Simulation of pollution by soil erosion and soil nutrient loss

D. A. Haith, L. J. Tubbs and N. B. Pickering

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CIP-gegevens

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Contents

1 Introduction

Water pollution from croplands is due to chemical and sediment transport in runoff and the leaching of soil chemicals by percolation. Measurements of these nonpoint sources is not easy; there have been few long-term attempts to monitor sediment and chemicals in agricultural drainage. Control of nonpoint-source pollution is also difficult, because soil and chemical losses are often associated with intensive cropping practices designed to maximize crop yields. Although the resource implications of intensive agriculture are recognized (Brown, 1981), national and international food needs are such that agricultural policy objectives strongly emphasize short-term production objectives, rather than long-term environmental quality and resource conservation goals.

A realistic approach to the management of agricultural nonpoint-source pollution must be based on information that quantifies the magnitudes of chemical and soil losses from croplands and the likely effects of potential controls. Mathematical simulation models are a practical means of generating that information. General models are available for predicting nutrients, sediment and pesticides in cropland runoff (Donigian et al., 1977; Knisel, 1980). In addition, more specific models have been constructed for nitrogen in runoff (Tseng, 1979), nitrogen in percolation (Addiscott, 1977; Haith, 1973; Saxton et al., 1977; Stewart et al., 1976) and pesticides in runoff (Haith, 1980; Steenhuis & Walter, 1980).

Agricultural nonpoint-source simulation models have been developed for various purposes, but few of them are operational tools for agricultural or environmental planning. Although the definition of 'operational' is somewhat arbitrary, the authors believe that an operational model should possess the following characteristics: (a) input data are generally available from standard published sources, (b) calibration is not needed, (c) model testing was done in field-scale validation studies, and (d) computational needs are sufficiently modest to permit long-term simulations.

Criteria (a) and (b) permit models to be run without expensive and time-consuming data collection and water-quality sampling programs. Validation studies (criterion (c)) are essential because all models are abstractions of the processes that, in this case, affect water, sediment and chemical behaviour. There is no a priori way of determining whether or not these simplified descriptions of complex phenomena lead to reasonable predictions. The final criterion, computational efficiency, is always a desirable model attribute, but it is especially important for nonpoint-source models. Chemical and sediment losses reflect hydrologic variability, and long simulation runs are often needed to realistically describe pollution probabilities.

This monograph describes a simulation model for cropland nutrient losses that was designed to meet these four operational criteria. The Cornell Nutrient Simulation (CNS) model is a combined hydrologic transport and soil chemistry model that estimates runoff, percolation, soil loss, nitrogen in percolation and runoff and phosphorus in runoff from homogeneously cropped fields. The model has a daily time-step for hydrologic processes and a monthly time-step for soil chemical balances. Although the mathematical description of the CNS model has been summarized previously (Tubbs & Haith, 1981), this monograph is the first attempt to document the model in a form suitable for potential users. Chapter 2 describes the general equations of the model. Chapter 3 discusses procedures that may be used to estimate model parameters. Chapter 4 presents the detailed results of validation studies for several small catchments in the United States. Chapter 5 is devoted to procedures for generating meteorologic input data for long-term simulations. Chapter 6, the final chapter, contains suggestions for model improvements. There are two appendices: Appendix A provides definitions of model variables and parameters; Appendix B comprises an annotated FORTRAN 77 listing of the CNS model and a sample computer run.

2 Model description

2.1 General structure

2.1.1 Introduction

The processes that influence sediment and nutrient losses in cropland drainage occur mainly near the soil surface. Thus the CNS model considers only those transport and chemical phenomena that occur within 30 cm of the soil surface. This layer is divided into zones of 10 and 20 cm, with runoff losses determined by conditions in the top 10 cm and percolation losses computed for both zones. The CNS model contains a hydrologic transport and soil chemistry submodels. The former submodel computes daily soil moisture and percolation volumes based on predicted runoff, evapotranspiration and snowmelt. The transport submodel also computes daily sediment loss in runoff due to rainfall erosion. The soil chemistry submodels determine monthly mass balances for soil nitrogen and phosphorus. Outputs from these submodels are monthly dissolved and solid-phase nitrogen and phosphorus in runoff, and dissolved nitrogen and phosphorus in percolation.

The dual time-steps in the CNS model were chosen for computational efficiency. Since hydrologic and erosive processes depend on cover and antecedent moisture conditions at the time of a rainfall or snowmelt event, they cannot be accurately modelled using time-steps larger than one day. However, similar restrictions are not necessary for nutrient balances. Soil chemical processes proceed relatively slowly and the timing of fertilizer applications and crop nutrient uptakes can seldom be predicted with certainty. Thus the dynamics of soil-nutrient budgets can largely be captured by a one-month time-step.

2.1.2 Major assumptions

The relatively simple structure of the CNS model imposes several limitations on its use. It is assumed that the top 30 cm of the soil profile drains completely during the day of a storm. Also, denitrification losses of nitrogen are neglected. Both conditions limit the model to well-drained soils that are not subject to surface waterlogging. Fertilizer additions of nitrogen and phosphorus are considered to be well mixed in the top 10 cm of soil, and hence the CNS model will underestimate runoff losses of dissolved nutrients for situations in which fertilizer is left on the soil surface. Since inorganic nitrogen is mobile and moves rapidly into the soil with infiltration, the underestimation will be less severe for nitrogen than for phosphorus. A final model limitation involves the neglect of organic

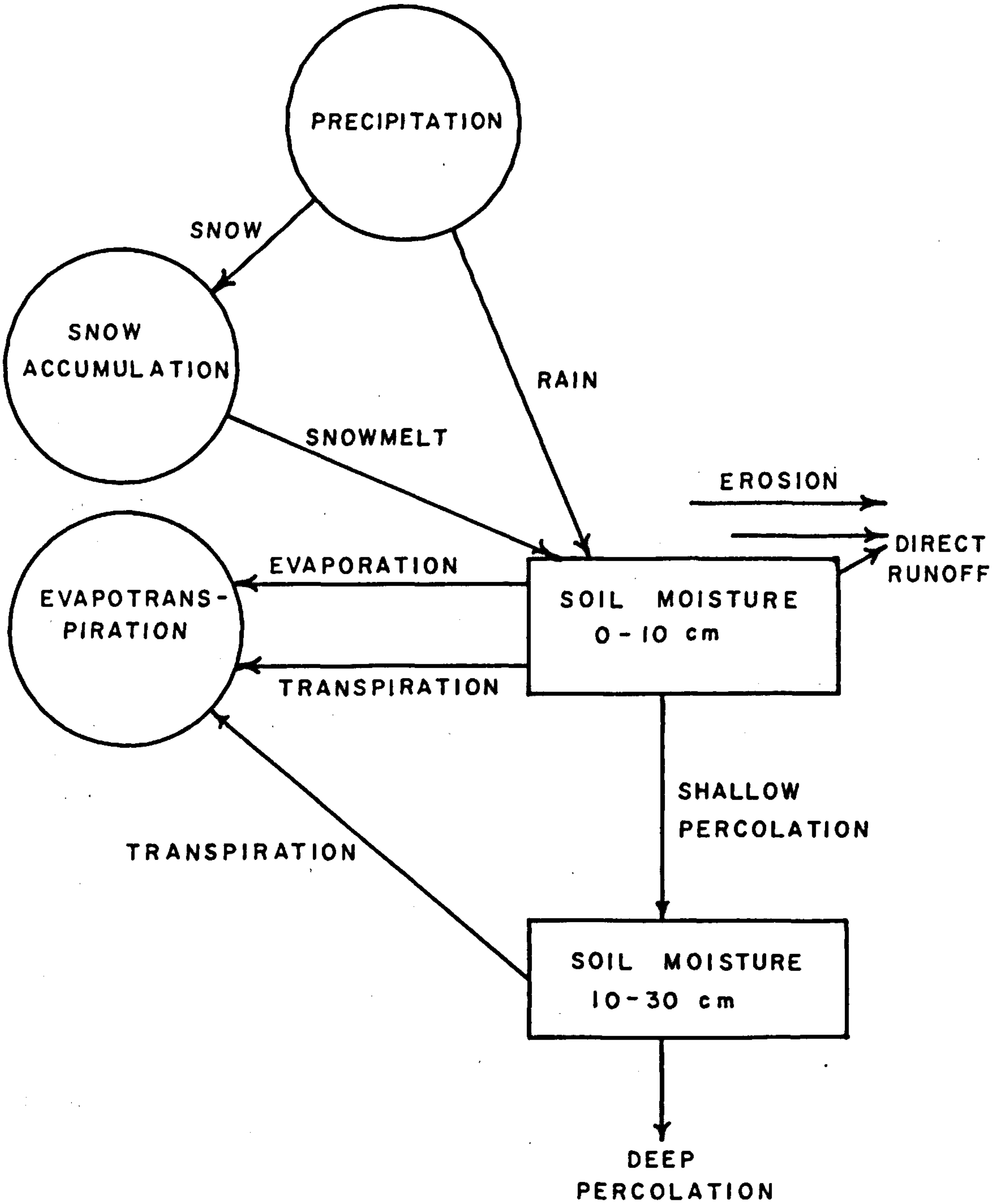

Figure 1. Hydrologic transport model

phosphorus sources. The model will not provide reliable estimates of dissolved phosphorus losses from sites receiving significant applications of organic wastes.

2.2 Hydrologic transport model

The general structure of the hydrologic model is shown in Figure 1. Soil moisture inputs are accounted for each day, and soil erosion is determined for each rainfall event.

2.2.1 Soil moisture

Soil moisture budgets are computed for the surface 10 cm (Zone 1) and the subsurface 20 cm (Zone 2):

$$d_1\theta_{1,t+1} = d_1\theta_{1t} + R_t + M_t - Q_t - E_{1t} - P_{1t} \quad (1)$$

and

$$d_2\theta_{2,t+1} = d_2\theta_{2t} + P_{1t} - E_{2t} - P_{2t}. \quad (2)$$

In these equations, R_t is rainfall on day t; M_t is snowmelt (water equivalent) on day t; Q_t is direct runoff on day t; E_{jt} is evapotranspiration from Zone j on day t (all in cm); θ_{jt} is available soil moisture, in Zone j at the beginning of day t (cm cm^{-1}); and d_j is the depth of soil Zone j (d_1 = 10 cm, d_2 = 20 cm). The maximum soil moisture for zone j is $\bar{\theta}_j$, the available water capacity.

The computational sequence for these equations is:

i) Runoff and evapotranspiration are determined and subtracted from soil water + rainfall + snowmelt.
ii) P_{1t} is determined from Zone 1.
iii) P_{1t} is added to Zone 2, and P_{2t} is computed.

Rainfall is obtained from PR_t, precipitation on day t (cm) and T_t, temperature on day t (°C).

$$R_t = PR_t \quad \text{for } T_t > 0 \quad (3)$$

If $T_t \leq$, then $R_t = 0$ and precipitation is assumed to be in form of snow. (4)

2.2.2 Snow and snowmelt

Snow accumulates on the soil surface whenever $T_t \leq 0$ and $PR_t > 0$. When $T_t > 0$, snowmelt occurs. If S_t = snow accumulation (cm of water) at the beginning of day t, then

$$S_{t+1} = S_t + PR_t, \quad \text{for } T_t \leq 0 \quad (4)$$

or

$$S_{t+1} = S_t - M_t, \quad \text{for } T_t > 0. \quad (5)$$

Snowmelt M_t is determined by the degree-day procedure described by Stewart et al. (1976):

$$M_t = \text{Min}\,[0.45\,T_t; S_t] \quad \text{for } T_t > 0. \quad (6)$$

Equation 6 limits M_t to the available snow.

2.2.3 Runoff

Direct runoff is computed by the U.S. Soil Conservation Service's Curve

Number Equation (Ogrosky & Mockus, 1964):

$$Q_t = \frac{(R_t + M_t - 0.2\,W_t)^2}{R_t + M_t + 0.8\,W_t}. \tag{7}$$

The detention parameter W_t (cm) in Equation 7 is determined from a curve number CN_t:

$$W_t = \frac{2540}{CN_t} - 25.4. \tag{8}$$

Curve numbers are usually selected from one of three values, CN_{I}, CN_{II} or CN_{III}, corresponding to three different antecedent precipitation conditions. However in the CNS model, CN_t is determined as a continuous function of soil moisture in Zone 1, as shown in Figure 2. The exception to this procedure is when snowmelt occurs. In this case the wettest antecedent moisture condition (III) is assumed, thus $CN_t = CN_{\mathrm{III}}$.

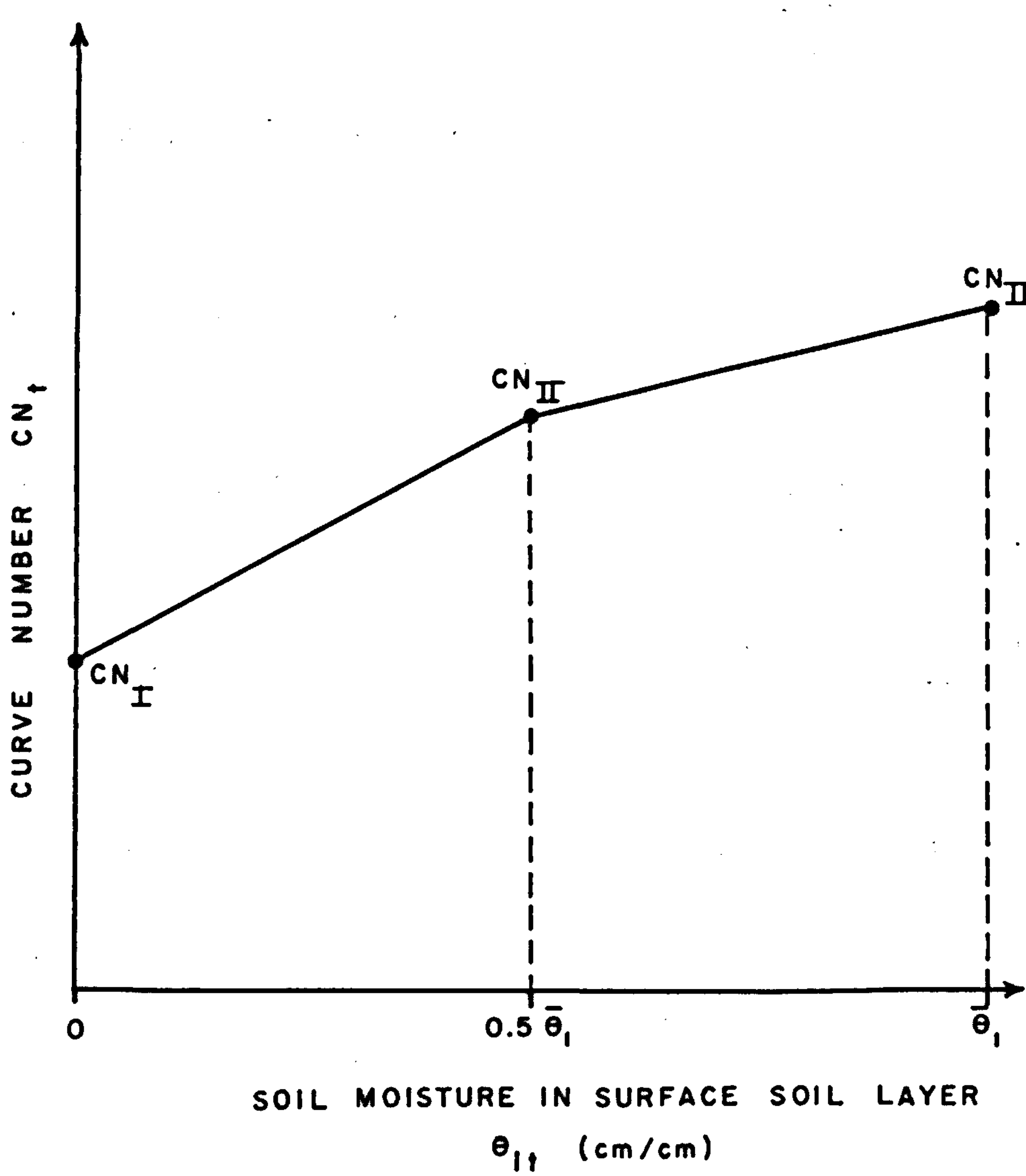

Figure 2. Runoff curve number as function of soil moisture

2.2.4 *Evapotranspiration*

Evapotranspiration consists of three sources: EV_t, evaporation (cm) from the soil surface on day t; and TR_{1t} and TR_{2t}, plant transpiration (cm) from the surface and subsurface zones on day t. Thus $E_{1t} = EV_t + T_{1t}$ and $E_{2t} = T_{2t}$. The relative amounts of evaporation and transpiration are determined by CP_t, the fraction of soil surface covered by crop canopy on day t. Both evaporation and transpiration are based on the equation developed by Hamon (1961) for potential evapotranspiration, PE_t (cm), on day t.

$$PE_t = \frac{(0.021\, DH_t^2)}{(T_t + 273)}\, e_{st} \qquad (9)$$

where DH_t is the daylight hours during day t, and e_{st}, the saturation vapor pressure on day t (mb), is a function of temperature.

Evaporation is adjusted for soil moisture

$$EV_t = \text{Min}\,[(\theta_{1t}/\bar{\theta}_1)(1 - CP_t)\, PE_t;\, d_1\theta_{1t}] \qquad (10)$$

and transpiration is satisfied first from the soil moisture in the surface zone:

$$T_{1t} = \text{Min}\,[CP_t PE_t;\, d_1\theta_{1t} - EV_t]. \qquad (11)$$

The remaining crop water requirement $CP_t PE_t - T_{1t}$ is met from the second zone provided sufficient water is available:

$$T_{2t} = \text{Min}\,[CP_t PE_t - T_{1t};\, d_2\theta_{2t}]. \qquad (12)$$

The crop canopy factor in the CNS model assumes the canopy development shown in Figure 3. Two dates, t_e and t_f, the days of crop emergence and full or 100% canopy must be specified. If L_t = fraction of the time to full canopy, or

$$L_t = \frac{t - t_e}{t_f - t_e} \quad \text{for } t_e \le t \le t_f \qquad (13)$$

then the canopy fraction is

$$CP_t = \frac{1.5\, L_t}{0.5 + L_t} \quad \text{for } t_e \le t \le t_f. \qquad (14)$$

For $t_f \le t \le t_h$, where t_h is the harvest date, $CP_t = 1.0$.
At all other times, $CP_t = 0$.

2.2.5 *Percolation*

Infiltration into soil Zone 1 can be expressed as $R_t + M_t - Q_t$. After addition of infiltration and subtraction of E_{1t}, percolation from Zone 1 is computed as any excess above available water capacity:

$$P_{1t} = \text{Max}\,[d_1\theta_{1t} + R_t + M_t - Q_t - E_{1t} - d_1\bar{\theta}_1;\, 0]. \qquad (15)$$

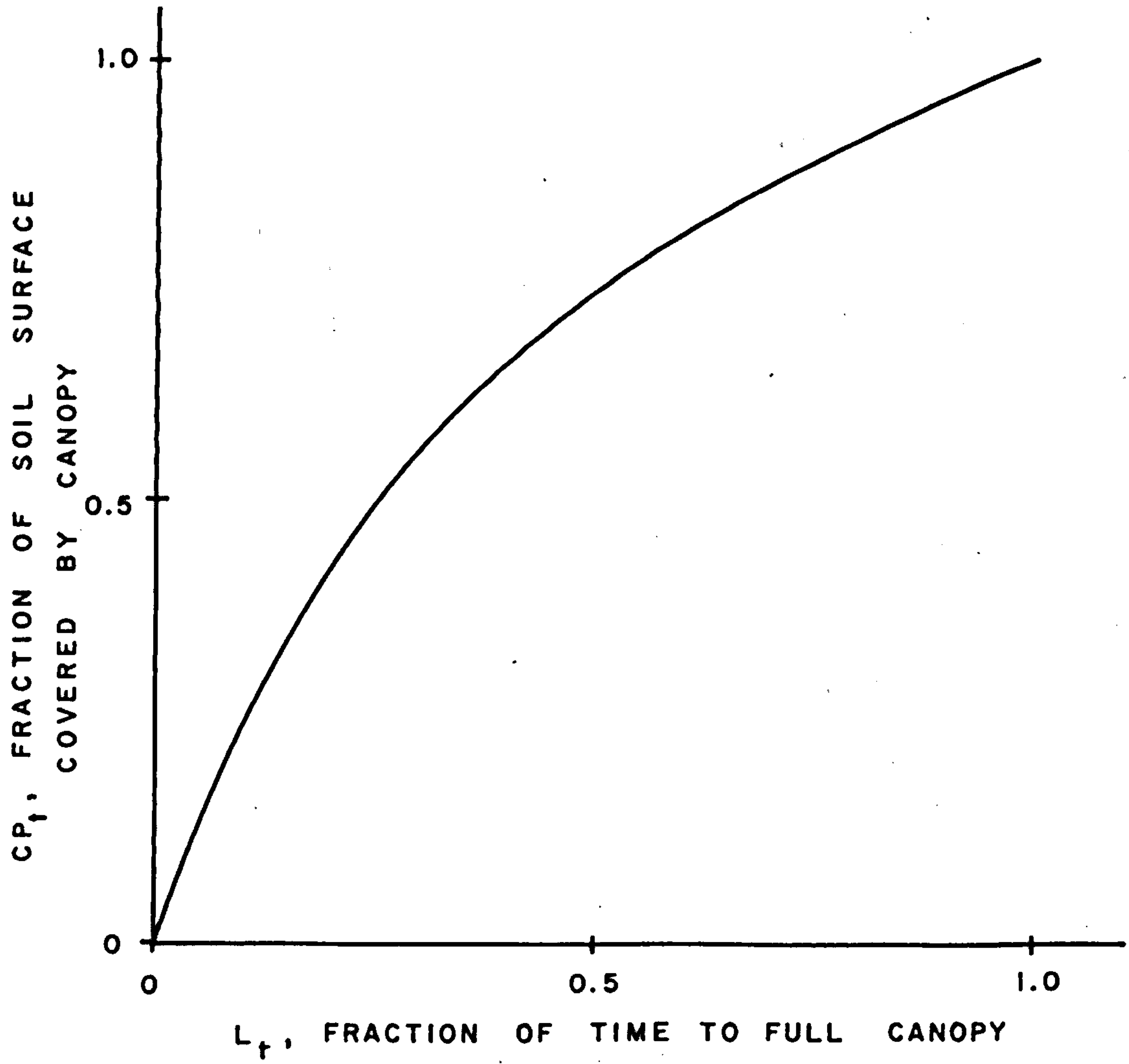

Figure 3. Crop canopy function

Similarly for Zone 2,

$$P_{2t} = \text{Max}\,[d_2\theta_{2t} - E_{2t} + P_{1t} - d_2\bar{\theta}_2;\,0]. \tag{16}$$

2.2.6 Sediment

The modified Universal Soil Loss Equation proposed by Williams (1975) is used to estimate edge-of-field sediment loss, X_t (t ha^{-1}), due to rainfall erosion (snowmelt erosion is assumed negligible).

$$X_t = \frac{11.8}{A}(V_t q_t)^{0.56} K(LS) P\, C_t \tag{17}$$

where K, (LS), C_t and P represent soil erodibility, topographic, cover and supporting practice factors, respectively; A is the field area (ha); V_t is runoff volume (m^3) given by 100 AQ_t; and q_t is peak runoff (m^3 s^{-1}).

Peak runoff can be estimated by assuming a runoff hydrograph as shown in Figure 4. In Figure 4, D_t is the rainstorm duration (h), D_c is the time of concentration (h) and D_a is the duration of initial abstraction (h) (i.e. the time from the start of rainfall until runoff begins). Since total runoff is equal to the area under the hydrograph,

$$Q_t = q_t' D_c + q_t' (D_t - D_a - D_c) = q_t' (D_t - D_a) \tag{18}$$

where q_t' is peak runoff expressed in units of cm h^{-1} ($q_t = 0.028\, q_t' A$). To determine D_a, it is assumed that the duration of abstraction is proportional to the amount of abstraction ($0.2W_t$ in Equation 7). Hence

$$\frac{D_a}{D_t} = \frac{0.2W_t}{R_t}. \tag{19}$$

Equation 18 can then be rearranged to give

$$q_t = 0.028A \left(\frac{R_t}{D_t}\right)\left(\frac{Q_t}{R_t - 0.2W_t}\right). \tag{20}$$

Substitution of Equation 20 into Equation 17 produces

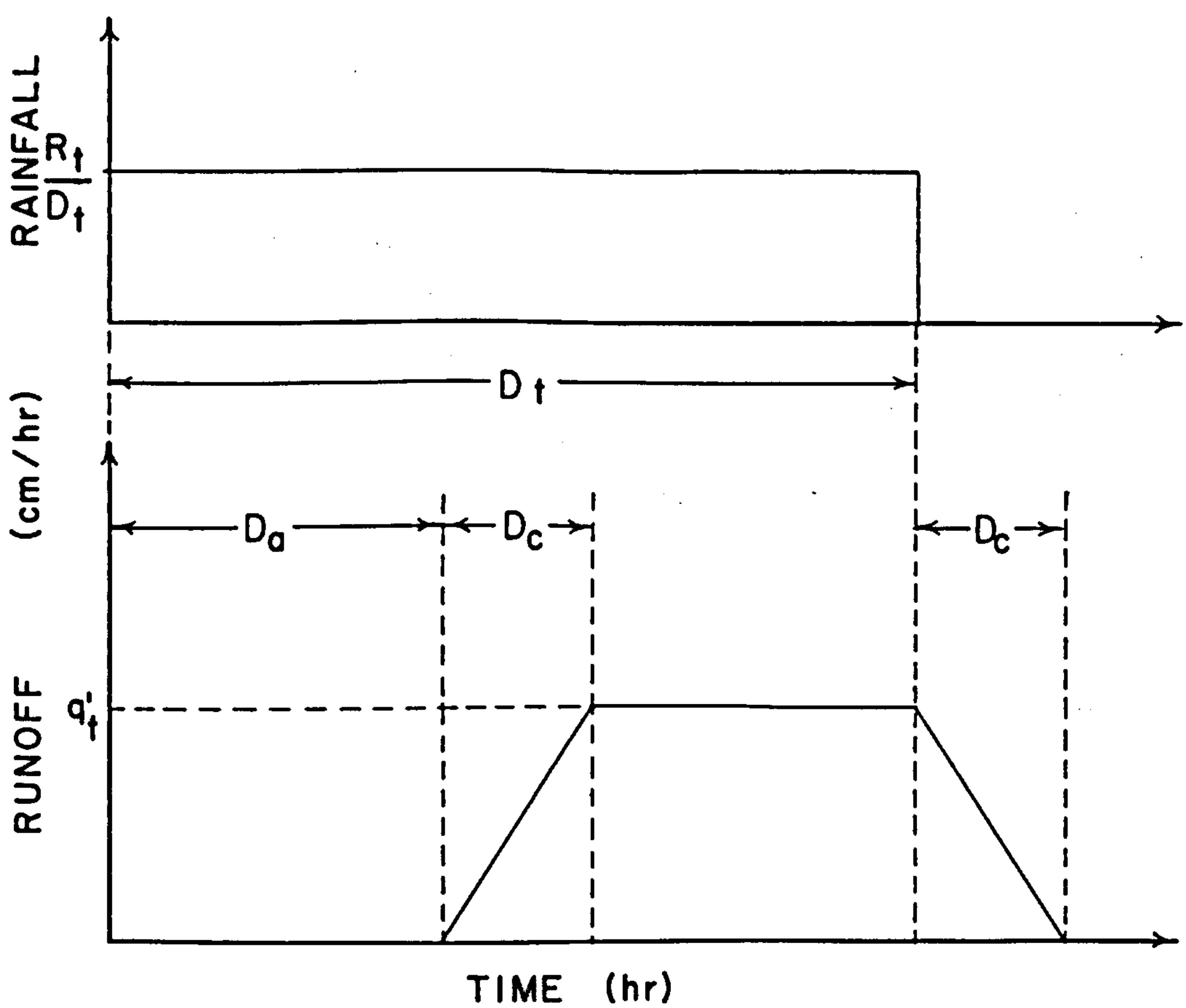

Figure 4. Procedure for estimating peak runoff

$$X_t = 21A^{0.12}Q_t^{1.12}\left(\frac{R_t/D_t}{R_t - 0.2W_t}\right)^{0.56} K(LS)PC_t. \quad (21)$$

2.3 Soil nitrogen model

Characteristics of the CNS model's soil nitrogen submodel are shown in Figure 5. Separate inventories of inorganic nitrogen are maintained for the top and bottom soil zones, but an organic nitrogen inventory is computed for the surface zone only. Nitrogen in either zone is assumed to be perfectly mixed. Only inorganic nitrogen in the top centimetre of the surface zone is considered available for runoff loss. The model neglects denitrification and other volatilization losses. Since nitrification is rapid in well-drained soils, and the model time-step is large (one month), the nitrification step is not modelled. Nitrogen fixation is not included explicity in the model. When legumes are modeled, it is assumed that the plants will scavenge the soil for inorganic nitrogen and fix their remaining needs. Fixed nitrogen associated with legumes is not considered to be available for loss in runoff or percolation.

The inorganic nitrogen balances are

$$I_{1,n+1} = I_{1n} + FN_n + m_n\bar{O}_n + ma_n\overline{MO_n} + RN_n - UN_{1n} - QN_n - PN_{1n} \quad (22)$$

and

$$I_{2,n+1} = I_{2n} + PN_{1n} - UN_{2n} - PN_{2n}. \quad (23)$$

In these equations, I_{jn} is soil inorganic nitrogen in Zone j at the beginning of month n, FN_n is the fertilizer and manure inorganic nitrogen applied to the soil during month n, $\bar{O}_n$ and $\overline{MO}_n$ are the average levels of stabilized and labile soil organic nitrogen in Zone 1 during month n, RN_n is inorganic nitrogen in precipitation during month n, UN_{jn} is crop nitrogen uptake from Zone j during month n, PN_{jn} is dissolved inorganic nitrogen in percolation from Zone j during month n, and QN_n is the dissolved inorganic nitrogen in runoff. All these values for nitrogen are expressed in kg ha^{-1}. In addition m_n and ma_n are the fractions of stabilized and labile soil organic nitrogen mineralized during month n.

It is assumed that organic nitrogen mineralization is largely confined to the surface zone. Hence mass balance are considered only for Zone 1:

$$O_{n+1} = O_n - m_n\bar{O}_n - XO_n \quad (24)$$

and

$$MO_{n+1} = MO_n - ma_n\overline{MO}_\mathrm{n} + ML_n. \quad (25)$$

Two mass balances are given for organic nitrogen to reflect the different mineralization rates of stabilized and organic nitrogen. Much of the organic nitrogen is relatively stable, and mineralizes slowly. However, fresh crop residues, manures and other organic wastes are much more labile, and mineralize rapidly.

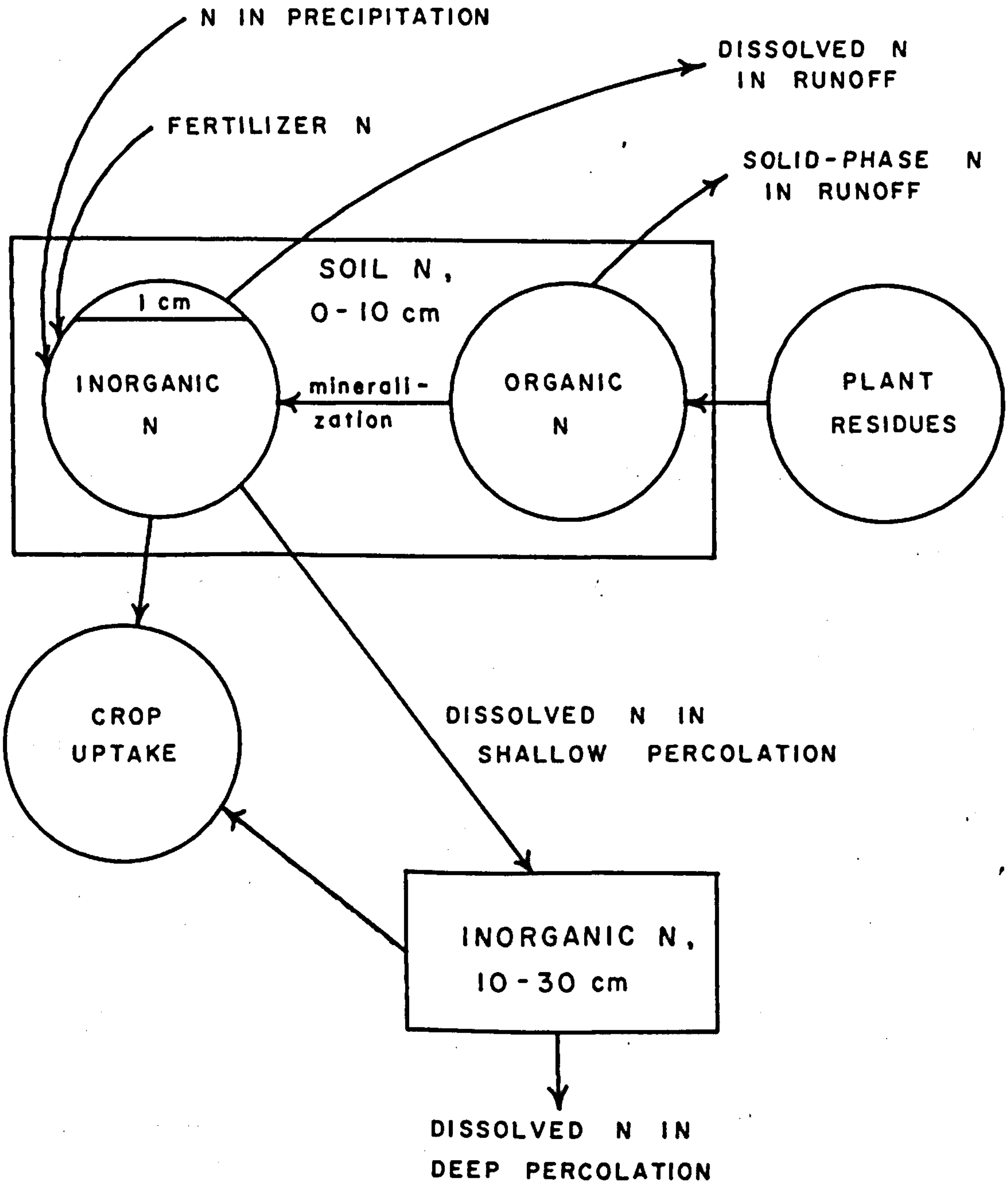

Figure 5. Soil nitrogen model

In Equations 24 and 25, O_n and MO_n are, respectively, the stable and labile organic nitrogen levels at the beginning of month n, ML_n is the addition of labile organic nitrogen in month n, and XO_n is the solid-phase runoff loss of organic nitrogen during month n. All these quantities are expressed in kg ha^{-1}. Runoff losses of solid-phase labile nitrogen are not considered, since MO_n is generally much smaller than O_n. Monthly averages are:

$$\overline{O}_n = \frac{O_n + O_{n+1}}{2} \tag{26}$$

and

$$\overline{MO}_n = \frac{MO_n + MO_{n+1}}{2}. \tag{27}$$

2.3.1. *Mineralization*

The mineralization rates m_n and ma_n depend on daily variations in temperature and soil water. Stanford et al. (1973) determined weekly rate constants for first-order degradation of potentially mineralizable soil nitrogen as a function of soil temperature. Potentially mineralizable nitrogen is the fraction of organic nitrogen considered susceptible to mineralization. Stanford & Epstein (1974) extended this work to evaluate soil water effects. Dividing the weekly rate constants obtained from these studies by seven gives k_t, the fraction of potentially mineralizable organic nitrogen mineralized in day t:

$$k_t = 7.3(10)^6 \left(\frac{\theta_{1t} + w_1}{\overline{\theta}_1 + w_1}\right) \exp[-6350/(T_t + 273)]. \tag{28}$$

Equation 28 is a Van 't Hoff-Arrhenius temperature relationship adjusted by a linear soil-moisture factor. The parameter w_1 is the volumetric soil wilting point (cm cm^{-1}). In the CNS model soil moisture θ_{1t} cannot exceed available water capacity ($\overline{\theta}_1$), and maximum mineralization rates are obtained when the soil is at field capacity ($\overline{\theta}_1 + w_1$). For daily temperatures $T_t \leq 0$°C, k_t is set equal to zero. Field capacities are often approximately twice the available water capacity (Brady, 1974); the computer program in Appendix B assumes that $\overline{\theta}_1 + w_1 = 2\overline{\theta}_1$.

If N_0 is the amount of potentially mineralizable organic nitrogen at the beginning of a month, and *nd* are the number of days in the month, the fraction of N_0 remaining at the end of the month is

$$K_{mn} = (1 - k_1)(1 - k_2) \ldots (1 - k_{nd}). \tag{29}$$

Thus a monthly mineralization rate is given by $1 - K_{mn}$. To relate this rate to the monthly organic nitrogen mineralization rates in Equations 22, 24, and 25, it is assumed that all labile organic nitrogen is potentially mineralizable, but that only 5% of the stabilized organic nitrogen is potentially mineralizable at any time. Under these assumptions

$$m_n = 0.05(1 - K_{mn}) \tag{30}$$

and

$$ma_n = 1 - K_{mn}. \tag{31}$$

2.3.2 Crop uptake

Total crop uptake of nitrogen in month n, UN_n (kg ha^{-1}) is approximated by the sigmoid function shown in Figure 6. If t_n is the day that ends month n, and PC_n is the percentage of total uptake that occurs by the end of month n, the function can be approximated by

$$PC_n = \frac{100\,TG}{1 + TG} \tag{32}$$

where

$$TG = \exp\left[7.324\left(\frac{t_n - t_e}{t_m - t_e}\right) - 3.662\right] \tag{33}$$

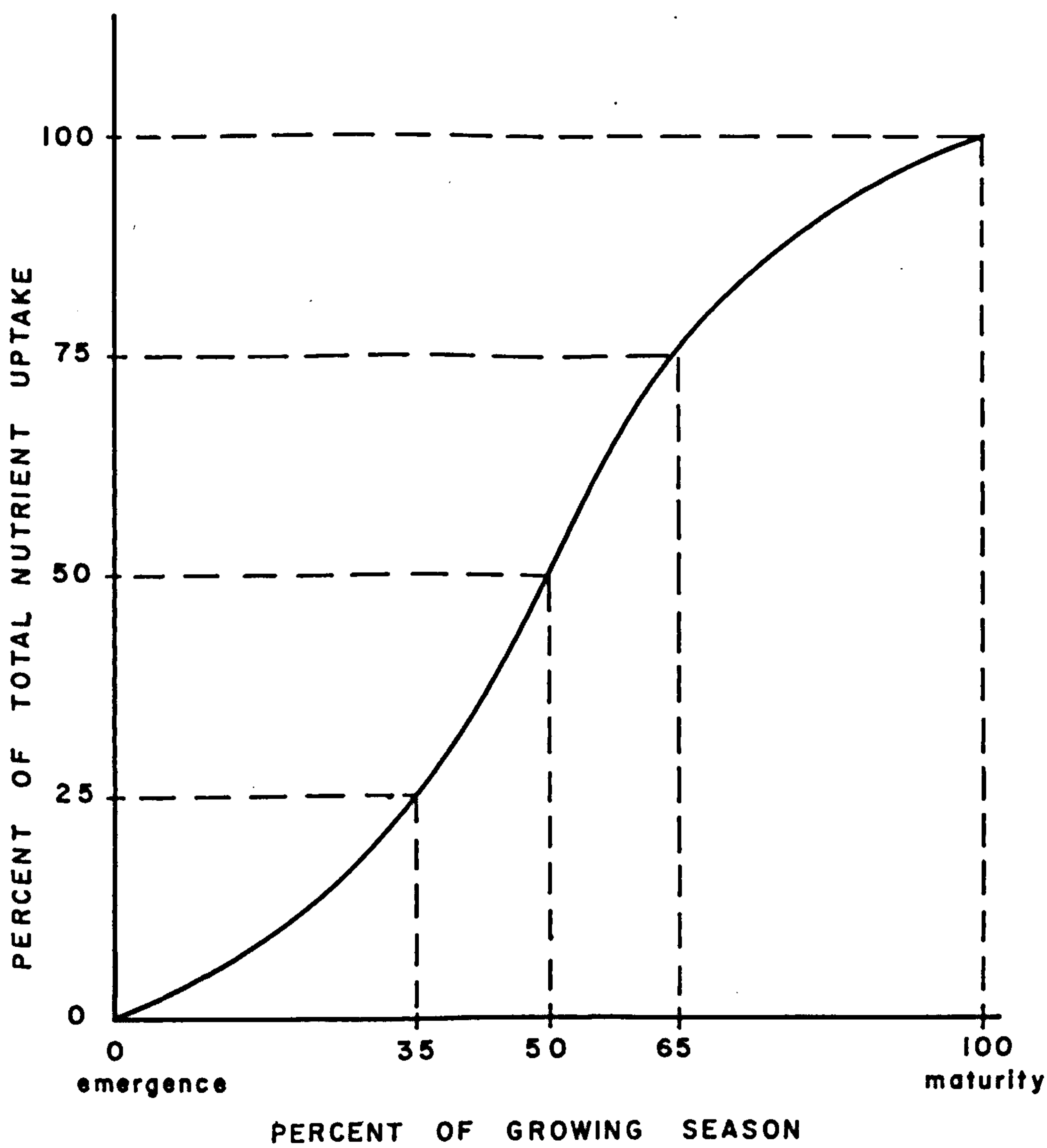

Figure 6. Crop growth function

and $PC_n = 0$ for $t_n \leq t_e$ (the emergence date), and $PC_n = 100$ for $t_n \geq t_m$ (the date of maturity). If UN is the total crop nitrogen uptake during the growing season, then

$$UN_n = \frac{(PC_n - PC_{n-1})\,UN}{100}. \tag{34}$$

If sufficient inorganic nitrogen is present in the top zone, all crop nitrogen is withdrawn from that zone ($UN_{1n} = UN_n$). Otherwise the remaining nitrogen requirement, $UN_n - UN_{1n}$, is taken from the second zone. If UN_n exceeds total inorganic nitrogen in the two zones, it is assumed that plant needs will be satisfied by nitrogen from below the 30 cm depth level in the soil profile.

2.3.3 *Runoff and percolation losses of inorganic nitrogen*

Both runoff and percolation losses of inorganic nitrogen are based on $\bar{I}_{jn}$, the average inorganic nitrogen (kg ha^{-1}) in Zone j during month n:

$$\bar{I}_{jn} = \frac{I_{jn} + I_{jn+1}}{2}. \tag{35}$$

It is assumed that nitrogen is well-mixed in both zones and only the inorganic nitrogen in the top centimetre of Zone 1 is available for runoff loss. Thus the 'runoff-available' inorganic nitrogen is $0.1\,\bar{I}_{1n}$. The portion that is actually lost is determined by the fraction of available water ($R_n + M_n$) that runs off (Q_n), and hence

$$QN_n = \frac{0.1\,Q_n \bar{I}_{1n}}{R_n + M_n}. \tag{36}$$

Percolation losses of nitrogen are computed in a similar manner as runoff losses; they are based on fractions of available water which percolate:

$$PN_{1n} = \frac{P_{1n}}{R_n + M_n + d_1\bar{\theta}_1}\,\bar{I}_{1n} \tag{37}$$

and

$$PN_{2n} = \frac{P_{2n}}{P_{1n} + d_2\bar{\theta}_2}\,\bar{I}_{2n}. \tag{38}$$

In Equations 36–38: R_n, M_n, Q_n, P_{1n} and P_{2n} are rainfall, smowmelt, runoff, Zone 1 percolation and Zone 2 percolation (cm), respectively, during month n. The last three values are obtained by summing the daily values from the hydrologic transport model.

2.3.4 *Runoff losses of organic nitrogen*

Organic nitrogen losses are in the solid-phase form. They are associated with

X_n, i.e. the sediment loss (t ha^{-1}) during month n. This sediment loss is obtained by summing the daily losses predicted by the hydrologic transport model. As before, solid-phase losses of labile organic nitrogen are neglected. Losses of stable organic nitrogen are represented by

$$XO_n = \frac{ER_N X_n \bar{O}_n}{1000\rho} \tag{39}$$

in which ρ is the bulk density (g cm^{-3}) of the surface soil and ER_N is an enrichment ratio for nitrogen. A value of $ER_N = 2.5$ has been used in all applications of the model.

2.3.5 *Computational sequence*

The soil nitrogen equations in the CNS model are not solved simultaneously. Rather, a sequence of computations is made according to the following steps:

Step 1

Equations 24 and 25 are solved for O_{n+1} and MO_{n+1}. Equation 26 is substituted into Equations 24 and 39. Equation 39 is inserted into Equation 24, which is rearranged as

$$O_{n+1} = O_n \; \frac{1 - S1/2 - m_n/2}{1 + S1/2 + m_n/2} \tag{24a}$$

In this Equation $S1 = ER_N X_n/1000\rho$. If O_{n+1} is negative, it is set to zero.

Similarly, Equation 25 is rearranged as

$$MO_{n+1} = \frac{(0.5 + 0.5\,K_{mn})\,MO_n + ML_n}{1.5 - 0.5\,K_{mn}} \tag{25a}$$

Organic nitrogen losses are described by Equation 39.

Step 2

Equations 26 and 27 are substituted into Equation 22. Equations 35–37 are similarly substituted and Equation 22 is solved for $I_{1,n+1}$:

$$I_{1,n+1} = \frac{I_{1n}(1 - W1/2) + FN_n + m_n\bar{O}_n + (1 - K_{mn})\overline{MO}_n - UN_{1n}}{1 + W1/2}. \tag{22a}$$

If $I_{1,n+1}$ is negative, it is set to zero. The variable $W1$ is given by

$$W1 = \frac{0.1\,Q_n}{R_n + M_n} + \frac{P_{1n}}{R_n + M_n + d_1\bar{\theta}_1}. \tag{40}$$

Step 3

Equation 35 is solved for $\bar{I}_{1n}$, and runoff and percolation losses are computed by Equations 36 and 37, respectively.

Step 4

If $I_{1,n+1}$ as determined from Equation 22a is negative, plant uptake, UN_{1n}, is reduced by a sufficient amount to make $I_{1,n+1}$ equal zero. Uptake from Zone 2 is given by $UN_{2n} = UN_n - UN_{1n}$. Appropriate substitutions are now made in Equation 23 to obtain

$$I_{2,n+1} = \frac{I_{2n}(1 - W2/2) + PN_{1n} - UN_{2n}}{1 + W2/2} \tag{23a}$$

where $W2 = P_{2n}/(P_{1n} + d_2\bar{\theta}_2)$ and $I_{2,n+1}$ is set to zero if negative. Equation 35 is solved for $\bar{I}_{2n}$ and Equation 38 is used to determine PN_{2n}.

2.4 Soil phosphorus model

The soil phosphorus model is based on an inventory equation for available phosphorus, i.e. that small portion of total soil phosphorus that in principle is available to plants. Interactions between available and either fixed or organic phosphorus are not incorporated in the model. The model is shown in Figure 7. The primary concern is with runoff losses and only the surface soil zone is modelled. The following mass balance applies in principle to the total available phosphorus (dissolved plus adsorbed phosphorus). However, since most of this phosphorus is adsorbed, total available phosphorus is approximately equal to adsorbed phosphorus. Thus,

$$AP_{n+1} = AP_n + FP_n - UP_n - QP_n - PP_n - XP_n \tag{41}$$

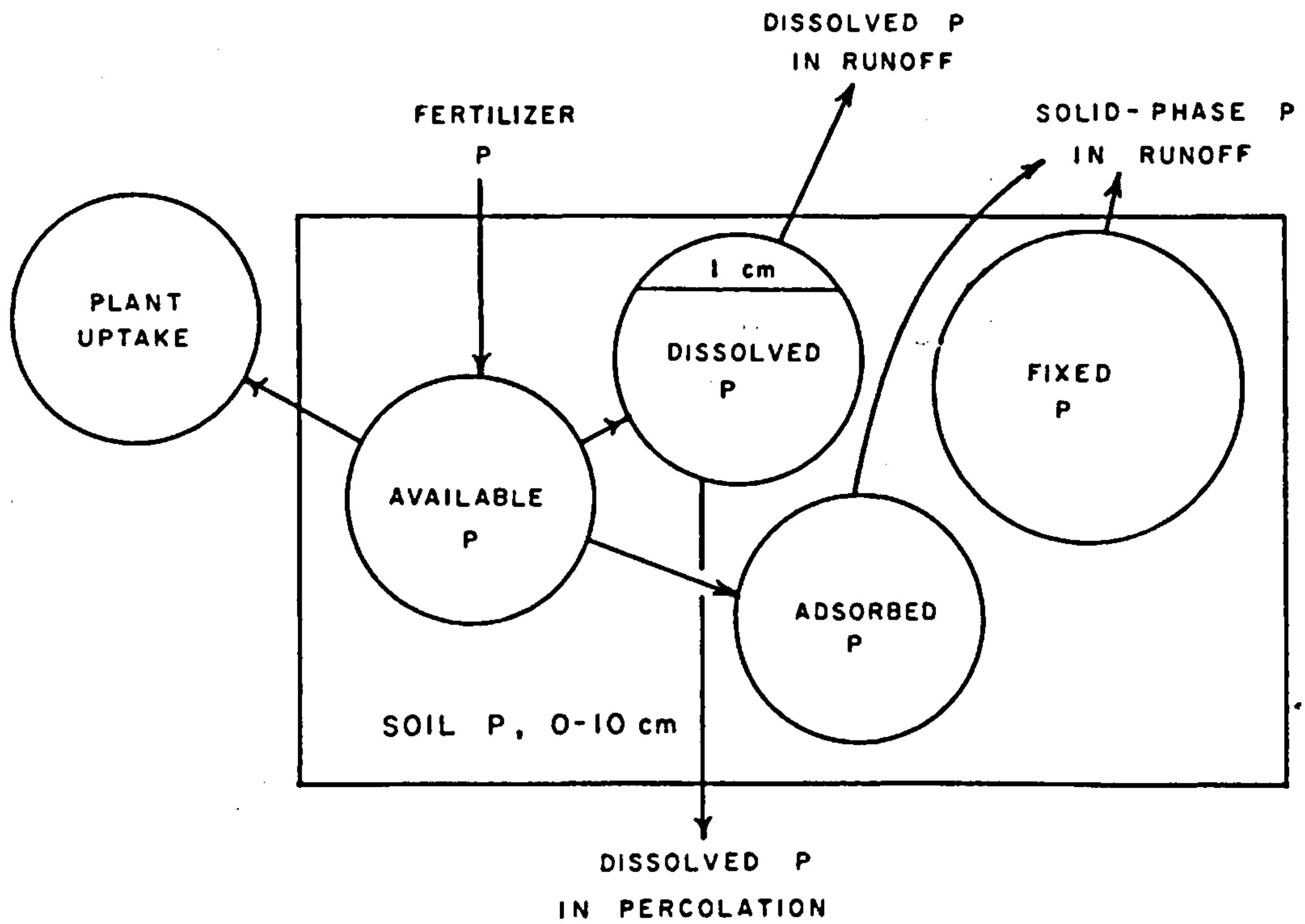

Figure 7. Soil phosphorus model

in which AP_n is available adsorbed soil phosphorus in surface soil zone (top 10 cm) at the beginning of month n, FP_n is fertilizer- and manure-available phosphorus during month n, UP_n is crop phosphorus uptake during month n, QP_n is dissolved phosphorus in runoff during month n, PP_n is dissolved phosphorus in percolation during month n, and XP_n is adsorbed available phosphorus in runoff during month n; all variables are expressed in kg ha^{-1}.

2.4.1 *Phosphorus partitioning*

The concentration of dissolved phosphorus in the soil solution is determined by a linear equilibrium isotherm:

$$a_n = \beta d_n \tag{42}$$

in which a_n is average concentration of adsorbed available phosphorus in the soil during month n (mg kg^{-1}), d_n is average concentration of dissolved available phosphorus in the soil solution during month n (mg l^{-1}) and β is a phosphorus adsorption coefficient. The average adsorbed available phosphorus in the soil (kg ha^{-1}) during month n is

$$\overline{AP}_n = \frac{AP_n + AP_{n+1}}{2} \tag{43}$$

and hence

$$a_n = \frac{\overline{AP}_n}{\rho} \tag{44}$$

and

$$d_n = \frac{\overline{AP}_n}{\beta\rho}. \tag{45}$$

The adsorption coefficient β can be obtained from the regression equation given by Haith (1979), which has soil % clay (%C) and pH as independent variables:

$$\beta = 5.1 + 2.2(\%C) + 26.4(pH - 6)^2 \tag{46}$$

Equation 46 is based on data from Enfield & Bledsoe (1975).

2.4.2 *Crop uptake*

Crop phosphorus uptake is determined in the same fashion as nitrogen uptake. If UP is the total phosphorus uptake during the growing season (kg ha^{-1}), then uptake in month n is

$$UP_n = \frac{(PC_n - PC_{n-1})\,UP}{100} \tag{47}$$

where PC_n is given in Equation 32.

2.4.3 *Runoff and percolation losses of dissolved phosphorus*

Concentrations of dissolved phosphorus in runoff and percolation are assumed to be the same as that of the soil solution. However, as with the modelling of dissolved nitrogen losses in runoff, only the phosphorus in the top centimetre of soil is considered available for runoff losses. Hence in computing QP_n, $\overline{AP}_n$ is replaced by 0.1 $\overline{AP}_n$, and the runoff losses, converted to kg ha^{-1}, are

$$QP_n = 0.01 = \frac{\overline{AP}_n}{\beta \rho} Q_n. \tag{48}$$

All available phosphorus in the surface zone is susceptible to percolation loss, hence

$$PP_n = 0.1 \quad \frac{\overline{AP}_n}{\beta \rho} P_{1n}. \tag{49}$$

2.4.4 *Runoff losses of solid-phase phosphorus*

Solid-phase runoff losses of phosphorus consist of both adsorbed and fixed phosphorus (Figure 7). Adsorbed losses are

$$XP_n = \frac{ERPX_n \overline{AP}_n}{1000 \rho}. \tag{50}$$

A phosphorus enrichment ratio of $ERP = 2.0$ is used. Total solid-phase phosphorus losses during month n, XSP_n (kg ha^{-1}), are

$$XSP_n = \frac{ERPX_n}{1000 \rho} (\overline{AP}_n + PF) \tag{51}$$

where PF (kg ha^{-1}) is the fixed phosphorus in Zone 1.

2.4.5 *Computational sequence*

The computational sequence for available phosphorus is similar to the nitrogen computations. Equations 43, 48, 49 and 50 are substituted into Equation 41 to produce

$$AP_{n+1} = \frac{AP_n(1 - Vr/2 - Vp/2 - Sp/2) + FP_n - UP_n}{1 + Vr/2 + Vp/2 + Sp/2} \tag{41a}$$

where

$$Vr = \frac{0.01 Q_n}{\beta \rho} \tag{52}$$

$$Vp = \frac{0.1 P_{1n}}{\beta \rho} \tag{53}$$

and

$$Sp = \frac{ERPX_n}{1000 \rho}. \tag{54}$$

Subsequently, $\overline{AP}_n$ is determined from Equation 43 and runoff and percolation losses are given by Equation 48, 49 and 51.

3 Input data for the CNS model

The CNS model relies on standardized input data that in principle are available from secondary sources and/or physical measurements of the actual field which is modelled. This chapter includes descriptions of the necessary model inputs and discussions of data sources. The inputs are summarized in Table 1 in five major groups.

3.1 Meteorologic data

Daily records of precipitation (PR_t), temperature (T_t) and storm duration (D_t) are required for the entire period to be simulated. Precipitation and temperatures are generally available as published records. Alternatively, synthetic records can be generated by the methods presented in Chapter 5. Storm duration records are much harder to obtain and generally they must be constructed from hourly precipitation data. The computer program given in Appendix B provides the option of performing calculations for only water movement and dissolved nutrient losses. Under this option, erosion is not computed and hence storm durations are not needed.

The evapotranspiration parameters DH_t and e_{st} can be obtained from standard references (e.g. Veihmeyer (1964) and Petterssen (1964)).

Daylight hours are a function of latitude: they are based on the yearly percentage of sunshine during each month at a particular latitude. Saturated vapor pressure (e_{st}) is a function of temperature. The sample input data given in Appendix B includes values of e_{st} for values of T_t ranging from 0 to 40 °C.

Table 1. CNS model inputs.

Parameters or data	Description
Meteorologic data	
D_t	storm duration, day t (h)
DH_t	daylight hours, day t (h)
e_{st}	saturated vapor pressure, day t (mb)
PR_t	precipitation, day t (cm)
T_t	mean air temperature, day t (°C)
Physical parameters	
A	field area (ha)
$\%C$	% clay (particles $\leq$ 0.002 mm) in Zone 1
ρ	soil bulk density, Zone 1 (g cm^{-3})

Table 1. continued

Parameters or data	Description
pH	soil pH, Zone 1
θ_j	available water capacity of Zone 1 (cm cm^{-1})
θ_{j0}	initial available moisture, Zone j (cm cm^{-1})
Nutrient parameters	
AP_0	initial available phosphorus in Zone 1 (kg ha^{-1})
ER_N	nitrogen enrichment ratio (ratio of sediment nitrogen content to soil nitrogen content)
ER_P	phosphorus enrichment ratio (ratio of sediment phosphorus content to soil phosphorus content)
FN_n	fertilizer and manure inorganic nitrogen application in month n (kg ha^{-1})
FP_n	fertilizer- and manure-available phosphorus applications in month n (kg ha^{-1})
I_{j0}	initial inorganic nitrogen in Zone j (kg ha^{-1})
ML_n	addition of labile organic nitrogen to Zone 1 in month n (kg ha^{-1})
MO_0	initial labile organic nitrogen in Zone 1 (kg ha^{-1})
O_0	initial stable organic nitrogen in Zone 1 (kg ha^{-1})
PF	fixed (non-adsorbed) phosphorus in Zone 1 (kg ha^{-1})
RN_n	inorganic nitrogen input from precipitation (kg ha^{-1})
UN	total crop nitrogen uptake (kg ha^{-1})
UP	total crop phosphorus uptake (kg ha^{-1})
Cropping dates	
t_p	day on which the soil surface is prepared for planting
t_e	day of crop emergence
t_f	day on which crop reaches full (100%) canopy cover of soil surface
t_m	day of crop maturity
t_h	day of crop harvest
t_n	day on which month n ends
Runoff and soil loss parameters	
C_t	cover factor on day t
CN_{I}, CN_{II}, CN_{III}	runoff curve numbers for antecedent moisture conditions I, II, III
K	soil erodibility
LS	topographic (length/slope) factor
P	supporting practice factor

3.2 Physical parameters

Field physical parameters are given by measurements or estimates of the relevant characteristics for the field being modelled. Soil properties can also be obtained from published soil surveys. Initial soil moistures (θ_{j0}) are required to begin the simulation. In the absence of direct meaurements, knowledge of typical moisture levels may be necessary. For example, in humid regions it is often reasonable to assume that soil moisture is at available water capacity during the winter months.

3.3 Nutrient parameters

Initial values for soil available phosphorus (AP_0), fixed phosphorus (PF) and stable organic nitrogen (O_0) are determined from soil samples or published surveys. The latter two nutrient forms can be approximated by total soil phosphorus and nitrogen, respectively, since most soil phosphorus is fixed and most soil nitrogen is in the stable organic form. Initial inorganic and labile organic nitrogen can be based on sampling or general knowledge of soil conditions. Alternatively, they can be detemined by long-term runs of the CNS model.

Fertilizer inputs (FN_n, FP_n) are general management variables which depend on cropping practices. crop nutrient uptakes can be estimated by multiplying crop yields by nutrient contents. Since the CNS model does not contain a crop growth model, average yields must be used in these determinations. Labile organic nitrogen additions (ML_n) will consist of manure or other waste applications plus crop residues following harvest.

Enrichment ratios are model inputs, but all applications of the CNS model to date have used $ER_N = 2.5$ and $ER_P = 2.0$. The CNS program given in Appendix B accepts an average nitrogen concentration in precipitation as input. Thus, the inorganic nitrogen load from precipitation (RN_n) is calculated internally by multiplying the concentration by precipitation.

3.4 Cropping dates

The five cropping dates are used for cover, nutrient, runoff, and soil-loss computations. When past conditions are modelled, the observed dates of the relevant cropping activities are used. For long-term simulations, average or typical dates must be used.

3.5 Runoff and soil-loss parameters

Detailed procedures for selection of the erosion parameters K, LS, P and C_t are given by Wischmeier & Smith (1978), but the general guidelines given in the following discussion may also be used.

The topographic factor LS can be computed directly from slope length λ (m) and angle α (Wischmeier & Smith, 1978):

$$LS = (\lambda/22.1)^b(65.41 \sin^2\alpha + 4.56 \sin\alpha + 0.065) \qquad (55)$$

The constant b is 0.5 for slopes of 5% or more, 0.4 for 3–5% slopes, 0.3 for

1–3% slopes, and 0.2 for slopes of less than 1%. The equation is considered valid for slope lengths of up to 300 m, although it was derived mainly using data from slope lengths of 100 m or less.

The practice factor P is equal to 1.0 in the absence of soil conservation practices such as terraces or contours. Values of P for these practices from Stewart et al. (1975) are given in Table 2. Representative values of K (soil erodibility) for use in soil-loss computations are given in Table 3 (Stewart et al., 1975).

Cover factor is a general measure of the degree to which the soil surface is protected by plant and residue cover. Wischmeier & Smith (1978) provide a detailed table of C_t as a function of crop rotation and residue management. As a first approximation, C_t is given by one minus the fraction of the soil surface protected by cover. Thus, in the absence of residues, $C_t \simeq 1 - CP_t$, where CP_t is given in Figure 3 and Equation 14.

Procedures for selecting curve numbers are given in Ogrosky & Mockus (1964) and Stewart et al. (1976). However, the suggested values are based on soils and cropping practices in the United States. In other areas, a more general procedure developed by the U.S. Bureau of Reclamation (1978) can be used. The approach is illustrated in Figure 8. Soil hydrologic group is identified by texture or saturated hydraulic conductivity. For the example in Figure 8, step 1 is identification of conductivity and step 2 selects the relevant crop. Step 3 depends on soil moisture level and leads to the curve number selection (68) by step 4. The CNS model requires three curve numbers and these can be read off Figure 8 at field capacity (CN_{III}), 50% (CN_{II}) and wilting point (CN_I). Soils can also be classified as A, B, C, D based on minimum infiltration rates, which are determined after prolonged soil wetting (Musgrave & Holtan, 1964). The appropriate limits are D: $\leq$ 0.15 cm h^{-1}; C: 15–40 cm h^{-1}; B: 0.40–0.75 cm h^{-1}; A: $\geq$ 0.75 cm h^{-1}.

Table 2. Values of supporting practice factor, P, for soil-loss computations.

Slope (%)	Practice factor	
	contouring	terracing*
1 - 2	0.60	$0.12n^{-\frac{1}{2}}$
2.1- 7	0.50	$0.10n^{-\frac{1}{2}}$
7.1–12	0.60	$0.12n^{-\frac{1}{2}}$
12.1–18	0.80	$0.16n^{-\frac{1}{2}}$
18.1–24	0.90	$0.18n^{-\frac{1}{2}}$

* n = number of terrace intervals on the field slope. These P values represent off-field sediment movement and assume 80% deposition.

Table 3. Values of soil erodibility, *K*, for three values (%) of organic matter content.

Soil texture	Soil erodibility		
	< 0.5%	2%	4%
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay	–	0.13–0.29	–

Source: Stewart et al., 1975.

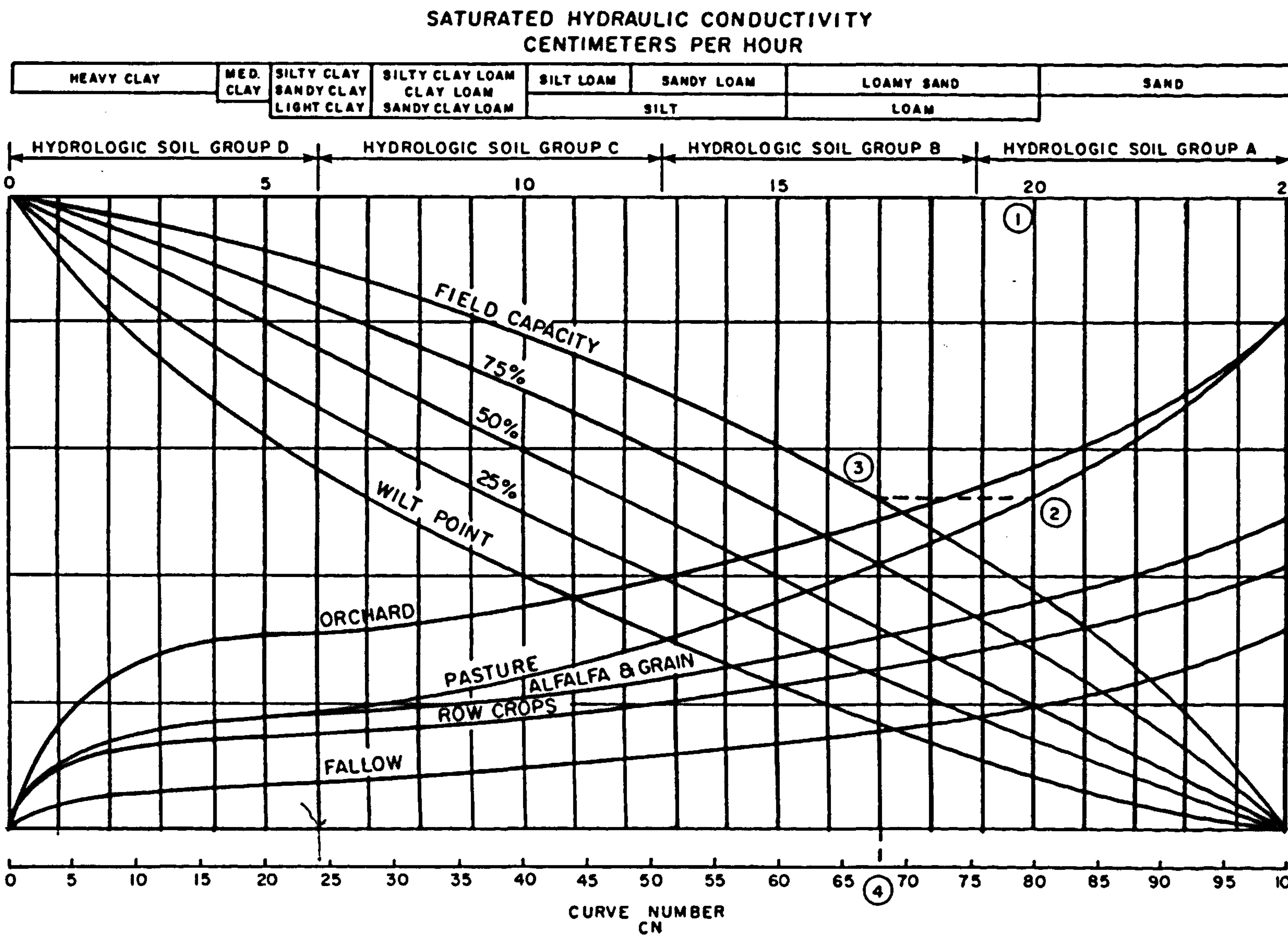

Figure 8. Bureau of Reclamation method for selection of curve number

4 Validation studies

The CNS model was tested using data collected in two previous field studies, one in Georgia and one in New York State. The Georgia sites are two small fields in Watkinsville, GA, that were monitored for runoff, sediment and nutrient loss in runoff from May 1974 to September 1975. Percolation data were not collected. The two fields have predominantly well-drained Cecil sandy loam soil. Field P2 is 1.3 ha; no conservation practices other than cross-slope cropping were used. The second field (P4) is slightly larger (1.4 ha), is terraced and had a winter cover crop. More detailed descriptions of these fields and their associated management practices are given in Smith et al. (1978) and Langdale et al. (1979). Sampling and analytical procedures are described in Smith et al. (1978).

The New York testing sites are six 0.3 ha plots in Aurora, NY, from which runoff, percolation and nutrient-loss data were collected from January 1972 to December 1973. Sediment data were available, but deposition in interceptor collection ditches prevented determination of reliable sediment and solid-phase nutrient losses. Hence, these portions of the CNS model were not used in the New York studies. The six Aurora fields are a subset of 24 plots upon which manure was applied at rates of 35, 100 or 200 t ha^{-1} in either winter, spring or fall. The denitrification losses, which are possible at high manure application rates, are not included in the CNS model, and hence the 100 and 200 t ha^{-1} plots were not used in validations.

The Lima and Kendaia silt loam soils at Aurora are moderately to poorly drained and are characterized by a relatively impermeable glacial till at 1 m depth. This produces slow drainage and occasional high water tables, which are not adequately described in the CNS model. However, 12 of the Aurora fields are tile-drained, including six of the 35 t ha^{-1} plots. These six plots were assumed to be reasonably consistent with the assumptions of the CNS model, so they were used for model testing. Management practices, sampling and analytical techniques are described in Klausner et al. (1976a, 1976b). Drainage characteristics of the Aurora fields are also discussed by Walter et al. (1979).

4.1 Model parameters for validation runs

Although the CNS model relies on standardized input data, which are in principle available from secondary sources, the determination of model parameters often requires interpretation and judgement. For example, the assignment of curve numbers and crop-cover factors is not straightforward, even though this information is readily available in tabular form. Field conditions seldom correspond exactly with the standard descriptions given for table entries, hence as-

Table 4. Soil and field parameters for validation watersheds.

Parameter	Field		
	P2	P4	A5, A8, A15, A9, A20, A21
A, Area (ha)	1.3	1.4	0.3
ρ, bulk density (g cm^{-3})	1.4	1.4	1.3
$\overline{\theta}_j$, available water capacity (cm cm^{-1})	0.15	0.15	0.16
$\%C$, percentage clay	13	15	11.1
pH	5.8	6.1	6.7
K, soil erodibility	0.28	0.28	
(LS), topographic factor	0.31	0.27	
P, supporting practice factor	0.6	0.5	
I_{10}, initial inorganic nitrogen, zone 1 (kg ha^{-1})	0	0	0
I_{20}, initial inorganic nitrogen, zone 2 (kg ha^{-1})	5	5	10
PF, fixed phosphorus (kg ha^{-1})	260	200	

sumptions and interpolations are often necessary. The model parameters used in the validation runs are given in Tables 4–10. The following discussion outlines data sources and any assumptions required to obtain the specific values.

4.1.1 *Soil and field parameters*

Soil and field parameters are given in Tables 4 and 5. With the exception of $\overline{\theta}_j$, K and I_{j0}, all parameters for the Watkinsville fields (P2 and P4) were taken from Smith et al. (1978). The available water capacity, $\overline{\theta}_j$ was obtained from the soil survey (Soil Conservation Service, 1968), and soil erodibility, K, was

Table 5. Additional soil parameters.

Field	Stable organic nitrogen, O_0 (kg ha^{-1})	Available phosphorus, AP_0 (kg ha^{-1})
P2	490	40
P4	670	30
A5	3770	28
A8	2280	30
A15	2830	13
A9	2750	5
A20	2150	9
A21	2120	7

taken from Barnett (1977). Bulk density, ρ, is the value at 15 cm, and the (LS) and P factors for the USLE are computed based on field slopes and slope lengths.

For the Aurora fields, ρ, $\bar{\theta}_j$, $\%C$ and pH are obtained from soil survey values (Soil Conservation Service, 1971). Stable organic nitrogen (O_0) and available phosphorus (AP_0) data were provided by S. D. Klausner, Department of Agronomy, Cornell University. Soil-loss factors were not determined for Aurora since no testing was done to establish sediment and solid-phase nutrient losses for these fields.

Initial values of soil inorganic nitrogen (I_{j0}) were not based on field measurements. For both locations, the model was run from 1 January: the soil contains relatively little inorganic nitrogen at that time. The values of I_{j0} given in Table 4 are based on values obtained by long-term (10–25 year) CNS model runs. Hence they are roughly equivalent to long-term average or steady-state values. Initial values of labile organic nitrogen (MO_0) were set at zero, and initial soil moisture levels (θ_{j0}) were assumed to be at available water capacity for both zones.

4.1.2 *Nutrient applications and crop uptakes*

Nutrient applications and crop uptakes are given in Tables 6 and 7. Applications of nutrients were obtained directly from Smith et al. (1978) or Klausner et al. (1976a). At Aurora it was assumed, based on studies by Lauer et al. (1976), that 85% of manure ammonia-nitrogen would volatilize shortly after application, hence the inorganic nitrogen application listed in Tables 6 and 7 include only 15% of the manure ammonia-nitrogen. Available phosphorus in manure was assumed equal to the dissolved phosphorus content. Crop nutrient uptakes at Watkinsville were estimated from yields given in Smith et al. (1978); Aurora values were obtained directly from Klausner et al. (1976a).

Labile organic nitrogen additions are from plant residues (corn stover) on P2 and P4 and from manure on A5, A8, A15, A9, A20 and A21.

Table 6. Nutrient applications and crop uptakes in first year [a].

Field	Applications [b] (kg ha^{-1})		Labile organic nitrogen	Crop [c] uptake (kg ha^{-1})	
	inorganic nitrogen	available phosphorus		nitrogen	phosphorus
P2	38(5) 100(6)	33(5)	18(10)	79	17
P4	38(5) 107(6)	33(5)	21(10)	11 Rye 94 Corn	3 20
A5	9(5) 25(6)	13(5) 11(6)	144(5)	73	15
A8	34(6)	20(6)	112(6)	73	15
A15	3(2)	14(2)	133(2)	73	15

Table 6. continued

Field	Applications[b] (kg ha^{-1})		Labile organic nitrogen	Crop[c] uptake (kg ha^{-1})	
	inorganic nitrogen	available phosphorus		nitrogen	phosphorus
	25(6)	11(6)			
A9	8(5)	13(5)	132(5)	73	15
	25(6)	11(6)			
A20	33(6)	20(6)	142(6)	73	15
A21	4(2)	13(2)	120(2)	73	15
	25(6)	11(6)			

[a] 1974 for P2 and P4; 1972 for remainder.
[b] Numbers in parentheses indicate the month of application in first year.
[c] Corn (maize) and rye on P4. All others corn.

Table 7. Nutrient applications and crop uptakes in second year[a].

Field	Applications[b] (kg ha^{-1})		Labile organic nitrogen	Crop[c] uptake (kg ha^{-1})	
	inorganic nitrogen	available phosphorus		nitrogen	phosphorus
P2	22(4)	31(4)	20(10)	101	21
	112(7)				
P4	22(4)	21(4)	17(10)	11 Rye	3
	112(7)			95 Corn	19
A5	2(4)	28(4)	158(4)	84	17
	25(6)	11(6)			
A8	27(6)	37(6)	170(6)	84	17
A15	4(1)	19(1)	132(1)	84	17
	25(6)	11(6)			
A9	2(4)	25(4)	153(4)	84	17
	25(6)	11(6)			
A20	27(6)	35(6)	156(6)	84	17
A21	5(1)	16(1)	145(1)	84	17
	25(6)	11(6)			

[a] 1975 for P2 and P4; 1973 for remainder.
[b] Numbers in parentheses indicate the month of application in second year.
[c] Corn (maize) and rye on P4. All others corn.

4.1.3 *Cropping dates, curve numbers and cover factors*

Cropping dates, curve numbers and cover factors are given in Tables 8–10. The cropping sequences given in the tables are based on ploughing, planting and harvesting dates given in Klausner et al. (1976a) and Smith et al. (1978). In addition, Smith et al. (1978) provided some data on canopy development. However, the estimated crop emergence, full (100%) canopy and maturity dates are guesses based on typical values for the two regions. Cover factors are linked to canopy development and were taken from Wischmeier & Smith (1978).

The CNS model is very sensitive to curve numbers and attempts were made to make the selections as objective as possible. In both locations, fallow curve numbers were used from the ploughing stage to that of 10% canopy. The only fields with a history of organic matter build-up were A9, A20 and A21 at Aurora, and these were considered to have 'good' hydrologic conditions. The remaining five fields were all 'poor'. The Watkinsville soil is in hydrologic group B. At Aurora the groups change from plot to plot: Plots A5 and A9 are predominantly Kendaia (Group C); Lima (Group B) is the major soil on A8, A15, A20, A21 (Jones and Zwerman, 1972). However, tile drainage changes these groupings artificially, increasing drainage and reducing runoff. Each field was thus assigned to the next lower runoff group: B for A5 and A9; and A for A8, A15, A20 and A21.

Table 8. Cropping dates, curve numbers and cover factors for watershed P2.

Crop	Date	Crop stage	Percentage canopy	Curve number, CN_{II}	Cover factor, C_t
None	1/1/74		0	79	0.36
	4/25/74	plough	0	86	0.61
Corn	5/3/74	emergence	0	86	0.61
			10	79	0.51
			50	79	0.42
			80	79	0.26
	7/1/74		100	79	0.26
	9/1/74	mature	100	79	0.26
	9/16/74	harvest	0	79	0.36
None	4/24/75	plough	0	86	0.36
Corn	6/1/75	emergence	0	86	0.36
			10	79	0.32
			50	79	0.29
			80	79	0.20
	7/1/75		100	79	0.20
	9/1/75	mature	100	79	0.20
	10/3/75	harvest	0	79	0.30

Table 9. Cropping dates, curve numbers and cover factors for watershed P4.

Crop	Date	Crop stage	Percentage canopy	Curve number, CN_{II}	Cover factor, C_t
Rye	1/1/74		100	72	0.05
	2/20/74	mature	100	72	0.05
	3/24/74	harvest	0	72	0.46
	4/23/74	plough	0	86	0.46
Corn	5/3/74	emergence	0	86	0.46
			10	74	0.42
			50	74	0.38
			80	74	0.22
	7/1/74		100	74	0.22
	9/1/74	mature	100	74	0.22
	9/16/74	harvest	0	74	0.47
Rye	11/2/74	emergence	0	74	0.47
			10	72	0.30
			50	72	0.15
			80	72	0.05
	12/1/74		100	72	0.05
	1/21/75	mature	100	72	0.05
	4/15/75	harvest	0	72	0.36
	4/24/75	plough	0	86	0.36
Corn	5/24/75	emergence	0	86	0.36
			10	74	0.32
			50	74	0.29
			80	74	0.20
	7/1/75		100	74	0.20
	9/1/75	mature	100	74	0.20
	9/16/75	harvest	0	74	0.45

Table 10. Cropping dates and curve numbers for Aurora watersheds.

Date	Stage	Percentage canopy	Curve Numbers, CN_{II}					
			A5	A8	A15	A9	A20	A21
1/1/72		0	86	77	77	78	67	67
5/23/72	ploughing (A9, A20, A21)	0	86	77	77	86	77	77
6/19/72	emergence	0	86	77	77	86	77	77
		10	81	72	72	78	67	67
8/17/72		100	81	72	72	78	67	67
10/11/72	mature	100	81	72	72	78	67	67
10/26/72	harvest	0	81	72	72	78	67	67

Table 10. continued

Date	Stage	Percentage canopy	Curve Numbers, CN_{11}					
			A5	A8	A15	A9	A20	A21
10/26/72	plough (A5, A8, A15)	0	86	77	77	78	67	67
4/25/73	plough (A9, A20, A21)	0	86	77	77	86	77	77
6/12/73	emergence	0	86	77	77	86	77	77
		10	81	72	72	78	67	67
8/11/73		100	81	72	72	78	67	67
10/15/73	mature	100	81	72	72	78	67	67
10/29/73	harvest	0	81	72	72	78	67	67
10/29/73	plough (A5, A8, A15)	0	86	77	77	78	67	67

4.2 Validation results

4.2.1 Watkinsville, GA, sites

In Table 11, measured nutrient, water and sediment losses are compared with CNS model predictions for the 17-month period of May 1974 to September 1975. Precipitation during this time was 123 cm on field P2 and 97 cm on field P4. Observed losses were taken from Smith et al (1978). Runoff predictions exceed observations by substantial amounts for both fields, although errors were smaller on P4. Dissolved nitrogen and phosphorus are over-predicted by approximately the same degree as runoff on P2, indicating that errors in these predictions are more likely due to faulty hydrologic parameters than serious errors in nutrient balances. Sediment and solid-phase nutrient predictions are quite reasonable, particularly, considering the crude and somewhat arbitrary nature of the models, predictive equations and parameters for these losses.

The most critical problem is with the simulated losses of dissolved phosphorus in runoff. Although the magnitudes of these losses are of the same order as the observations, the large predicted reduction from P2 to P4 was not observed. This was the only substantial difference in losses between the two fields that was not accounted for by the model (see Table 12). The probable source of error is the absence of a source term in the CNS model for the leaching of phosphorus from plant material during the colder months. January, February and March accounted for 56% of the observed dissolved phosphorus loss from P4, which had a rye cover crop in winter. The loss for P2, which had no winter plant cover, was 29%.

Table 11. Comparison of CNS model predictions with observed runoff, sediment and nutrient losses for Georgia sites (May 1974–September 1975).

	Field P2		Field P4	
	observed	predicted	observed	predicted
Runoff (cm)	28.0	40.2	19.7	23.3
Sediment (t ha^{-1})	7.3	9.5	1.9	1.2
Dissolved nitrogen in runoff (kg ha^{-1})	3.6[a]	5.9	2.0[a]	2.4
Solid-phase nitrogen in runoff (kg ha^{-1})	9.4[b]	8.2	3.5[b]	1.4
Dissolved phosphorus in runoff (kg ha^{-1})	0.31[c]	0.46	0.34[c]	0.19
Solid-phase phosphorus in runoff (kg ha^{-1})	5.8[d]	4.5	1.6[d]	0.4

[a] NO_3 nitrogen + NH_4 nitrogen in solution.
[b] Total Kjeldahl nitrogen in sediment.
[c] PO_4 phosphorus.
[d] Total phosphorus in sediment.

Table 12. Comparison of observed and predicted variations between fields P2 and P4.

	Percentage change from P2 to P4	
	observed	predicted
Runoff	−30	−42
Sediment	−74	−87
Dissolved nitrogen in runoff	−44	−58
Solid-phase nitrogen in runoff	−63	−83
Dissolved phosphorus in runoff	+10	−59
Solid-phase phosphorus in runoff	−72	−93

4.2.2 *Aurora, NY, sites*

The six New York fields are far from ideal for model testing. Not only are the sites artificially drained, but the primary nutrient sources are manure applications. The CNS model is not well-suited for either of these characteristics. Nevertheless, the Aurora validation studies were considered essential, since the Georgia simulations provided no testing of either the percolation or snowmelt portions of the CNS model. During the two-year testing period at Aurora there was 189 cm of precipitation, 14% of which fell in June 1972, when hurricane Agnes passed over the sites. Observed and predicted losses for the six New York fields are shown in Table 13. Observed values were provided by S. D. Klausner, Department of Agronomy, Cornell University.

The percolation observations revealed another problem with these sites. Percolation was improbably high on two of the fields (A5 and A9), which suggests that water flows were not independent. For this reason, comparisons of the mean losses shown in Table 13 are more relevant than comparisons of the separate fields. On this basis, runoff and percolation predictions are relatively accurate. Predictions of dissolved nitrogen in runoff are underestimated, which indicates that more manure nitrogen was available for runoff than had been estimated for model input values. Observed dissolved-phosphorus losses were nearly an order of magnitude greater than the predictions. The CNS model assumes that manure-available phosphorus can be described by the same equilibrium relationships as phosphorus in the soil. The assumption appears to be untenable. The overestimation of predicted dissolved nitrogen in percolation is not as serious as it may appear. Measured nitrogen losses are based on tile drainage at 100 cm depths, while predicted values are for percolation from the top 30 cm of soil. Additional nitrogen losses due to plant uptake and denitrification are likely in the downward movement of nitrogen to the 100 cm depth. Also, this movement is not instantaneous, and substantial amounts of inorganic nitrogen remain in the soil between 30 and 100 cm.

Table 13. Comparison of CNS model predictions with observed runoff, percolation and dissolved nutrient losses for New York sites (January 1972–December 1973).

Field	Runoff (cm)		Percolation (cm)		Dissolved nitrogen in runoff ($kg\ ha^{-1}$)		Dissolved phosphorus in runoff ($kg\ ha^{-1}$)		Dissolved nitrogen in percolation ($kg\ ha^{-1}$)	
	observed	predicted	observed	predicted	observed	predicted	observed	predicted	observed	predicted
A5	25.4	35.6	166.9	64.9	8.0	6.0	0.63	0.26	118.2	124.8
A8	7.9	17.6	21.1	82.8	0.9	1.3	0.45	0.10	27.2	75.4
A15	15.5	17.6	24.9	82.8	7.0	1.9	1.43	0.07	29.8	105.5
A9	15.3	24.7	145.0	76.1	3.1	2.9	0.24	0.08	120.8	96.9
A20	23.5	10.6	53.0	89.8	12.6	0.8	1.17	0.02	49.6	79.0
A21	8.3	10.6	85.0	89.8	5.1	0.9	0.95	0.03	111.2	79.4
Mean	16.0	19.5	82.7	81.0	6.1	2.3	0.81	0.09	76.1	93.5

4.2.3 Validation summary

The credibility of a mathematical simulation model is largely subjective. No model is a complete picture of reality. Rather, models are sets of hypotheses concerning the fundamental aspects of physical and biochemical phenomena. Given the unavoidable errors in data collection and analyses, as well as the judgement required in estimating model parameters, models cannot be proven to be correct. However comparison of model predictions with field measurements can provide some indication of consistency and accuracy. Based on these validation studies, the CNS model appears to be a reasonable means of estimating nutrient losses from croplands. It accounts for differences in crop, soil and weather characteristics and reflects the impacts of management practices such as runoff and erosion control and fertilizer applications. However, the model is not a satisfactory means for estimating the effects of manure maanagement. Neither is it useful in comparing dissolved phosphorus losses from fields with substantially different plant covers.

5 Generation of synthetic weather records

Simulation models of nonpoint-source pollution require weather input data. These data include continuous records of precipitation, temperature, and, depending on the simulation model, meteorologic variables related to evaporation and snowmelt. Modelling applications are often based on relatively short weather records. Nonpoint-source pollution is an inherently random phenomenon, and reliance on records has shortcomings. Rational evaluation of nonpoint sources should include estimates of the probabilities associated with pollution loads, and weather records may cover too short a period for the long-term simulations needed to provide reliable estimates. In these cases synthetic weather sequences, which are consistent with historical data, can be used as simulation inputs.

This chapter presents an evaluation of several simple weather-generating schemes for use in nonpoint-source pollution studies. Three basic weather models of daily precipitation and temperature are proposed and compared. Model 1 is a simple approach requiring only secondary weather data (monthly precipitation and temperature means) to determine model parameters. Model 2 is similar, but requires one additional precipitation parameter. Model 3 is a more elaborate scheme that requires analysis of primary data. This last model contains parameters that are not generally summarized in weather publications, so weather records must be analyzed to extract the necessary information.

The three models are evaluated by two types of comparisons with weather records. The first test is based on statistical comparisons between generated and historical weather sequences for three locations in the United States (Aurora, NY; Ames, IA; and Watkinsville, GA). The second and perhaps more critical test is based on outputs from the CNS model. Twenty-five and fifty year runs of the model were made using historical and generated weather sequences. The CNS model outputs of runoff, percolation and dissolved nitrogen and phosphorus losses obtained from synthetic weather inputs were statistically compared to outputs obtained with historical weather inputs.

5.1 Generating models for daily precipitation and temperature

5.1.1 Precipitation

Many models have been proposed for generating daily precipitation data. Because of the high number of zeros, the data are suitable for treatment as a discrete distribution or a mixture of discrete and continuous distributions. The structure of wet and dry days can be modeled using a Markov chain or an alternating renewal process. The alternating renewal process has been used by Green (1964) and Cole & Sheriff (1972). Since the early use of the Markov chain in stochastic precipitation modelling by Gabriel & Neumann (1961), there have been many other applications (Weiss, 1964; Hopkins & Robillard, 1964; Wiser, 1966; Feyerherm & Bark, 1967; Jones et al., 1972; Woolhiser et al., 1973; Haan et al., 1976; Chin, 1977; Buishand, 1978; Carey & Haan, 1978; Selvalingham & Muira ,1978; Woolhiser & Pegram, 1979; Bruhn et al., 1979; and Larsen & Pense, 1982). These approaches indicate that high-order multiple-state chains are more accurate, but they require a large number of parameters. In many cases, it was found that the performance of first-order two-state chains appeared satisfactory. This approach effectively breaks the distribution into discrete (dry days) and continuous (wet days) portions where the amounts for the latter portions are modelled by a continuous distribution function.

For the continuous portion, many different distributions have been used, gamma and exponential distributions being most popular. The exponental model has a thinner tail than is often seen in daily precipitation data (Skees & Shenton, 1974; Mielke & Johnson, 1974). The latter authors introduced some generalized beta distributions of the second kind that have thicker tails and have closed-form distributions. Other researchers have used the mixed exponential (Woolhiser & Pegram, 1979) to achieve this.

Assuming that a first-order Markov chain adequately describes wet and dry day occurrences, conditional precipitation probabilities are given by

$$P_m(R_i \leqslant r_i | r_{i-1} = 0) = P_m(D_i | D_{i-1}) + P_m(W_i | D_{i-1}) \cdot F_m(r_i) \qquad (56)$$

and

$$P_m(R_i \leqslant r_i | r_{i-1} > 0) = P_m(D_i | W_{i-1}) + P_m(W_i | W_{i-1}) \cdot F_m(r_i). \qquad (56)$$

In these equations R_i is measurable precipitation (in cm) on day i and r_i is a particular value of R_i. Dry and wet days are indicated by D_i and W_i, respectively. Conditional events, such as the occurrence of a dry day on day i given that the previous day was dry, are indicated by $(D_i | D_{i-1})$. A wet day is defined as a day with precipitation exceeding the measurement threshold. The conditional probabilities $P_m(\cdot)$ are for period m and $F_m(r_i)$ is the distribution function for R_i in period m.

The conditional probabilities on the right side of Equations 56 and 57 can be computed from primary data (precipitation records) or determined from a general regression equation proposed by Hershfield (1970):

$$P(D_i | D_{i-1}) = 0.1718 + 0.8462[1 - P(W_i)] \qquad (58)$$

for $0.0213 \leq P(W_i) \leq 1.0$

where $P(W_i)$ is the unconditional probability of a wet day. The equation has a correlation coefficient of 0.991. The conditional probability $P(D_i | W_{i-1})$ can be computed from $P(D_i | D_{i-1})$ using the equation

$$P(D_i) = 1 - P(W_i) = P(D_{i-1})\,P(D_i | D_{i-1}) + P(W_{i-1})\,P(D_i | W_{i-1}). \tag{59}$$

Since $P(W_i) = P(W_{i-1})$ and $P(D_i) = P(D_{i-1})$, the equation can be rearrranged to give

$$P(D_i | W_{i-1}) = \frac{[1 - P)(W_i)]\,[1 - P(D_i | D_{i-1})]}{P(W_i)}. \tag{60}$$

Replacing the probabilities $P(\cdot)$ with their period counterparts $P_m(\cdot)$ produces the required conditional probabilities for Equations 56 and 57.

Three marginal distributions for precipitation were investigated: the exponential, beta-P and gamma distributions. The exponential distribution is given by

$$F_m(r_i) = 1 - e^{-\lambda_m r_i} \quad \text{for } r_i > 0. \tag{61}$$

Precipitation means, variances and coefficients of skew are given by $\mu_m = 1/\lambda_m$, $\sigma_m{}^2 = 1/\lambda_m{}^2$, and $\gamma_m = 2$. Thus the distribution is completely specified by precipitation means.

Since precipitation data are often more skewed than indicated by the exponential distribution, a second simple model was proposed based on a two-parameter version of the beta-P distribution described by Mielke & Johnson (1974):

$$F_m(r_i) = 1 - \left(1 - \frac{r_i}{c_m}\right)^{1/d_m} \quad \text{for } r_i > 0. \tag{62}$$

The parameter d_m is related to skew by

$$\gamma_m = \frac{2\,[(1/d_m) - 1]\,(1 + 2d_m)^{1/2}}{(1/d_m) + 1} \quad \text{for } d_m > -1/3. \tag{63}$$

Values of d_m can be selected that reflect the skew of the records. A value of $d_m = -0.1$ was used for the three locations in this study. The resulting one-parameter distribution is

$$F_m(r_i) = 1 - \left(1 - \frac{r_i}{c_m}^{-10}\right) \quad \text{for } r_i > 0 \tag{64}$$

for which $\mu_m = -(c_m/9)$, $\sigma_m{}^2 = c_m{}^2/64.8$ and $\gamma_m = 2.81$.

The third distribution used is the gamma distribution:

$$F_m(r_i) = \frac{{}_0\!\int^{r_i} \beta_m{}^{\alpha_m} r_i{}^{\alpha_m - 1} \exp(-\beta_m r_i)\, dr_i}{\Gamma(\alpha_m)} \quad \text{for } r_i > 0 \tag{65}$$

with $\mu_m = (\alpha_m/\beta_m)$, $\sigma_m{}^2 = \alpha_m/\beta_m{}^2$ and $\gamma_m = 2/(\alpha_m)^{1/2}$.

5.1.2 Temperature

Modelling of daily temperature has been attempted by a number of researchers (Jones et al., 1972; Bruhn et al., 1979; Richardson, 1981; Larsen &

Pense, 1982). In general, a lag-one Markov model in conjunction with the normal distribution is used.

Two models were investigated in this study, one of which assumes independence of temperature and precipitation:

$$T_i = \mu_{Tm} + \rho(T_{i-1} - \mu_{Tm}) + \sigma_{Tm} n_i (1 - \rho^2)^{1/2}. \quad (66)$$

In this equation T_i is the temperature (°C) on day i, μ_{Tm} and σ_{Tm} are temperature mean and standard deviation, respectively, for period m, ρ is the lag-one autocorrelation coefficient and n_i is a normally distributed random variable with zero mean and unit variance.

The only parameter readily available from secondary data sources is mean monthly temperature. A regression equation for σ_{Tm} on μ_{Tm} was developed for monthly values from the three weather records used in the study. The equation is

$$\sigma_{Tm} = 5.72 - 0.122\,\mu_{Tm} \quad \text{for } \mu_{Tm} \leq 46.9\,°\text{C}. \quad (67)$$

The correlation coefficient is 0.92. Computation of ρ gave the values of 0.664, 0.632 and 0.652 for the three records. A value of $\rho = 0.65$ was chosen as an appropriate constant to use.

The second model is based on the hypothesis that wet- and dry-day temperature populations are different. This was verified by comparing means and standard deviations of wet- and dry-day temperatures for the three study locations. Over 70% of the means were significantly different and standard deviations show 35% differences. The model is

$$T_i = \mu_{Tm}(k) + \rho(jk)[\sigma_{Tm}(k)/\sigma_{Tm}(j)]\,[T_{i-1} - \mu_{Tm}(j)] + \\ + \sigma_{Tm}(k) n_i [1 - \rho^2(jk)]^{1/2} \quad (68)$$

The indices j and k give the precipitation status (dry or wet) on days i–1 and i, respectively. This model differs from Richardson's (1981) in that the lag-one autocorrelation is conditioned on the occurrence of the precipitation sequences. Four values of ρ are used to account for the four possible lag-one sequences (*DD*, *DW*, *WD*, *WW*).

5.1.3 Testing of distributions

It should be expected that actual weather data will not conform to the simple distributions and approximations used in these models. For example, Table 14 summarizes the results of chi-squared goodness of fit tests for the three marginal precipitation distributions. The tests were applied to the records for all values of daily precipitation exceeding 0, 0.5 and 1.0 cm. Although each distribution fits poorly when all precipitation events are considered, samples limited to the higher precipitation values conform more closely to the distributions. These events are likely to be the most critical in producing nonpoint-source pollution from runoff. The two-parameter gamma distribution is in all cases superior to

Table 14. Goodness of fit tests ($P \leqslant 0.1$) for marginal precipitation distributions against weather records.

Location	Model	Number of months failing goodness of fit test		
		$r_i > 0$ cm	$r_i > 0.5$ cm	$r_i > 1.0$ cm
Aurora, NY	1. Exponential	12	12	12
	2. Beta-P	12	9	9
	3. Gamma	9	3	1
Ames, IA	1. Exponential	12	8	9
	2. Beta-P	10	5	4
	3. Gamma	6	0	0
Watkinsville, GA	1. Exponential	11	6	6
	2. Beta-P	10	5	5
	3. Gamma	4	1	1

the single-parameter exponential and beta-P distributions.

A similar evaluation was made of the normal distribution of wet- and dry-day temperatures. Tests were made to determine if the 72 samples sets (wet and dry days for 12 months at 3 locations) exhibited significant skewness or kurtosis. The method outlined in Snedecor & Cochran (1967) was used. In all, 35 out of 72 distributions have skewness significantly different from zero. Only one deviation is in excess of the value 1. Analysis of the kurtosis data shows that 36 out of 72 distributions have significant kurtosis. The maximum deviation from the expected kurtosis for the normal distribution was 2. Deviations were equally distributed between summer and winter months, wet and dry days, and positive and negative differences.

A binomal distribution was used to test the differences between conditional dry-day probabilities calculated from Equations 58 and 60, and those determined from the historic data. Of the computed probabilities, only eight were significantly (at 1%, 5% or 10% levels) different from observed probabilities.

5.1.4 Model summaries

The equations for precipitation and temperature were combined into three generating models for daily precipitation and temperature:

Model 1 (exponential precipitation, normal temperature): Equations 56, 57, 58, 60, 61, 66 and 67.

Model 2 (beta precipitation, normal temperature): Equations 56, 57, 58, 60, 64, 66 and 67.

Model 3 (gamma precipitation, normal temperature dependent on precipitation): Equations 56, 57, 65 and 68.

Models 1 and 2 are implemented using monthly mean precipitation and temperatures from secondary sources provided the general relationships for skew, temperature correlation and standard deviations are accepted. Parameters for Model 3 are obtained from analysis of primary data, i.e. records of daily precipitation and temperature. Unlike Models 1 and 2 for which the period m is monthly, Model 3 uses a two-week period.

5.2 Comparisons of generated weather sequences

For comparison of generated and historic sequences, 50 years of meteorologic data were generated by all three models. Use of multiple runs was considered unnecessary, since there is low annual autocorrelation in the historic precipitation and temperature data. The generation programs used the GGUBS and GGAMS algorithms from the IMS library of subroutines for the generation of random numbers and gamma variates, respectively. For the generation of normal variables, a simple approximation described by Ramberg & Schmeiser (1972) was used. The equation

$$n = \frac{p^{0.135} - (1-p)^{0.135}}{0.1975} \tag{69}$$

where p is a uniform random variable between 0 and 1, standard normal variables (mean = 0, variance = 1) produces with an error of less than 0.5% for $0 \leq p \leq 0.9975$.

Statistics of the 50-year sequences were compared with those obtained from 25-year weather records for Aurora, NY, Ames, IA and Watkinsville, GA.

5.2.1 Precipitation

Table 15 summarizes comparisons between several statistics of the generated and historical precipitation sequences. A statistic can be said to be 'preserved' when there is no significant difference between the historical and generated values. Tests were based on the assumption that differences between generated and historic moments are normally distributed. All three models do poorly at preserving skewness; Models 1 and 2 do not preserve standard deviations for most months. Means are not included in Table 15 since they are preserved by all models. In addition to the tests of standard deviation and skew coefficients, comparisons were made for mean monthly precipitation and probability distributions of wet and dry periods (numbers of consecutive wet or dry days) for each month. None of the 36 monthly means showed significant differences between generated and historical values for any model. The comparisons of wet and dry periods involved the comparison of 144 distributions, 36 dry and 36 wet for Models 1 and 2 and identical numbers for Model 3 (Models 1 and 2 use the same conditional probabilities). Only three of the generated distributions differed (two at the 5% level, and one at the 1% level) from their historical counterparts.

Table 15. Comparison of precipitation moments for generated sequences against historical sequences.

Precipitation moments	Aurora, NY			Ames, IA			Watkinsville, GA		
Model:	1	2	3	1	2	3	1	2	3
Standard deviations of wet-day precipitation									
Number of months without significant differences [a] from historic sequences	2	2	12	1	6	11	5	7	11
Average absolute difference between generated and historical moments (%)	32	25	5	28	17	7	24	14	5
Coefficient of skew of wet-day precipitation									
Number of months without significant differences[a] from historic sequences	1	2	3	2	4	2	4	2	2
Average absolute difference between generated and historical moments (%)	36	14	8	24	12	12	28	7	5

[a] At $P \leqslant 0.01$, $P \leqslant 0.05$ or $P \leqslant 0.10$.

All three precipitation models capture the general characteristics of the weather records (means, wet and dry periods). In addition, Model 3, which is based on a gamma distribution, preserves nearly all standard deviations of daily precipitation and has relatively small skewness errors. Model 1, based on the exponential distribution, is the least accurate model, with errors of up to 36%.

5.2.2 Temperature

Models 1 and 2 both used Equation 66 to generate daily temperatures; no distinction was made between wet and dry days. Model 3 is based on the more elaborate Equation 68, which considers precipitation sequences. Table 16 indicates the differences in the average monthly temperature means and standard deviations obtained from the generated and historical sequences. Tests were based on the same normality assumption used for precipitation testing (Section 5.2.1). As expected, Model 3 produced smaller differences. None of the monthly means produced by Model 3 were significantly different from historical means, but six of the 36 dry-day standard deviations were significant at the 1% or 5%

Table 16. Absolute percentage difference between average monthly generated- and historic-temperature moments.

	Wet days		Dry days	
	Models 1 & 2	Model 3	Models 1 & 2	Model 3
Means				
Aurora, NY	4	<1	5	<1
Ames, IA	38	1	22	3
Watkinsville, GA	16	<1	8	<1
Standard Deviations				
Aurora, NY	1	2	4	4
Ames, IA	8	1	2	2
Watkinsville, GA	19	2	7	2

level. Somewhat surprisingly, Models 1 and 2 produced 12, 25, 18 and 21 nonsignificant differences (each from a possible 36) for monthly wet-day means, dry-day means, wet-day standard deviations and dry-day standard deviations, respectively.

5.3 Operational testing of weather models

The statistical tests described in the previous section indicate the degree to which the three weather generating models produce sequences that are statistically consistent with historical weather data. As might be expected with these simple models, the results were mixed. Certain characteristics of the historical data were preserved in the generated sequences, but others were not. The only general conclusion appears to be that Model 3 is superior to Models 1 and 2.

The comparison of generated and historical weather sequences cannot test the operational validity of a weather model. Rather, it is necessary *to evaluate the value of a model for its intended purpose.* In the present case, generated sequences are proposed as inputs to simulation models of nonpoint-source pollution. Thus more relevant tests are based on the effects of model selection on pollution predictions.

The 50-year generated sequences of daily precipitation and temperature for each model and location were used as inputs to the CNS model. The 25-year records were also used in comparable simulations.

The purpose of long-term simulations in nonpoint-source studies is to provide more reliable estimates of pollutant loadings than can be obtained from short-term analyses and to estimate the probabilities associated with various loadings. Plans for control of nutrients in surface and ground waters are usually based on annual loadings. Operational testing involved comparisons of annual runoff, percolation and losses of dissolved nitrogen in runoff and percolation and dissolved phosphorus in runoff from identical five-hectare fields under a continuous corn cropping in a moderately well-drained soil. Both probability distributions of annual water and nutrient fluxes and mean annual fluxes were used for these comparisons.

Probability distributions of fluxes produced by historical and generated weather inputs were compared using the Smirnov statistic as given in Conover (1971). Table 17 shows the results of these tests. Eight of the 45 distributions were significantly different at the 5% or 1% levels from their counterparts produced from historical records. All of the significantly different distributions were produced from Models 1 and 2.

Mean annual fluxes are compared in Table 18 using the Mann-Whitney test. Five of the 45 means produced from generated weather inputs were significantly different than those produced from historical weather inputs. Four of these means were associated with percolation means produced by Models 1 and 2. The maximum difference in percolation means is 13%. The only other significant variation is a 20% difference in dissolved nitrogen in runoff associated with Model 1.

The operational testing of the three weather-generating models revealed relatively few differences between CNS model outputs produced from historical and

Table 17. Comparison of probability distributions of annual water and nutrient fluxes against historical records using the Smirnov statistic.

CNS output	Weather model	Aurora, NY	Ames, IA	Watkinsville, GA
Runoff (cm)	1	*[a]		
	2			
	3			
Percolation (cm)	1		*	*
	2		*	*
	3			
Dissolved nitrogen in runoff (kg ha^{-1})	1			**
	2			*
	3			
Dissolved phosphorus in runoff (kg ha^{-1})	1	*		
	2			
	3			
Dissolved nitrogen in percolation (kg ha^{-1})	1			
	2			
	3			

[a] *Significant $P \leqslant 0.1$; ** significant $P \leqslant 0.05$; all other cases are not significant $P > 0.1$.

Table 18. Comparison using Mann-Whitney test of mean annual water and nutrient fluxes obtained from CNS model runs for historic and generated weather inputs.

CNS output	Weather input	Means		
		Aurora, NY	Ames, IA	Watkinsville, GA
Runoff (cm)	Historical	10.6	15.4	31.3
	Model 1	8.9	13.7	26.4
	Model 2	9.7	14.6	28.3
	Model 3	11.1	14.1	28.7
Percolation (cm)	Historical	34.4	30.9	52.8
	Model 1	35.1	34.8*	59.4**
	Model 2	34.8	34.4*	58.3*
	Model 3	34.5	31.5	54.3
Dissolved nitrogen in runoff ($kg\ ha^{-1}$)	Historical	1.06	1.90	1.82
	Model 1	0.99	1.79	1.45**
	Model 2	1.07	1.88	1.53
	Model 3	1.21	1.97	1.70
Dissolved phosphorus in runoff ($kg\ ha^{-1}$)	Historical	0.11	0.16	0.31
	Model 1	0.10	0.14	0.26
	Model 2	0.10	0.15	0.28
	Model 3	0.11	0.14	0.28
Dissolved nitrogen in percolation ($kg\ ha^{-1}$)	Historical	46.1	57.3	44.7
	Model 1	46.6	58.9	45.4
	Model 2	46.5	58.8	45.2
	Model 3	46.2	59.0	44.5

* Significant $P \leqslant 0.1$; ** significant $P \leqslant 0.05$.

generated weather sequences. No significant differences were observed for Model 3.

5.4 Summary

Three simple models for generating daily precipitation and temperature input sequences for the CNS model have been evaluated. All models assume a first-order Markov chain for wet- and dry-day occurrences and normal distributions for temperature. Model 1 has an exponential marginal precipitation distribution and a lag-one autocorrelation temperature model that is unrelated to precipitation. Model 2 is similar, but has a modified beta-P precipitation distribution that is adjusted to produce larger coefficients of skew than the exponential. Models 1 and 2 can in principle be used with only monthly mean precipitation and temperature data. Model 3 includes a gamma precipitation distribution and a temperature autocorrelation model dependent on precipitation. Parameters for Model 3 can only be obtained from analysis of daily weather records.

Comparison of generated and historical weather sequences for three locations indicated that none of the models consistently generated sequences that were statistically identical to historical sequences, although Model 3 performed substantially better than the other two models.

Operational testing of the three models involved comparisons of CNS model outputs produced by long-term runs using historical weather data and synthetic sequences. This testing indicated that all of the three generating models would be adequate means for producing CNS model weather input sequences.

6 Model refinements

Modelling is an iterative process. Any model can be improved, since it is only an approximate abstraction of a real physical and/or biological system. Construction of a model often leads to improved understanding of a system, and this new knowledge may point to modifications that can be made in the model. A newer model may be produced that provides even better understanding, which again leads to yet another improved model. If modelling is not an end in itself, iterations must stop at some point so that the model can be made available to potential users. The selection of a stopping point is difficult, because researchers always feel that the next iteration will produce a better model.

The CNS model is no exception to this process. The model presented in this monograph is the result of four iterations of model building and validation. The final iteration has indicated several refinements that model users may wish to consider in their applications of the CNS model. These possible modifications involve surface nutrients, soil organic nitrogen, crop growth and storm erosivities.

6.1 Surface nutrients

Since the CNS model assumes that nutrients applied to the soil surface in fertilizers and manure are well-mixed in the top 10 cm of soil (Zone 1; Figures 5 and 7, Chapter 2), runoff losses of nutrients left on the soil surface will be underestimated. As we noted in Chapter 2, the underestimation will be most severe for dissolved phosphorus. Accordingly, a useful addition to the CNS model would be a separate mass balance of available phosphorus in the top centimetre of soil. The approach would be comparable to that used by Haith (1980) in modelling pesticide runoff.

6.2 Soil organic nitrogen

Equations 24 and 25, in Chapter 2, describe mass balances for stable and labile organic nitrogen. However, they do not consider interactions between the two forms, and furthermore, since all waste and plant residue organic nitrogen is treated as labile organic nitrogen, there is no mechanisms in the CNS model to increase levels of stable soil organic nitrogen over time. Thus, the model assumes a continual depletion of soil fertility. Although this is a valid approximation for many continuous cropping situations, it does not describe crop rotations that return large quantities of plant residues to the soil.

The easiest mathematical approach to describe this phenomenon is to link the labile and stable organic nitrogen equations. For example, at the end of any year the remaining organic nitrogen in the labile supply may be added to the stable supply. Alternatively, applications of waste and plant organic nitrogen can be divided into stable and labile portions.

6.3 Crop growth

Many computations in the CNS model are based on plant behaviour. Crop cover factors are used in evapotranspiration and erosion calculations, and crop nutrient uptakes are determined from plant growth rates. Also, planting, harvesting and crop development dates are required as model inputs. The CNS model's handling of crop growth is wholly empirical, with no adjustment of plant behaviour to reflect environmental conditions.

A logical extension of the CNS model would be to include a general model of plant growth. A simple model based on moisture stress and growing season temperatures would appear to be adequate. An example model for corn is given by Lorber & Haith (1981).

6.4 Storm erosivities

The rainfall erosion equation used in the CNS model is comparable to the Universal Soil Loss Equation of Wischmeier & Smith (1978). The only difference is the replacement of rainfall erosivity with a runoff transport factor involving total and peak runoff as proposed by Williams (1975) (Equation 17, Chapter 2). Since the CNS hydrologic model has a daily time-step, a hydrograph shape must be assumed to detemine peak runoff (Figure 4). Obviously, all storm hydrographs are not identical, and the general form used in the CNS model is essentially arbitrary. Furthermore, the procedure does not always provide reasonable sediment loss predictions (Haith, 1980).

Now, it is not clear what alternative procedure should be used to compute storm sediment losses, particularly given the constraint of a daily model time-step. Perhaps the most reasonable approach is to use the general procedures based on rainfall intensity and kinetic energy suggested by Wischmeier & Smith (1978).

References

Addiscott, T. M., 1977. A simple computer model for leaching in structured soils. Journal of Soil Science 28: 554-563.

Barnett, A. P., 1977. A decade of K-factor evaluation in the southeast. In: G. R. Foster (Ed.): Soil erosion: prediction and control. Proceedings of a national conference on soil erosion, West Lafayette, Ind., USA, 1976. Soil Conservation Society of America, Ankeny, Iowa, pp. 97-104.

Brady, N. C., 1974. The nature and properties of soils (8th ed.). MacMillan, New York, N.Y.

Brown, L. R., 1981. World population growth, soil erosion and food security. Science 214: 995-1002.

Bruhn, J. A., W. E. Fry & G. W. Fick, 1979. Weather: a stochastic simulation model of daily weather. Mimeo 79-1. Department of Plant Pathology, Cornell University, Ithaca, N.Y.

Bureau of Reclamation, 1978. Drainage manual. U.S. Government Printing Office, Washington, D.C.

Buishand, T. A., 1978. Some remarks on the use of daily rainfall models. Journal of Hydrology 36(3/4): 295-308.

Carey, D. I. & C. T. Haan, 1978. Markov process for simulating daily point rainfall. Proceedings of the American Society of Civil Engineers. Journal of the Irrigation and Drainage Division, 104(IR1): 111-125.

Chin, E. H., 1977. Modeling daily precipitation occurrence process with Markov chain. Water Resources Research 13 (6): 949-956.

Cole, J. A. & J. D. F. Sherriff, 1972. Some single- and multi-site models of rainfall within discrete time increments. Journal of Hydrology 17(1/2): 97-113.

Conover, W. J., 1971. Practical nonparametric statistics. John Wiley & Sons, New York, N.Y.

Donigian, A. S., Jr., D. C. Beyerlein, H. H. Davis Jr., & N. H. Crawford, 1977. Agricultural runoff management (ARM) model version II: refinement and testing. Report EPA-600/3-77-098. U.S. Environmental Protection Agency, Athens, Ga.

Enfield, C. G. & B. E. Bledsoe, 1975. Kinetic model for orthophosphate reactions in mineral soils. Report EPA-600/2-75-022. U.S. Environmental Protection Agency, Corvallis, Oreg.

Feyerherm, A. M. & L. D. Bark, 1967. Goodness of fit of a Markov chain model for sequences of wet and dry days. Journal of Applied Meteorology 6: 700-773.

Gabriel, K. R. & J. Neumann, 1961. A Markov chain model for daily rainfall occurrence at Tel Aviv. Royal Meteorological Society 88: 90-95.

Green, J. R., 1964. A model for rainfall occurrence. Journal of the Royal Statistical Society 26 (Series B): 345-353.

Haan, C. T., D. M. Allen & J. O. Street, 1976. A Markov chain model of daily rainfall. Water Resources Research 12(3): 443-449.

Haith, D. A., 1973. Optimal control of nitrogen losses from land disposal areas. Proceedings of the American Society of Civil Engineers. Journal of the Environmental Engineering Division, 99(EE6): 923-937.

Haith, D. A., 1980. A mathematical model for estimating pesticide losses in runoff. Journal of Environmental Quality 9(3): 428-433.

Haith, D. A., 1979. Effects of soil and water conservation practices on edge-of-field nutrient losses. In: D. A. Haith & R. C. Loehr (Eds): Effectiveness of soil and water conservation practices for pollution control. Report EPA-600/3-79-106. U.S. Environmental Protection Agency, Athens, Ga pp. 72–105.

Hamon, W. R., 1961. Estimating potential evapotranspiration. Proceedings of the American Society of Civil Engineers. Journal of the Hydraulics Division, 87(HY3): 107-120.

Hershfield, D. M., 1970. A comparison of conditional and unconditional probabilities for wet- and dry-day sequences. Journal of Applied meteorology 9: 825-827.

Hopkins, J. W. & P. Robillard, 1964. Some statistics of daily rainfall occurrence for the Canadian Prairie provinces. Journal of Applied Meteorology 3: 600-602.

Jones, J. W., R. F. Colwick & E. D. Threadgill, 1972. A simulated environmental model for temperature, evaporation, rainfall and soil moisture. Transactions of the American Society of Agricultural Engineers 15: 366-372.

Jones, G. D. & P. J. Zwerman, 1972. Rates and timing of nitrogen fertilization in relation to nitrate-nitrogen outputs and concentrations in the water from interceptor tile drains. College of Agriculture and Life Sciences, Cornell University, Ithaca, N.Y. Search Agriculture 2(6).

Klausner, S. D., P. J. Zwerman & D. R. Coote, 1976a. Design parameters for the land application of dairy manure. Report EPA-600/2-76-187. U.S. Environmental Protection Agency, Athens, Ga.

Klausner, S. D., P. J. Zwerman & D. F. Ellis, 1976b. Nitrogen and phosphorus losses from winter disposal of dairy manure. Journal of Environmental Quality 5(1): 47-49.

Knisel, W. G. (Ed.), 1980. CREAMS: a field scale model for chemicals, runoff and erosion from agricultural management systems. Conservation Research Report 26. Science and Education Administration, U.S. Department of Agriculture, Washington, D.C.

Langdale, G. W., R. A. Leonard, W. G. Fleming & W. A. Jackson, 1979. Nitrogen and chloride movement in small upland Piedmont watersheds. Journal of Environmental Quality 8(1): 49-57.

Larsen, G. A. & R. B. Pense, 1982. Stochastic simulation of climatic data for agronomic models. Agronomy Journal 74: 510-514.

Lauer, D. A., D. R. Bouldin & S. D. Klausner, 1976. Ammonia volatilization from dairy manure spread on the soil surface. Journal of Environmental Quality 5(2): 134-141.

Lorber, M. & D. A. Haith, 1981. A corn yield model for operational planning and management. Transactions of the American Society of Agricultural Engineers 24(6): 1520-1525.

Meilke, P. W., Jr. & E. S. Johnson, 1974. Some generalized beta distributions of the second kind having desirable application features in hydrology and meteorology. Water Resources Research 10(2): 223-226.

Musgrave, G. W. & H. N. Holtan, 1964. Infiltration. In: V. T. Chow (Ed.): Handbook of applied hydrology. McGraw-Hill, New York, N.Y. Chapter 12.

Ogrosky, H. O. & V. Mockus, 1964. Hydrology of agricultural lands. In: V. T. Chow (Ed.): Handbook of applied hydrology. McGraw-Hill, New York, N.Y., Chapter 21.

Petterssen, S. 1964. Meteorology. In: V. T. Chow (Ed.): Handbook of applied hydrology. McGraw-Hill, New York, N.Y. Chapter 3.

Ramberg, J. S. & B. W. Schmeiser, 1972. An approximate method for generating symmetric random variables. Communications of the Association of Computing Machinery 15(11): 987-990.

Richardson, C. W., 1981. Stochastic generation of daily precipitation, temperature, and solar radiation. Water Resources Research 17(1): 182-190.

Saxton, K. E., G. E. Schuman & R. E. Burwell, 1977. Modeling nitrate movement and dissipation in fertilized soils. Proceedings of the Soil Science of America 41: 265-271.

Selvalingham, S. & M. Muira, 1978. Stochastic modeling of monthly and daily rainfall. Water Resources Bulletin 14(5): 1105-1120.

Skees, P. M. & L. R. Shenton, 1974. Comments on the statistical distribution of rainfall per period under various transformations. Proceedings of the symposium on statistical hydrology, Tucson, Arizona. Miscellaneous Publication No. 1275. U.S. Department of Agriculture, Washington, D.C., pp. 172-196.

Smith, C. N., G. W. Bailey, R. A. Leonard & G. W. Langdale, 1978. Transport of agricultural chemicals from small upland Piedmont watersheds. Report EPA-600/3-78-056. U.S. Environmental Protection Agency, Athens, Ga.

Snedecor, G. W. & W. G. Cochran, 1967. Statistical methods. Iowa State University Press, Ames, Iowa.

Soil Conservation Service, 1968. Soil survey of Clarke and Oconee Counties, Georgia, U.S. Department of Agriculture, Washington, D.C.

Soil Conservation Service, 1971. Soil survey of Cayuga County, New York. U.S. Department of Agriculture, Washington, D.C.

Stanford, G. & E. Epstein, 1974. Nitrogen mineralization-water relations in soils. Proceedings of the Soil Science Society of America 38: 103-107.

Stanford, G., M. H. Frere & D. H. Schwaninger, 1973. Temperature coefficient of soil nitrogen mineralization. Soil Science 115(4): 321-323.

Steenhuis, T. S. & M. F. Walter, 1980. Closed form solution for pesticide loss in runoff water. Transactions of the American Society of Agricultural Engineers 23(3): 615-628.

Stewart, B. A., D. A. Woolhiser, W. H. Wischmeier, J. H. Caro & M. H. Frere, 1975. Control of water pollution from cropland – Vol. I. Report EPA-600/2-75-026a. U.S. Environmental Protection Agency, Washington, D.C.

Stewart, B. A., D. H. Woolhiser, W. H. Wischmeier, J. H. Caro & M. H. Frere, 1976. Control of water pollution from cropland – Vol. II. Report EPA-600/2-75-026b. U.S. Environmental Protection Agency, Washington, D.C.

Tseng, W. T. T., 1979. A system procedure for land use and water quality planning in a rural watershed. Ph.D. dissertation, Cornell University, Ithaca, N.Y. Available from University Microfilms, Ann Arbor, Mich., U.S.A.

Tubbs, L. J. & D. A. Haith, 1981. Simulation model for agricultural nonpoint source pollution. Journal of the Water Pollution Control Federation 53(9): 1425-1433.

Veihmeyer, F. J., 1964. Evapotranspiration. In: V. T. Chow (Ed.): Handbook of applied hydrology. McGraw-Hill, New York, N.Y., Chapter 11.

Walter, M. F., R. D. Black & P. J. Zwerman, 1979. Tile flow response in a layered soil. Transactions of the American Society of Agricultural Engineers 22(3): 577-581.

Weiss, L. L., 1964. Sequences of wet and dry days described by a Markov chain probability model. Monthly Weather Review 93: 511-516.

Williams, J. R. 1975. Sediment-yield prediction with universal equation using runoff energy factor. In: Present and prospective technology for predicting sediment yields and sources. report ARS-S-40. U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C., pp. 244-252.

Wischmeier, W. H. & D. D. Smith, 1978. Predicting rainfall erosion losses: a guide to conservation planning. Agricultural Handbook 537. U.S. Government Printing Office, Washington, D.C.

Wiser, E. H., 1966. Monte Carlo method applied to precipitation-frequency analyses. Transactions of the American Society of Agricultural Engineers 9: 538-542.

Woolhiser, D. A. & G. G. S. Pegram, 1979. Maximum likelihood estimation of Fourier coefficients to describe seasonal variations of parameters in stochastic daily precipitation models. Journal of Applied Meteorology 1: 34-42.

Woolhiser, D. A., E. Rovey & P. Todorovic, 1973. Temporal and spatial variation of parameters for the distribution of N-day precipitation. In: E. F. Schulz, V. A. Koelzer & K. Mahmood (Eds): Floods and droughts. Proceedings of the Second International Symposium on Hydrology. Water Resources Publication, Fort Collins, Colo., pp. 605-614.

Appendix A. CNS variables

Definitions of the major variables used in the CNS model are given in Table 19. Also listed are their corresponding symbols in the FORTRAN program, which is given in Appendix B. Variables used in intermediate steps of the model derivation, described in Chapter 2, are not shown. No symbol is assigned to model variables that are not used in the program.

Table 19. CNS model variables and corresponding program symbols.

CNS model variable	Program symbol	Description of variable
A	Area	field area (ha)
a_n	–	average concentration of adsorbed available phosphorus during month n (mg kg^{-1})
AP_n	Apn	adsorbed available phosphorus in Zone 1 at beginning of month n (kg ha^{-1})
$\overline{AP}_n$	–	average adsorbed available phosphorus in Zone 1 during month n (kg ha^{-1})
β	Beta	phosphorus adsorption coefficient (l kg^{-1})
CN_t	–	runoff curve number, day t
CN_{I}, CN_{II}, CN_{III}	Cn	runoff curve numbers for antecedent moisture conditions I, II, III
C_t	Ct	cover factor, day t
CP_t	Cpt	fraction of soil surface covered by crop canopy on day t
D_t	Da	storm duration, day t (h)
d_j	–[a]	depth of Zone j (cm): $d_1 = 10$, $d_2 = 20$
d_n	–	average concentration of dissolved available phosphorus in soil solution during month n (mg l^{-1})
DH_t	Dt	daylight hours, day t (h)
E_{jt}	–	evapotranspiration from Zone j during day t (cm)
e_{st}	Est	saturation vapour pressure, day t (mb)
ER_N	Ern	nitrogen enrichment ratio
ER^P	Erp	phosphorus enrichment ratio
EV_t	Evt	evaporation from Zone 1 during day t (cm)
Fn_n	Fnn	fertilizer and manure inorganic nitrogen applied during month n (kg ha^{-1})
FP_n	Fpn	fertilizer and manure available phosphorus applied during month n (kg ha^{-1})
I_{jn}	I1n, I2n	inorganic nitrogen in Zone j at beginning of month n (kg ha^{-1})
$\overline{I}_{jn}$	–	average inorganic nitrogen in Zone j during month n (kg ha^{-1})

CNS model variable	Program symbol	Description of variable
K	KLSP[b]	soil erodibility
K_{mn}	Kmn	fraction of potentially mineralizable organic nitrogen remaining at end of month n
L_t	–	fraction of elapsed time to full canopy
LS	KLSP[b]	erosion topographic factor
M_n	Ml	snowmelt (water equivalent) during month n (cm)
m_n	Mn	fraction of stable organic nitrogen mineralized during month n
M_t	Mt	snowmelt (water equivalent) during day t (cm)
ma_n	–	fraction of labile organic nitrogen mineralized during month n
ML_n	Moln	addition of labile organic nitrogen during month n (kg ha^{-1})
MO_n	Mann	labile organic nitrogen in Zone 1 at beginning of month n (kg ha^{-1})
$\overline{MO_n}$	–	average labile organic nitrogen in Zone 1 during month n (kg ha^{-1})
O_n	Orgn	stable organic nitrogen in Zone 1 at beginning of month n (kg ha^{-1})
$\overline{O}_n$	–	average stable organic nitrogen in Zone 1 during month n (kg ha^{-1})
P	KLSP[b]	erosion supporting practice factor
P_{jn}	P1n, P2n	percolation from Zone j during month n (cm)
P_{jt}	P1, P2	percolation from Zone j during day t (cm)
PC_n	–	percentage of crop nutrient uptake that occurs by the end of month n
PE_t	Pet	potential evapotranspiration during day t (cm)
PF	Pf	fixed phosphorus in Zone 1 (kg ha^{-1})
PN_{jn}	Pn1n, Pn2n	dissolved inorganic nitrogen in percolation from Zone j during month n (kg ha^{-1})
PP_n	Ppn	dissolved phosphorus in percolation from Zone 1 during month n (kg ha^{-1})
PR_t	Prec	precipitation during day t (cm)
Q_n	Qn	runoff during month n (cm)
Q_t	Qt	runoff during day t(cm)
QN_n	QNn	dissolved inorganic nitrogen in runoff during month n (kg ha^{-1})
QP_n	QPn	dissolved phosphorus in runoff during month n (kg ha^{-1})
R_n	Rl	rainfall during month n (cm)
R_t	Rt	rainfall during day t (cm)
RN_n	Rnn	nitrogen in precipitation during month n (kg ha^{-1})
ρ	Rho	soil bulk density, Zone 1 (g cm^{-3})
Sp	Sp	collection of variables (Equation 54)
S_t	St	snow accumulation (water equivalent) at beginning of day t (cm)

CNS model variable	Program symbol	Description of variable
S_l	Sl	collection of variables ($ER_N X_n/1000\rho$)
t_e	Demrg	Day of crop emergence
t_f	D100	day of full crop canopy
TG	Tgr1, Tgr2	crop growth factor (Equation 33)
t_h	Dharv	day of crop harvest
T_{jt}	T1t, T2t	transpiration from Zone j on day t (cm)
t_m	Dmat	day of crop maturity
t_n	Endm	day on end of month n
t_p	Ddisk	day on which soil surface is prepared for planting
T_t	Temp	temperature on day t (°C)
$\bar{\theta}_j$	Thbar1, Thbar2[a]	available water capacity of Zone j (cm cm^{-1})
θ_{jt}	Dtheta1, Dtheta2[a]	available water in Zone j at beginning of day t (cm cm^{-1})
UN	Un	total crop nitrogen uptake (kg ha^{-1})
UN_n	–	crop nitrogen uptake during month n (kg ha^{-1})
UN_{jt}	Un1n, Un2n	crop nitrogen uptake from Zone j during month n (kg ha^{-1})
UP	Up	total crop phosphorus uptake (kg ha^{-1})
UP_n	Upn	crop phosphorus uptake during month n (kg ha^{-1})
Vp	Vp	collection of variables (Equation 53)
Vr	Vr	collection of variables (Equation 52)
W_t	Wtp	runoff detention parameter for day t (cm)
$W1$	W1	collection of variables (Equation 40)
$W2$	W2	collection of variables [$P_{2n}/(P_{1n} + d_2\bar{\theta}_2)$]
X_n	Xnc	edge-of-field sediment loss during month n (t ha^{-1})
X_t	Xt	edge-of-field sediment loss during day t (t ha^{-1})
XO_n	XOn	solid-phase loss of organic nitrogen in runoff during month n (kg ha^{-1})
XP_n	–	loss of adsorbed available phosphorus in runoff during month n (kg ha^{-1})
XSP_n	Xpn	total solid-phase phosphorus loss in runoff during month n (kg ha^{-1})

[a] In the program d_j, $\bar{\theta}_j$ and $\bar{\theta}_{jt}$ are given in product terms. Thus Dtheta1 $= d_1\theta_{1t}$ and Thbar1 $= d_1\bar{\theta}_1$, etc.

[b] In the program K, LS and P are given as the single product KLSP.

Appendix B. Computer listings

This appendix comprises a listing of the computer program (written in FORTRAN 77) of the CNS model, a listing of the input data used in the validation run for field P2 (described in Chapter 4) and a listing of the output from that validation run.

Output headings can be changed by the user. The current headings are defined as:

F.OR.N	$= O_{n+1}$,	in kg ha^{-1}
F.IN.1	$= I_{1,n+1}$,	in kg ha^{-1}
F.IN.2	$= I_{2,n+1}$,	in kg ha^{-1}
F.PHOS	$= AP_{n+1}$,	in kg ha^{-1}
RUNOFF	$= Q_n$,	in cm
R.IN.N	$= QN_n$,	in kg ha^{-1}
R.SOLP	$= QP_n$,	in kg ha^{-1}
R.OR.N	$= XO_n$,	in kg ha^{-1}
R.FIXP	$= XSP_n$,	in kg ha^{-1}
TOT.LCH	$= P_{2n}$,	in cm
LCH.N	$= PN_{2n}$,	in kg ha^{-1}
LCH.P	$= PP_n$,	in kg ha^{-1}
SLOSS	$= X_n$,	in kg ha^{-1}
CROPN	$= UN_n$,	in kg ha^{-1}

```
C       CORNELL NUTRIENT SIMULATION (CNS) - FORTRAN VERSION - 11/15/81
C
C       The CNS model is a soil water and nutrient model of two soil zones
C       (0 - 10 cm and 10 - 30 cm).  Additions and subtractions from the soil
C       water content of both zones are computed daily, using daily precip-
C       itation and temperature data.  An optional soil erosion model requires
C       daily data for storm durations.  The soil nutrient model is updated
C       monthly, and requires fertilization, crop uptake, and soils data.  The
C       units and format for input data may be derived from the sample data
C       given or from the CNS model description.  The model runs from January
C       1 to December 31, for any number of years.  Operation of the model
C       requires an elementary understanding of the FORTRAN language, and the
C       ability to set up separate input data files on the intended system.
C       Direct any questions or comments to D. A. Haith, Dept. of Agricultural
C       Engineering, Cornell University.
C
        Character*120 Dayhdr, Monhdr     !Output headers
        Character*3 Cmonth(12)
C
```

```
   Integer Cn (11, 3, 2),  !Curve numbers by crop, AMC type,
                           !and growing season vs. fallow;
                           !dimension (Nyear+1, 3, 2)
  &        Demrg (0:11),   !Julian date of crop emergence
  &        D100 (0:11),    !Julian date of 100% canopy
  &        Dmat (0:11),    !Julian date of crop maturity
  &        Dharv (0:11),   !Julian date of harvest
  &        Ddisk (0:11),   !Julian date of discing
                           !All dates dimensioned (0:Nyear+1)
  &        Endm (25),      !End of month indicators;
                           !dimensioned (Nyear*12+1)
  &        I, N,           !Current day and month indicators
  &        M,              !=1 in growing season, =2 in fallow period
  &        Mnth,           !Current month indicator
  &        NP,             !Number of days in current month
  &        Nyear,          !Number of years simulated
  &        Outp,           !=1 for daily summaries, =2 for monthly
  &        Soil,           !If =1 then soilloss computed, =0 if not
  &        J, K, Y         !Counting variables
C
   Real    Apn,            !Available P in zone 1 in month n
  &        Area,           !Area of study plot (ha)
  &        Beta,           !P adsorption coefficient (l/kg)
  &        C,              !Current day's C factor for USLE
  &        CI,             !Inorganic N conc. in precipitation (mg/l)
  &        Cpt,            !Canopy development (fraction) on day t
  &        Ct,             !C factors by crop for 5 crop
                           !stages (seedbed to fallow);
                           !dimensioned (0:Nyear+1, 5)
  &        Da,             !Daily storm duration (hours)
                           !dimension to number of days simulated
  &        Dt,             !Daylight hours on day t by month
  &        Dtheta1, Dtheta2,      !Soil water in zones 1 and 2 (cm)
  &        Ern, Erp,       !Enrichment ratios for soil N and P
  &        Est,            !Vector of vapor pressure vs. temperature;
                           !given data values from Chow (1964)
  &        Evt,            !Evaporation from zone 1 on day t
  &        Fnn,            !Fertilizer inorganic N applied (kg/ha-mo),
  &        Fpn             !Fertilizer available P applied (kg/ha-mo);
                           !both dimensioned (Nyear*12)
   Real    I1n, I2n,       !Inorganic N in zones 1 and 2 (kg/ha)
  &        KLSP,           !Product of K, LS, and P factors in USLE
  &        Kmn,            !Mineralization rate constant, f(temp)
  &        Mann,           !Manure organic N remaining in zone 1
  &        Mn,             !Fraction of organic N mineralized in month
  &        Mnrc,           !Mineralization constant (2-4% per year)
  &        Moln,           !Plant residue N applied (kg/ha-mo);
                           !dimensioned (Nyear*12)
  &        Mt,             !Snowmelt (cm of water) on day t
  &        M1,             !Cumulative snowmelt for month (cm)
  &        Orgn,           !Organic N in zone 1 (kg/ha)
  &        Pet,            !Potential evapotranspiration on day t
  &        Pf,             !Fixed P in surface zone (kg/ha)
  &        Pn1n, Pn2n,     !Inorganic N in percolation from zones
                           !1 and 2 in month n (kg/ha)
  &        Ppn,            !Available P in percolation in month n
  &        Prec,           !Precipitation on day t (cm)
                           !dimension to number of days simulated
  &        P1n, P2n        !Total percolation from zones 1 and 2 in
                           !month n (cm)
   Real    P1t, P2t,       !Percolation from zones 1 and 2 on day t (cm)
  &        Pg, Pm, Pp, P1, P2, !Holding variables for old balances
```

```
     &          Qn,               !Total direct runoff for month n (cm)
     &          QNn,              !Inorganic N in runoff in month n (kg/ha)
     &          QPn,              !Available P in runoff in month n (kg/ha)
     &          Qt,               !Direct runoff on day t (cm)
     &          Rho,              !Soil bulk density in zone 1 (g/cc)
     &          RNn,              !Inorganic N in precip. in month n (kg/ha)
     &          Rl,               !Cumulative rainfall in current month (cm)
     &          Rt,               !Rainfall on day t (cm)
     &          St,               !Initial snowpack water on day t (cm)
     &          Sumt,             !Sum of average temperatures for month
     &          Temp,             !Average air temperature on day t
                                  !dimension to number of days simulated
     &          Thbar1, Thbar2,   !Available water capacity of zones 1 and 2
                                  !(cm)
     &          T1t, T2t,         !Transpiration from zones 1 and 2 on day t
                                  !(cm)
     &          Un,               !Total yearly inorganic N uptake (kg/ha),
     &          Up,               !Total yearly available P uptake (kg/ha);
                                  !uptakes dimensioned (Nyear+1)
     &          Un1n, Un2n        !Crop inorganic N uptake from zones 1 and 2
                                  !in month n (kg/ha)
        Real    Upn,              !Crop available P uptake in month n (kg/ha)
     &          Wt,               !Detention parameters for SCS equation
                                  !(computed directly from CN);
                                  !dimensioned (Nyear+1, 3, 2)
     &          Wtp,              !Detention parameter on day t (cm)
     &          Xnc,              !(Total monthly erosion)*C  (T/ha)
     &          Xon,              !Organic N in eroded soil in month n (kg/ha)
     &          Xpn,              !Fixed and adsorbed P in eroded soil in
                                  !month n (kg/ha)
     &          Xt,               !Soil erosion on day t (T/ha)
     &          Yrtemp,           !Sum of average monthly temperatures over
                                  !zero for the year (deg. C)
     &          Qntot, Qnntot, Qpntot,          !Yearly summation variables
     &          Xontot, Xpntot, P2ntot, Pn2ntot,
     &          Ppntot, Xnctot, Untot,
     &          W1, W2, D11, S1, Sp,            !Holding variables
     &          Vp, Vr, Tgr1, Tgr2, Texp
C
C       Program is currently dimensioned for up to 10 years simulated -
C       increase the subscripts of the following variables according to
C       the above variable list to model longer periods
C
        Common Ct(0:11, 5), Da(730), Dt(12), Est(40), Fnn(120),
     &          Fpn(120), Moln(120), Prec(730), Temp(730), Un (11),
     &          Up (11), Wt(11, 3, 2)
C
        Data Cmonth /'JAN','FEB','MAR','APR','MAY','JUN','JUL','AUG',
     &          'SEP','OCT','NOV','DEC'/
C
        Data Sumt, Rnn, St, Ml, Rl, Qn, Mann, P1n, P2n, Xnc, Qntot,
     &          Qnntot, Qpntot, Xontot, Xpntot, P2ntot, Pn2ntot,
     &          Xnctot, Untot / 19 * 0. /
C
C       'Sys$Output' is the terminal output device
C
        Open (Unit = 1, Name = 'Sys$Output', Type = 'Unknown', Err = 10)
        Open (Unit = 2, Name = 'Precip.Dat', Type = 'Old', Err = 10)
        Open (Unit = 3, Name = 'Temper.Dat', Type = 'Old', Err = 10)
        Open (Unit = 4, Name = 'Duration.Dat', Type = 'Old', Err = 10)
        Open (Unit = 5, Name = 'Main.Dat', Type = 'Old', Err = 10)
        Go To 20
```

```
C
   10   Write (1, 11)
   11   Format (/' Input data file error - file not found')
        Stop
C
   20   Continue
C
C       Input model parameters
C
        Read (5, *) Nyear, Outp, Soil, Dayhdr, Monhdr, Endm, Dt, Est,
     &          Thbar1, Thbar2, Ci, Rho, Ern, Erp, Beta, Area, Mnrc,
     &          Yrtemp, Orgn, I1n, I2n, Apn, Pf
C
        Read (5, *) (((Cn (I, J, K), K = 1, 2), J = 1, 3),
     &          I = 1, Nyear + 1)
        Read (5, *) (Ddisk (I), I = 0, Nyear + 1)
        Read (5, *) (Demrg (I), I = 0, Nyear + 1)
        Read (5, *) (D100 (I), I = 0, Nyear + 1)
        Read (5, *) (Dmat (I), I = 0, Nyear + 1)
        Read (5, *) (Dharv (I), I = 0, Nyear + 1)
        Read (5, *) (Un (I), I = 1, Nyear + 1)
        Read (5, *) (Up (I), I = 1, Nyear + 1)
        Read (5, *) (Fnn (I), I = 1, Nyear * 12)
        Read (5, *) (Fpn (I), I = 1, Nyear * 12)
        Read (5, *) (Moln (I), I = 1, Nyear * 12)
C
        If (Soil .eq. 1) Read (5, *) KLSP, ((Ct (I, J), J = 1, 5),
     &          I = 0, Nyear + 1)
C
        Read (2, *) Prec
        Read (3, *) Temp
        If (Soil .eq. 1) Read (4, *) Da
C
C       Print output headers
        If (Outp .eq. 1) Write (1, 12) Dayhdr
   12   Format (/' ', a120)
C
C       Initialize model parameters
        Do 15 I = 1, Nyear + 1
        Do 15 J = 1, 3
        Do 15 K = 1, 2
   15   Wt (I, J, K) = 2540. / Cn (I, J, K) - 25.4
        Dtheta1 = Thbar1
        Dtheta2 = Thbar2
        Kmn = 1.
        Mnth = 1
        M = 1
        Y = 1
        N = 1
        I = 0
C
C       Start simulation
        Do 50 While (N .le. Nyear * 12)
        Mt = 0
        Cpt = 0
        Xt = 0
        Qt = 0
        Wtp = 0
        P1t = 0
        P2t = 0
        I = I + 1
        Sumt = Sumt + Temp (I)
```

```
      Rnn = Rnn + 0.1 * Ci * Prec (I)
C
C     Compute potential evapotranspiration (Pet)
      Pet = 0
      If (Temp (I) .gt. 1 .and. St .eq. 0) Pet = 0.021 *
     &        Est (Int (Temp (I))) * Dt (Mnth) ** 2 /
     &        (Temp (I) + 273)
      If (Pet .lt. 0) Pet = 0
C
C     Update snow accumulation balance
      If (Temp (I) .le. 0) St = St + Prec (I)
      If (Temp (I) .le. 0) Prec (I) = 0
      If (Temp (I) .gt. 0) Mt = 0.45 * Temp (I)
      If (Mt .gt. St) Mt = St
      St = St - Mt
      Ml = Ml + Mt
      Rt = Prec (I)
      Rl = Rl + Rt
C
C     Determine the current crop stage and C factor
   30 If (I .lt. Ddisk (Y)) Then
              C = Ct (Y - 1, 5)
              M = 1
              End If
C
      If (I .ge. Ddisk (Y) .and. I .lt. Demrg (Y)) Then
              C = Ct (Y, 1)
              M = 2
              End If
C
      If (I .ge. Demrg (Y) .and. I .lt. D100 (Y)) Then
C
C             Compute fractional canopy cover
              Cpt = 1.5 * (I - Demrg (Y)) / ((D100 (Y)
     &                - Demrg (Y)) / 2 + I - Demrg (Y))
              M = 1
              If (Cpt .lt. 0.1) Then
                      M = 2
                      C = Ct (Y, 1)
                      End If
              If (Cpt .ge. 0.1 .and. Cpt .lt. 0.5) C = Ct (Y, 2)
              If (Cpt .ge. 0.5 .and. Cpt .lt. 0.8) C = Ct (Y, 3)
              If (Cpt .ge. 0.8) C = Ct (Y, 4)
              End If
C
      If (I .ge. D100 (Y) .and. I .lt. Dharv (Y)) Then
               C = Ct (Y, 4)
               M = 1
               Cpt = 1
               End If
C
C     If a new crop has just started, repeat the above procedure for
C     the new cropping practices
      If (I .eq. Dharv (Y)) Then
              Y = Y + 1
              Go To 30
              End If
C
C     Compute direct runoff
      Wtp = Wt (Y, 3, M)
      If (Rt + Mt .gt. 0) Then
              If (Dthetal .lt. Thbarl) Wtp = Wt (Y, 3, M) + ((Thbarl
     &                - Dthetal) / (Thbarl / 2)) * (Wt (Y, 2, M) -
```

```
     &                   Wt (Y, 3, M))
                   If (Dthetal .lt. Thbarl / 2) Wtp = Wt (Y, 2, M) +
     &                   ((Thbarl / 2 - Dthetal) / (Thbarl / 2)) *
     &                   (Wt (Y, 1, M) - Wt (Y, 2, M))
                   If (St .gt. 0 .or. Mt .gt. 0 .or. Temp (I) .lt. 0)
     &                   Wtp = Wt (Y, 3, M)
                   If (Rt + Mt .gt. 0.2 * Wtp) Qt = (Rt + Mt - 0.2 * Wtp)
     &                   ** 2 / (Rt + Mt + 0.8 * Wtp)
                   Qn = Qn + Qt
                   End If
C
C       Update water balances by subtracting evapotranspiration and
C       transpiration, adding rainfall and snowmelt, and subtracting
C       runoff.  Any surplus or deficit from zone 1 is transferred to
C       zone 2.
        Evt = (1 - Cpt) * Pet * Dthetal / Thbarl
        If (Evt .gt. Dthetal) Evt = Dthetal
        Tlt = Cpt * Pet
        If (Tlt .gt. Dthetal - Evt) Tlt = Dthetal - Evt
        T2t = Cpt * Pet - Tlt
        If (T2t .gt. Dtheta2) T2t = Dtheta2
C
        Dthetal = Dthetal - Evt - Tlt + Rt + Mt - Qt
        Dtheta2 = Dtheta2 - T2t
        If (Dthetal .gt. Thbarl) Then
                   Plt = Dthetal - Thbarl
                   Pln = Pln + Plt
                   Dtheta2 = Dtheta2 + Plt
                   Dthetal = Thbarl
                   If (Dtheta2 .gt. Thbar2) Then
                         P2t = Dtheta2 - Thbar2
                         P2n = P2n + P2t
                         Dtheta2 = Thbar2
                         End If
                   End If
C
C       If soilloss estimate required, compute soil loss times the daily
C       C factor
        If (Soil .eq. 1 .and. St + Mt .eq. 0 .and. Rt .gt. 0.2 * Wtp)
     &             Then
                   Xt = 21. * Area ** 0.12 * Qt ** 1.12 * (Rt / (Da (I) *
     &                   (Rt - 0.2 * Wtp))) ** 0.56
                   Xnc = Xnc + Xt * C
                   End If
C
C        Compute mineralization constant based on average temperature
        If (Temp (I) .gt. 0) Kmn = Kmn * (1 - 7300000 * Exp (-6350 /
     &             (Temp (I) + 273.)) * (Dthetal + Thbarl) / (2. * Thbarl))
C
C       Output daily summaries if required
        If (Outp .eq. 1) Write (1, 21) Cmonth (Mnth), I - Endm (N),
     &             Prec (I), Temp (I), Mt, St, Evt, Tlt, Qt, Plt, P2t,
     &             Dthetal, Dtheta2, Cpt, C, Xt
   21   Format (' ', a3, i3, 14f8.3)
C
C       If this is the end of month, update nutrient balances
        If (I .ne. Endm (N + 1)) Go to 50
        If (Outp .eq. 1 .or. Mnth .eq. 1) Write (1, 12) Monhdr
C
C       Compute mineralization rate
        Mn = 0.05 * (1. - Kmn)
C
```

```
C       If required, compute soil loss parameters
        If (Soil .eq. 1) Then
                Sl = 0.001 * Xnc * KLSP * Ern / Rho
                Sp = Sl * Erp / Ern
                End If
C
C       Compute potential crop uptakes
        Unln = 0
        Un2n = 0
        Upn = 0
        If (I .gt. Demrg (Y) .and. Dmat (Y) .gt. Endm (N)) Then
                Texp = Dmat (Y) - Demrg (Y)
                If (Endm (N) .lt. Demrg (Y)) Tgrl = 0.
                If (Endm (N) .ge. Demrg (Y)) Tgrl = Exp
     &                  (7.324 * (Endm (N) - Demrg (Y)) /
     &                  Texp - 3.662)
                If (I .gt. Dmat (Y)) Tgr2 = 1000.
                If (I .le. Dmat (Y)) Tgr2 = Exp (7.324 *
     &                  (I - Demrg (Y)) / Texp - 3.662)
C
                Unln = Un (Y) * (Tgr2 / (1 + Tgr2) -
     &                  Tgrl / (1 + Tgrl))
                Upn = Up (Y) * (Tgr2 / (1 + Tgr2) -
     &                  Tgrl / (1 + Tgrl))
                End If
C
C       Update nitrogen balance in zone 1
        Pl = Iln
        P2 = I2n
        PP = Apn
        Pg = Orgn
        Pm = Mann
        Mann = ((0.5 + Kmn / 2.) * Mann + Moln (N)) /
     &          (1.5 - Kmn / 2.)
        Orgn = Orgn * (1 - Sl/2. - Mn/2.) / (1 + Sl/2. + Mn/2.)
        If (Orgn .lt. 0.) Orgn = 0.
        Dll = Rnn + Fnn (N) + Mn * (Orgn + Pg) / 2. +
     &          (1. - Kmn) * (Mann + Pm) / 2.
        If (Rl + Ml .gt. 0.) Wl = 0.1 * Qn / (Rl + Ml) +
     &          Pln / (Rl + Ml + Thbarl)
        If (Rl + Ml .le. 0.) Wl = Pln / Thbarl
        Iln = (Iln * (1 - Wl/2) - Unln + Dll) / (1 + Wl/2)
        If (Iln .lt. 0.) Iln = 0.
        If (Rl + Ml .gt. 0.) Qnn = 0.1 * Qn * (Iln + Pl) /
     &          (2. * (Rl + Ml))
        Pnln = Pln * (Iln + Pl) / (2. * (Rl + Ml + Thbarl))
C
C       Compute crop N uptake that is unsatisfied by zone 1
C       inorganic N
        Un2n = Unln - Pl - Dll + Qnn + Pnln + Iln
        Unln = Unln - Un2n
C
C       Update zone 2 inorganic N balance
        W2 = P2n / (Pln + Thbar2)
        I2n = (I2n * (1 - W2/2.) + Pnln - Un2n) / (1 + W2/2.)
        If (I2n .lt. 0.) I2n = 0.
        Pn2n = W2 * (I2n + P2) / 2.
        Un2n = P2 + Pnln - Pn2n - I2n
C
C       Update soil P model
        Vr = 0.01 * Qn / (Rho * Beta)
        Vp = 0.1 * Pln / (Rho * Beta)
```

```
      Apn = ((1 - Vr/2 - Vp/2 - Sp/2) * Apn + Fpn (N) -
     &        Upn) / (1 + Vr/2 + Vp/2 + Sp/2)
      Qpn = Vr * (Apn + Pp) / 2
      Ppn = Vp * (Apn + Pp) / 2
C
C     If required, compute solid-phase nutrient loadings
      If (Soil .eq. 1) Then
              Xon = Sl * (Orgn + Pg) / 2
              Xpn = Sp * (Apn + Pp + 2 * Pf) / 2
              End If
C
C     Update yearly summary variables
      Qntot = Qntot + Qn
      Qnntot = Qnntot + Qnn
      Qpntot = Qpntot + Qpn
      Xontot = Xontot + Xon
      Xpntot = Xpntot + Xpn
      Xnctot = Xnctot + Xnc * KLSP
      P2ntot = P2ntot + P2n
      Pn2ntot = Pn2ntot + Pn2n
      Ppntot = Ppntot + Ppn
      Untot = Untot + Un1n + Un2n
C
C     Output monthly summaries
      Write (1, 31) Cmonth(Mnth), Orgn, I1n, I2n, Apn, Qn,
     &        Qnn, Qpn, Xon, Xpn, P2n, Pn2n, Ppn,
     &        1000. * Xnc * KLSP, Un1n + Un2n
   31 Format (' ', a3, 4f8.1, 8f8.3, f8.1, f7.1)
C
      N = N + 1
      Kmn = 1.
      Mnth = Mnth + 1
      If (Mnth .eq. 13) Then
              Mnth = 1
C
C             Output yearly summaries
              Write (1, 41) Qntot, Qnntot, Qpntot, Xontot,
     &                Xpntot, P2ntot, Pn2ntot, Ppntot,
     &                1000. * Xnctot, Untot
   41         Format (' Yearly Totals:', 21x, 8f8.3, f8.1,
     &                f7.1//)
              Qntot = 0.
              Qnntot = 0.
              Qpntot = 0.
              Xontot = 0.
              Xpntot = 0.
              P2ntot = 0.
              Pn2ntot = 0.
              Ppntot = 0.
              Xnctot = 0.
              Untot = 0.
              End If
      Qn = 0.
      Qnn = 0.
      Pn1n = 0.
      Pn2n = 0.
      Xnc = 0.
      Ml = 0.
      Rl = 0.
      Sumt = 0.
      Rnn = 0.
      P1n = 0.
      P2n = 0.
```

```
      If (Outp .eq. 1 .and. N .le. Nyear * 12) Write
   &           (1, 12) Dayhdr
C
 50   Continue
      Stop
      End
```

MAIN SOILS AND CROP DATA - MAIN.DAT

```
2  2  1

'  DAY     PREC     TEMP     MELT     SNOW     EVAP      ET        QT        P1T     P2T
     TH1      TH2      CAN       C        XT'
'MON  F.OR.N  F.IN.1  F.IN.2  F.PHOS  RUNOFF  R.IN.N  R.SOLP  R.OR.N  R.FIXP
 TOT.LCH   LCH.N   LCH.P   SLOSS  CROPN'

0 31 59 90 120 151 181 212 243 273 304 334 365 396 424 455 485 516 546 577
608 638 669 699 730

10.1 10.5 11.8 12.7 13.6 14.5 14.0 13.1 12.3 11.0 10.1 9.6

6.57 7.06 7.58 8.13 8.72 9.35 10.02 10.73 11.48 12.28 13.12 14.02
14.97 15.98 17.05 18.18 19.37 20.64 21.97 23.38 24.87 26.44 28.09
29.84 31.67 33.61 35.65 37.80 40.06 42.43 44.93 47.55 50.31 53.20
56.23 59.42 62.76 66.26 69.92 73.77

1.5 3.0  0.08  1.4  2.5 2.0  34.8  1.29  0.03  200

490 5 5 40 260

62 72 79 86 91 94    62 72 79 86 91 94    62 72 79 86 91 94

0 115 479 1000
0 123 517 1000
0 182 548 1000
0 244 609 1000
0 259 641 1000

79 101 0
17 21 0

0 0 0 0 38 100 0 0 0 0 0 0
0 0 0 22 0 0 112 0 0 0 0 0
0 0 0 0 33 0 0 0 0 0 0 0
0 0 0 21 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 18 0 0
0 0 0 0 0 0 0 0 0 20 0 0

0.052

1 1 1 1 0.36
0.61 0.51 0.42 0.26 0.36
0.36 0.32 0.29 0.20 0.30
0.30 1 1 1 1
```

0.00	0.41	0.94	0.43	0.00	0.00	0.86	0.00	0.00	0.00
0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.21
0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.25	0.66	0.00
0.00	0.00	0.00	0.00	0.00	0.00	4.19	0.41	0.00	0.00
0.00	0.00	0.00	0.00	1.65	2.31	0.00	0.00	0.00	0.41
0.00	0.00	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	1.65
0.00	0.00	0.00	0.89	0.00	0.20	0.00	1.80	0.00	0.00
0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.13	2.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.23	0.00	0.89	1.90	0.00	0.00	0.00	0.00	0.00
0.25	1.27	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00
0.00	0.00	7.01	0.00	0.00	0.71	0.00	0.00	0.00	0.00
1.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00
0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.19	0.00	0.00	0.00	0.00	0.00	0.00	10.79	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00
0.00	0.00	0.00	0.28	1.40	0.00	1.27	7.19	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	2.64	0.00
0.00	2.79	0.00	0.00	0.00	0.76	0.00	5.00	1.50	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.70	0.00	0.00	1.09	0.00	0.79	0.00	0.00	2.29	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00
0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00
0.00	0.00	2.21	0.51	0.00	0.00	0.00	2.39	0.71	0.00
0.20	0.00	2.21	0.00	0.00	0.00	0.00	0.38	0.86	0.00
0.00	0.00	1.50	0.00	2.59	0.00	2.31	0.00	0.00	0.00
0.00	0.00	0.00	1.60	0.00	0.00	0.00	0.25	2.69	0.46
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99	3.61
1.12	0.00	0.00	0.00	0.00	0.00	1.12	0.00	0.00	0.00
0.00	3.91	2.31	2.11	0.00	0.00	0.00	0.00	0.00	2.79
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.89	0.00	0.00	0.71	0.36	2.26	9.40	1.75	0.00	1.70
0.00	3.20	0.00	0.00	0.00	0.00	0.00	2.74	0.00	0.00
0.00	0.00	0.00	1.37	0.00	0.00	6.50	0.00	0.00	0.00
0.00	0.00	0.00	0.51	0.13	0.10	0.00	0.00	2.11	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.61	0.25	0.00	3.43	0.00	0.00
0.00	4.29	0.00	0.00	0.00	0.00	0.00	0.00	1.80	0.00
1.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.25	0.00	3.61	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	1.12	7.11	0.00	0.00	0.00
0.00	0.00	0.00	0.10	0.61	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12	0.00	0.00
0.00	0.36	0.00	0.00	0.00	0.89	0.00	0.00	2.69	0.10
0.00	0.20	0.99	0.00	0.00	0.10	0.00	0.00	0.00	4.29
0.00	0.00	0.00	0.13	0.86	0.00	0.00	0.89	0.00	0.00

0.51	0.00	0.43	0.51	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	3.00	0.58	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.24	0.10	0.00	0.00	0.94	0.00	1.40
0.00	0.00	0.00	0.00	5.11	0.00	0.00	0.00	0.00	3.51
0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.00
0.00	0.00	0.00	0.00	2.54	1.27	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	5.08	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	3.53	0.00	1.22	0.43	0.13
2.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.13
0.00	0.74	0.00	0.00	0.00	0.30	0.00	0.00	0.48	0.79
0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.30	0.00	0.00
0.00	0.00	0.00	0.00	0.63	1.65	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.42	0.13	0.00	0.00	0.00	0.03	0.00

6.4	9.2	10.8	16.1	9.2	5.0	6.1	11.7	8.3	11.7
8.3	7.5	9.7	16.1	14.4	5.6	2.8	0.0	8.1	16.4
18.1	10.6	11.4	13.9	15.0	13.1	13.9	18.3	16.9	13.3
18.3	15.3	11.4	13.6	11.9	12.5	18.3	13.1	5.0	6.1
4.7	10.8	6.7	0.3	1.9	7.2	8.1	10.0	15.3	14.4
5.8	7.8	7.8	13.3	9.4	11.1	10.6	7.5	8.6	-2.5
-0.6	3.9	7.8	14.2	15.6	16.1	17.2	19.4	20.8	20.6
19.2	20.0	22.2	15.0	15.8	10.6	8.9	10.8	9.4	5.8
8.6	15.8	19.4	11.4	7.2	9.2	11.9	5.3	8.3	11.4
18.1	18.3	15.6	17.5	21.7	19.4	21.4	18.9	11.4	9.2
10.0	13.9	9.4	10.6	13.3	17.5	21.1	20.8	14.4	13.9
12.5	12.5	15.0	17.8	16.4	19.2	18.1	14.2	11.9	15.6
18.3	21.1	20.6	21.4	22.2	22.5	22.8	20.3	14.7	15.6
15.3	16.9	21.1	22.5	22.5	20.0	19.7	19.4	21.9	22.5
23.9	24.7	25.6	21.9	21.7	21.9	23.3	23.9	22.5	17.8
18.9	18.9	21.7	24.4	25.8	23.9	23.1	22.5	21.7	21.1
22.8	24.4	23.3	24.2	24.4	21.4	21.1	21.4	23.3	22.2
23.9	18.6	19.7	23.3	26.4	24.7	25.8	23.9	21.1	21.9
20.8	20.3	19.2	21.7	22.5	23.9	26.1	24.4	24.4	24.4
24.7	25.0	24.4	25.6	26.1	25.8	24.7	25.3	26.1	26.4
26.9	25.6	24.7	26.4	27.2	25.0	23.1	23.3	24.4	23.3
25.6	23.9	26.1	26.9	28.3	24.7	26.4	25.6	25.3	25.3
25.6	23.9	22.2	23.3	25.6	26.1	24.4	24.4	26.1	24.2
25.6	24.7	25.8	25.8	25.6	23.9	23.9	23.9	24.2	24.7
25.8	26.7	26.9	28.3	26.7	25.8	25.8	26.1	25.0	23.1
20.8	18.1	16.9	20.6	21.7	22.2	23.6	24.7	25.6	25.6
25.3	23.3	23.6	24.4	22.8	21.7	21.9	25.0	18.3	17.2
13.6	13.9	17.5	19.4	24.4	21.1	17.5	15.8	13.9	10.6
10.8	13.6	17.5	19.4	20.0	15.8	17.2	18.1	18.9	20.0
20.0	21.4	17.5	16.1	16.7	13.3	11.1	8.6	9.2	11.7
13.9	17.2	18.1	19.7	19.4	19.4	21.1	20.3	19.2	20.0
20.8	18.9	16.9	13.9	10.3	12.2	10.8	12.8	12.2	9.4
7.5	9.7	4.7	6.4	13.6	11.9	14.2	14.2	9.7	12.2
11.1	11.9	6.9	4.4	3.9	6.4	6.4	6.7	2.2	2.8
7.5	5.3	5.3	4.7	5.8	8.1	3.1	5.6	6.9	9.2
7.8	7.5	5.3	7.5	2.2	2.8	3.1	6.1	8.3	7.5
8.3	12.5	12.5	5.3	9.2	13.9	11.7	16.7	15.3	11.7
5.3	6.9	6.7	5.0	5.8	6.1	5.6	9.2	14.2	13.1
7.2	2.2	-1.1	5.0	7.2	6.1	6.7	11.7	6.9	4.2
6.4	7.2	7.5	11.9	11.1	11.4	15.8	17.8	20.3	19.4
15.0	9.7	2.8	1.1	4.4	8.9	2.5	3.1	5.6	4.7
14.2	14.2	9.7	9.2	11.9	15.0	17.8	14.4	10.8	6.4
8.9	7.2	16.7	11.1	8.6	10.8	9.4	9.2	10.8	0.8
0.3	1.4	5.8	10.3	14.2	5.3	2.5	4.7	9.2	13.3
16.9	10.3	8.1	8.3	11.4	8.6	11.4	15.3	17.5	18.9
17.8	18.1	13.1	8.9	11.7	15.8	19.4	13.3	8.3	15.0
15.3	11.4	9.2	11.7	11.4	12.2	14.4	15.6	17.5	15.8
11.1	9.7	10.8	13.9	13.3	18.1	18.9	20.0	16.4	15.3
16.7	16.9	20.6	22.8	22.5	21.7	23.9	22.5	21.9	19.4
22.2	18.6	20.3	16.9	18.9	20.6	18.9	21.7	20.8	20.0
20.8	21.4	20.6	21.4	21.9	20.0	22.8	22.5	22.8	23.6
25.6	25.8	26.1	25.8	24.7	23.6	24.7	23.6	24.4	24.2
23.6	21.9	21.7	23.3	24.4	24.7	24.4	23.9	20.6	21.9
23.1	24.4	22.8	22.2	23.6	24.2	25.8	26.1	24.4	25.0
24.2	23.1	21.9	21.9	24.2	24.7	26.4	26.4	26.7	26.9
26.9	26.1	26.7	27.5	26.7	25.6	26.7	27.5	28.1	27.5
25.6	25.3	26.1	25.0	25.6	22.5	23.9	25.0	26.4	26.7
25.8	25.8	25.8	26.7	26.4	26.1	25.8	26.1	25.8	25.0

24.4	25.0	26.1	27.2	26.1	25.8	23.9	24.7	23.6	24.7
25.3	25.8	26.9	26.9	27.8	28.1	28.1	28.1	27.2	26.1
26.7	26.7	26.7	28.6	28.6	29.4	29.7	28.1	25.0	25.0
24.7	25.8	25.0	25.3	26.7	28.1	28.3	26.7	22.5	25.3
25.8	26.1	24.4	26.1	19.7	17.2	16.4	17.5	20.0	23.9
24.2	23.6	23.9	20.8	23.1	17.5	16.4	17.2	17.2	18.1
18.9	14.2	13.9	17.2	20.8	20.6	23.1	22.2	20.0	21.4
23.1	21.4	22.2	22.5	21.1	20.8	12.5	10.3	12.5	14.7
15.8	16.7	18.1	20.3	18.1	18.1	19.2	19.4	14.2	10.3
11.1	14.2	16.4	18.3	18.9	18.3	21.7	21.1	20.0	22.8
18.9	15.3	6.9	4.4	6.1	10.6	12.2	13.6	13.6	16.1
9.2	4.7	2.8	5.0	5.8	5.6	10.0	10.8	11.9	14.4
9.2	6.7	10.6	10.8	11.9	13.6	13.3	6.7	5.0	3.9
7.2	8.3	10.6	15.3	14.2	12.2	7.5	-0.8	-3.3	1.4
1.7	1.1	3.6	2.2	2.5	6.1	4.4	4.4	3.6	6.7

STORM DURATION DATA FILE - DURATION.DAT

0.0	1.0	3.0	3.0	0.0	0.0	5.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	4.0	4.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	12.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0
12.0	0.0	0.0	0.0	1.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	2.0	0.0	3.0	0.0	0.0	0.0	8.0	0.0	1.0	0.0	2.0	0.0	0.0
0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	1.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0	0.0	2.0	3.0	0.0	0.0	1.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0	2.0	0.0	0.0	0.0	0.0
3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	2.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	0.0	3.0	0.6	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	10.0	0.0	0.0	0.5	0.0	0.0	0.0
2.0	0.0	3.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	15.8	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	4.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	4.9	0.0	0.0	0.0	12.2	4.0	0.0	0.0	0.0	6.0	2.0	0.0
1.0	0.0	6.8	0.0	0.0	0.0	0.0	3.0	3.1	0.0	0.0	0.0	11.0	0.0	2.4
0.0	6.2	0.0	0.0	0.0	0.0	0.0	0.0	9.3	0.0	0.0	0.0	2.0	7.4	3.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	13.0	5.0	0.0	0.0	0.0	0.0
0.0	3.3	0.0	0.0	0.0	0.0	13.0	2.3	1.6	0.0	0.0	0.0	0.0	0.0	4.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0	1.0
5.3	10.1	3.2	0.0	5.3	0.0	4.7	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0
0.0	0.0	0.0	2.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0
2.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	2.0	1.0	0.0	4.1	0.0	0.0	0.0	3.3	0.0	0.0	0.0
0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	1.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
3.0	0.0	0.0	1.0	1.0	0.0	1.0	5.0	0.0	0.0	1.0	0.0	0.0	0.0	2.9
0.0	0.0	0.0	1.0	3.0	0.0	0.0	1.0	0.0	0.0	2.0	0.0	3.0	2.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	2.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0
0.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0	0.0	6.6	0.0	0.0	0.0	0.0	9.6
0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	1.0
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0					

VALIDATION RUN - P2 WATERSHED

MON	F.OR.N	F.IN.1	F.IN.2	F.PHOS	RUNOFF	R.IN.N	R.SOLP	R.OR.N	R.FIXP	TOT.LCH	LCH.N	LCH.P	SLOSS	CROPN
JAN	488.9	3.9	4.5	39.7	0.225	0.015	0.002	0.034	0.016	3.895	2.677	0.318	38.4	0.0
FEB	487.9	2.9	3.6	39.1	1.892	0.063	0.015	0.203	0.099	6.385	2.745	0.516	232.6	0.0
MAR	486.9	2.9	3.2	38.9	0.285	0.017	0.002	0.076	0.037	2.208	1.430	0.177	87.4	0.0
APR	485.7	2.9	2.8	38.7	0.370	0.017	0.003	0.070	0.034	3.118	1.517	0.248	80.2	0.0
MAY	483.7	27.2	6.0	68.9	1.221	0.133	0.013	0.293	0.152	4.878	2.456	0.634	338.6	9.7
JUN	481.7	77.2	24.0	62.2	2.535	0.991	0.034	0.518	0.280	3.755	5.768	0.909	601.0	26.8
JUL	478.0	35.1	34.7	55.1	4.866	2.622	0.059	2.045	1.086	0.000	0.000	0.274	2386.2	30.5
AUG	475.7	16.6	33.3	52.2	1.171	0.208	0.013	0.285	0.150	3.333	11.886	0.719	334.3	9.8
SEP	474.2	15.3	36.2	52.1	0.128	0.044	0.001	0.009	0.004	0.000	0.000	0.119	10.0	0.0
OCT	473.2	16.6	36.2	52.1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0
NOV	472.3	15.9	38.6	52.0	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.069	0.3	0.0
DEC	471.3	9.6	27.5	51.1	2.211	0.229	0.023	0.303	0.160	6.008	18.333	0.828	359.8	0.0
Yearly Totals:					14.904	4.339	0.166	3.835	2.020	33.579	46.812	4.813	4469.0	76.9

MON	F.OR.N	F.IN.1	F.IN.2	F.PHOS	RUNOFF	R.IN.N	R.SOLP	R.OR.N	R.FIXP	TOT.LCH	LCH.N	LCH.P	SLOSS	CROPN
JAN	470.1	6.4	16.2	50.2	2.628	0.167	0.027	0.427	0.225	8.034	15.888	0.835	507.5	0.0
FEB	468.4	4.9	9.3	49.0	4.914	0.154	0.050	0.737	0.389	10.429	9.879	1.062	879.6	0.0
MAR	466.2	4.4	5.5	47.7	9.757	0.185	0.097	1.304	0.688	11.193	5.818	1.111	1562.2	0.0
APR	464.7	22.9	6.8	68.2	3.314	0.454	0.039	0.459	0.251	4.018	3.498	0.478	552.7	0.0
MAY	462.4	17.2	9.3	67.1	3.047	0.399	0.042	0.623	0.353	6.788	5.561	0.942	753.2	0.0
JUN	460.1	0.0	5.4	62.3	3.522	0.339	0.047	0.857	0.483	1.905	2.403	0.373	1041.0	20.7
JUL	458.1	52.1	13.0	50.3	0.083	0.018	0.001	0.013	0.007	0.000	0.000	0.450	15.7	55.3
AUG	456.3	24.2	21.4	45.5	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.160	0.6	22.2
SEP	454.5	15.8	22.5	44.4	0.747	0.113	0.007	0.070	0.037	2.977	7.188	0.562	85.9	2.6
OCT	452.8	11.5	17.3	43.9	0.826	0.116	0.007	0.282	0.151	5.143	11.915	0.507	348.7	0.0
NOV	451.6	8.9	12.6	43.4	0.790	0.082	0.007	0.247	0.133	5.454	9.657	0.488	306.3	0.0
DEC	450.7	6.7	10.3	43.1	0.480	0.070	0.004	0.144	0.078	3.209	5.923	0.285	179.2	0.0
Yearly Totals:					30.110	2.097	0.329	5.165	2.796	59.148	77.729	7.254	6232.4	100.9