2,310) T(1),RW(1),Q1(1),SSI(1),HYDTKN(1),HYDANH(1),
    1SSCON(1),HYDNO3(1),HYDSNH(1)
    WRITE (4,315)T(1),Q1(1)
C
C***** CALL SUBROUTINE 'TRANS' TO BEGIN THE NITROGEN *****
C***** TRANSFORMATIONS *****
C
    CALL TRANS(N,NDUR,NDELTA,DX)
C
C **** START COMPUTATION FOR EACH HYDROGRAPH PRINT LINE AT DT*KPR.
C
    DO 220 L=2,NDT
    LM1=L-1
    T(L)=T(LM1)
C
C **** CONTINUITY EQUATION FOR TIME INCREMENTS DT.
C
    DO 170 J=1,KPR
    SPT=0.
    DO 35 IC=1,NPART
    35 SPT=SPT+SI(NN,IC)
    T(L)=T(L)+DTM
C
C **** CALCULATE NET RAINFALL FOR EACH GAGE AND SURFACE CONDITION
AND
C **** UPDATE INFILTRATION CAPACITIES WITHIN GAGE AREA ON TIME OR NET
C **** RAINFALL CHANGE.
C
    DO 90 JJ=1,NRG
    NF(JJ)=NF(JJ)-1
    ITR=JTR(JJ)
    ITRM1=ITR-1
    IF (T(L)-TC(JJ,ITR)) 60,60,40
    40 IF (T(L)-TMAX) 50,230,230
C
C **** NEW RAINFALL RATE, ALLOW FOR DTM BRIDGING TC VALUE.
C
    50 DI=T(L)-TC(JJ,ITR)
    ITRP1=ITR+1
    RATE(JJ)=CU*(RC(JJ,ITRP1)*DI+RC(JJ,ITR)*(DTM-DI))/DTM
    JTR(JJ)=JTR(JJ)+1
    ITR=ITRP1
C
C **** ADD WHOLE HISTOGRAM BLOCK TO TOTAL PRECIPITATION IN
C **** PROPORTION TO WATERSHED AREA COVERED.
C

```

```

PREC=PREC+RC(JJ,ITR)*(TC(JJ,ITR)-TC(JJ,ITR-1))*FRA(JJ)/60.
C
C **** CALCULATE NET RAINFALL FOR EACH COVER.
C
60 DO 70 I=1,ICR
  R(JJ,I)=RAIN(RATE(JJ),PIT(JJ,I),PER(I))
  IF (R(JJ,I).EQ.SR(JJ).AND.NF(JJ).GT.0) GO TO 70
  SR(JJ)=R(JJ,I)
  NF(JJ)=-NFI
70 CONTINUE
  RATE(JJ)=RC(JJ,ITR)*CU
  IF (NF(JJ).GT.0) GO TO 90
C
C **** CALCULATION OF INFILTRATION CAPACITY FOR EACH OVERLAND
ELEMENT.
C
  DO 80 M=1,N
  IF (MOD(RANE(M),256).NE.JJ) GO TO 80
  K=MOD(SUR(M),256)
  KK=SOIL(M)/256
  FILTS(M)=FILT(A(KK),PIV(M),P(KK),FC(KK),GWC(KK),DR(M),S(M),R(JJ,K)
  1,CU2,ROUGH(K),HU(K),NEXP)
80 CONTINUE
  NF(JJ)=NFI
90 CONTINUE
C
C **** CONTINUITY EQUATION EXPLICIT SOLUTION FOR EACH ELEMENT DURING
C **** TIME INCREMENT, DT.
C
  DO 170 M=1,N2
  SSTOR=S(M)+SS(M)
  IF (SSTOR.LT.0.) SSTOR=0.
  IF (M.GT.N) GO TO 100
C
C **** OVERLAND ELEMENT.
C
  I=MOD(RANE(M),256)
  K=MOD(SUR(M),256)
  KK=SOIL(M)/256
  SUPP=.5*SSTOR+QI(M)+R(I,K)
  FIL=FILTS(M)
  IF (FIL.GT.SUPP) FIL=SUPP
  PIV(M)=PIV(M)+DR(M)-FIL
  SDR=SDR+DR(M)
  FLIN=QI(M)+R(I,K)-FIL
  GO TO 110
C
C **** CHANNEL ELEMENT.
C
100 K=21
  FLIN=QI(M)+CHDR+DIN(M)
C
C **** COMBINE INITIAL INFLOW, OUTFLOW AND STORAGE WITH ACCUMULATED
C **** INFLOW.
C

```

```

110 FHS=FLINS(M)+FLIN
    IF (SSTOR.GT.DIR(K)) GO TO 130
C
C **** NO RUNOFF FROM ELEMENT.
C
120 S(M)=FHS
    SS(M)=0.
    FLINS(M)=FLIN+FHS
    IF (Q(M).EQ.0.) GO TO 170
    D=-Q(M)
    Q(M)=0.
    GO TO 150
C
C **** DIRECT SOLUTION OF CONTINUITY EQUATION BY LINEARIZATION.
C
130 Y=SC*(SSTOR-DIR(K))
    IY=Y+1.
    IF (IY.LT.300) GO TO 140
    WRITE (2,330) M
    STOP
140 Y=IY-1
    QL=B(M)*QA(IY)
    QD=B(M)*(QA(IY+1)-QA(IY))
    SSTOR=(FHS-QL+QD*(Y+DIR(K)*SC))/(1.+QD*SC)
    IF (SSTOR.LE.DIR(K)) GO TO 120
    Q2=QL+QD*((SSTOR-DIR(K))*SC-Y)
    D=Q2-Q(M)
    Q(M)=Q2
    SS(M)=SSTOR-S(M)
    S(M)=SSTOR
    FLINS(M)=FLIN+SSTOR-Q2
C
C.....SEDIMENT CALCULATION.....
C
150 IF (M.LE.N) GO TO 156
C
C.....COMPUTE TRANSPORT/DEPOSITION FOR CHANNEL FLOW
C
    CALL SED(CWID(M),0.,1.,0.,M,N,KK,DX)
C
C***** COMPUTE SOLUBLE AND SEDIMENT-BOUND NITROGEN *****
C***** FOR CHANNEL FLOW *****
C
    DO 151 IC=1,NPART
    CALL SEDNIT(STOTKN(M,IC),STOLD(M,IC),STOANH(M,IC),CELTKN(M,IC),
1SEDNEW(IC),CELANH(M,IC),Q(M),SI(M,IC),TKNIN(M,IC),ANHIN(M,IC),
2TKNSEL(M),ANHSEL(M),SESEL(IC),TKNOUT(IC),ANHOUT(IC),SE(IC),
3STNEW(IC))
    SI(M,IC)=0.0
151 CONTINUE
    CALL SOLNIT(M,N,Q2,QI(M),R(I,K),QINO3(M),QINH4(M),VOLSZ(M),
1CELNO3(M),STORNO(M),SZNO3(M),FILNO3(M),QENO3,CELSNH(M),STORNH(M),
2SZNH4(M),FILNH4(M),QENH4,DT,FIL)
C

```

C.....REMEMBER ALL CHANNEL FLOW MOVES WITH ITS "COLUMN" DESIGNATOR

C

```
K=NC(M)
QI(K)=QI(K)+D
IF(QI(K).LT.0.0)QI(K)=0.0
QINO3(K)=QINO3(K)+QENO3
QINH4(K)=QINH4(K)+QENH4
DO 152 IC=1,NPART
  SI(K,IC)=SI(K,IC)+SE(IC)
  TKNIN(K,IC)=TKNIN(K,IC)+TKNOUT(IC)
  ANHIN(K,IC)=ANHIN(K,IC)+ANHOUT(IC)
```

152 CONTINUE

```
IF(M.NE.N2) GO TO 170
```

```
DO 154 IC=1,NPART
```

```
  ER(IC)=ER(IC)+SE(IC)
```

154 CONTINUE

```
GO TO 170
```

C

C....COMPUTE TRANSPORT/DEPOSITION FOR OVERLAND FLOW

C

```
156 C=CDR(K)*SKDR(KK)
```

```
  CALL SED(DX,R(I,K),C,DIR(K),M,N,KK,DX)
```

C

C***** COMPUTE SOLUBLE AND SEDIMENT-BOUND NITROGEN *****

C***** FOR OVERLAND FLOW *****

C

```
DO 157 IC=1,NPART
```

```
  CALL SEDNIT(STOTKN(M,IC),STOLD(M,IC),STOANH(M,IC),CELTKN(M,IC),
```

```
  1SEDNEW(IC),CELANH(M,IC),Q(M),SI(M,IC),TKNIN(M,IC),ANHIN(M,IC),
```

```
  2TKNSEL(M),ANHSEL(M),SESEL(IC),TKNOUT(IC),ANHOUT(IC),SE(IC),
```

```
  3STNEW(IC))
```

```
  SI(M,IC)=0.0
```

157 CONTINUE

```
  CALL SOLNIT(M,N,Q2,QI(M),R(I,K),QINO3(M),QINH4(M),VOLSZ(M),
```

```
  1CELNO3(M),STORNO(M),SZNO3(M),FILNO3(M),QENO3,CELSNH(M),STORNH(M),
```

```
  2SZNH4(M),FILNH4(M),QENH4,DT,FIL)
```

C

C.....PROPORTION OUTFLOW AND SEDIMENT TO DOWNSLOPE ADJACENT ROW

C.....AND COLUMN ELEMENTS.....

C

```
IF(M.LT.N2) GO TO 160
```

```
DO 158 IC=1,NPART
```

```
  ER(IC)=ER(IC)+SE(IC)
```

158 CONTINUE

160 CONTINUE

```
I=NR(M)
```

```
K=NC(M)
```

```
ZRFL=RFL(M)
```

```
DRA=D*ZRFL
```

```
QI(I)=QI(I)+DRA
```

```
QI(K)=QI(K)+D-DRA
```

```
IF(QI(I).LT.0.)QI(I)=0.0
```

```
IF(QI(K).LT.0.)QI(K)=0.0
```

```
DIVNO3=QENO3*ZRFL
```

```
QINO3(I)=QINO3(I)+DIVNO3
```

```

QINO3(K)=QINO3(K)+QENO3-DIVNO3
DIVSNH=QENH4*ZRFL
QINH4(I)=QINH4(I)+DIVSNH
QINH4(K)=QINH4(K)+QENH4-DIVSNH
DO 162 IC=1,NPART
  SRA=SE(IC)*ZRFL
  SI(I,IC)=SI(I,IC)+SRA
  SI(K,IC)=SI(K,IC)+SE(IC)-SRA
  DIVTKN=TKNOUT(IC)*ZRFL
  TKNIN(I,IC)=TKNIN(I,IC)+DIVTKN
  TKNIN(K,IC)=TKNIN(K,IC)+TKNOUT(IC)-DIVTKN
  DIVANH=ANHOUT(IC)*ZRFL
  ANHIN(I,IC)=ANHIN(I,IC)+DIVANH
  ANHIN(K,IC)=ANHIN(K,IC)+ANHOUT(IC)-DIVANH
162 CONTINUE
170 CONTINUE
  IF (CHN.LT.1..OR.SDR.EQ.0.) GO TO 180
C
C **** CALCULATE TILE DRAINAGE AND GROUNDWATER CONTRIBUTION.
C
  XPR=KPR
  CALL DRAIN (DR,DC,DIN,N,N1,N2,STD,TIAL,RFL,NR,NC)
  SDR=SDR-STD*XPR
  CHDR=SDR*GRF/XPR/CHN
  SDR=SDR*(1.-GRF)
C
C **** OUTPUT PRINT SECTION.
C
  180 Q1(L)=QI(NN)/CONV
  SIG=0.
  DO 185 IC=1,NPART
185  SIG=SIG+SI(NN,IC)
  SSI(L)=SIG*DT
  IF (QI(NN).GT.0.) GO TO 190
  SSSCON(L)=0.
  GO TO 200
190 SSSCON(L)=(SIG-SPT)/(SIG-SPT+QI(NN)*CE6)*1000000.
200 IF (Q1(L).GT.QMAX) QMAX=Q1(L)
  IF (SSCON(L).GT.CMAX) CMAX=SSCON(L)
  VOL=VOL+Q1(L)
  RW(L)=0.
  DO 210 I=1,NRG
  J=JTR(I)
210 RW(L)=RW(L)+RC(I,J)*FRA(I)
  IF (RW(L).GT.RMAX) RMAX=RW(L)
C
C***** OUTPUT PRINT SECTION FOR THE NITROGEN MODELS *****
C
  TKNSUM=0.0
  ANHSUM=0.0
  DO 215 IC=1,NPART
  TKNSUM=TKNSUM+TKNIN(NN,IC)
215 ANHSUM=ANHSUM+ANHIN(NN,IC)
  HYDTKN(L)=TKNSUM*DT/1000000
  HYDANH(L)=ANHSUM*DT/1000000

```

```

SUMNO3=SUMNO3+QINO3(NN)*DT
SUMSNH=SUMSNH+QINH4(NN)*DT
IF(QI(NN).GT.0.)GO TO 216
HYDNO3(L)=0.0
HYDSNH(L)=0.0
GO TO 217
216 HYDNO3(L)=QINO3(NN)/QI(NN)*1000
HYDSNH(L)=QINH4(NN)/QI(NN)*1000
217 QINO3(NN)=0.0
QINH4(NN)=0.0
C
C **** PRINT ONE HYDROGRAPH LINE.....
C
WRITE (2,310) T(L),RW(L),Q1(L),SSI(L),HYDTKN(L),HYDANH(L),
1SSCON(L),HYDNO3(L),HYDSNH(L)
WRITE (4,315) T(L),Q1(L)
220 CONTINUE
C
C **** END OF HYDROGRAPH. PRINT TOTAL RUNOFF AND RAINFALL.
C
L=NDT+1
230 VOL=(VOL-.5*Q1(L-1))*DT*FLOAT(KPR)/3600.
X1=SSI(L-1)/AREA
WRITE (2,320) PREC,PP(IT+1),VOL,PP(IT+1),X1,PP(IT+5),PP(IT+7)
C
CC...PRINT PARTICLE SIZE DISTRIBUTION OF ERODED SEDIMENT...
C
DO 232 IC=1,NPART
ERG=ERG+ER(IC)
232 CONTINUE
IF(ERG.LE.0.) GO TO 238
DO 234 IC=1,NPART
ER(IC)=ER(IC)/ERG*100.
234 CONTINUE
WRITE(2,405)
WRITE(2,410)(IC,ER(IC),IC=1,NPART)
238 CONTINUE
C
C **** DISPLAY STRUCTURAL PRACTICE EFFECTIVENESS.
C
K=NMAX+2
M=K+ISTRUC-1
DO 240 I=K,M
SIG=0.
DO 235 IC=1,NPART
235 SIG=SIG+SI(I,IC)
IF (SIG.EQ.0.) GO TO 240
SIG=SIG*DT
J=I-K+1
WRITE (2,370) J,SIG,PP(IT+5)
240 CONTINUE
C
C **** INDIVIDUAL ELEMENT SEDIMENT LOSS (-) OR GAIN (+).
C
X=10000./DX/DX

```

```

IF (IT.EQ.0) X=X*4.356
WRITE (2,340) (PP(IT+5),PP(IT+7),I=1,4)
C
C **** OUTPUT INDIVIDUAL ELEMENT NET SEDIMENTATION AMOUNTS AND
GROSS
C **** STATISTICAL VALUES.
C
SPAERO=0.
SPADEP=0.
SPASUM=0.
SPASS=0.
C
C **** COMPUTE STATISTICS ON OVERLAND FLOW ELEMENTAL SEDIMENT
YIELDS.
C
DO 250 I=1,N
SEL(I)=SEL(I)*DT*X
IF (SEL(I).GT.SPADEP) SPADEP=SEL(I)
IF (SEL(I).LT.SPAERO) SPAERO=SEL(I)
SPASUM=SPASUM+SEL(I)
250 SPASS=SPASS+SEL(I)*SEL(I)
WRITE (2,360) (I,SEL(I),I=1,N)
NM1=N-1
SPASD=DSQRT((SPASS-SPASUM*SPASUM/FLOAT(N))/FLOAT(NM1))
SPAERO=-SPAERO
WRITE (2,350) SPAERO,PP(IT+5),PP(IT+7),SPADEP,PP(IT+5),PP(IT+7),SP
1ASD,PP(IT+5),PP(IT+7),PP(IT+5)
C
C **** NOW, OUTPUT NET DEPOSITION FOR CHANNEL AREAS.
C
J=N+1
DO 260 I=J,N2
260 SEL(I)=SEL(I)*DT
WRITE (2,360) (NR(I),SEL(I),I=J,N2)
C
C***** OUTPUT FINAL DATA FOR NITROGEN LOSSES *****
C
CALL OUTN(DX,DT,PP(12),PP(14),N,N2,X1,L,AREA,NN,TKNSUM,
1ANHSUM,SUMNO3,SUMSNH)
C
C **** PLOTTING SECTION. THIS SECTION OF CODE WILL CREATE THE INPUT
C **** FILE FOR SUBROUTINE HYPLT ON DEVICE 8. SOME OF THE COMMANDS
C **** ARE MACHINE DEPENDENT AND ALL ARE PRESENTLY DISABLED. TO USE,
C **** SIMPLY REMOVE THE C IN COLUMN 1, ADD SUBROUTINE HYPLT TO THE
C **** PROGRAM, AND APPEND THE CALCOMP LIBRARY TO THE INPUT FILE.
C **** THERE ARE TWO FORMAT STATEMENTS (380 AND 390) THAT MUST ALSO
C **** HAVE THE COMMENT DESIGNATION REMOVED!
C
L=L-1
REWIND 8
WRITE (8,380) L1,RMAX,QMAX,CMAX,IT,PP
C
C **** COPY HYDROGRAPH TO STORAGE TAPE.
C
DO 270 I=1,L

```

```

C 270 WRITE (8,390) T(I),RW(I),Q1(I),SSCON(I)
C   CALL HYPLT (L1,T,RW,Q1,SSCON,RMAX,QMAX,CMAX,IT,PP)
275 STOP
C
C **** FORMATS.
C
280 FORMAT (19A4)
290 FORMAT (1H1,52H DISTRIBUTED HYDROLOGIC AND WATER QUALITY
SIMULATIO
1N/16X,23HBY ANSWERS VER 4.840815/19A4)
300 FORMAT (/24X,'OUTLET HYDROGRAPHS--VER 4.840815'/32X,' YIELDS-KG',
115X,'CONCENTRATIONS-MG/L'/22X,
2'-----',1X,'-----'/
32X,'TIME RAINFALL RUNOFF',2X,'SEDIMENT SEDIMENT BOUND NITR.',2X,
4'SEDIMENT',3X,'SOLUBLE NUTR.'/
52X,'MIN.',3X,'MM/H',4X,'MM/H',6X,'KG',7X,'TKN',6X,'ADS-NH4',
616X,'NO3',5X,'NH4'/)
310 FORMAT (1X,F6.1,F7.2,F9.4,F9.0,F11.3,F11.3,F10.0,F9.1,F7.1)
315 FORMAT (F10.1,F10.5)
320 FORMAT (4X,28HRUNOFF VOLUME PREDICTED FROM,F7.2,A4,14H OF
RAINFALL
1 =,F7.3,A4/15X,19HAVERAGE SOIL LOSS =,F7.0,1X,2A4)
330 FORMAT (///5X,48HMEAN FLOW DEPTH GREATER THAN EXPECTED AT
ELEMENT,
1I5/56H CONDITION OCCURRED BECAUSE THIS ELEMENT'S SLOPE IS
MUCH,31H
2 LESS THAN WATERSHED AVERAGE OR,/,28H CIRCULAR FLOW PATTERNS
ARE ,
358H PRESENT IN THIS VICINITY. RECOMMENDED CORRECTIVE ACTION:./60H
4 INCREASE EXPECTED PEAK RUNOFF VALUE (SF) IN SUBROUTINE DATA,10H
O
5R MODIFY,/,24HELEMENT FLOW DIRECTIONS.)
340 FORMAT (///19X,36HINDIVIDUAL ELEMENT NET SEDIMENTATION/1X,4(2X,16HE
1ELEMENT SEDIMENT)/1X,4(4X,3HNO.,3X,2A4))
350 FORMAT (1X,'MAX EROSION RATE =',F7.0,2A4,2X,'MAX DEPOSITION RATE
=
1',F7.0,2A4,/,23X,'STD. DEV. =',F7.0,2A4,/,24X,'CHANNEL DEPOSITION
2 --',A4,/,4(4X,'NO. AMOUNT'))
360 FORMAT (4(I7,F11.0))
370 FORMAT (21H STRUCTURAL PRACTICE,I3,32H REDUCED TOTAL SEDIMENT
YIE
1LD BY,F9.0,A4)
C 380 FORMAT (I4,2F7.2,F7.0,I3/12A4)
C 390 FORMAT (3F10.2,F10.0)
405 FORMAT(/20X,26HPARTICLE SIZE DISTRIBUTION/
*24X,18HOF ERODED SEDIMENT/)
410 FORMAT(17X,15HPARTICLE CLASS ,I1,2H =,F6.2,8H PERCENT)
C
END
SUBROUTINE DATA (NDT,KPR,N,CONV,CU,SF,IT,NN,ICR,NFI,CU2,ISTRUC,SB,
1TMIN,TMAX,NRG,DX,GRF,NEXP,DC,PP,FILTS,CWID,AREA,DT,NMAX,
2NDUR,NDELTA)
IMPLICIT REAL*8 (A-H,O-Z)
C
C ***** SUBROUTINE TO INPUT WATERSHED DATA.

```

```

C
C..... PARAMETERS USED IN THE EXTENDED SED SUBROUTINE
C
COMMON /ZSEDI/ NPART,NWASH,NWASH1
COMMON /ZSEDR/ VISCOS,AGRAV,SWH2O,YALCON,SE(5),VS(2000),DIA(5),SG
1(5),FV(5),CY1(5),CY2(5),CY4(5),DIAMM(5),EQSDIA(5),EDMM(5),F(20,5)
2,PERCLA(20,5),CE1,CE2,CE3,CE4,CE5,CE6
C
C***** PARAMETERS FOR THE NITROGEN TRANSPORT MODELS *****
C
COMMON /CINPUT/ CNIT(4,40),FERT(2,10),TEMP
C
COMMON /NTRANS/ NIT(2000),MAN(2000)
C
COMMON /ELEM/ PERPOT(2000),EDI(2000),TPOR(20),SM(20)
C
COMMON /SEDSOL/ CELNO3(2000),CELSNH(2000),XNO3(2000),XNH4(2000),FI
2LNO3(2000),FILNH4(2000),SZNO3(2000),SZNH4(2000),VOLSZ(2000),STOTKN
3(2000,5),STOLD(2000,5),STOANH(2000,5),SEDNEW(5),TKNIN(2010,5),ANH1
4N(2010,5),TKNSEL(2000),ANHSEL(2000),SEDSSEL(5),TKNOUT(5),ANHOUT(5),
5STNEW(5),QINO3(2010),QINH4(2010),STORNO(2000),STORNH(2000),CELTKN(
62000,5),CELANH(2000,5)
C
C**** MAXIMUM NUMBER OF SOIL TYPES IS 20.
C
COMMON /CSOIL/ A(20),P(20),FC(20),GWC(20),SKDR(20)
DIMENSION TP(20), DF(20), ASM(20), FCAP(20)
C
C**** MAXIMUM NUMBER OF SURFACE AND CROP TYPES IS 20.
C
COMMON /CROUGH/ ROUGH(20),HU(20),DIR(21),PIT(5,20),PER(20),CDR(20)
C
C**** MAXIMUM NUMBER OF OVERLAND ELEMENTS PLUS CHANNEL ELEMENTS
C**** IS 50.
C
C***** IT IS EXPECTED THAT ARRAY "IEL" (IN SUBROUTINE DATA) WILL
C***** BE OF SUCH A SIZE THAT IT WILL OVERLAY (BE EQUIVALENCED TO)
C***** THE SPACE IN ARRAYS SI AND QI TOGETHER. THEREFORE IT IS
C***** NECESSARY THAT THESE TWO ARRAYS BE KEPT ADJACENT IN THEIR
C***** COMMON BLOCK. NOTE: THE ACTUAL NUMBER OF ELEMENTS THAT
C***** CAN BE DIMENSIONED IN IEL WILL DEPEND ON THE WORD LENGTH
C***** OF THE MACHINE BEING USED, E.G. ON A MACHINE WHICH USES
C***** A SINGLE WORD INTEGER AND A DOUBLE WORD REAL, THE NUMBER
C***** OF ELEMENTS IN IEL CAN BE FOUR TIMES THE NUMBER OF ELEMENTS
C***** IN ARRAY SI.
C
COMMON /CFLOW/ Q(2000),RFL(2000),FLINS(2000),SS(2000),PIV(2000),B(
12000),NR(2000),NC(2000),DR(2000),S(2000),SL(2000),SEL(2000),SI(201
20,5),QI(2010),DIN(2000),SST(2000,5)
C
C***** ARRAYS SI AND QI MUST BE DIMENSIONED TO A SIZE = NMAX+ISTRUC+2
C***** TO HOLD, IN ORDER, SEDIMENT AND FLOW FROM THE WATERSHED
OUTLET
C***** ELEMENT, STRUCTURAL PRACTICES AND ANY "LEAKY" ELEMENTS.
C

```

EQUIVALENCE (TP(1),SST(1,1)),(DF(1),SST(21,1)),(ASM(1),SST(41,1))
 EQUIVALENCE (FCAP(1),SST(61,1)), (ITEMP(1),SST(81,1))
 EQUIVALENCE (IRR(1),SST(101,1))
 EQUIVALENCE (RN(1),SEL(1))
 EQUIVALENCE (WID(1),SEL(41)), (CN(1),SEL(51))
 EQUIVALENCE (CBAR(1),SEL(80)), (SPER(1),SEL(101)), (CROP(1,1),SEL
 1(121)), (NSTRUC(1),SEL(161))
 DIMENSION CROP(20,2), RN(20), DIRM(20), CBAR(20), SPER(20), NSTRUC
 1(4), STRNAM(3,4)
 EQUIVALENCE (DIRM(1),DIR(1))

C

C **** MAXIMUM NUMBER OF RAINGAGES IS 4 WITH 35 VALUES PER GAGE.

C

COMMON /CRGAGE/ RC(8,35),TC(8,35),R(8,20),FRA(8),JTR(8),RATE(8),SR
 1(8),NF(8)
 DIMENSION IRR(4), IG(4), DATE(2)
 EQUIVALENCE (IEL(1,1,1),SI(1,1))
 DIMENSION IEL(3,103,15), ITEMP(15)
 DIMENSION IELC(3,103,2), ITEMPC(2)
 DIMENSION FILTS(2000), CWID(2000)
 EQUIVALENCE (TIAL(1),RANE(1)), (SUR(1),SOIL(1))
 EQUIVALENCE (DIN(1),CHAN(1))
 COMMON /CSURF/ SUR(2000),RANE(2000)
 INTEGER SUR,SOIL(2000),TIAL(2000),RANE,CHAN(2000)

C

C **** MAXIMUM NUMBER OF CHANNEL TYPES IS 10.

C

DIMENSION WID(10), CN(10), PP(14), TITLE(11)
 LOGICAL STRUC
 CHARACTER*4 C1, C2, C3, C4, C5, C6, PRI, UN, UNITS, PR, TEST
 CHARACTER*4 PP, TITLE, STRNAM, DATE
 CHARACTER*2 IG, IELC, ITEMPC, ISTL
 CHARACTER JBEG
 DATA C1,C2,C3,C4,C5,C6,PRI,UN/'RAI','SI','SO','SU','CH',
 1'EL','PRIN','METR'/
 DATA ISTL/'TI'/

C

C **** NOW, STORE THE NAMES OF THE STRUCTURAL PRACTICES.

C

DATA STRNAM/'PTO','TERR','ACES','POND','S, L','AKES','G. W','ATER
 1','WAYS','FIEL','D BO','RDER'/
 STRUC=.FALSE.

C

C ***** NUMBER OF STRUCTURAL PRACTICES PERMITTED. ARRAYS STRNAM
 AND

C ***** NSTRUC MUST BE REDIMENSIONED IF ISTRUC IS MODIFIED. ALSO, THE

C ***** ADITIONAL STRUCTURE NAMES MUST BE ADDED TO THE DATA
 STATEMENT.

C

ISTRUC=4
 IT=0
 OUTSID=0.
 TMAX=0.
 TMIN=1.E+10

C

```

C **** INPUT UNITS USED IN SIMULATION AND OUTPUT PRINT CONTROL.
C
C   READ (1,800) UNITS,PR
C
C **** INPUT NUMBER OF RAINGAGES AND DATE OF EVENT.
C
C   READ (1,810) TEST,NRG,DATE
C   IF (NRG.GT.8) GO TO 540
C   IF (TEST.NE.C1) GO TO 580
C
C **** INPUT SEPARATE RAINFALL HYETOGRAPHS FOR EACH RAINGAGE.
C
C   DTMIN=900.
C   TINT=DTMIN
C   DO 20 I=1,NRG
C   FRA(I)=0.
C   READ (1,830) IG(I)
C   K=2
C   KM1=1
10  READ (1,740) JBEG,TC(I,K),RC(I,K)
C   IF (K.GT.2) TINT=TC(I,K)-TC(I,KM1)
C   IF (TINT.LT.DTMIN) DTMIN=TINT
C   K=K+1
C   KM1=K-1
C   IF (JBEG.EQ.' ' .OR. JBEG.EQ.'0') GO TO 10
C   IF (JBEG.NE.'1') GO TO 570
C   IF (K.GT.35) GO TO 540
C   IF (TC(I,2).LT.TMIN) TMIN=TC(I,2)
C   IF (TC(I,KM1).GT.TMAX) TMAX=TC(I,KM1)
20  IRR(I)=K
C
C **** INSERT SAME START AND FINISH TIME FOR EACH RAINGAGE RECORD.
C
C   DO 30 I=1,NRG
C   K=IRR(I)
C   KM1=K-1
C   TC(I,1)=TMIN
C   RC(I,1)=0.
C   IF (TC(I,KM1).EQ.TMAX) IRR(I)=IRR(I)-1
C   TC(I,K)=TMAX
30  RC(I,K)=0.
C
C ***** DEFINE DEFAULT SIMULATION REQUIREMENTS. MAXIMUM NUMBER OF
C ***** HYDROGRAPH PRINT POINTS IS 101 (THIS IS THE NUMBER THAT WILL BE
C ***** OUTPUT). NORMAL TIME STEP IS 60 SECONDS AND NORMAL TIME STEP
C ***** FOR INFILTRATION IS 180 SECONDS. MAXIMUM EXPECTED RUNOFF
C ***** RATE
C ***** IS 2 INCHES (50.8 MM) PER HOUR. IF A SEGMENTED CURVE ERROR
C ***** OCCURS DURING SIMULATION, INCREASE SF BY 50 PERCENT UNTIL
C ***** THAT
C ***** PROBLEM CEASES (IT MAY NOT BE THE ONLY PROBLEM, THOUGH).
C ***** FOR WATERSHEDS WITH LARGE ELEMENTS (GREATER THAN 5 ACRES),
C ***** MILD TOPOGRAPHY (LESS THAN 1 PERCENT AVERAGE SLOPES), OR
C ***** MANY ELEMENTS (MORE THAN 1000), THE SIMULATION TIME STEP, DT,
C ***** SHOULD BE INCREASED TO NO MORE THAN 300 SECONDS (5 MINUTES).

```

C ***** SIMILARLY, FOR SMALL ELEMENTS (LESS THAN 1 ACRE), SEVERE
 C ***** TOPOGRAPHY, OR WATERSHEDS WITH ONLY A FEW ELEMENTS, THE
 C ***** SIMULATION TIME STEP SHOULD BE DECREASED TO 15 - 30 SECONDS.

C
 C... INPUT SIMULATION REQUIREMENTS

C
 READ (1,810) TEST
 IF (TEST.NE.C2) GOTO 580
 READ (1,1030) NDT,DT,NFI,SF
 C
 IF (UNITS.EQ.UN) IT=7
 IF (PRI.NE.PR) GO TO 50
 WRITE (2,660) DATE
 DO 40 I=1,NRG
 L=IRR(I)
 40 WRITE (2,670) IG(I),PP(IT+1),PP(IT+2),(TC(I,K),RC(I,K),K=2,L)
 50 IF (DT.GT.DTMIN*60.) WRITE (2,880)
 KPR=(TMAX-TMIN)/DT/FLOAT(NDT)*60.+1.
 IF (PRI.EQ.PR) WRITE(2,630) DT,NFI,SF,PP(IT+1),PP(IT+2)
 NFI=NFI/IFIX(SNGL(DT))

C
 C **** INPUT INFILTRATION AND SOIL DATA.

C
 READ (1,810) TEST
 IF (TEST.NE.C3) GO TO 580
 READ (1,780) ISR
 IF (PRI.EQ.PR) WRITE (2,750) PP(IT+1),PP(IT+2),PP(IT+1),PP(IT+2),P
 1P(IT+1)
 IF (ISR.GT.20) GO TO 530
 ASMBAR=0.
 FPBAR=0.
 DO 60 I=1,ISR
 READ (1,790) TP(I),FCAP(I),FC(I),A(I),P(I),DF(I),ASM(I),SKDR(I)
 SPER(I)=0.

C
 C***** ADDITION FOR NITROGEN TRANSPORT MODEL *****

C
 TPOR(I)=TP(I)
 SM(I)=ASM(I)
 C
 IF (PRI.EQ.PR) WRITE (2,640) I,TP(I),FCAP(I),FC(I),A(I),P(I),DF(I)
 1,ASM(I),SKDR(I)

C
 CC.....WATER TEMPERATURE ASSUMED TO BE 20 DEG.C. (68 DEG.F.).....
 CC.....AT OTHER TEMPERATURES ADJUST VISCOS AND SWH2O.....

C
 AGRAV=32.174
 VISCOS=0.0000108
 SWH2O=62.32
 IF(UNITS.NE.UN) GO TO 58
 AGRAV=9.8066352
 VISCOS=0.000001003352832
 C SWH2O=9789.69088
 SWH2O=999.1677535
 58 CONTINUE

```

60 CONTINUE
C
C .... ADDITIONAL CALCULATIONS FOR EXTENDED SEDIMENT MODEL
C
  WRITE(2,1040)
  READ(1,1050)NPART,NWASH
  WRITE(2,1060)NPART,NWASH
  NWASH1=NWASH+1
  IF(NWASH.EQ.NPART) NWASH1=1
  VISCOS=1./VISCOS
  READ(1,1070)(DIAMM(IC),SG(IC),FV(IC),IC=1,NPART)
  DO 70 IC=1,NPART
    IF(UNITS.EQ.UN) GO TO 61
    DIA(IC)=DIAMM(IC)*.0032808399
    GO TO 62
  61  DIA(IC)=DIAMM(IC)*0.001
  62  IF(FV(IC).LE.0.00000001) GO TO 63
      GO TO 70
C
CC.....CALCULATION OF PARTICLE FALL VELOCITIES.....
C
  63  FV(IC)=AGRAV*(SG(IC)-1.)*VISCOS*DIA(IC)**2/18.
      X1=DIA(IC)*VISCOS
      REYN=FV(IC)*X1
      IF(REYN.LE.0.1) GO TO 70
      X2=DSQRT(4.*AGRAV*(SG(IC)-1.)*DIA(IC)/3.)
      DO 69 I=1,10
        CD=24./REYN+3./DSQRT(REYN)+.34
        FV(IC)=X2/DSQRT(CD)
        REYN=FV(IC)*X1
  69  CONTINUE
  70  CONTINUE
C
CC.....CALCULATION OF EQUIVALENT SAND DIAMETERS.....
C
  DO 78 IC=1,NPART
    IF(SG(IC).GT.2.645) GO TO 77
    X4=FV(IC)*VISCOS
    DS=DSQRT(10.90909091*FV(IC)/(AGRAV*VISCOS))
    REYN=X4*DS
    IF(REYN.LE.0.1) GO TO 76
    X3=FV(IC)**2/(AGRAV*2.2)
    DO 75 II=1,20
      DS=X3*(24./REYN+3./DSQRT(REYN)+.34)
      REYN=X4*DS
  75  CONTINUE
  76  EQSDIA(IC)=DS
      GO TO 78
  77  EQSDIA(IC)=DIA(IC)
  78  CONTINUE
      X3=304.8
      IF(UNITS.EQ.UN) X3=1000.
      DO 79 IC=1,NPART
  79  EDMM(IC)=EQSDIA(IC)*X3
      WRITE(2,1080)PP(IT+4)

```

```

WRITE(2,1090)(IC,DIAMM(IC),EDMM(IC),SG(IC),FV(IC),IC=1,NPART)
WRITE(2,1100)
READ(1,1105)
DO 85 J=1,ISR
READ(1,1110)(F(J,I),I=1,NPART)
85 WRITE(2,1120)J,(F(J,I),I=1,NPART)
C
C***** INPUT DISTRIBUTION OF CLAY IN PARTICLE CLASSES FOR THE *****
C***** NITROGEN TRANSPORT MODELS *****
C
WRITE(2,1150)
READ(1,1105)
DO 86 J=1,ISR
READ(1,1140) (PERCLA(J,IC),IC=1,NPART)
WRITE(2,1160) J,(PERCLA(J,IC),IC=1,NPART)
86 CONTINUE

C
C **** INPUT DRAINAGE AND GROUNDWATER CONSTANTS.
C
READ (1,980) NEXP,DC,GRF
IF (PR1.EQ.PR) WRITE (2,990) NEXP,DC,PP(IT+1),GRF
C
C **** INPUT CROP AND SURFACE ROUGHNESS DATA.
C
READ (1,810) TEST
IF (TEST.NE.C4) GO TO 580
READ (1,940) ICR
IF (PR1.EQ.PR) WRITE (2,950) PP(IT+1),PP(IT+1),PP(IT+1)
IF (ICR.GT.20) GO TO 550
DO 87 I=1,ICR
CBAR(I)=0.
READ (1,620) CROP(I,1),CROP(I,2),PIT(1,I),PER(I),ROUGH(I),HU(I),RN
1(I),DIRM(I),CDR(I)
IF (ROUGH(I).GT.1.0.OR.ROUGH(I).LE.0.) GO TO 590
IF (PR1.EQ.PR) WRITE (2,960) I,CROP(I,1),CROP(I,2),PIT(1,I),PER(I)
1,ROUGH(I),HU(I),RN(I),DIRM(I),CDR(I)
87 CONTINUE

C
C***** CALL SUBROUTINE 'XINPUT' TO INPUT INFORMATION FOR THE *****
C***** NITROGEN TRANSPORT MODELS *****
C
CALL XINPUT(NDUR,NDELTA)
C
C **** INPUT CHANNEL DATA.
C
READ (1,810) TEST
IF (TEST.EQ.C6) GO TO 80
IF (TEST.NE.C5) GO TO 580
READ (1,920) M
IF (M.GT.10) GO TO 510
READ (1,760) (WID(I),CN(I),I=1,M)
IF (PR1.EQ.PR) WRITE (2,650) PP(IT+4),(I,WID(I),CN(I),I=1,M)
C

```

```

C **** INPUT OUTFLOW ELEMENT POSITION.
C
  READ (1,820) TEST,TITLE
  IF (TEST.NE.C6) GO TO 580
  80 READ (1,610) DX,NIOUT,NJOUT
C
C **** EVALUATE CONSTANTS FOR USE WITH METRIC OR ENGLISH UNITS.
C **** METRIC UNITS.
C
  DX2=DX*DX
  AREA=DX2/1.E+4
  CU1=DX2/1.E+3
  CU2=DT/DX2*500.
  CU=DX2/3.6E+6
  CONST=DX/(2./DT*DX2)**1.6667
  IF (UNITS.EQ.UN) GO TO 90
C
C **** CONVERT TO ENGLISH UNITS.
C
  CU1=CU1/.012
  CU=CU/.012
  CU2=CU2*.012
  CONST=1.486*CONST
  AREA=AREA/4.3560
C
C **** INPUT INDIVIDUAL ELEMENT TOPOGRAPHICAL DATA.
C
  90 NPAR=17
     NPAR2=15
C
C **** CHANGE DIMENSION STATEMENT BELOW IF JMAX IS CHANGED.
C
  JMAX=103
  NMAX=2000
  N=0
  II=0
  SCMIN=9.
  SCMAX=0.
  SCBAR=0.
  SMIN=9.
  SMAX=0.
  SBAR=0.
  TBAR=0.
  DO 100 J=1,JMAX
  100 IEL(3,J,3)=0
C
C **** INPUT FIRST ROW OF ELEMENTAL DATA.
C
  READ (1,680) (ITEMP(K),K=1,7),(ITEMPC(L),L=1,2),(ITEMP(K),K=8,15)
  CALL RELEM (IEL,ITEMP,N,MOUT,NIOUT,NJOUT,ISR,ICR,NMAX,JMAX,NPAR,
  1IELC,ITEMPC,NPAR2)
C
C **** PUT WATERSHED ELEMENTAL DATA INTO SINGLE DIMENSIONED ARRAYS.
C
  110 CALL RELEM (IEL,ITEMP,N,MOUT,NIOUT,NJOUT,ISR,ICR,NMAX,JMAX,NPAR,

```

```

1IELC,ITEMPC,NPAR2)
JS=IEL(2,1,2)
DO 270 J=1,JS
JM1=J-1
I=IEL(2,J,3)
IF (I.EQ.0) GO TO 270
SL(I)=FLOAT(IEL(2,J,4))/1000.
IF (SL(I).LT.SMIN) SMIN=SL(I)
IF (SL(I).GT.SMAX) SMAX=SL(I)
SBAR=SBAR+SL(I)
CHAN(I)=IEL(2,J,6)/100
IF (CHAN(I).GT.10) WRITE (2,1020) CHAN(I),I
SS(I)=FLOAT(IEL(2,J,8))/1000.

```

```

C
C***** PUT DATA FROM THE ELEMENTAL DATA FILE TO BE USED *****
C***** IN THE NITROGEN TRANSPORT MODEL INTO ARRAYS *****

```

```

C
  NIT(I)=IEL(2,J,12)
  MAN(I)=IEL(2,J,13)
  PERPOT(I)=FLOAT(IEL(2,J,14))/100.
  EDI(I)=FLOAT(IEL(2,J,15))/10.

```

```

C
C **** IF CHANNEL SLOPE NOT SPECIFIED, ASSUME IT'S HALF OVERLAND SLOPE.

```

```

C
  IF (SS(I).LE.0.) SS(I)=.5*SL(I)
  TIAL(I)=0
  IF (IELC(2,J,2).NE.ISTL) GO TO 120
  TIAL(I)=256
  TBAR=TBAR+1.
120 M=FLOAT(IEL(2,J,5))/90.+1.
  MM1=M-1

```

```

C
C **** EVALUATE OUTFLOW PROPORTIONS TO ADJACENT COLUMN AND ROW
ELEMENTS.

```

```

C
  ANG=(FLOAT(IEL(2,J,5))-90.*FLOAT(MM1))*0.01745329
  X=SIN(ANG)+COS(ANG)
  IX=CHAN(I)
  IF (IX.EQ.0) GO TO 130

```

```

C
C **** EVALUATE CONVEYANCE FOR CHANNEL ELEMENTS.

```

```

C
  II=II+1
  CWID(II)=WID(IX)
  SS(II)=SS(I)
  IF (SS(I).LT.SCMIN) SCMIN=SS(I)
  IF (SS(I).GT.SCMAX) SCMAX=SS(I)
  SCBAR=SCBAR+SS(I)
  PIV(II)=CONST/CN(IX)/X*(DX/WID(IX)/X)**0.6667*DSQRT(SS(I))

```

```

C
C **** NOW DETERMINE THE ELEMENT(S) THAT RECEIVE OUTFLOW FROM THE
C **** CURRENT ELEMENT. NOTE: IS IS LEGAL FOR AN ELEMENT WITH A
C **** SHADOW CHANNEL ELEMENT TO SHOW FLOW, AT THIS TEST POINT, THAT
C **** WOULD OTHERWISE BE OUTSIDE THE CATCHMENT.

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```

C

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```

130 GO TO (140,150,150,140,140), M
140 IF ((J.GE.JMAX.OR.IEL(2,J+1,3).EQ.0).AND.CHAN(I).EQ.0.AND.IEL(2,J,
15).NE.270.AND.I.NE.MOUT) WRITE (2,770) IEL(2,J,1),J
NR(I)=IEL(2,J+1,3)
GO TO (160,160,170,170,160), M
150 IF ((J.LE.1.OR.IEL(2,JM1,3).EQ.0).AND.IEL(2,J,5).NE.90.AND.I.NE.MO
1UT.AND.CHAN(I).EQ.0) WRITE (2,770) IEL(2,J,1),J
NR(I)=IEL(2,JM1,3)
GO TO (160,160,170,170,160), M
160 IF (IEL(1,J,3).EQ.0.AND.IEL(2,J,5).NE.0.AND.CHAN(I).EQ.0.AND.IEL(2
1,J,5).NE.360.AND.I.NE.MOUT) WRITE (2,770) IEL(2,J,1),J
NC(I)=IEL(1,J,3)
GO TO 180
170 IF (IEL(3,J,3).EQ.0.AND.IEL(2,J,5).NE.180.AND.I.NE.MOUT.AND.CHAN(I
1).EQ.0) WRITE (2,770) IEL(2,J,1),J
NC(I)=IEL(3,J,3)
180 IF (ANG.GT..78539816) GO TO 190
RFL(I)=.5*SIN(ANG)/COS(ANG)
GO TO 200
190 RFL(I)=1-.5*SIN(1.5707963-ANG)/COS(1.5707963-ANG)
200 GO TO (210,220,210,220,210), M
210 RFL(I)=1.-RFL(I)
C
C **** ELIMINATE FALSE RECEIVING ELEMENTS WHICH MAY CAUSE
OUT-OF-RANGE
C **** SUBSCRIPTS FOR SOME BOUNDARY ELEMENTS.
C
220 IF (RFL(I).LT.0.01) NR(I)=NC(I)
IF (RFL(I).GT.0.99) NC(I)=NR(I)
C
C **** "LEAKY" ELEMENTS (THOSE WITH PARTIAL FLOW OUTSIDE THE
WATERSHED)
C **** MUST DIVERT THAT PARTIAL FLOW INTO A SPECIAL PSUEDO ELEMENT.
C
IF (NC(I).GT.0.OR.I.EQ.MOUT) GO TO 230
C
C **** THIS ELEMENT LEAKS, DIVERT IT INTO SPECIAL "BOTTOMLESS PIT".
C
NC(I)=NMAX+ISTRUC+2
C
C **** ADD TO TOTAL NON-CONTRIBUTING AREA.
C
OUTSID=OUTSID+1.-RFL(I)
230 IF (NR(I).GT.0.OR.I.EQ.MOUT) GO TO 240
NR(I)=NMAX+ISTRUC+2
OUTSID=OUTSID+RFL(I)
C
C **** GET CROP/MGMT NUMBER.
C
240 I1=IEL(2,J,7)
CBAR(I1)=CBAR(I1)+1.
C
C **** PUT CROP/MANAGEMENT NUMBER IN LOW BYTE AND SOIL TYPE NUMBER
IN

```

```

C **** NEXT BYTE OF (SOIL: SUR).
C
  K=MOD(IEL(2,J,6),100)
  SPER(K)=SPER(K)+1.
  SOIL(I)=(K*256)+I1
  ASMBAR=ASMBAR+ASM(K)
  FPBAR=FPBAR+FCAP(K)
  B(I)=CONST*DSQRT(SL(I))*X/RN(I1)
C
C **** MAKE SPECIAL ADJUSTMENTS TO ACCOUNT FOR STRUCTURAL
PRACTICES,
C **** BUT FIRST SEE IF ANY ARE PRESENT IN THIS ELEMENT.
C
  IF (IEL(2,J,9).NE.0) CALL STRUCT (I,J,NC(I),NR(I),RFL(I),IEL,JMAX,
1NPAR,NMAX,STRUC,NSTRUC,ISTRUC,X,DX,WID,SS(II+1),SS(I),PIV(II+1),CN
2,CWID(II+1),CHAN(I),CONST,SL(I),II,SCMIN,SCMAX,SCBAR,ANG,IELC,NPAR
32)
C
C **** RENUMBER RAINGAGES TO 1,2,...,NRG IN ORDER OF HYETOGRAPH INPUTS.
C
  DO 250 K=1,NRG
  IF (IELC(2,J,1).EQ.IG(K)) GO TO 260
250 CONTINUE
  WRITE (2,600) IELC(2,J,1),IEL(2,J,1),J,IG(1)
  K=1
C
C **** PUT RAINGAGE NUMBER IN LOW BYTE AND TILE NUMBER IN NEXT BYTE
C **** OF (TIAL:RANE).
C
260 RANE(I)=TIAL(I)+K
270 CONTINUE
  JS=IEL(3,1,2)
  IF (ITEMP(3).NE.999.AND.IEL(3,JS,1).NE.ITEMP(1)) GO TO 110
  ITEMP(3)=999
  IF (JS.NE.JMAX) GO TO 110
  IF (N+II.GT.NMAX) GO TO 520
  X=N
  ASMBAR=ASMBAR/X
  FPBAR=FPBAR/X
  SB=AREA
  AREA=AREA*(X-OUTSID)
  CONV=CU*(X-OUTSID)
  SBAR=SBAR/X
  IF (II.GT.0) SCBAR=SCBAR/FLOAT(II)
  NN=N+1
C
C **** OUTPUT STATISTICAL SUMMARY OF WATERSHED CHARACTERISTICS.
C
  TBAR=TBAR/X
  WRITE (2,690) TITLE,SB,PP(IT+3),N,II,AREA,PP(IT+3),SMIN,SBAR,SMAX,
1SCMIN,SCBAR,SCMAX,TBAR,DC,PP(IT+1),ASMBAR,FPBAR,GRF,MOUT,NIOUT,NJO
2UT
  WRITE (2,700) PP(IT+1),PP(IT+2),PP(IT+1),PP(IT+2),PP(IT+1)
  DC=DC*CU/24.

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SB=CONST*DSQRT(SBAR)/RN(1)
J=0
DO 330 I=1,ICR
IF (CBAR(I).LE.0..AND.I.LT.ICR) GO TO 330
CBAR(I)=CBAR(I)/X
IF (J.GE.ISR) GO TO 320
280 J=J+1
DO 300 JJ=J,ISR
IF (SPER(JJ).LE.0.) GO TO 300
FPBAR=FC(JJ)+A(JJ)*(1.-ASM(JJ))*P(JJ)
SPER(JJ)=SPER(JJ)/X
IF (CBAR(I).LE.0.) GO TO 290
WRITE (2,710) CROP(I,1),CROP(I,2),CBAR(I),PER(I),RN(I),CDR(I),JJ,S
1PER(JJ),FC(JJ),FPBAR,DF(JJ),SKDR(JJ)
CBAR(I)=0.
GO TO 310
290 WRITE (2,720) JJ,SPER(JJ),FC(JJ),FPBAR,DF(JJ),SKDR(JJ)
GO TO 310
300 CONTINUE
J=ISR
GO TO 320
310 J=JJ
IF (I.LT.ICR) GO TO 330
IF (J.LT.ISR) GO TO 280
320 IF (CBAR(I).GT.0.) WRITE (2,730) CROP(I,1),CROP(I,2),CBAR(I),PER(I
1),RN(I),CDR(I)
330 CONTINUE
NR(MOUT)=NN
NC(MOUT)=NN
IF (I.IE.0) GO TO 340
N2=N
GO TO 410
C
C **** DETERMINE SHADOW ELEMENT CONTINUITY.
C **** FIND CHANNEL SEGMENTS.
C
340 DO 350 J=1,N
IF (CHAN(J).EQ.0) GO TO 350
C
C **** USE THE ROW FLOW POINTER TO REMEMBER ORIGINAL ELEMENT
NUMBER
C **** OF THIS CHANNEL ELEMENT, SINCE THE FLOW COMPONENT IN THE ROW
C **** DIRECTION IS 0.
C
NR(NN)=J
NN=NN+1
350 CONTINUE
C
C **** MOVE CHANNEL PARAMETERS TO END OF ARRAYS.
C
N2=NN-1
N1=N+1
DO 390 I=N1,N2
I1=I-N
B(I)=PIV(I1)

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```

C      CWID(I)=CWID(I1)
C      SL(I)=SS(I1)
C      J=NR(I)
C      I1=NC(J)
C      I2=NR(J)
C
C **** IF CERTAIN STRUCTURES ARE PRESENT IN AN ELEMENT WITH A SHADOW
C **** ELEMENT, IT IS LIKELY THAT THE RECEIVING CHANNEL ELEMENT WILL
C **** NOT BE GETTING THE MAJOR OUTFLOW.
C
C      IF (I1.GT.NMAX) GO TO 360
C      IF (I2.GT.NMAX) GO TO 380
C
C **** THIS ELEMENT DOES NOT CONTAIN A STRUCTURE; THEREFORE, THE
C **** RECEIVING CHANNEL ELEMENT SHOULD BE IN THE DIRECTION OF THE
C **** PREDOMINANT FLOW COMPONENT.
C
C      IF (RFL(J).LT.0.207107) GO TO 380
C      IF (RFL(J).GT.0.792893) GO TO 360
C
C **** FLOW DIRECTION IS PREDOMINANTLY DIAGONAL.
C ***** IF ROW FLOW DESTINATION NUMBER IS LESS THAN CURRENT ELEMENT
C ***** NUMBER, THE DIAGONAL POINTS TO THE LEFT AND THE DIAGONAL
C ***** DESTINATION ELEMENT CAN BE COMPUTED BY SUBTRACTING ONE FROM
C ***** THE CONVENTIONAL OVERLAND FLOW COLUMN DESTINATION NUMBER.
C
C      IF (I2.LT.J) GO TO 370
C      I1=I1+1
C      GO TO 380
360 I1=I2
C      GO TO 380
370 I1=I1-1
C
C **** MAKE CERTAIN THE RECEIVING ELEMENT IS A CHANNEL ELEMENT.
C
C      380 IF (CHAN(I1).LT.1.AND.J.NE.MOUT) GO TO 560
C
C **** TEMPORARILY ASSIGN THE ORIGINAL OVERLAND FLOW ELEMENT
C **** NUMBER
C **** AS THE DESTINATION FOR THE SHADOW OUTFLOW. THIS IS NECESSARY
C **** UNTIL NEW NUMBERS ARE ASSIGNED TO ALL SHADOW ELEMENTS.
C
C      NC(I)=I1
C
C **** MAKE ALL OVERLAND FLOW FROM THIS ELEMENT GO INTO ITS SHADOW
C **** ELEMENT, UNLESS IT CONTAINS A STRUCTURAL PRACTICE.
C
C      IF (NR(J).LE.NMAX) NR(J)=I
C      IF (NC(J).LE.NMAX) NC(J)=I
390 CONTINUE
C
C **** FIND REAL CHANNEL SEGMENT NUMBER INTO WHICH EACH CHANNEL
C **** SEGMENT FLOWS.
C
C      DO 400 J=N1,N2

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I=NC(J)
NC(J)=NR(I)
C
C **** IF THIS ELEMENT CONTAINS A STRUCTURAL MEASURE, ITS CORRECT
C **** CHANNEL ELEMENT NUMBER MAY BE PRESENT ONLY IN ARRAY NC.
C
IF (NC(J).GT.NMAX) NC(J)=NC(I)
C
C **** FORCE ALL CHANNEL FLOW TO USE ONLY COLUMN FLOW DIRECTIONS.
C
400 RFL(J)=0.
J=NR(MOUT)
NC(J)=NN
C
C **** OUTPUT DATA CONCERNING ANY STRUCTURAL PRACTICES.
C
410 IF (.NOT.STRUC) GO TO 430
WRITE (2,1000)
DO 420 I=1,ISTRUC
IF (NSTRUC(I).NE.0) WRITE (2,1010) I,(STRNAM(J,I),J=1,3),NSTRUC(I)
420 CONTINUE
C
C **** EVALUATE INITIAL CONDITIONS.
C
430 DO 440 I=1,N2
S(I)=0.
440 FLINS(I)=0.
C
C **** CONVERT SOIL CONSTANTS.
C
DO 450 I=1,ISR
FC(I)=CU*FC(I)
TP(I)=TP(I)*CU1*DF(I)
A(I)=CU*A(I)*(DT/TP(I))**P(I)
450 GWC(I)=(1.-FCAP(I))*TP(I)/DT
C
C **** INITIALIZE VALUES SPECIFIC TO INDIVIDUAL ELEMENTS.
C
Y=1./X
DO 460 I=1,N
K=2
IS=SOIL(I)/256
IC=MOD(SUR(I),256)
PIV(I)=(1.-ASM(IS))*TP(IS)/DT
C
C **** CONTINUE FOR SURFACE INITIAL CONDITION.
C
J=MOD(RANE(I),256)
IF (TC(J,2).LT.(TMIN+1.1)) K=3
FRA(J)=FRA(J)+Y
SUPP=RC(J,K)*(1.-PER(IC))*CU
X=FILT(A(IS),PIV(I),P(IS),FC(IS),GWC(IS),DR(I),S(I),SUPP,CU2,ROUGH
1(IC),HU(IC),NEXP)
FILTS(I)=X
IF (X.GT.SUPP) X=SUPP

```

```

460 FLINS(I)=SUPP-X
C
C **** CONVERT SURFACE VALUES.
C
  DO 480 I=1,ICR
C   DIRM(I)=0.10*HU(I)
  DO 470 J=1,NRG
470 PIT(J,I)=PIT(1,I)*CU1/DT
  ADIR=HU(I)*ROUGH(I)*(DIRM(I)/HU(I))**(1./ROUGH(I))
480 DIR(I)=ADIR*2.*CU1/DT
C
C **** SET CHANNEL RETENTION TO ZERO.
C
  DIR(21)=0.
  J=NMAX+ISTRUC+2
  DO 500 I=1,J
  IF (I.GT.NMAX) GO TO 490
  Q(I)=0.
  SS(I)=0.
  SEL(I)=0.
  DO 484 IZ=1,NPART
484 SST(I,IZ)=0.
  DIN(I)=0.
490 QI(I)=0.
  DO 494 IZ=1,NPART
494 SI(I,IZ)=0.
500 CONTINUE
C
CC....CALCULATION OF COEFFICIENTS FOR YALINS EQUATION.....
C
  DO 505 IC=1,NPART
  CY1(IC)=EQSDIA(IC)*VISCOS
  CY2(IC)=1.65*AGRAV*EQSDIA(IC)
  CY4(IC)=2.65*EQSDIA(IC)*SWH2O
505 CONTINUE
  SGD2=DSQRT(AGRAV*.5)
  DO 506 IC=1,N
  K=MOD(SUR(IC),256)
  VS(IC)=SGD2*DSQRT(SL(IC)*DT/DX2)
506 CONTINUE
  IF(N2.EQ.N) GO TO 508
  DO 507 IC=N1,N2
  VS(IC)=SGD2*DSQRT(SL(IC)*DT/(DX*CWID(IC)))
507 CONTINUE
508 CONTINUE
  RETURN
C
C **** ERROR MESSAGES.
C
510 WRITE (2,930)
  STOP
520 WRITE (2,840)
  STOP
530 WRITE (2,860)
  STOP

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540 WRITE (2,850)
 STOP
 550 WRITE (2,870)
 STOP
 560 WRITE (2,890) J
 STOP
 570 WRITE (2,900) NRG,J
 STOP
 580 WRITE (2,910) TEST
 STOP
 590 WRITE (2,970) ROUGH(I),CROP(I,1),CROP(I,2)
 STOP

C
 C **** FORMATS.

C
 600 FORMAT (1X,27HRAIN DATA MISSING FOR GAGE ,A2,12H, AT ELEMENT,I4,1H
 1,,I4,7H: GAGE ,A2,10H DATA USED)
 610 FORMAT (16X,F7.2/17X,I4,8X,I4)
 620 FORMAT (11X,2A4,6X,F3.2,6X,F3.2,5X,F3.2,4X,F4.2,3X,F4.3,6X,F5.3,
 *3X,F5.4)
 630 FORMAT (/1X,27HSIMULATION TIME INCREMENT =,F6.1,8H SECONDS/1X,
 *38HINFILTRATION CAPACITY CALCULATED EVERY,I5,8H SECONDS/1X,
 *22HEXPECTED RUNOFF PEAK =,F5.1,2A4)
 640 FORMAT (I4,2PF9.1,F11.1,0PF11.2,F8.2,F7.2,F9.1,2PF10.1,0PF9.2)
 650 FORMAT (/1X,18HCHANNEL
 PROPERTIES/1X,4HTYPE,3X,5HWIDTH,3X,11HMANNI
 1NG'S N/9X,A4/(I4,F8.1,F11.3))
 660 FORMAT (/5X,33HRAINFALL HYETOGRAPH FOR EVENT OF ,2A4)
 670 FORMAT (/5X,12HGAGE NUMBER ,A2/5X,11HTIME - MIN.,7X,15HRAINFALL RA
 1TE -,2A4/(F14.1,F24.2))
 680 FORMAT (2I3,I2,I3,3I4,3X,A2,1X,A2,2X,I4,I3,2I4,I8,I4,I7,I4)
 690 FORMAT (/5X,11A4,/,5X,'WATERSHED CHARACTERISTICS',/, 'NUMBER OF',
 1F6.2,A4,' OVERLAND FLOW ELEMENTS =',I5,/,1X,'NUMBER OF CHANNEL SEG
 2MENTS =',I3,/,1X,'AREA OF CATCHMENT =',F8.1,A4,/,1X,'CATCHMENT SL
 3OPE: MIN =,2PF7.2,' AVE =,F7.2,' MAX =,F7.2,' PERCENT',/,1X,
 4CHANNEL SLOPE: MIN =,F7.2,' AVE =,F7.2,' MAX =,F7.2,' PERCE
 5NT',/,1X,'PERCENT OF AREA TILED =,F6.1,' WITH A D.C. OF,0PF5.2,A
 64,/'24H',/, 'MEAN ANTECEDENT SOIL MOISTURE =,2PF4.0,', FIELD CAPA
 7CITY =,F4.0,' PERCENT SATURATION',/, 'GROUNDWATER RELEASE FRACTIO
 8N =,0PF7.4,/,1X,'OUTLET IS ELEMENT',I5,' AT ROW',I4,' COL',I4)
 700 FORMAT (/,' SURFACE COVER/MANAGEMENT CONDITIONS',8X,'SOIL
 ASSOCIAT
 1ION PROPERTIES',/,3X,'CROP PERCENT PERCENT N',4X,'C',5X,'NO. PER
 2CENT FC',4X,'INITIAL CONTROL K',/,9X,'PRESENT COVER',18X,'PRE
 3SENT',4A4,' DEPTH',A4)
 710 FORMAT (1X,2A4,2PF6.1,F7.0,0PF6.3,F7.4,I4,2PF7.1,0PF7.1,1X,2F8.1,F
 17.2)
 720 FORMAT (I39,2PF7.1,0PF7.1,1X,2F8.1,F7.2)
 730 FORMAT (1X,2A4,2PF6.1,F7.0,0PF6.3,F6.2)
 740 FORMAT (A1,F9.0,F10.0)
 750 FORMAT (/1X,15HSOIL PROPERTIES/1X,4HSOIL,2X,8HPOROSITY,2X,10HFIEL
 1D CAP.,2X,22HINFILTRATION
 CONSTANTS,2X,7HCONTROL,2X,10HANTECEDENT,
 21X,7HEROSION/7X,8H(PERCENT,3X,8H(PERCENT,6X,2HFC,7X,1HA,6X,1HP,5X,
 34HZONE,5X,8HMOISTURE,3X,6HCONST./9X,5HVOL.),6X,5HSAT.),4X,2A4,2A4,

49X,A4,3X,13H(PERCENT SAT))
 760 FORMAT (18X,F4.0,27X,F5.0)
 770 FORMAT (8H ELEMENT,I4,1H,,I4,27H FLOWS OUT OF THE WATERSHED)
 780 FORMAT (18X,I4)
 790 FORMAT (10X,F3.2,6X,F3.2,6X,F5.2,5X,F5.3,5X,F3.2,6X,F5.1,7X,F3.2,5
 1X,F3.2)
 800 FORMAT (1X,A4,52X,A4)
 810 FORMAT (A4,15X,I1,25X,2A4)
 820 FORMAT (A4,24X,11A4)
 830 FORMAT (16X,A2)
 840 FORMAT (37H NUMBER OF SHED+CHAN ELEMENTS EXCEEDS,10H
 DIMENSION)
 850 FORMAT (32H RAINFALL DATA EXCEEDS DIMENSION)
 860 FORMAT (31H NO. OF SOILS EXCEEDS DIMENSION)
 870 FORMAT (36H NO. OF CROPS EXCEEDS DIMENSION SPEC)
 880 FORMAT (47H ANALYSIS IS NOT ACCURATE IF RAINFALL INTENSITY,28H INT
 IERVALS ARE LESS THAN DT.)
 890 FORMAT (39HCHANNELS DISCONTINUOUS NEAR ELEMENT NO.,I5)
 900 FORMAT (1X,37HHYETOGRAPH DATA MISSING OR INCORRECT,,24H FIRST
 COLU
 1MN NOT 0 OR 1/I4,40H GAGES REQUESTED. BAD LINE BEGINS WITH: ,A2)
 910 FORMAT (24HINCORRECT INPUT SEQUENCE,36H OR HEADER CARD. CARD
 BEGI
 1NS WITH: ,A4)
 920 FORMAT (30X,I3)
 930 FORMAT (39H NO. OF CHANNEL TYPES EXCEEDS DIMENSION)
 940 FORMAT (31X,I3)
 950 FORMAT (/7H COVER /20HMANAGEMENT PRACTICES/3X,4HCROP,6X,
 19HMAX. POT.,3X,7HPERCENT,2X,6HROUGH.,2X,6HROUGH.,2X,
 29HMANNING'S,2X,9HMAX. RET.,2X,7HEROSION/11X,12HINTERCEPTION,
 33X,5HCOVER,3X,6HCOEFF.,2X,6HHEIGHT,6X,1HN,8X,5HDEPTH,5X,
 46HCONST./14X,A4,25X,A4,16X,A4)
 960 FORMAT (1X,I2,1X,2A4,F7.2,2PF12.0,OPF8.2,F8.1,F10.3,F10.2,F10.2)
 970 FORMAT (20H ROUGHNESS COEFF. OF,F8.2,27H IS OUT OF RANGE FOR
 CROP:
 1 ,2A4)
 980 FORMAT (20X,I2/39X,F5.2/31X,E10.3)
 990 FORMAT (/1X,19HDRAINAGE EXPONENT =,I2/1X,22HTILE DRAINAGE COEFF.
 =
 1,F5.2,A4,4H/24H/1X,30HGROUNDWATER RELEASE FRACTION =,E10.3)
 1000 FORMAT (/3X,28HSTRUCTURAL MEASURES
 INCLUDED,/10X,4HTYPE,9X,6HNUMBE
 1R)
 1010 FORMAT (I7,2X,3A4,I6)
 1020 FORMAT (1X,11HCHANNEL NO.,I5,15H AT ELEMENT NO.,I5)
 1030 FORMAT (39X,I4/17X,F5.1/39X,I5/23X,F5.2)
 1040 FORMAT(/20X,31HPARTICLE SIZE DISTRIBUTION DATA/
 1050 FORMAT(/36X,I2/36X,I2/
 1060 FORMAT(14X,37H NUMBER OF PARTICLE SIZE CLASSES =,I2/
 *14X,37H NUMBER OF WASHLOAD CLASSES =,I2)
 1070 FORMAT(1X,F15.8,F15.3,F15.7)
 1080 FORMAT(3X,5HCLASS,3X,6HDIA,MM,7X,9HEQSAND,MM,10X,2HSG,3X,
 *14HFALL VELOCITY,,A4,2H/S)
 1090 FORMAT(5X,I1,4X,F6.3,2F15.3,F15.7)
 1105 FORMAT(1X)

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1110 FORMAT(1X,8F6.3)
1100 FORMAT(/1X,47HPARTICLE SIZE DISTRIBUTION OF SOILS AS DETACHED/
*2X,34HCLASS 1 2 3 4 5)
1120 FORMAT(1X,4H SOIL,I2,5F6.3)
1140 FORMAT(5X,8F7.3)
1150 FORMAT(/1X,'FRACTION OF CLAY IN EACH PARTICLE CLASS'/
12X,'CLASS 1 2 3 4 5')
1160 FORMAT(1X,'SOIL ',I2,5F6.3)
C
END
SUBROUTINE STRUCT (I,J,NC,NR,RFL,IEL,JMAX,NPAR,NMAX,STRUC,NSTRUC,I
1STRUC,X,DX,WID,SSII,SSI,PIV,CN,CWID,CHAN,CONST,SL,II,SCMIN,SCMAX,S
2CBAR,ANG,IELC,NPAR2)
IMPLICIT REAL*8 (A-H,O-Z)
C
C ***** SUBROUTINE TO ADJUST PARAMETERS TO REFLECT STRUCTURAL
PRACTICES
C ***** INSTALLED WITHIN AN ELEMENT.
C
DIMENSION IEL(3,JMAX,NPAR2), NSTRUC(ISTRUC), WID(10), CN(10)
DIMENSION IELC(3,JMAX,2)
INTEGER CHAN,PRACT
LOGICAL STRUC
CHARACTER*2 IELC
C
C **** SWITCH TO APPROPRIATE HANDLER FOR EACH STRUCTURAL TYPE.
C
PRACT=IEL(2,J,9)
IF (PRACT.GT.ISTRUC.OR.PRACT.LT.0) GO TO 90
STRUC=.TRUE.
NSTRUC(PRACT)=NSTRUC(PRACT)+1
GO TO (10,60,70,80), PRACT
C
C **** HANDLE PONDS AND TILE-OUTLET TERRACES BY USING A TRAP
EFFICIENCY
C **** APPROACH, FOR BOTH SEDIMENT AND WATER.
C
C **** CASE 1 IS FOR A PTO.
C
10 TRAP=.90
C
C **** CHECK FOR A POSSIBLE SHADOW CHANNEL ELEMENT.
C
20 IF (CHAN.EQ.0) GO TO 40
C
C **** IT'S A CHANNEL ELEMENT, DOES IT REQUIRE DIAGONAL FLOW?
C
IF (ANG.LT..3926991.OR.ANG.GT.1.178097) GO TO 40
C
C **** FLOW IS DIAGONAL, CHANGE DESTINATION ELEMENT NUMBERS.
C
IF (NR.LT.I) GO TO 30
NR=NC+1
NC=NC+1
GO TO 40

```

```

30 NR=NC-1
   NC=NC-1
C
C **** THE PREDOMINANT OVERLAND DIRECTION IS MAINTAINED AND THAT
C **** ELEMENT WILL RECEIVE THE UNTRAPPED FLOW AND SEDIMENT.
C
40 IF (RFL.GT..5) GO TO 50
   RFL=TRAP
   NR=NMAX+1+PRACT
   RETURN
50 RFL=1.-TRAP
   NC=NMAX+1+PRACT
   RETURN
C
C **** PONDS ARE SIMILAR TO PTO'S, BUT HAVE A HIGHER TRAP EFFICIENCY.
C
60 TRAP=.95
   GO TO 20
C
C **** GRASSED WATERWAYS DIRECTLY AFFECT ONLY THE VEGETAGED AREA
OF
C **** THE ELEMENT IN WHICH THEY ARE LOCATED, BUT THEY MUST ALSO
ASSURE
C **** THAT THIS ELEMENT HAS A SHADOW CHANNEL ELEMENT.
C
70 IF (CHAN.NE.0) GO TO 80
C
C **** CURRENT ELEMENT DOES NOT HAVE A SHADOW CHANNEL ELEMENT,
MAKE ONE.
C
   CHAN=IEL(2,J,11)
   IF (CHAN.EQ.0) CHAN=1
   II=II+1
   CWID=WID(CHAN)
   PIV=CONST/CN(CHAN)/X*(DX/CWID/X)**.6667*DSQRT(SSI)
   SSII=SSI
   IF (SSI.LT.SCMIN) SCMIN=SSI
   IF (SSI.GT.SCMAX) SCMAX=SSI
   SCBAR=SCBAR+SSI
C
C **** NOW ACCOUNT FOR VEGETATED AREA BY REDUCING THE SEDIMENT
C **** DETACHMENT BY FLOW FOR THIS ELEMENT BY AN AMOUNT
PROPORTIONAL
C **** TO THE VEGETATED AREA. SINCE FLOW DETACHMENT IS DIRECTLY
C **** PROPORTIONAL TO THE OVERLAND SLOPE, ADJUST THAT PARAMETER.
C
C **** FIELD BORDERS HAVE A SIMILAR EFFECT TO THE VEGETATED AREA
C **** OF GRASSED WATERWAYS.
C
80 TRAP=FLOAT(IEL(2,J,10))/DX
   IF (TRAP.GT..5) TRAP=.5
   SL=SL*(1.-TRAP)
   RETURN
C

```

```

C **** CHECK TO SEE IF IT'S A MANAGEMENT PRACTICE BEFORE SPOUTING OFF.
C
90 IF (PRACT.GT.10.AND.PRACT.LT.13) RETURN
   WRITE (2,100) IEL(2,J,9),IEL(2,J,1),J
   RETURN
C
100 FORMAT (14H PRACTICE NO.,I3,7H IN ROW,I4,5H, COL,I4,20H ILLEGAL A
1ND IGNORED)
C
END
SUBROUTINE DRAIN (DR,DC,DIN,N,N1,N2,STD,TIAL,RFL,NR,NC)
IMPLICIT REAL*8 (A-H,O-Z)
C
C ***** SUBROUTINE FOR SUBSURFACE DRAINAGE.
C
DIMENSION DR(2000), DIN(2000), RFL(2000)
INTEGER NR(2000),NC(2000),TIAL(2000)
C
C **** SET ALL CHANNEL INFLOWS TO ZERO.
C
DO 10 I=N1,N2
10 DIN(I)=0.
   STD=0.
C
C **** ROUTE DRAINAGE FROM TILES.
C
DO 50 I=1,N
DRANE=0.
IF (TIAL(I).LT.256) GO TO 40
IF (DR(I).GT.DC) GO TO 20
DRANE=DR(I)
GO TO 30
20 DRANE=DC
30 STD=STD+DRANE
40 DRANE=DRANE+DIN(I)
   DD=RFL(I)*DRANE
   J=NR(I)
   K=NC(I)
   DIN(J)=DIN(J)+DD
   DIN(K)=DIN(K)-DD+DRANE
50 DIN(I)=0.
   RETURN
C
END
FUNCTION FILT(A,PIV,P,FC,GWC,DR,S,R,CU2,ROUGH,HU,NEXP)
IMPLICIT REAL*8 (A-H,O-Z)
C
C ***** CALCULATION OF INFILTRATION CAPACITY.
C
C **** POTENTIAL INFILTRATION CAPACITY -- WHOLE SURFACE COVERED.
C
IF (PIV) 30,40,10
C
C **** UNSATURATED INFILTRATION ZONE.
C

```

```

10 FMAX=A*PIV**P+FC
   IF (PIV.LT.GWC) GO TO 20
   DR=0.
   GO TO 50
20 DR=FC*(1.-PIV/GWC)**NEXP
   GO TO 50
C
C **** INFILTRATION ZONE SATURATED.
C
30 PIV=0.
40 DR=FC
   FMAX=FC
C
C **** ADJUST INFILTRATION ACCORDING TO FRACTION OF AREA INUNDATED.
C **** REMAINING AREA INFILTRATES AT RAINFALL RATE.
C
50 IF (R.GE.FMAX.OR.HU.LE.0.) GO TO 70
   DEP=S*CU2
   IF (DEP.GT.1.E-10) GO TO 60
   FWA=0.
   GO TO 90
60 FH=DEP/HU/ROUGH
   IF (FH.LT.1.) GO TO 80
C
C **** ENTIRE SURFACE INUNDATED OR RAINFALL RATE EXCEEDS SOIL
C **** INFILTRATION CAPACITY.
C
70 FILT=FMAX
   RETURN
C
C **** INFILTRATION CAPACITY REDUCED BELOW ITS POTENTIAL VALUE.
80 FWA=FH**(1.-ROUGH)
90 FILT=FWA*FMAX+(1.-FWA)*R
   RETURN
C
   END
   FUNCTION RAIN(RATE,PIT,PER)
   IMPLICIT REAL*8 (A-H,O-Z)
C
C ***** DETERMINATION OF NET RAINFALL RATE.
C
   IF (PIT) 40,50,10
10 RIT=PER*RATE
   IF (RIT-PIT) 20,30,30
20 RAIN=RATE-RIT
   PIT=PIT-RIT
   RETURN
30 RAIN=RATE-PIT
   PIT=0.
   RETURN
40 PIT=0.
50 RAIN=RATE
   RETURN
   END
C

```

```

C
CC.....SHIELDS DIAGRAM EXTENDED BY MANTZ (1977).....
C
  FUNCTION SHIELD(REYN)
  IMPLICIT REAL*8 (A-H,O-Z)
  IF(REYN.LE. 1. ) GO TO 30
  IF(REYN.LE. 6.0) GO TO 40
  IF(REYN.LE. 20. ) GO TO 50
  IF(REYN.LE.450. ) GO TO 20
10 CONTINUE
  SHIELD=.06
  RETURN
20 SHIELD=DEXP(-3.9793+.19212*DLOG(REYN))
  RETURN
30 SHIELD=.1*REYN**(-.3)
  RETURN
40 SHIELD=DEXP(-2.3026-.5546*DLOG(REYN))
  RETURN
50 SHIELD=0.033
  RETURN
  END
C
SUBROUTINE SED(XZW,XR,C,XDIR,M,N,KK,DX)
IMPLICIT REAL*8 (A-H,O-Z)
C
COMMON /ZSEDI/ NPART,NWASH,NWASH1
COMMON /ZSEDR/ VISCOS,AGRAV,SWH2O,YALCON,SE(5),VS(2000),DIA(5),SG
1(5),FV(5),CY1(5),CY2(5),CY4(5),DIAMM(5),EQSDIA(5),EDMM(5),F(20,5)
2,PERCLA(20,5),CE1,CE2,CE3,CE4,CE5,CE6
C
COMMON /SEDSOL/ CELNO3(2000),CELSNH(2000),XNO3(2000),XNH4(2000),FI
2LNO3(2000),FILNH4(2000),SZNO3(2000),SZNH4(2000),VOLSZ(2000),STOTKN
3(2000,5),STOLD(2000,5),STOANH(2000,5),SEDNEW(5),TKNIN(2010,5),ANHI
4N(2010,5),TKNSEL(2000),ANHSEL(2000),SEDSEL(5),TKNOUT(5),ANHOUT(5),
5STNEW(5),QINO3(2010),QINH4(2010),STORNO(2000),STORNH(2000),CELTKN(
62000,5),CELANH(2000,5)
C
COMMON /CFLOW/ Q(2000),RFL(2000),FLINS(2000),SS(2000),PIV(2000),B(
12000),NR(2000),NC(2000),DR(2000),S(2000),SL(2000),SEL(2000),SI(201
20,5),QI(2010),DIN(2000),SST(2000,5)
C
DIMENSION SE1(5),SE2(5),DELTA(5),PS(5),TF(5),TFMSE2(5)
*,DS1(5),DS2(5),S22(5)
NP=1
IF(Q(M).GT.0.) GO TO 30
C
C.....NO OUTFLOW, ALL SEDIMENT ASSUMED DEPOSITED.....
C
GO TO 10
5 NP=NWASH1
10 CONTINUE
DO 20 IC=NP,NPART
  SEL(M)=SEL(M)+.5*(SST(M,IC)+SI(M,IC))
  SST(M,IC)=SI(M,IC)

```

```

SE(IC)=0.
C SI(M,IC)=0.
C*****
STNEW(IC)=0.0
SEDNEW(IC)=0.0
SEDSEL(IC)=.5*(SST(M,IC)+SI(M,IC))
C*****
20 CONTINUE
IF(NP.EQ.NWASH1.AND.NWASH.NE.0) GO TO 65
RETURN
C
C.....OUTFLOW.....
C
30 CONTINUE
SMDIR=S(M)-XDIR
IF(SMDIR.LE.0.) GO TO 10
C
C.....CALCULATE TRANSPORT CAPACITY FOR EACH .....
C.....PARTICLE SIZE CLASS.....
C
SDEL=0.
VSTAR=VS(M)*DSQRT(SMDIR)
CY5=VSTAR*XZW
DO 50 IC=NWASH1,NPART
REYN=CY1(IC)*VSTAR
YCR=SHIELD(REYN)
DELTA(IC)=VSTAR**2/(CY2(IC)*YCR)-1.0
IF(DELTA(IC).LE.0) GO TO 45
SIGMA=1.65908*DELTA(IC)*DSQRT(YCR)
PS(IC)=YALCON*DELTA(IC)*(1.-DLOG(1.+SIGMA)/SIGMA)
SDEL=SDEL+DELTA(IC)
GO TO 50
45 CONTINUE
DELTA(IC)=0.
PS(IC)=0.
50 CONTINUE
IF(SDEL.LE.0.) GO TO 5
DO 60 IC=NWASH1,NPART
TF(IC)=PS(IC)*DELTA(IC)/SDEL*CY5*CY4(IC)
60 CONTINUE
C
65 CONTINUE
AREA=DX*XZW
IF(M.GT.N) GO TO 70
C
CC....CALCULATE RAINFALL DETACHMENT & POTENTIAL FLOW DETACHMENT....
C
DETR=CE3*C*XR*XR/AREA*.40
DETF=CE4*C*SL(M)*Q(M)*DX
GO TO 75
70 DETR=0.
DETF=0.
75 CONTINUE
DRFT=DETR+DETF
X1=Q(M)/S(M)

```

```

X2=1./(1.+X1)
IF(NP.EQ.NWASH1.AND.NWASH.NE.0) GO TO 310
X3=X1*X2
X4=1./X1
DO 80 IC=NWASH1,NPART
  DS1(IC)=SI(M,IC)+F(KK,IC)*DETR
  DS2(IC)=DS1(IC)+F(KK,IC)*DETF
  S22(IC)=(SST(M,IC)+DS2(IC))*X2
  SE1(IC)=(SST(M,IC)+DS1(IC))*X3
  SE2(IC)=S22(IC)*X1
80 CONTINUE
C
C.....APPORTION ANY TRANSPORT EXCESS TO DEFICITS.....
C
  NPM=NPART-NWASH
90 I1=0
  I2=0
  I3=0
  SDEL=0.
  TFXCES=0.
  DO 150 IC=NWASH1,NPART
    TFMSE2(IC)=TF(IC)-SE2(IC)
    IF(TFMSE2(IC))130,140,110
C
C.....TRANSPORT > SE2.....
C
110 I1=I1+1
    TFXCES=TFXCES+TFMSE2(IC)
    TF(IC)=SE2(IC)
    GO TO 150
C
C.....TRANSPORT < SE2.....
C
130 I3=I3+1
    SDEL=SDEL+DELTA(IC)
140 I2=I2+1
150 CONTINUE
    IF(SDEL.LE.0.) GO TO 200
    IF(I1.EQ.NPM.OR.I2.EQ.NPM.OR.I3.EQ.NPM) GO TO 200
    DO 160 IC=NWASH1,NPART
      IF(TFMSE2(IC).GE.0..OR.DELTA(IC).LE.0.) GO TO 160
      TF(IC)=TF(IC)+TFXCES*DELTA(IC)/SDEL
      IF(I3.EQ.1) GO TO 170
160 CONTINUE
    GO TO 90
170 IF(TF(IC).GT.SE2(IC)) TF(IC)=SE2(IC)
C
C.....SOLVE CONTINUITY EQUATION FOR SEDIMENT TRANSPORT....
C
200 CONTINUE
    DO 300 IC=NWASH1,NPART
      IF(TF(IC).LT.SE1(IC)) GO TO 240
      IF(TF(IC).LT.SE2(IC)) GO TO 220
C
C.....MAXIMUM RAINFALL AND FLOW DETACHMENT.....

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```

C.....NO DEPOSITION.....
C
  SST(M,IC)=DS2(IC)-SE2(IC)+S22(IC)
  SE(IC)=SE2(IC)
  SEL(M)=SEL(M)-F(KK,IC)*DRFT
C*****
  STNEW(IC)=S22(IC)/2.
  SEDNEW(IC)=F(KK,IC)*DRFT
  SEDSEL(IC)=0.0
C*****
  GO TO 290
C
C.....MAXIMUM RAINFALL, PARTIAL FLOW DETACHMENT.....
C.....NO DEPOSITION.....
C
  220  ZI2=TF(IC)*(1.+X4)-SST(M,IC)
       SEL(M)=SEL(M)+SI(M,IC)-ZI2
       SST(M,IC)=ZI2+TF(IC)*(X4-1.)
       SE(IC)=TF(IC)
C*****
  STNEW(IC)=TF(IC)*X4/2.
  SEDNEW(IC)=ZI2-SI(M,IC)
  SEDSEL(IC)=0.0
C*****
  GO TO 290
C
C.....DEPOSITION, NO FLOW DETACHMENT.....
C
  240  RE=FV(IC)*AREA/Q(M)
       IF(RE.GT.1.) RE=1.
       DP=RE*(SE1(IC)-TF(IC))
       SE(IC)=SE1(IC)-DP
       ZI2=SE(IC)*(1.+X4)-SST(M,IC)
       IF(ZI2.LT.0.) ZI2=0.
       SEL(M)=SEL(M)+SI(M,IC)-ZI2
       SST(M,IC)=ZI2+SE(IC)*(X4-1.)
C*****
  STNEW(IC)=SE(IC)*X4/2.
  SEDNEW(IC)=F(KK,IC)*DETR
  SEDSEL(IC)=SEDNEW(IC)-(ZI2-SI(M,IC))
C*****
C  SI(M,IC)=0.
  290  IF(SE(IC).LT.0.) SE(IC)=0.
       IF(SST(M,IC).LT.0.) SST(M,IC)=0.
  300  CONTINUE
       IF(NWASHEQ.0) GO TO 410
C
C....WASH LOAD CALCULATIONS.....
C
  310  CONTINUE
       DO 400 IC=1,NWASH
          DS=SI(M,IC)+F(KK,IC)*DRFT
          S2=(SST(M,IC)+DS)*X2
          SE(IC)=S2*X1
          SST(M,IC)=DS-SE(IC)+S2

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```

      IF(SST(M,IC).LT.0.)SST(M,IC)=0.
      SEL(M)=SEL(M)-F(KK,IC)*(DETR+DETF)
C*****
      STNEW(IC)=S2/2.
      SEDNEW(IC)=F(KK,IC)*DRFT
      SEDSEL(IC)=0.0
C*****
C   SI(M,IC)=0.
   400 CONTINUE
   410 CONTINUE
      RETURN
      END
      SUBROUTINE RELEM (IEL,ITEMP,N,MOUT,NIOUT,NJOUT,ISR,ICR,NMAX,JMAX,N
1PAR,IELC,ITEMPC,NPAR2)
      IMPLICIT REAL*8 (A-H,O-Z)
C
C ***** SUBROUTINE TO SET UP NEXT ROW OF WATERSHED ELEMENTAL DATA.
C **** INTO THE PROPER POSITION OF THE "3-ROW PER PASS" ARRAY.
C
      DIMENSION IEL(3,JMAX,NPAR2), ITEMPC(NPAR2)
      DIMENSION IELC(3,JMAX,2), ITEMPC(2)
      CHARACTER*2 IELC, ITEMPC
C
C **** "RIPPLE" ROW 2 INTO ROW 1 AND ROW 3 INTO ROW 2, THEN ZERO
C **** THE THIRD ROW.
C
      DO 20 J=1,JMAX
      NZZ=NPAR-2
      DO 10 I=1,NZZ
      IEL(1,J,I)=IEL(2,J,I)
10 IEL(2,J,I)=IEL(3,J,I)
20 IEL(3,J,3)=0
      DO 25 J=1,JMAX
      DO 23 I=1,2
      IELC(1,J,I)=IELC(2,J,I)
23 IELC(2,J,I)=IELC(3,J,I)
25 CONTINUE
C
C **** SET UP POSSIBLE LAST ROW TEST FLAG.
C
      IEL(3,1,2)=JMAX
      IF (ITEMP(3).EQ.999) RETURN
C
C **** NOW TRANSFER CURRENT WATERSHED ELEMENTAL DATA INTO THE
THIRD
C **** ROW OF THE "3-ROW PER PASS" ARRAY.
C
C ***** IEL(I,J,3) CONTAINS THE POSITION NUMBER FOR THAT ELEMENT IN
C ***** THE SINGLE DIMENSION ARRAYS USED FOR SIMULATION ANALYSIS.
C ***** IEL(I,1,2) CONTAINS THE COLUMN NUMBER OF THE LAST WATERSHED
C ***** ELEMENT IN THE ROW.
C
      30 J=ITEMP(2)
      K=MOD(ITEMP(6),100)
      ITEMPC(6)=ITEMP(6)/100*100+K

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```

IF (K.LE.0.OR.K.GT.ISR) GO TO 80
IF (ITEMP(7).LE.0.OR.ITEMP(7).GT.ICR) GO TO 90
IF (J.GT.JMAX) GO TO 50
C
C **** TRANSFER PARAMETER DATA FROM A SINGLE ELEMENT.
C
  NZZ=NPAR-2
  DO 40 I=1,NZZ
40 IEL(3,J,I)=ITEMP(I)
  DO 45 I=1,2
45 IELC(3,J,I)=ITEMPC(I)
C
C **** REMEMBER AS POSSIBLE LAST ELEMENT IN CURRENT ROW.
C
  IEL(3,1,2)=J
C
C **** REMEMBER ROW NUMBER OF THIS ELEMENT.
C
  IC=ITEMP(1)
C
C **** SAVE ELEMENT'S SEQUENCE NUMBER.
C
  N=N+1
  IF (N.GT.NMAX) GO TO 60
  IEL(3,J,3)=N
  IF (ITEMP(1).EQ.NIOUT.AND.J.EQ.NJOUT) MOUT=N
  IF (ITEMP(3).NE.0) RETURN
C
C **** NOW READ PARAMETERS FOR NEXT ELEMENT.
C
  READ (1,100) (ITEMP(K),K=1,7),(ITEMPC(L),L=1,2),(ITEMP(K),K=8,15)
  IF (ITEMP(1).LT.IC.OR.ITEMP(1).GT.IC+1.OR.(ITEMP(2).LE.J.AND.ITEMP
1(1).EQ.IC)) GO TO 70
  IF (ITEMP(1).EQ.IC) GO TO 30
  RETURN
50 WRITE (2,110) ITEMPC(1),J
  STOP
C
C **** ERROR MESSAGES.
C
60 WRITE (2,120) ITEMPC(1),J
  STOP
70 WRITE (2,130) ITEMPC(1),ITEMPC(2)
  STOP
80 WRITE (2,140) K,ITEMPC(1),J
  STOP
90 WRITE (2,150) ITEMPC(7),ITEMPC(1),J
  STOP
C
100 FORMAT (2I3,I2,I3,3I4,3X,A2,1X,A2,2X,I4,I3,2I4,I8,I4,I7,I4)
110 FORMAT (23H COLUMN NO. FOR ELEMENT,I4,1H,,I4,24H EXCEEDS IEL() DIM
  IENSION)
120 FORMAT (45H NO. OF ELEMENTS EXCEEDS DIMENSION AT
ELEMENT,I4,1H,,I4
  1)

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130 FORMAT (40H ELEMENT DATA OUT OF SEQUENCE AT ELEMENT,I4,1H,,I4)
140 FORMAT (1X,9H SOIL TYPE,I4,22H SPECIFIED FOR ELEMENT,I4,1H,,I4,15H
1IS NOT DEFINED)
150 FORMAT (1X,9HCROP TYPE,I4,22H SPECIFIED FOR ELEMENT,I4,1H,,I4,15H
1IS NOT DEFINED)
C
C   END
C
C   SUBROUTINE XINPUT(NDUR,NDELTA)
C
C***** THIS SUBROUTINE INPUTS INFORMATION TO BE USED IN THE *****
C***** NITROGEN TRANSPORT MODELS *****
C
C   IMPLICIT REAL*8 (A-H,O-Z)
C
C   COMMON /CINPUT/ CNIT(4,40),FERT(2,10),TEMP
C
C***** INPUT: DURATION, TIME STEP, AND MEAN DAILY TEMPERATURE FOR *****
C***** TRANSFORMATIONS *****
C
C   READ (1,30) NDUR,NDELTA,TEMP
C   WRITE (2,40) NDUR,NDELTA,TEMP
C
C***** INPUT INITIAL NITROGEN SOIL MAKEUPS *****
C
C   READ (1,50) NIT
C   WRITE (2,70)
C   DO 10 J=1,NIT
C   READ (1,60) CNIT(1,J),CNIT(2,J),CNIT(3,J),CNIT(4,J)
C   WRITE (2,80) J,CNIT(1,J),CNIT(2,J),CNIT(3,J),CNIT(4,J)
C   CNIT(1,J)=CNIT(1,J)/1000000
C   CNIT(2,J)=CNIT(2,J)/1000000
10 CONTINUE
C   READ (1,90) MAN
C   WRITE (2,100)
C   DO 20 J=1,MAN
C   READ (1,110) FERT(1,J),FERT(2,J)
C   WRITE (2,120) J,FERT(1,J),FERT(2,J)
20 CONTINUE
C   RETURN
C
C***** FORMATS *****
C
30 FORMAT (/31X,I6/38X,I5/43X,F5.1)
40 FORMAT (//1X,'DURATION OF TRANSFORMATIONS =' ,I6,1X,'MIN.'/
11X,'TIME INCREMENT FOR TRANSFORMATIONS =' ,I5,1X,'MIN.'/1X,
2'MEAN TEMPERATURE DURING TRANSFORMATIONS =' ,F5.1,1X,'DEGREES C')
50 FORMAT (/42X,I2)
60 FORMAT (15X,F5.1,12X,F5.1,12X,F5.2,12X,F5.2)
70 FORMAT (/1X,'INITIAL NITROGEN SOIL MAKEUPS'/1X,'NO.',5X,
1'ORGANIC-N',5X,'ADSORBED-NH4',5X,'SOLUBLE-NO3',5X,'SOLUBLE-NH4'/
29X,'----- MG-N/KG-SOIL -----',5X,'----- MG-N/HA -----')
80 FORMAT (1X,I2,8X,F6.1,10X,F6.1,11X,F6.2,12X,F6.2)
90 FORMAT (/44X,I2)
100 FORMAT (/1X,'NO.',5X,'NITRATE APPLIED',5X,'AMMONIUM APPLIED'/

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112X,'(KG-N/HA)',11X,'(KG-N/HA)')
110 FORMAT (19X,F6.2,16X,F6.2)
120 FORMAT (1X,I2,9X,F6.2,13X,F6.2)
C
END
C
SUBROUTINE TRANS(N,NDUR,NDELTA,DX)
C
C***** THIS SUBROUTINE WILL PERFORM THE NITROGEN TRANSFORMATIONS
*****
C***** BEFORE THE RAINFALL EVENT OCCURS *****
C
IMPLICIT REAL*8 (A-H,O-Z)
C
C.... PARAMETERS USED IN THE EXTENDED SED SUBROUTINE
C
COMMON /ZSEDI/ NPART,NWASH,NWASH1
COMMON /ZSEDR/ VISCOS,AGRAV,SWH2O,YALCON,SE(5),VS(2000),DIA(5),SG
1(5),FV(5),CY1(5),CY2(5),CY4(5),DIAMM(5),EQSDIA(5),EDMM(5),F(20,5)
2,PERCLA(20,5),CE1,CE2,CE3,CE4,CE5,CE6
C
C***** PARAMETERS FOR THE NITROGEN TRANSPORT MODELS *****
C
COMMON /CINPUT/ CNIT(4,40),FERT(2,10),TEMP
C
COMMON /NTRANS/ NIT(2000),MAN(2000)
C
COMMON /ELEM/ PERPOT(2000),EDI(2000),TPOR(20),SM(20)
C
COMMON /SEDSOL/ CELNO3(2000),CELSNH(2000),XNO3(2000),XNH4(2000),FI
2LNO3(2000),FILNH4(2000),SZNO3(2000),SZNH4(2000),VOLSZ(2000),STOTKN
3(2000,5),STOLD(2000,5),STOANH(2000,5),SEDNEW(5),TKNIN(2010,5),ANHI
4N(2010,5),TKNSEL(2000),ANHSEL(2000),SEDSSEL(5),TKNOUT(5),ANHOUT(5),
5STNEW(5),QINO3(2010),QINH4(2010),STORNO(2000),STORNH(2000),CELTKN(
62000,5),CELANH(2000,5)
EQUIVALENCE (SUR(1),SOIL(1))
COMMON /CSURF/ SUR(2000),RANE(2000)
INTEGER SUR,SOIL(2000)
IF(NDUR.EQ.0)GO TO 10
C
C***** INITIALIZE RATE CONSTANTS *****
C
XKAN=3.0
XKSA=5.0
XKAS=.75
C
C***** ADJUST RATE CONSTANTS FOR TEMPERATURE *****
C
IF(TEMP.GT.35.0)TEMP=35
TAB=TEMP+273
XKO=EXP(17.753-6350.5/TAB)/168.0
ADJK=2**((35.0-TEMP)/10.0)
XKAN=XKAN/ADJK
XKSA=XKSA/ADJK
XKAS=XKAS/ADJK

```

```
NT=NDUR/NDELTA
DELTH=FLOAT(NDELTA)/60.0
DELTD=FLOAT(NDELTA)/1440.0
```

```
C
C***** CALCULATE WATER CONTENT CORRECTION FACTORS *****
```

```
C
C
10 DO 50 M=1,N
   KK=SOIL(M)/256
   IF(SM(KK).LE.0.9)WCCOEF=1.111*SM(KK)
   IF(SM(KK).GT.0.9)WCCOEF=10.0-10.0*SM(KK)
```

```
C
C
LL=NIT(M)
BD=(1-TPOR(KK))*2.65
TKN=CNIT(1,LL)*BD*100000
ANH4=CNIT(2,LL)*BD*100000
SNH4=CNIT(4,LL)
SNO3=CNIT(3,LL)
II=MAN(M)
FERTNO=FERT(1,II)
FERTNH=FERT(2,II)
POTMIN=PERPOT(M)*TKN
SNO3=SNO3+FERTNO
SNH4=SNH4+FERTNH
SUM=0.0
IF(NDUR.EQ.0)GO TO 30
```

```
C
C***** PERFORM TRANSFORMATIONS *****
```

```
C
C
DO 20 I=1,NT
  DPOTN=POTMIN*(1-EXP(-XKO*DELTH))*WCCOEF
  DSNO3=SNH4*XKAN*DELTD*WCCOEF
  DANH4=SNH4*XKSA*DELTD-ANH4*XKAS*DELTD
  DSNH4=DPOTN-DSNO3-DANH4
  POTMIN=POTMIN-DPOTN
  SNO3=SNO3+DSNO3
  ANH4=ANH4+DANH4
  SNH4=SNH4+DSNH4
  SUM=SUM+DPOTN
20 CONTINUE
   TKNOLD=TKN
   TKN=TKN-SUM
```

```
C
C***** OUTPUT FINAL CONCENTRATIONS FOR EACH CELL *****
```

```
C
C
IF(M.EQ.1)WRITE(4,70)NDUR,NDELTA,TEMP
WRITE(4,80)M,TKNOLD,SUM,TKN,ANH4,SNO3,SNH4
```

```
C
C***** CONVERT CONCENTRATIONS *****
```

```
C
C
30 TKN=TKN/BD*10.0
   ANH4=ANH4/BD*10.0
   DO 40 IC=1,NPART
     CELTKN(M,IC)=TKN*PERCLA(KK,IC)/F(KK,IC)
     CELANH(M,IC)=ANH4*PERCLA(KK,IC)/F(KK,IC)
```

```

40 CONTINUE
  CELNO3(M)=SNO3/(TPOR(KK)*100.0)
  CELSNH(M)=SNH4/(TPOR(KK)*100.0)
50 CONTINUE
C
C***** INITIALIZE VARIABLES FOR LATER USE IN THE SOLUBLE *****
C***** NUTRIENT SUBROUTINE *****
C
  DO 60 M=1,N
  KK=SOIL(M)/256
  VOLSZ(M)=DX*DX*EDI(M)*.01*TPOR(KK)
  SZNO3(M)=CELNO3(M)*VOLSZ(M)
  SZNH4(M)=CELSNH(M)*VOLSZ(M)
  XNO3(M)=SZNO3(M)
  XNH4(M)=SZNH4(M)
  FILNO3(M)=0.0
  FILNH4(M)=0.0
60 CONTINUE
  RETURN
C
C***** FORMATS *****
C
70 FORMAT(19X,'OUTPUT FROM THE TRANSFORMATION SUBROUTINE'//
17X,'DURATION OF TRANSFORMATIONS =',I5,1X,'MIN.!'
27X,'TIME INCREMENT FOR TRANSFORMATIONS =',I4,1X,'MIN.!'
37X,'MEAN DAILY TEMPERATURE =',F5.1,1X,'DEGRESS C'//
411X,'NUTRIENT CONCENTRATIONS FOR EACH CELL AFTER
TRANSFORMATIONS'
51X,'CELL',4X,'INITIAL',4X,'ORGANIC N',5X,'FINAL',7X,'FINAL',
67X,'FINAL',7X,'FINAL'/2X,'NO.',4X,'ORG-N',4X,'MINERALIZED',
74X,'ORG-N',6X,'ADS-NH4',5X,'SOL-NO3',5X,'SOL-NH4'/8X,'(KG/HA)',
85X,'(KG/HA)',5X,'(KG/HA)',5X,'(KG/HA)',5X,'(KG/HA)',5X,'(KG/HA)')
80 FORMAT(1X,I4,1X,2F9.2,4X,4F11.2)
90 FORMAT(/2I4,2F7.2,I4,2F7.2)
  END
C
  SUBROUTINE SEDNIT(STOTKN,STOLD,STOANH,CELTKN,SEDNEW,CELANH,
1Q2,SI,TKNIN,ANHIN,TKNSEL,ANHSEL,SEDSSEL,TKNOUT,ANHOUT,SE,STNEW)
  IMPLICIT REAL*8 (A-H,O-Z)
C
C***** SUBROUTINE TO CALCULATE REMOVAL OF SEDIMENT-BOUND *****
C***** NITROGEN FOR EACH CELL *****
C
  TKNSTR=STOTKN*STOLD
  ANHSTR=STOANH*STOLD
  TKNNEW=CELTKN*SEDNEW
  ANHNEW=CELANH*SEDNEW
  IF(Q2.GT.0.)GO TO 20
C
C***** FOR DISCHARGE LESS THAN ZERO ALL NITROGEN IS DEPOSITED *****
C
  IF(SI.LE.0..AND.STOLD.LE.0.)GO TO 10
  TKNCON=(TKNIN+TKNSTR)/(SI+STOLD)
  ANHCON=(ANHIN+ANHSTR)/(SI+STOLD)
  TKNSEL=TKNSEL+SEDSSEL*TKNCON

```

```

      ANHSEL=ANHSEL+SESEL*ANHCON
10  TKNCON=0.0
      ANHCON=0.0
      GO TO 30
C
C***** FOR DISCHARGE GREATER THAN ZERO..... *****
C
      20 IF(SI.LE.0..AND.STOLD.LE.0..AND.SEDNEW.LE.0.)GO TO 10
         TKNCON=(TKNIN+TKNSTR+TKNNEW)/(SI+STOLD+SEDNEW)
         ANHCON=(ANHIN+ANHSTR+ANHNEW)/(SI+STOLD+SEDNEW)
         TKNSSEL=TKNSSEL-TKNNEW+SESEL*TKNCON
         ANHSEL=ANHSEL-ANHNEW+SESEL*ANHCON
      30 TKNOUT=TKNCON*SE
         ANHOUT=ANHCON*SE
         STOTKN=TKNCON
         STOANH=ANHCON
C
C***** RESET VARIABLES *****
C
      TKNIN=0.0
      ANHIN=0.0
      STOLD=STNEW
      RETURN
      END
C
      SUBROUTINE SOLNIT(M,N,Q2,Q1,R,QINO3,QINH4,VOLSZ,CELNO3,STORNO,
1  SZNO3,FILNO3,QENO3,CELSNH,STORNH,SZNH4,FILNH4,QENH4,DT,FIL)
      IMPLICIT REAL*8 (A-H,O-Z)
C
C***** THIS SUBROUTINE WILL CALCULATE THE AMOUNT OF SOLUBLE *****
C***** NITRATE AND AMMONIUM LEAVING A CELL AT THE END OF THE *****
C***** END OF A TIME STEP *****
C
C***** INITIALIZE VARIABLES *****
C
      EXT=.35
      QENO3=0.0
      QENH4=0.0
C
C***** IF CHANNEL ELEMENT GO TO LINE 50 *****
C
      IF(M.GT.N)GO TO 50
C
C***** CALCULATE INFLOW, OUTFLOW, AND STORAGE VOLUMES *****
C
      VOLOUT=(FIL+Q2)*DT
      DENOM=Q2+FIL+SSTOR
      IF(DENOM.LE.0.0)GO TO 60
C
C***** CALCULATE MASS AND CONCENTRATION OF NUTRIENTS *****
C***** IN INFLOW AND SOIL STORAGE *****
C
      AINNO3=(RNO3*R+QINO3)*DT
      AINNH4=(RNH4*R+QINH4)*DT
      IF(R.LE.0.0.AND.QI.LE.0.0)GO TO 5

```

```

CINNO3=(RNO3*R+QINO3)/(R+QI)
CINNH4=(RNH4*R+QINH4)/(R+QI)
5  RATIO=VOLOUT/VOLSZ
   IF(RATIO.GT.1.0)EXTFAC=(1-(1-EXT)**RATIO)
   IF(RATIO.LE.1.0)EXTFAC=EXT*RATIO
   IF(CELNO3.LT.CINNO3)GO TO 10
C
C***** PERFORM MASS BALANCE FOR SOLUBLE NITRATE *****
C
TNO3=AINNO3+STORNO+SZNO3*EXTFAC
OUTNO3=Q2/DENOM*TNO3
FILNO3=FILNO3+FIL/DENOM*TNO3
STORNO=SSTOR/DENOM*TNO3
SZNO3=SZNO3-SZNO3*EXTFAC
GO TO 20
10 TNO3=AINNO3+STORNO+SZNO3
   DENOM=DENOM*DT+VOLSZ
   OUTNO3=Q2/DENOM*TNO3*DT
   FILNO3=FILNO3+FIL/DENOM*TNO3*DT
   STORNO=SSTOR/DENOM*TNO3*DT
   SZNO3=VOLSZ/DENOM*TNO3
20 CELNO3=SZNO3/VOLSZ
   QENO3=OUTNO3/DT
C
C***** PERFORM MASS BALANCE FOR SOLUBLE AMMONIUM *****
C
DENOM=Q2+FIL+SSTOR
IF(CELSNH.LT.CINNH4)GO TO 30
TNH4=AINNH4+STORNH+SZNH4*EXTFAC
OUTNH4=Q2/DENOM*TNH4
FILNH4=FILNH4+FIL/DENOM*TNH4
STORNH=SSTOR/DENOM*TNH4
SZNH4=SZNH4-SZNH4*EXTFAC
GO TO 40
30 TNH4=AINNH4+STORNH+SZNH4
   DENOM=DENOM*DT+VOLSZ
   OUTNH4=Q2*DT/DENOM*TNH4
   FILNH4=FILNH4+FIL*DT/DENOM*TNH4
   STORNH=SSTOR*DT/DENOM*TNH4
   SZNH4=VOLSZ/DENOM*TNH4
40 CELSNH=SZNH4/VOLSZ
   QENH4=OUTNH4/DT
   GO TO 60
C
C***** CHANNEL ELEMENTS *****
C
50 AINNO3=QINO3*DT
   AINNH4=QINH4*DT
   TNO3=AINNO3+STORNO
   TNH4=AINNH4+STORNH
   DENOM=Q2+SSTOR
   IF(DENOM.LE.0.0)GO TO 60
   OUTNO3=Q2/DENOM*TNO3
   OUTNH4=Q2/DENOM*TNH4
   STORNO=SSTOR/DENOM*TNO3

```

```
STORNH=SSTOR/DENOM*TNH4
QENO3=OUTNO3/DT
QENH4=OUTNH4/DT
```

C

```
C***** RESET VARIABLES *****
```

C

```
60 QINO3=0.0
   QINH4=0.0
   RETURN
   END
```

C

```
   SUBROUTINE OUTN(DX,DT,PP12,PP14,N,N2,X1,L,AREA,NN,TKNSUM,
1ANHSUM,SUMNO3,SUMSNH)
```

C

```
C***** THIS SUBROUTINE WILL OUTPUT THE ACCUMULATED *****
```

```
C***** NITROGEN LOSSES FROM EACH CELL *****
```

C

```
   IMPLICIT REAL*8 (A-H,O-Z)
```

C

```
   COMMON /SEDSOL/ CELNO3(2000),CELSNH(2000),XNO3(2000),XNH4(2000),FI
2LNO3(2000),FILNH4(2000),SZNO3(2000),SZNH4(2000),VOLSZ(2000),STOTKN
3(2000,5),STOLD(2000,5),STOANH(2000,5),SEDNEW(5),TKNIN(2010,5),ANHI
4N(2010,5),TKNSEL(2000),ANHSEL(2000),SESEL(5),TKNOUT(5),ANHOUT(5),
5STNEW(5),QINO3(2010),QINH4(2010),STORNO(2000),STORNH(2000),CELTKN(
62000,5),CELANH(2000,5)
```

C

```
   COMMON /CFLOW/ Q(2000),RFL(2000),FLINS(2000),SS(2000),PIV(2000),B(
12000),NR(2000),NC(2000),DR(2000),S(2000),SL(2000),SEL(2000),SI(20
20,5),QI(2010),DIN(2000),SST(2000,5)
```

```
   CHARACTER*4 PP12,PP14
```

```
   AVGTKN=0.0
```

```
   AVGANH=0.0
```

```
   X=10000./DX/DX
```

```
   WRITE(3,100)(PP12,PP14,I=1,4)
```

```
   DO 10 I=1,N
```

```
     TKNSEL(I)=TKNSEL(I)*DT*X/1000000
```

```
     ANHSEL(I)=ANHSEL(I)*DT*X/1000000
```

```
     AVGTKN=AVGTKN-TKNSEL(I)
```

```
     AVGANH=AVGANH-ANHSEL(I)
```

```
10 CONTINUE
```

```
   WRITE(3,110)(I,TKNSEL(I),I=1,N)
```

```
   WRITE(3,120)(PP12,PP14,I=1,4)
```

```
   WRITE(3,110)(I,ANHSEL(I),I=1,N)
```

```
   AVGNO3=0.0
```

```
   AVGSNH=0.0
```

```
   WRITE(3,130)(PP12,PP14,I=1,4)
```

```
   DO 20 I=1,N
```

```
     XNO3(I)=(SZNO3(I)-XNO3(I))*X
```

```
     XNH4(I)=(SZNH4(I)-XNH4(I))*X
```

```
     FILNO3(I)=FILNO3(I)*X
```

```
     FILNH4(I)=FILNH4(I)*X
```

```
     AVGNO3=AVGNO3-XNO3(I)-FILNO3(I)
```

```
     AVGSNH=AVGSNH-XNH4(I)-FILNH4(I)
```

```
20 CONTINUE
```

```
   WRITE(3,110)(I,XNO3(I),I=1,N)
```

```

WRITE(3,140)(PP12,PP14,I=1,4)
WRITE(3,110)(I,XNH4(I),I=1,N)
J=N+1
WRITE(3,150)
DO 30 I=J,N2
TKNSEL(I)=TKNSEL(I)*DT/1000000
ANHSEL(I)=ANHSEL(I)*DT/1000000
30 CONTINUE
WRITE(3,110)(NR(I),TKNSEL(I),I=J,N2)
WRITE(3,160)
WRITE(3,110)(NR(I),ANHSEL(I),I=J,N2)
WRITE(3,170)
WRITE(3,110)(I,FILNO3(I),I=1,N)
WRITE(3,180)
WRITE(3,110)(I,FILNH4(I),I=1,N)
SSI=X1*AREA
AVGTKN=AVGTKN/N
AVGANH=AVGANH/N
AVGNO3=AVGNO3/N
AVGSNH=AVGSNH/N
TKNSUM=TKNSUM*DT/1000000
ANHSUM=ANHSUM*DT/1000000
WRITE(2,190)SSI,X1,TKNSUM,AVGTKN,ANHSUM,AVGANH,SUMNO3,AVGNO3,
1SUMSNH,AVGSNH
RETURN

```

C

```

C***** FORMATS *****
100 FORMAT(/12X,51HINDIVIDUAL ELEMENT NET SEDIMENT-BOUND NITROGEN
LOS
1S/1X,4(10X,8HSEDIMENT)/1X,4(2X,16HELEMENT BOUND N)/
21X,4(4X,3HNO.,3X,2A4))
110 FORMAT(4(I7,F11.3))
120 FORMAT(/15X,45HINDIVIDUAL ELEMENT NET ADSORBED AMMONIUM LOSS/
11X,4(10X,8HADSORBED)/1X,4(2X,16HELEMENT AMMONIUM)/
21X,4(4X,3HNO.,3X,2A4))
130 FORMAT(/16X,43HINDIVIDUAL ELEMENT NET SOLUBLE NITRATE LOSS/
14(11X,7HSOLUBLE)/1X,4(2X,16HELEMENT NITRATE)/1X,4(4X,3HNO.,3X,
22A4))
140 FORMAT(/16X,44HINDIVIDUAL ELEMENT NET SOLUBLE AMMONIUM
LOSS/1X,
14(2X,16HELEMENT AMMONIUM)/1X,4(4X,3HNO.,3X,2A4))
150 FORMAT(/14X,45HCHANNEL NET SEDIMENT-BOUND N DEPOSITION -- KG/
14(4X,3HNO.,5X,6HAMOUNT))
160 FORMAT(/14X,46HCHANNEL NET ADSORBED AMMONIUM DEPOSITION -- KG/
14(4X,3HNO.,5X,6HAMOUNT))
170 FORMAT(/6X,60HINDIVIDUAL ELEMENT SOLUBLE NITRATE LOST IN
FILTRATE
1 -- KG/HA/4(4X,3HNO.,5X,6HAMOUNT))
180 FORMAT(/6X,61HINDIVIDUAL ELEMENT SOLUBLE AMMONIUM LOST IN
FILTRAT
1E -- KG/HA/4(4X,3HNO.,5X,6HAMOUNT))
190 FORMAT(/5X,'POLLUTANT',22X,'YIELD AT OUTLET',3X,'AVG. YIELD'/
143X,'KG',12X,'KG/HA'/5X,'SEDIMENT',20X,F15.2,F16.2//5X,
2'SEDIMENT-BOUND NITROGEN',5X,F15.6,F16.6//5X,'ADSORBED AMMONIUM',
311X,F15.6,F16.6//5X,'SOLUBLE NITRATE',13X,F15.6,F16.6//5X,

```

4'SOLUBLE AMMONIUM',12X,F15.6,F16.6)
END
C\$ENTRY

APPENDIX C: Computer Simulation Data Files

Prices Fork Farm Plots

STANDARD PREDATA FILE FOR PRICES FORK PLOT C
METRIC UNITS ARE USED ON INPUT/OUTPUT PRINT
RAINFALL DATA FOR 1 RAINGAUGES FOR EVENT OF 06/23/85
GAUGE NUMBER R1

| | | |
|---|------|-------|
| 0 | 00. | 0.00 |
| 0 | 65. | 49.00 |
| 0 | 120. | 0.00 |
| 0 | 150. | 49.20 |
| 0 | 181. | 0.00 |
| 0 | 211. | 49.80 |
| 1 | 250. | 0.00 |

SIMULATION CONSTANTS FOLLOW
NUMBER OF LINES OF HYDROGRAPH OUTPUT = 101
TIME INCREMENT = 30. SEC.
INFILTRATION CAPACITY CALCULATED EVERY 180, SECONDS
EXPECTED RUNOFF PEAK = 50.4 MM/H
SOIL INFILTRATION, DRAINAGE AND GROUNDWATER CONSTANTS FOLLOW
NUMBER OF SOILS = 2
S 1, TP =.48, FP =.74, FC =17.00, A =86.67, P =.65, DF =90.00, ASM =.51, K =.30
S 2, TP =.48, FP =.74, FC =17.00, A =86.67, P =.65, DF =90.00, ASM =.61, K =.30
PARTICLE SIZE AND TRANSPORT DATA FOLLOWS
NUMBER OF PARTICLE SIZE CLASSES = 4
NUMBER OF WASH LOAD CLASSES = 1
SIZE SPECIFIC GRAVITY FALL VELOCITY

| | | |
|-------|------|-----|
| 0.002 | 2.65 | 0.0 |
| 0.200 | 2.65 | 0.0 |
| 0.030 | 1.80 | 0.0 |
| 0.400 | 1.60 | 0.0 |

PARTICLE SIZE FRACTIONS
.029 .033 .317 .621
.029 .033 .317 .621
FRACTION OF CLAY IN PARTICLE CLASSES
S 1, 0.127 0.000 0.361 0.511
S 2, 0.127 0.000 0.361 0.511
DRAINAGE EXPONENT = 3,
DRAINAGE COEFFICIENT FOR TILE DRAINS = 0.00 MM/24HR
GROUNDWATER RELEASE FRACTION = .001
SURFACE ROUGHNESS AND CROP CONSTANTS FOLLOW
NUMBER OF CROPS AND SURFACES = 1
C 1, CROP= PLOT 1, PIT=.00, PER=.00,
RC=.43,HU=60.0,N=.200,DIRM=6.000,C=.4330
TRANSFORMATION INPUT VARIABLES FOLLOW
DURATION OF TRANSFORMATIONS = 00000 MIN.
TIME INCREMENT FOR TRANSFORMATIONS = 60 MIN.
MEAN TEMPERATURE DURING TRANSFORMATIONS = 20.0 DEGREES C
NITROGEN SOIL MAKEUPS FOLLOW
NUMBER OF INITIAL NITROGEN SOIL MAKEUPS = 1
N 1, ORG-N =629.0, ADS-NH4 =73.50, SOL-NO3 =.1088, SOL-NH4 =.0163
FERTILIZER MANAGEMENT PRACTICES FOLLOW

NUMBER OF FERTILIZER MANAGEMENT PRACTICES = 1

F 1, NITRATE = 25.00 AMMONIUM = 25.00

CHANNEL SPECIFICATIONS FOLLOW

NUMBER OF TYPES OF CHANNELS = 1,

CHANNEL 1 WIDTH = 0.00 M., ROUGHNESS COEFF. = .000

ELEMENT SPECIFICATIONS FOR PRICES FORK PLOT 1

EACH ELEMENT IS 3.66 M. SQUARE

OUTFLOW FROM ROW 5 COLUMN 1 NIT MAN PERPOT EDI

1 1 54 270 1 1 R1 0 1 1 23 10

2 1 63 270 1 1 R1 0 1 1 20 10

3 1 78 270 1 1 R1 0 1 1 15 10

4 1 70 270 1 1 R1 0 1 1 15 10

5 1 9 52 270 1 1 R1 0 1 1 20 10

APPENDIX D: Sample Output

Surface Transport Model Output

1 DISTRIBUTED HYDROLOGIC AND WATER QUALITY SIMULATION
BY ANSWERS VER 4.840815
STANDARD PREDATA FILE FOR PRICES FORK PLOT C

RAINFALL HYETOGRAPH FOR EVENT OF 06/23/75

GAGE NUMBER R1

| TIME - MIN. | RAINFALL RATE - MM/H |
|-------------|----------------------|
| 0.0 | 0.00 |
| 65.0 | 49.00 |
| 120.0 | 0.00 |
| 150.0 | 49.20 |
| 181.0 | 0.00 |
| 211.0 | 49.80 |
| 250.0 | 0.00 |

SIMULATION TIME INCREMENT = 30.0 SECONDS
INFILTRATION CAPACITY CALCULATED EVERY 180 SECONDS
EXPECTED RUNOFF PEAK = 50.4 MM/H

SOIL PROPERTIES

SOIL POROSITY FIELD CAP. INFILTRATION CONSTANTS CONTROL
ANTECEDENT EROSION

| | (PERCENT VOL.) | (PERCENT SAT.) | FC MM/H | A MM/H | P | ZONE | MOISTURE MM (PERCENT SAT) | CONST. |
|---|----------------|----------------|---------|--------|------|------|---------------------------|--------|
| 1 | 48.0 | 74.0 | 17.00 | 86.67 | 0.65 | 90.0 | 51.0 | 0.30 |
| 2 | 48.0 | 74.0 | 17.00 | 86.67 | 0.65 | 90.0 | 61.0 | 0.30 |

PARTICLE SIZE DISTRIBUTION DATA

NUMBER OF PARTICLE SIZE CLASSES = 4
NUMBER OF WASHLOAD CLASSES = 1

| CLASS | DIA,MM | EQSAND,MM | SG | FALL VELOCITY, M /S |
|-------|--------|-----------|-------|---------------------|
| 1 | 0.002 | 0.002 | 2.650 | 0.0000036 |
| 2 | 0.200 | 0.200 | 2.650 | 0.0263375 |
| 3 | 0.030 | 0.021 | 1.800 | 0.0003910 |
| 4 | 0.400 | 0.226 | 1.600 | 0.0320289 |

PARTICLE SIZE DISTRIBUTION OF SOILS AS DETACHED

| CLASS | 1 | 2 | 3 | 4 | 5 |
|--------|-------|-------|-------|-------|---|
| SOIL 1 | 0.029 | 0.033 | 0.317 | 0.621 | |
| SOIL 2 | 0.029 | 0.033 | 0.317 | 0.621 | |

FRACTION OF CLAY IN EACH PARTICLE CLASS

| CLASS | 1 | 2 | 3 | 4 | 5 |
|-------|---|---|---|---|---|
|-------|---|---|---|---|---|

SOIL 1 0.127 0.000 0.361 0.511
SOIL 2 0.127 0.000 0.361 0.511

DRAINAGE EXPONENT = 3
TILE DRAINAGE COEFF. = 0.00 MM/24H
GROUNDWATER RELEASE FRACTION = 0.100E-02

COVER

MANAGEMENT PRACTICES

| CROP | MAX. POT. | PERCENT ROUGH. | ROUGH. | MANNING'S | MAX. RET. | | |
|----------|--------------|----------------|--------|-----------|-----------|-------|--------|
| EROSION | | | | | | | |
| | INTERCEPTION | COVER | COEFF. | HEIGHT | N | DEPTH | CONST. |
| | MM | | MM | MM | | | |
| 1 PLOT 1 | 0.00 | 0. 0.43 | 60.0 | 0.200 | 6.00 | 0.43 | |

DURATION OF TRANSFORMATIONS = 0 MIN.
TIME INCREMENT FOR TRANSFORMATIONS = 60 MIN.
MEAN TEMPERATURE DURING TRANSFORMATIONS = 20.0 DEGREES C

INITIAL NITROGEN SOIL MAKUPS

| NO. | ORGANIC-N | ADSORBED-NH4 | SOLUBLE-NO3 | SOLUBLE-NH4 |
|-----|--------------|--------------|-------------|-------------|
| | MG-N/KG-SOIL | | MG-N/HA | |
| 1 | 629.0 | 73.5 | 0.11 | 0.02 |

| NO. | NITRATE APPLIED | AMMONIUM APPLIED |
|-----|-----------------|------------------|
| | (KG-N/HA) | (KG-N/HA) |
| 1 | 25.00 | 25.00 |

CHANNEL PROPERTIES

| TYPE | WIDTH | MANNING'S N |
|------|-------|-------------|
| | M | |
| 1 | 0.0 | 0.000 |

PRICES FORK PLOT 1

WATERSHED CHARACTERISTICS

NUMBER OF 0.00 HA OVERLAND FLOW ELEMENTS = 5
NUMBER OF CHANNEL SEGMENTS = 0
AREA OF CATCHMENT = 0.0 HA
CATCHMENT SLOPE: MIN = 5.20 AVE = 6.34 MAX = 7.80 PERCENT
CHANNEL SLOPE: MIN = 900.00 AVE = 0.00 MAX = 0.00 PERCENT
PERCENT OF AREA TILED = 0.0 WITH A D.C. OF 0.00 MM/24H
MEAN ANTECEDENT SOIL MOISTURE = 51., FIELD CAPACITY = 74. PERCENT SATURATION
GROUNDWATER RELEASE FRACTION = 0.0010
OUTLET IS ELEMENT 5 AT ROW 5 COL 1

SURFACE COVER/MANAGEMENT CONDITIONS SOIL ASSOCIATION PROPERTIES

| CROP | PERCENT | PERCENT | N | C | NO. | PERCENT | FC | INITIAL | CONTROL |
|--------|---------|----------|--------|---|---------|---------|------|---------|---------|
| K | | | | | | | | | |
| | PRESENT | COVER | | | PRESENT | MM/H | MM/H | DEPTH | MM |
| PLOT 1 | 100.0 | 0. 0.200 | 0.4330 | 1 | 100.0 | 17.0 | 71.5 | 90.0 | 0.30 |

OUTLET HYDROGRAPHS--VER 4.840815

| | | | YIELDS-KG | | | CONCENTRATIONS-MG/L | | |
|---------------|----------|---------|-----------|----------|---------|---------------------|----------|-------|
| TIME | RAINFALL | RUNOFF | SEDIMENT | SEDIMENT | BOUND | NITR. | SEDIMENT | |
| SOLUBLE NUTR. | | | | | | | | |
| MIN. | MM/H | MM/H | KG | TKN | ADS-NH4 | | NO3 | NH4 |
| 0.0 | 0.00 | 0.0000 | 0. | 0.000 | 0.000 | 0. | 0.0 | 0.0 |
| 2.5 | 49.00 | 0.0000 | 0. | 0.000 | 0.000 | 0. | 0.0 | 0.0 |
| 5.0 | 49.00 | 0.0000 | 0. | 0.000 | 0.000 | 0. | 0.0 | 0.0 |
| 7.5 | 49.00 | 0.0000 | 0. | 0.000 | 0.000 | 0. | 0.0 | 0.0 |
| 10.0 | 49.00 | 0.0000 | 0. | 0.000 | 0.000 | 0. | 0.0 | 0.0 |
| 12.5 | 49.00 | 0.0000 | 0. | 0.000 | 0.000 | 0. | 0.0 | 0.0 |
| 15.0 | 49.00 | 0.0000 | 0. | 0.000 | 0.000 | 0. | 0.0 | 0.0 |
| 17.5 | 49.00 | 0.0000 | 0. | 0.000 | 0.000 | 0. | 0.0 | 0.0 |
| 20.0 | 49.00 | 0.0735 | 0. | 0.000 | 0.000 | 1526. | 207.5 | 206.7 |
| 22.5 | 49.00 | 0.7566 | 0. | 0.000 | 0.000 | 8807. | 456.0 | 454.3 |
| 25.0 | 49.00 | 2.7100 | 0. | 0.000 | 0.000 | 13069. | 634.5 | 632.2 |
| 27.5 | 49.00 | 6.6017 | 0. | 0.000 | 0.000 | 13667. | 812.0 | 809.1 |
| 30.0 | 49.00 | 12.1684 | 1. | 0.000 | 0.000 | 13565. | 904.4 | 901.1 |
| 32.5 | 49.00 | 17.9342 | 1. | 0.001 | 0.000 | 13376. | 837.8 | 834.8 |
| 35.0 | 49.00 | 22.7406 | 2. | 0.001 | 0.000 | 13124. | 686.4 | 683.8 |
| 37.5 | 49.00 | 26.3340 | 3. | 0.002 | 0.000 | 12810. | 521.4 | 519.5 |
| 40.0 | 49.00 | 28.9024 | 4. | 0.003 | 0.000 | 12477. | 379.1 | 377.7 |
| 42.5 | 49.00 | 30.5788 | 5. | 0.003 | 0.000 | 12192. | 242.7 | 241.8 |
| 45.0 | 49.00 | 31.4190 | 6. | 0.004 | 0.000 | 12009. | 179.0 | 178.3 |
| 47.5 | 49.00 | 31.7840 | 7. | 0.005 | 0.001 | 11893. | 120.8 | 120.4 |
| 50.0 | 49.00 | 31.9251 | 8. | 0.005 | 0.001 | 11820. | 92.2 | 91.9 |
| 52.5 | 49.00 | 31.9752 | 9. | 0.006 | 0.001 | 11774. | 66.8 | 66.5 |
| 55.0 | 49.00 | 31.9921 | 10. | 0.007 | 0.001 | 11747. | 52.8 | 52.6 |
| 57.5 | 49.00 | 31.9975 | 11. | 0.007 | 0.001 | 11731. | 40.9 | 40.8 |
| 60.0 | 49.00 | 31.9992 | 12. | 0.008 | 0.001 | 11721. | 30.3 | 30.2 |
| 62.5 | 49.00 | 31.9998 | 13. | 0.009 | 0.001 | 11716. | 25.2 | 25.1 |
| 65.0 | 49.00 | 31.9999 | 15. | 0.009 | 0.001 | 11713. | 18.8 | 18.7 |
| 67.5 | 0.00 | 18.7630 | 15. | 0.010 | 0.001 | 13495. | 19.0 | 18.9 |
| 70.0 | 0.00 | 9.8519 | 16. | 0.010 | 0.001 | 15863. | 17.3 | 17.3 |
| 72.5 | 0.00 | 5.1332 | 16. | 0.010 | 0.001 | 18860. | 15.6 | 15.5 |
| 75.0 | 0.00 | 2.6585 | 16. | 0.010 | 0.001 | 22840. | 14.4 | 14.4 |
| 77.5 | 0.00 | 1.3327 | 17. | 0.010 | 0.001 | 28440. | 13.8 | 13.8 |
| 80.0 | 0.00 | 0.6246 | 17. | 0.011 | 0.001 | 36310. | 12.6 | 12.6 |
| 82.5 | 0.00 | 0.2554 | 17. | 0.011 | 0.001 | 17598. | 7.5 | 7.5 |
| 85.0 | 0.00 | 0.0751 | 17. | 0.011 | 0.001 | 7687. | 6.2 | 6.2 |
| 87.5 | 0.00 | 0.0064 | 17. | 0.011 | 0.001 | 3547. | 13.7 | 13.6 |
| 90.0 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 92.5 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 95.0 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 97.5 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 100.0 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 102.5 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 105.0 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 107.5 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 110.0 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 112.5 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 115.0 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 117.5 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |
| 120.0 | 0.00 | 0.0000 | 17. | 0.011 | 0.001 | 0. | 0.0 | 0.0 |

| | | | | | | | | |
|-------|-------|---------|-----|-------|-------|---------|-----|-----|
| 122.5 | 49.20 | 0.2922 | 17. | 0.011 | 0.001 | 2576. | 1.0 | 1.0 |
| 125.0 | 49.20 | 1.8542 | 17. | 0.011 | 0.001 | 10591. | 2.2 | 2.2 |
| 127.5 | 49.20 | 5.2908 | 17. | 0.011 | 0.001 | 12360. | 3.9 | 3.9 |
| 130.0 | 49.20 | 10.6199 | 17. | 0.011 | 0.001 | 12777. | 6.0 | 6.0 |
| 132.5 | 49.20 | 16.7221 | 18. | 0.011 | 0.001 | 12827. | 5.3 | 5.3 |
| 135.0 | 49.20 | 22.0838 | 18. | 0.012 | 0.001 | 12740. | 5.2 | 5.2 |
| 137.5 | 49.20 | 26.0635 | 19. | 0.012 | 0.001 | 12573. | 4.3 | 4.3 |
| 140.0 | 49.20 | 28.8557 | 20. | 0.013 | 0.001 | 12345. | 4.0 | 4.0 |
| 142.5 | 49.20 | 30.6726 | 21. | 0.013 | 0.002 | 12128. | 3.5 | 3.5 |
| 145.0 | 49.20 | 31.5822 | 22. | 0.014 | 0.002 | 11983. | 3.2 | 3.2 |
| 147.5 | 49.20 | 31.9731 | 23. | 0.015 | 0.002 | 11887. | 2.7 | 2.7 |
| 150.0 | 49.20 | 32.1223 | 25. | 0.015 | 0.002 | 11824. | 2.3 | 2.2 |
| 152.5 | 0.00 | 18.8412 | 25. | 0.016 | 0.002 | 13595. | 2.2 | 2.2 |
| 155.0 | 0.00 | 9.8890 | 26. | 0.016 | 0.002 | 15963. | 2.1 | 2.1 |
| 157.5 | 0.00 | 5.1504 | 26. | 0.017 | 0.002 | 18967. | 1.9 | 1.9 |
| 160.0 | 0.00 | 2.6671 | 27. | 0.017 | 0.002 | 22959. | 1.7 | 1.7 |
| 162.5 | 0.00 | 1.3370 | 27. | 0.017 | 0.002 | 28578. | 1.6 | 1.6 |
| 165.0 | 0.00 | 0.6268 | 27. | 0.017 | 0.002 | 36475. | 1.5 | 1.5 |
| 167.5 | 0.00 | 0.2565 | 27. | 0.017 | 0.002 | 17685. | 0.9 | 0.9 |
| 170.0 | 0.00 | 0.0756 | 27. | 0.017 | 0.002 | 8025. | 0.7 | 0.7 |
| 172.5 | 0.00 | 0.0065 | 27. | 0.017 | 0.002 | 3563. | 1.6 | 1.6 |
| 175.0 | 0.00 | 0.0000 | 27. | 0.017 | 0.002 | 0. | 0.0 | 0.0 |
| 177.5 | 0.00 | 0.0000 | 27. | 0.017 | 0.002 | 0. | 0.0 | 0.0 |
| 180.0 | 0.00 | 0.0000 | 27. | 0.017 | 0.002 | 0. | 0.0 | 0.0 |
| 182.5 | 49.80 | 0.1192 | 27. | 0.017 | 0.002 | 1008. | 0.1 | 0.1 |
| 185.0 | 49.80 | 2.0075 | 27. | 0.017 | 0.002 | 8269. | 0.3 | 0.3 |
| 187.5 | 49.80 | 6.2419 | 27. | 0.017 | 0.002 | 10410. | 0.6 | 0.6 |
| 190.0 | 49.80 | 12.6111 | 27. | 0.017 | 0.002 | 11237. | 0.8 | 0.8 |
| 192.5 | 49.80 | 19.2152 | 28. | 0.018 | 0.002 | 11756. | 0.7 | 0.7 |
| 195.0 | 49.80 | 24.4341 | 29. | 0.018 | 0.002 | 12042. | 0.7 | 0.7 |
| 197.5 | 49.80 | 28.0581 | 29. | 0.019 | 0.002 | 12113. | 0.7 | 0.7 |
| 200.0 | 49.80 | 30.4789 | 30. | 0.019 | 0.002 | 12043. | 0.6 | 0.6 |
| 202.5 | 49.80 | 31.7598 | 31. | 0.020 | 0.002 | 11974. | 0.6 | 0.6 |
| 205.0 | 49.80 | 32.3811 | 33. | 0.021 | 0.002 | 11912. | 0.5 | 0.5 |
| 207.5 | 49.80 | 32.6463 | 34. | 0.021 | 0.002 | 11863. | 0.5 | 0.5 |
| 210.0 | 49.80 | 32.7474 | 35. | 0.022 | 0.003 | 11827. | 0.4 | 0.4 |
| 212.5 | 0.00 | 24.5289 | 36. | 0.023 | 0.003 | 12777. | 0.4 | 0.4 |
| 215.0 | 0.00 | 13.0247 | 36. | 0.023 | 0.003 | 14957. | 0.4 | 0.4 |
| 217.5 | 0.00 | 6.7392 | 37. | 0.023 | 0.003 | 17727. | 0.3 | 0.3 |
| 220.0 | 0.00 | 3.5000 | 37. | 0.023 | 0.003 | 21275. | 0.3 | 0.3 |
| 222.5 | 0.00 | 1.7975 | 37. | 0.024 | 0.003 | 26054. | 0.3 | 0.3 |
| 225.0 | 0.00 | 0.8776 | 37. | 0.024 | 0.003 | 32909. | 0.3 | 0.3 |
| 227.5 | 0.00 | 0.3839 | 37. | 0.024 | 0.003 | 15490. | 0.2 | 0.2 |
| 230.0 | 0.00 | 0.1325 | 37. | 0.024 | 0.003 | 21679. | 0.2 | 0.2 |
| 232.5 | 0.00 | 0.0227 | 37. | 0.024 | 0.003 | 2920. | 0.2 | 0.2 |
| 235.0 | 0.00 | 0.0000 | 37. | 0.024 | 0.003 | 0.***** | | |
| 237.5 | 0.00 | 0.0000 | 37. | 0.024 | 0.003 | 0. | 0.0 | 0.0 |
| 240.0 | 0.00 | 0.0000 | 37. | 0.024 | 0.003 | 0. | 0.0 | 0.0 |
| 242.5 | 0.00 | 0.0000 | 37. | 0.024 | 0.003 | 0. | 0.0 | 0.0 |
| 245.0 | 0.00 | 0.0000 | 37. | 0.024 | 0.003 | 0. | 0.0 | 0.0 |
| 247.5 | 0.00 | 0.0000 | 37. | 0.024 | 0.003 | 0. | 0.0 | 0.0 |
| 250.0 | 0.00 | 0.0000 | 37. | 0.024 | 0.003 | 0. | 0.0 | 0.0 |

RUNOFF VOLUME PREDICTED FROM 102.58 MM OF RAINFALL = 43.970 MM
AVERAGE SOIL LOSS = 5594. KG/HA

PARTICLE SIZE DISTRIBUTION
OF ERODED SEDIMENT

PARTICLE CLASS 1 = 2.97 PERCENT
 PARTICLE CLASS 2 = 3.27 PERCENT
 PARTICLE CLASS 3 = 32.30 PERCENT
 PARTICLE CLASS 4 = 61.46 PERCENT

INDIVIDUAL ELEMENT NET SEDIMENTATION

ELEMENT SEDIMENT ELEMENT SEDIMENT ELEMENT SEDIMENT ELEMENT
 SEDIMENT

| NO. | KG/HA | NO. | KG/HA | NO. | KG/HA | NO. | KG/HA |
|-----|--------|-----|--------|-----|--------|-----|--------|
| 1 | -4357. | 2 | -5235. | 3 | -6477. | 4 | -6855. |
| 5 | -6624. | | | | | | |

MAX EROSION RATE = 6855. KG/HA MAX DEPOSITION RATE = 0. KG/HA
 STD. DEV. = 1071. KG/HA

CHANNEL DEPOSITION -- KG

| NO. | AMOUNT | NO. | AMOUNT | NO. | AMOUNT | NO. | AMOUNT |
|-----|--------|-----|--------|-----|--------|-----|--------|
|-----|--------|-----|--------|-----|--------|-----|--------|

| POLLUTANT | YIELD AT OUTLET | | AVG. YIELD |
|-------------------------|-----------------|----------|------------|
| | KG | KG/HA | |
| SEDIMENT | 37.47 | 5593.79 | |
| SEDIMENT-BOUND NITROGEN | | 0.023653 | 3.763970 |
| ADSORBED AMMONIUM | | 0.002764 | 0.439828 |
| SOLUBLE NITRATE | 0.057442 | | 8.576242 |
| SOLUBLE AMMONIUM | 0.057230 | | 8.544647 |