Chapter 13

Nitrate Leaching and Economic Analysis Package (NLEAP): Model Description and Application

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A computer applications model (nitrate leaching and economic analysis package or NLEAP) was developed to implement the theories, methods, and equations described in this and other chapters of the publication. The computer program is user oriented and designed for use by farmers, extension personnel, and action agencies such as the U.S. Soil Conservation Service (SCS) who required rapid, site-specific estimates of nitrate-N (NO_3-N) leaching potential under agricultural crops along with potential impacts of NO_3-N leaching on associated aquifers. The user supplies or selects basic information concerning on-farm management practices, soils, climate, and economics. The model then translates this information into projected N budgets, potential NO_3-N leaching below the root zone, economic impacts, and potential off-site effects of NO_3-N leaching. Considerable use is made of regional soil and climate databases; or the user can supply his own information for all or part of these inputs. Also, the model can be configured (via internal coefficients) to conform to local conditions and requirements.

The NLEAP model uses a three-phase approach to the problem. These phases include an annual screening analysis that provides initial estimates of potential NO_3-N leaching, while monthly and event-by-event water and N budgets are used for more-detailed analyses. The initial screening analysis provides a rapid means of identifying potential NO_3-N leaching problems and suggesting additional steps in the analysis. The user is encouraged to try the screening analysis first, and then to use the more-detailed approaches if significant potential NO_3-N leaching is identified.

 Managing Nitrogen for Groundwater Quality and Farm Profitability.

13-1 MODEL DESCRIPTION

13-1.1 Screening Analysis

The screening analysis uses the simplified annual water and N-budget approach together with equations described in chapter 12 and elsewhere in this publication. The leaching index (LI) is computed using the methods described by Williams and Kissel in chapter 4 of this book. Estimates of NO_3-N available for leaching (NAL) and annual leaching risk potential (ALRP) are computed using an automated version of the procedures discussed in chapter 12.

13-1.2 Detailed Analyses

The detailed analyses use optional monthly and event-by-event approaches throughout the year to compute water and N budgets. The soil profile model (Fig. 13-1) is divided into two horizons, the upper foot (30.5 cm) and the remaining portion, if any, from 1 ft down to the bottom of the root zone or a root-restricting layer. This approach is similar to the one used in the COFARM model (Shaffer et al., 1984). In the model, soil C and N transformations are confined to the upper horizon. These include denitrification,

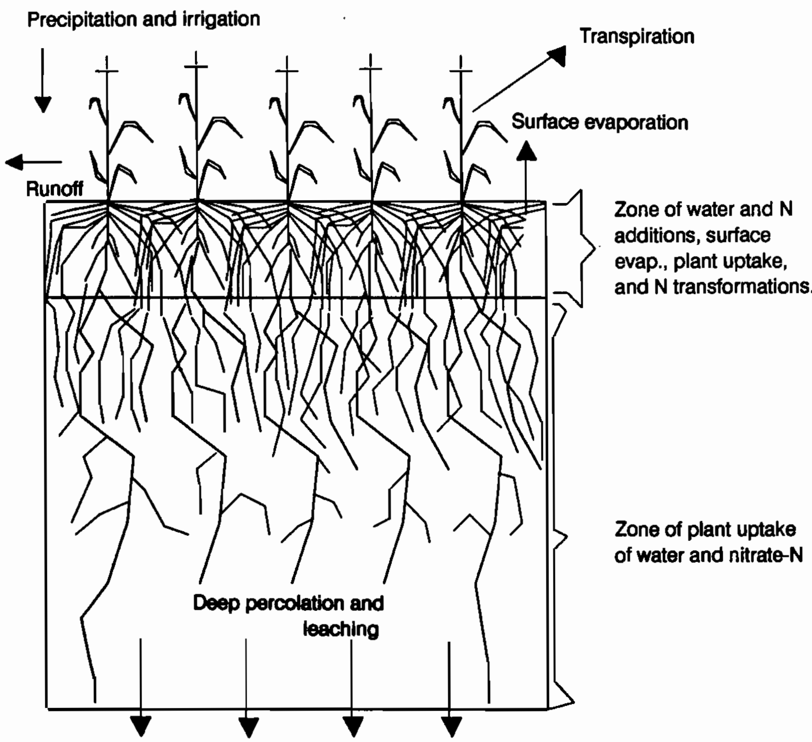


Fig. 13-1. Soil profile model.

gaseous loss of ammonia (NH_3), mineralization of soil organic matter, nitrification, and mineralization-immobilization associated with crop residues, manure, and other organic wastes. Crop uptake of N may occur in either horizon depending on the depth of root penetration. Nitrate-N can be transported from the upper to the lower horizon, and leaching of NO_3-N can occur from either horizon.

13-1.2.1 Nitrate-Nitrogen Available for Leaching

Nitrate-N available for leaching, NAL (lb/acre), in the root zone on a monthly and event-by-event basis is calculated from a N budget as follows:

$$\text{NAL} = N_f + N_p + N_{rsd} + N_n - N_{plt} - N_{det} - N_{oth} \qquad [1]$$

where N_f is NO_3-N added to the soil from fertilizers (lb/[acre time step]), N_p is NO_3-N added from precipitation and irrigation water (lb/[acre time step]), N_{rsd} is residual NO_3-N in the soil profile (lb/acre), N_n is NO_3-N produced from nitrification of ammonium-N (NH_4-N) (lb/[(acre time step]), N_{plt} is NO_3-N uptake by the crop (lb/[acre time step]), N_{det} is NO_3-N lost to denitrification (lb/[acre time step]), and N_{oth} is NO_3-N lost to runoff and erosion (lb/[acre time step]). Both the monthly and event-by-event approaches compute NAL using Eq. [1] and use similar, if not identical, equations for each term. The monthly approach uses time steps that terminate on the last day of each month and provide estimates for water and N budgets starting on the first day of the month. With the event-by-event approach, the time spans are taken between each individual precipitation, irrigation, fertilizer application, and tillage event. The monthly and event-by-event approaches use the following methods for each term and major process in Eq. [1].

13-1.2.2 Ammonium-Nitrogen Nitrification

The term for nitrification of NH_4-N is calculated using,

$$N_n = K_n(\text{TFAC})(\text{WFAC})(\text{ITIME}) \qquad [2]$$

subject to the constraint $N_n \leq \text{NAF}$, where k_n is the zero order rate coefficient for nitrification (lb/acre/d), TFAC is the temperature stress factor (0–1), WFAC is the soil water stress factor (0–1), ITIME is the length of the time step (d), and NAF is the NH_4-N content of the top foot (lb/acre) at the end of the time step. The use of nitrification inhibitors is simulated by reducing the magnitude of the rate coefficient, k_n. NAF is calculated using the equation,

$$\text{NAF} = \text{NAF}_f + \text{NAF}_p + \text{NAF}_{rsd} + \text{NOMR} + \text{NRESR} + \text{NMANR} - \text{NPLTA} - N_{NH_3} - \text{NAF}_{oth} \qquad [3]$$

where NAF_f is NH_4-N added from fertilizers (lb/[acre time step]), NAF_p is NH_4-N added from precipitation and irrigation (lb/[acre time step]]), NAF_{rsd} is residual soil NH_4-N from the previous time step (lb/acre), NOMR is NH_4-N mineralized from soil organic matter (lb/[acre time step]), NRESR is net mineralization of NH_4-N from crop residues (lb/[acre time step]), NMANR is net mineralization from manure plus other organic wastes (lb/[acre time step]), NPLTA is plant uptake of NH_4-N (lb/[acre time step]), N_{NH_3} is NH_3-N volatilization (lb/[acre time step]), and NAF_{oth} is NH_4-N lost to runoff and erosion (lb/[acre time step]). Here the assumption is made that NH_4-N does not leach or move with the water.

13-1.2.3 Temperature Stress Factor

The soil temperature stress factor, TFAC, used above and in the other N transformation processes is computed using an Arrenhius equation of the form,

$$TFAC = 1.68E9\ (EXP\{-13.0/[(1.99E - 3)(TMOD + 273)]\}) \quad [4]$$

where TMOD equals $(T-32)/1.8$ when $T \leq 86$ °F, and TMOD equals 60 $- (T-32)/1.8$ when $T > 86$ °F, and T is soil temperature (°F). The TFAC has a range of 0.0 to 1.0. This equation (Fig. 13-2) was developed using data reported by Gilmour (1984) and Marion and Black (1987). Equation [4] approximately doubles the rate for each 18 °F increase in soil temperature below a maximum of 86 °F and halves the rate for equivalent increases above the maximum.

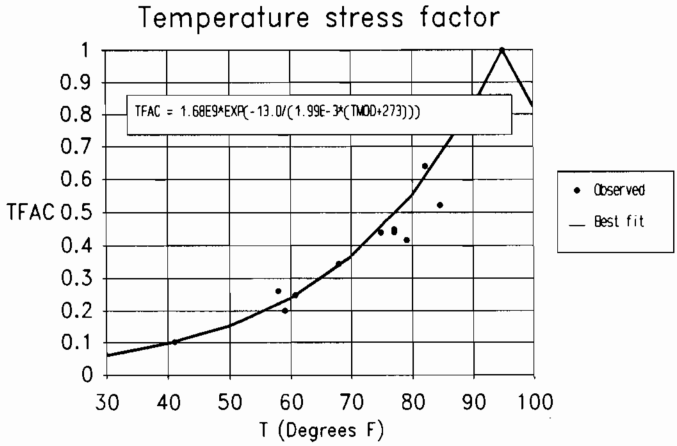


Fig. 13-2. Calculation of temperature stress.

13-1.2.4 Soil Water Stress Factor

The soil water factor, WFAC (also range 0.0-1.0), is computed as a function of percent water-filled pore space (WFP) by using curves fitted to data developed by Linn and Doran (1984) and Nommik (1956) for aerobic and anaerobic processes. For aerobic processes such as mineralization and nitrification,

$$\text{WFAC} = 0.0075(\text{WFP}) \quad [5]$$

for WFP $\leq$ 20,

$$\text{WFAC} = -0.253 + 0.0203(\text{WFP}), \quad [6]$$

for WFP $\geq$ 20 and $<$ 59, and

$$\text{WFAC} = 41.1\{\text{EXP}[(-0.0625)(\text{WFP})]\} \quad [7]$$

for WFP $\geq$ 59, and for anaerobic processes such as denitrification,

$$\text{WFAC} = 0.000304\{\text{EXP}[(0.0815)(\text{WFP})]\}. \quad [8]$$

13-1.2.5 Soil Organic Matter Mineralization

Mineralization of soil organic matter is calculated using,

$$\text{NOMR} = k_{omr}(\text{OMR})(\text{TFAC})(\text{WFAC})(\text{ITIME}) \quad [9]$$

where NOMR is the NH_4-N mineralized (lb/[acre time step]), k_{omr} is the rate coefficient, and OMR is soil organic matter (lb/acre). The base value for k_{omr} was obtained from chapter 6, by Schepers and Mosier.

13-1.2.6 Crop Residue and Other Organic Matter Mineralization

Mineralization of crop residues and other organic materials such as manure is computed using the following equations,

$$\text{CRES} = P_c\,(\text{RES}) \quad [10]$$

where RES represents the residues (lb/acre), P_c is the residue fraction that is carbon, and CRES is the C content of the residues (lb/acre), and

$$\text{CRESR} = k_{resr}(\text{CRES})(\text{TFAC})(\text{WFAC})(\text{ITIME}) \quad [11]$$

where CRESR is the residue C metabolized (lb/[acre time step]), and k_{resr} is the first order rate coefficient (1/d). The residue C is updated after each time step using,

$$\text{CRES} = \text{CRES} - \text{CRESR} \quad [12]$$

constrained by CRESR $\leq$ CRES, and net mineralization-immobilization is determined using,

$$\text{NRESR} = (\text{CRESR})(1/\text{CN} - 0.042) \qquad [13]$$

constrained by − NRESR ≤ NAF + N1T1, when NRESR < 0.0, where NRESR is the net residue-N mineralized (lb/[acre time step]), CN is the current C/N ratio of the residues, and N1T1 is the NO_3-N content of the top foot. The N content of the decaying residues is updated after each time step using,

$$\text{NRES} = \text{NRES} - \text{NRESR} \qquad [14]$$

constrained by NRESR ≤ NRES and a new value for CN is computed for the next time step,

$$\text{CN} = \text{CRES}/\text{NRES}, \qquad [15]$$

where NRES is the N content of the crop residues, manure, or other organic wastes (lb/[acre time step]). The mineralization of manure and other organic wastes is calculated using the same basic equation set for crop residues given above, with manure or organic wastes substituted for crop residues.

Equations [10] through [13] assume: (i) that crop residues contain an average percentage of C (manure and other organic wastes are assigned percentages depending on specific type), (ii) that net mineralization/immobilization equals zero at a CN value of 24, and (iii) that the CN value for soil microbes is 6.0. Values for percent N in manures and crop residues were taken from chapter 6 by Shepers and Mosier (Tables 6-4 and 6-5), and chapter 5 by Meisinger and Randall (Table 5-4). The first order rate coefficients, k_{resr} and k_{manr}, have values depending on the material being decomposed and the current CN value. In general, fresh materials are assigned a higher rate coefficient until a CN value is reached where most of the faster pool has been decomposed and a lower rate coefficient is required.

13-1.2.7 Crop Nitrogen Uptake

Nitrogen taken up by the crop (N_{plt}) is calculated using the following relationships,

$$N_{dmd} = (\text{YG})(\text{TNU})(\text{fNU})(\text{ITIME}) \qquad [16]$$

where N_{dmd} is N uptake demand (lb/[acre time step]), YG is yield goal or maximum yield in appropriate units, TNU is total N uptake (lb/harvest unit), and fNU is fractional N uptake demand at the midpoint of the time step. A normalized curve relating fNU to relative crop growth stage is shown in Fig. 13-3. The N uptake demand is proportioned between the upper and lower soil horizons according to the relative water uptake. Nitrogen available for uptake in each horizon is computed as follows,

$$\text{Navail}_1 = \text{NAF} + \text{N1T1} \qquad [17]$$

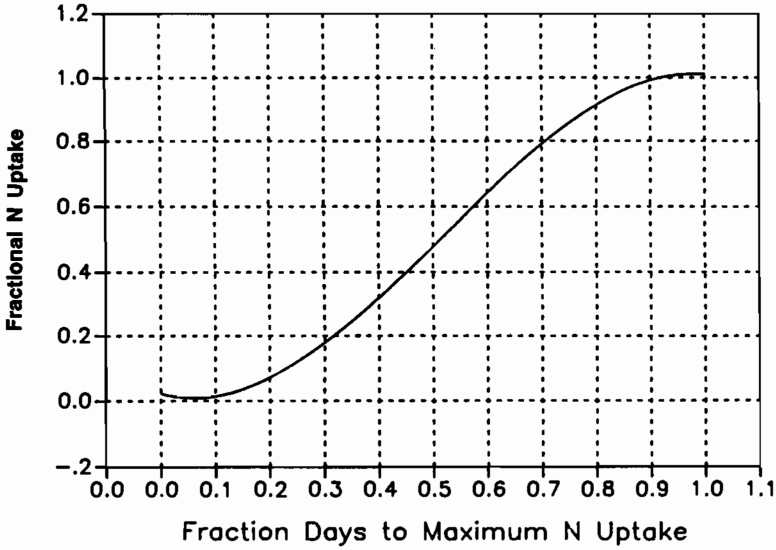


Fig. 13-3. Crop N uptake as a function of relative growth stage.

for the upper horizon, and

$$\text{Navail}_2 = \text{N1T2} \quad [18]$$

for the lower horizon, where N1T2 is the NO_3-N content in the lower horizon (lb/acre). In each case, the uptake demand for each layer is constrained by the N availability. Therefore, N_{plt} is set equal to the smaller of N_{dmd} or (Navail_1 + Navail_2). Plant uptake of NH_4-N (NPLTA) is calculated from total N uptake in the upper foot according to the fraction of NO_3-N plus NH_4-N that is NH_4-N.

13-1.2.8 Soil Nitrogen Uptake by Legumes

Soil N uptake by legumes is taken as either the N demand by the crop or the sum of Navail_1 and Navail_2, whichever is smaller. If the N demand is greater than the N available in the soil, the plant is assumed to obtain the difference from N_2 fixation.

13-1.2.9 Nitrogen Loss to Ammonia Volatilization

Nitrogen lost to NH_3 volatilization (N_{NH_3}) during the same time steps discussed above is calculated using,

$$N_{NH_3} = k_{af}(\text{NAF}_s)(\text{TFAC})(\text{ITIME}) \quad [19]$$

subject to the constraint, $N_{NH_3} \leq \text{NAF}_s$, where N_{NH_3} is NH_3-N volatilized (lb/[acre time step]), k_{af} is the rate constant for NH_3 volatilization, and NAF_s is the NH_4-N content of the surface (lb/acre). The particular value for

k_{af} is a function of fertilizer application method, occurrence of precipitation, cation exchange capacity of surface soil, and percent residue cover (chapter 5 by Meisinger and Randall, Table 5-6.1). In the case of manure, k_{af} is a function of the type of manure and application method (chapter 5 by Meisinger and Randall, Table 5-3.1 and 5-3.2).

13-1.2.10 Nitrogen Loss to Denitrification

Nitrogen lost to denitrification (N_{det}) during the time spans ending with precipitation and irrigation events is computed using the equation,

$$N_{det} = k_{det}(N1T1)(TFAC)[NWET + WFAC(ITIME - NWET)] \quad [20]$$

subject to the constraint, $N_{det} \leq N1T1$, where N_{det} is NO_3-N denitrified (lb/[acre time step]), k_{det} is the rate constant for denitrification, N1T1 is the NO_3-N content of the top foot (lb/acre), and NWET is the number of days with precipitation or irrigation during the time step. The value assigned to k_{det} is a function of percent soil organic matter, soil drainage class, type of tillage, presence of manure, tile drainage, type of climate, and occurrence of pans (chapter 5 by Meisinger and Randall, Table 5-7). Equation [20] has the advantage that maximal denitrification occurs on the wet days, while an estimate of denitrification under average soil water conditions is made for the dry portions of the time step. For the monthly analysis, an estimated number of wet days is available from the database, while the event-by-event method either stops on precipitation and irrigation events where NWET equals 1 or other events where NWET equals 0.

13-1.2.11 Water Available for Leaching

Water available for leaching (WAL) is calculated after each precipitation and irrigation event using the two-layer soil model and the following relationships,

$$WAL1 = P_e - ET1 - (AWHC1 - S_{t1}) \quad [21]$$

constrained by $WAL1 \geq 0.0$, and

$$WAL = WAL1 - ET2 - (AWHC2 - S_{t2}) \quad [22]$$

constrained by $WAL \geq 0.0$, where WAL1 is water available for leaching from the top foot (in.), ET1 is potential evapotranspiration associated with the top foot (in./time step), AWHC1 is the available water-holding capacity of the top foot (in.), WAL is water available for leaching from the bottom of the soil profile (in.), P_e is effective precipitation (in.), ET2 is potential evapotranspiration from the lower horizon (in.), S_{t1} is available water in the top foot at the end of the previous time step (in.), AWHC2 is the available water-holding capacity of the lower horizon (in.), and S_{t2} is available water in the lower horizon at the end of the previous time step.

13-1.2.12 Potential Evapotranspiration

Potential evapotranspiration is computed using pan evaporation data and appropriate coefficients as follows,

$$ET_p = [(EV_p)(k_{pan})(k_{crop}) + (EV_p)(k_{pan})(1 - k_{crop})](ITIME) \quad [23]$$

where ET_p is potential evapotranspiration (in./time step), EV_p is average daily pan evaporation during the time step (in./day), k_{pan} is the pan coefficient, and k_{crop} is the crop coefficient. ET_p is proportioned between potential evaporation at the soil surface, ET_{ps}, and potential transpiration, ET_{pt}, using normalized curves for each crop to compute k_{crop} (FAO, 1986). ET_{pt} is then proportioned between the upper and lower soil horizons according to the relative root distributions. Actual surface evaporation for any time step is taken as the minimum value of either ET_{ps} or the soil water available for evaporation. Actual transpiration for each time step and soil horizon is taken as the minimum value of either the potential transpiration for that layer or the remaining soil water above the permanent wilting point. If one horizon is depleted of water, an attempt is made to extract the water from the other horizon.

13-1.2.13 Nitrate-Nitrogen Leached

Nitrate-N leached, NL (lb/acre), during a time step is computed using an exponential relationship similar to the one given by Williams and Kissel (chapter 4),

$$NL1 = (NAL1)\{1 - EXP[(-K)(WAL1)/POR1]\} \quad [24]$$

$$NAL = NAL2 + NL1, \text{ and} \quad [25]$$

$$NL = (NAL)\{1 - EXP[(-K)(WAL)/POR2]\} \quad [26]$$

where NL1 is NO_3-N leached from the top foot (lb/acre), K is the leaching coefficient (unitless), POR1 is the porosity of the top foot (in.), NAL is NO_3-N available for leaching from the root zone (lb/acre), NL is NO_3-N leached from the bottom of the root zone (lb/acre), and POR2 is the porosity of the lower horizon (in.).

Total NO_3-N leached for any month or year is computed by summing the leaching obtained from each time step during the period of interest.

13-1.3 Leaching Risk Analysis

The risks associated with leaching of NO_3-N from the soil root zone are presented in three parts beginning with general solute movement risks associated with the soil, climate, and management conditions, followed with estimates of NO_3-N leaching risks, and finally an aquifer risk combining the movement and NO_3-N leaching aspects with aquifer properties.

13-1.3.1 Soil Profile Leaching Risks

The risks of moving NO_3-N below a soil profile given any soil, climate, and management combination, but without consideration of the mass or concentration of NO_3-N being leached can be estimated using part of Eq. [26] and the porosities of the upper and lower horizons as follows,

Movement Risk Index (MRI) =

$$1 - \exp[(-K)(WAL)/(POR1 + POR2)] \quad [27]$$

The MRI is equal to zero when no leaching of NO_3-N is expected during the period of interest and becomes equal to 1.0 when all the NO_3-N available for leaching (NAL) in the root zone is expected to move out of this region. MRI values between these extremes represent intermediate points. Like the leaching index (LI), which only applies to water movement, MRI is primarily a measure of water management and climate impacts on general leaching. It says little about the actual presence or leaching of NO_3-N. The MRI does indicate whether NO_3-N might be expected to move if present. The annual leaching risk potential (ALRP) index combines the LI with NAL and aquifer properties to produce qualitative estimates of NO_3-leaching risks. The actual amount of NO_3-N moving (NL) depends on the values for NO_3-N available for leaching (NAL) as shown in Eq. [26].

The risk of moving recently leached NO_3-N and deep residual NO_3-N (if any) located in the vadose zone below the root zone to an underlying aquifer can be estimated using an expression developed in chapter 8 by Smith and Cassel,

$$\text{Depth} = \text{WAL}/\text{AWHC}_d/12 \quad [28]$$

where depth is maximum depth of water penetration below the root zone (ft), $AWHC_d$ is water-holding capacity of the material underlying the root zone (in./in.), WAL is water available for leaching below the root zone (in.), and 12 converts in. to ft.

13-1.3.2 Aquifer Risks

The potential impact of NL on underlying aquifers depends on several additional factors: travel time to the aquifer, presence or absence of a confining layer, volume of water moving with the NL, initial concentration of NO_3-N in the aquifer, mixing volume of the aquifer, volume and quality of other water moving into the aquifer, volume of water leaving the aquifer (pumped + tile drains + other flows), and permeability of the aquifer. With these factors in mind, an aquifer risk index (ARI) for NO_3-N leaching can be computed at the present or a future time T (days, months, or years) by applying the following equation under steady-state water flow conditions. A present-day calculation would require historical information on aquifer conditions and NO_3-N leaching.

$$ARI = 0.369[N_0 + (NL)(A) + N_{sl} - N_l]/AMV \qquad [29]$$

where AMV is the aquifer mixing volume (acre-ft), N_0 is the initial NO_3-N content of the AMV (lb), NL is soil NO_3-N leached to the aquifer (lb/[acre time step]), A is the area of the field or farm (acre), N_{sl} is NO_3-N entering the AMV from sources outside the farm or field of interest (lb/time step), N_l is NO_3-N leaving the AMV in pumped wells, tile drains, and other flows (lb/time step), and 0.369 converts lb/acre-ft to parts per million (ppm). Equation [27] assumes that the upper portion (usually a few feet in depth) of a shallow aquifer (called the AMV) can be defined where an approximate complete mix is occurring with respect to the sources and sinks of NO_3-N. N_0 is calculated using,

$$N_0 = 2.71(N_c)(AA)(W) \qquad [30]$$

where N_c is the initial NO_3-N concentration in the AMV (ppm) (mg/L), AA is the surface area of the aquifer (acre), W is thickness of the AMV (ft) multiplied by its porosity, and 2.71 converts ppm·acre-ft to lb/acre-ft. N_{Sl} is calculated by multiplying associated flows (acre-ft/time step) times their concentration of NO_3-N (ppm) times 2.71. N_l is computed in a similar fashion by multiplying N_c times the corresponding discharge volumes (acre-ft/time step) times 2.71. For steady-state conditions, aquifer discharge volume equals input volume.

In general, for underlying shallow aquifers used for drinking water or classified as class I (chapter 2 by Fletcher), any values for ARI >10 would indicate a need for increased monitoring and study. Other aquifer classes would be less vulnerable to the effects of NO_3-N leaching.

13-2 MODEL IMPLEMENTATION AND USE

The purpose of this section is to provide a general description of NLEAP and to introduce the reader to the capabilities and limitations of the model. NLEAP user's need to be aware of the following disclaimer:

The user assumes all risks and responsibilities for the use and application of NLEAP and interpretation of its results. The authors and their affiliated institutions, USDA and other U.S. Government agencies, and the Soil Science Society of America (SSSA) will not be liable to NLEAP users for any damages, including lost profits, lost savings, lost time, actions by regulatory agencies, or any other direct or indirect incidental or consequential damages occurring from the use of or inability to use NLEAP, its databases, its results, or its documentation for any purpose.

Installation and startup instructions for NLEAP are presented in Appendix IV.

A detailed user's instruction guide, NLEAP Reference Guide, is available on floppy diskette along with the model and databases. This guide includes installation instructions, operational details, sample case studies, and interpretation guidelines. On-line instructions are also available within the NLEAP model.

The NLEAP model is designed to run on IBM AT or 100% compatible computers. The user interface is written in Microsoft C, Version 6.0, while the computations are done using Microsoft FORTRAN 77, Version 5.0. Communication between the two languages is done using internal common block storage areas. Extensive use is made of data entry screens with pop-up data selection and help menus. Internal checking is done for correct data type and range. Regionalized soils and climate databases are included for direct use, and the user can create and store his own local data files containing farm- and field-specific information that can be developed from the user's own information together with the supplied databases. The model is designed so that internal coefficients can be configured for local conditions by scientists and local soil-crop managers.

13-2.1 Databases

To decrease the storage requirements for soils and climate data, the USA was subdivided into four regions along state boundaries (Table 13-1). Both the soils and climate databases are provided on floppy diskettes specific for each region. Users can purchase a single set or any combinations. The correct regional database must be present if information is to be extracted for any state on the regional list. This does not prevent a user from applying the model in states where the regional database has not been obtained; however, the required soils and climate information will have to be entered entirely at the computer keyboard or created by modifying data obtained from the available on-line databases. The soils data were summarized from the SCS Soils-5 and Soils-6 databases, SCS (1990), in cooperation with SCS personnel in Lincoln, NE; Ames, IA; and Fort Collins, CO. These data represent the majority of the agricultural soils found in each region. In general, they include 80% of the soils in each soil survey area (SSA) plus any soils in the lower 20% group that have a sand texture and an associated acreage of 2000 or more acres. Please note that the NLEAP soils data sets only include information from completed soil surveys. Only those soil properties required by NLEAP and available from SCS were included in the regional data sets. The following soil properties are available on the NLEAP database:

1. Hydrologic group.
2. Drainage class.
3. Presence or absence of water and root restrictive layers and their depths if present.
4. Percent organic matter.
5. Bulk density.
6. pH.
7. Cation exchange capacity.
8. Plant available water-holding capacity.
9. Soil water content at 15 bars.
10. Percent coarse fragements by volume.

Table 13-1. Database regions.

Region 1, Upper Midwest	
Illinois	Nebraska
Indiana	North Dakota
Iowa	Ohio
Michigan	South Dakota
Minnesota	Wisconsin
Region 2, Southern	
Alabama	Missouri
Arkansas	North Carolina
Florida	Oklahoma
Georgia	South Carolina
Kansas	Tennessee
Mississippi	Texas
Louisiana	Virginia
Kentucky	West Virginia
Region 3, Northeastern	
Connecticut	New Hampshire
Delaware	New Jersey
Maine	Pennsylvania
Maryland	Rhode Island
Massachusetts	Vermont
New York	Washington, DC
Region 4, Western	
Alaska	Montana
Arizona	New Mexico
California	Nevada
Colorado	Oregon
Hawaii	Utah
Idaho	Wyoming
	Washington

The user loads soil data from the database by selecting the appropriate soil series name and surface texture from the menu list provided for each state, county, and soil survey area.

The NLEAP climate database was developed, in part, from the TD3200 Summary of the Day Cooperative Observer Network database of the National Climate Data Center, Earthinfo, Inc. (1989). Stations were selected in each state and surrounding states based on the simultaneous availability of pan, precipitation, and air-temperature data, plus a historical record of 10 or more years. The total number of stations available for each state includes both stations within the state and stations located nearby in adjacent states. The regional climate data sets are derived from the period of record at each station. They contain monthly and daily precipitation and monthly average pan evaporation and air temperature for an average or typical year, a wet year, and a dry year at each station. The average year was chosen from the existing historical record based on average annual precipitation and reasonable agreement with monthly average precipitation values for that site. The wet and dry years were chosen based on the 90 and 10 percentiles, respectively, for annual precipitation recorded at each station. Missing pan evaporation data for the winter months were estimated by extrapolating information from stations and years with full-year records.

13–2.2 Operating NLEAP

13–2.2.1 Model Set-up and Conventions

NLEAP should be installed on an IBM AT or 100% compatible computer equipped with DOS 2.1 or newer, a hard disk drive, EGA or VGA color board and monitor, and a math coprocessor chip. The model will run, but less efficiently, on computers equipped with CGA and monochrome boards and monitors, and on computers not equipped with math coprocessors. The use of computers that do not have hard disk drives is not recommended. Installation of the model involves creating a directory on the hard disk drive and then copying all the supplied NLEAP files into the directory. The model is started by typing NLP and then pressing Enter or CR.

NLEAP is a self-contained program will full access to the soils and climate databases, state index files, and user data sets all of which reside on disk files. The soils, watershed, aquifer, climate, and management data displayed on input and output screens are contained within the program's volatile (temporary) memory and are not saved to the disk unless the user requests the model to write a user data file. When entering information on the data input screens, the user can either use the material from the database files or enter his own data. A mix of the two data sources is possible, and the results can be stored in a user data file for later retrieval and use. Whenever the user tells the model to perform calculations, the appropriate inputs to the equations are always taken directly from the input data screens.

As previously noted above, after proper installation of the NLEAP program and associated databases, the model is started by typing NLP and then pressing the Enter or CR key. An initial banner screen, Fig. 13–4 always appears that identifies the NLEAP model along with the version and release date. Press any key to display the MAIN menu screen (Fig. 13–5) which controls general operation of the model. First-time users should select menu item (5) Instructions to learn more about the basic operating conventions. In addition, relevant instructions can be accessed from each screen by pressing the F5 function key. Selection of menu item (1) initiates entry of designations for state, county, SSA, farm or owner identification, and farm field name. Menu items (2) through (4) select the type of analysis to be performed. The screening analysis is a computerized version of the "hand" method described in chapter 12. The monthly analysis uses climate and management inputs on a monthly basis together with monthly time steps to compute the water and N budgets. The event-by-event analysis uses daily precipitation and specific dates for fertilizer additions and tillage to give a more-detailed analysis of a particular case. In general, the event-by-event method is preferred whenever any significant NO_3-N leaching may occur, or when a human drinking water source (aquifer) is involved. The user can use MAIN menu item (7) to send images of the tabular output screens and the summary report

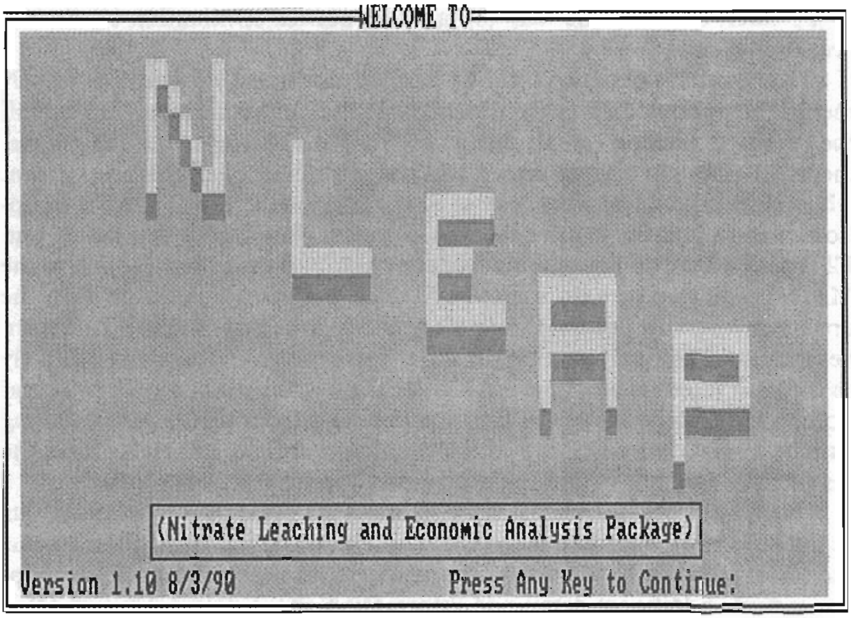


Fig. 13-4. NLEAP banner screen.

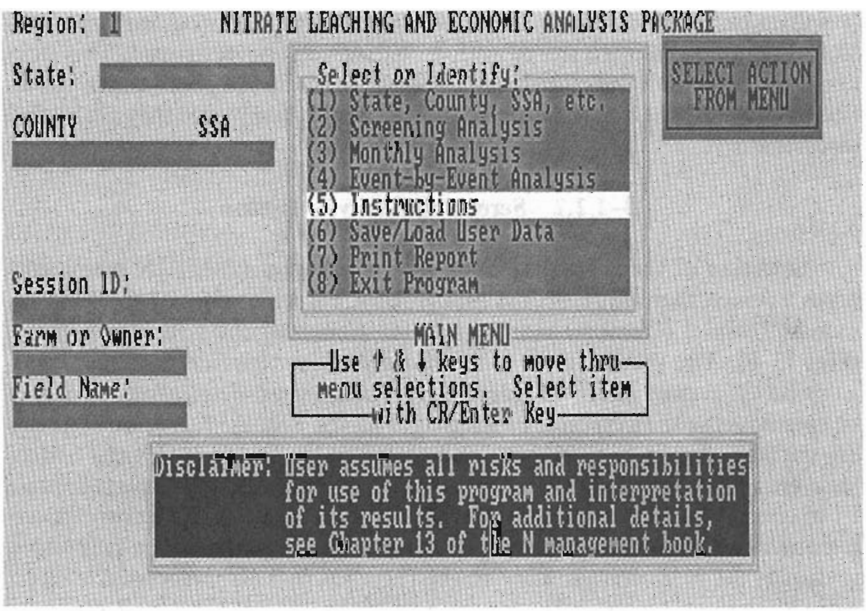


Fig. 13-5. MAIN menu screen.

to a printer. MAIN menu item (8) provides normal termination of the current model run.

The model is designed to allow ease of movement between the MAIN menu, the various data entry screens, and the output screens. In general, the keyboard function keys F1, F2, and F3; and the Esc key control this movement. F1 exits the current screen and transfers control to the next screen, while F2 exits and transfers control to the pervious screen, F3 exists to options menus, and Esc exits to the MAIN menu. Please note that the F1 and F2 function keys do not operate from the MAIN menu. Menu's such as the MAIN menu that contain a moveable selection bar are operated with the up and down arrow keys on the data key pad followed by the Enter or Return keys to make the final selection. In some cases, control is transferred directly to the next screen if an appropriate selection is made. Additional information on the specific use of the F__ function keys from various menus along with details on data entry and editing within input fields are available in the instructions writeup within the model and the separate instructions file.

Numerous pop-up menus and help boxes are provided at various points in the data entry and output screens, and elsewhere. Some of these menus appear automatically whenever a particular field is addressed. These pop-ups provide additional detail and information about data entry and often provide a menu of selections. The item selected is then transferred to the data entry field.

The user data file capability mentioned earlier is designed to allow the current set of input data shown on the input data screens to be saved to a user defined disk file for later retrieval and use. Access to this feature is from item (6) of the MAIN menu. A reload of a user file that was saved previously will cause the information to be overwritten into the program's memory slots. Any previous data stored within NLEAP will be destroyed. This does not apply to the soil and climate data-bases that cannot be permanently modified by the user, but can be changed on a temporary basis once they are loaded into memory.

13-2.2.2 Screening Analysis Option

Selection of the Screening Analysis option, item (2) MAIN menu, displays a screen that requests data inputs for the starting date of the run, annual and winter (October-March) precipitation, and soil hydrologic group (Fig. 13-6). The precipitation data are needed for three climate scenarios, a dry (low), average, and wet (high) precipitation year. This information can be entered from the keyboard or selected from the Climate Database by pressing the F3 function key. F3 can also be used to load and display the hydrologic group from the Soils Database. Once this information is displayed, press F1 to compute and display estimates for the numerical LI and a corresponding qualitative index, the leaching index severity. F2 should then be pressed to display the NAL computation screen (Fig. 13-7). This screen allows direct entry of values for NO_3-N sources and sinks, or NLEAP will compute values based on your entries for climate, management, and soils data. The

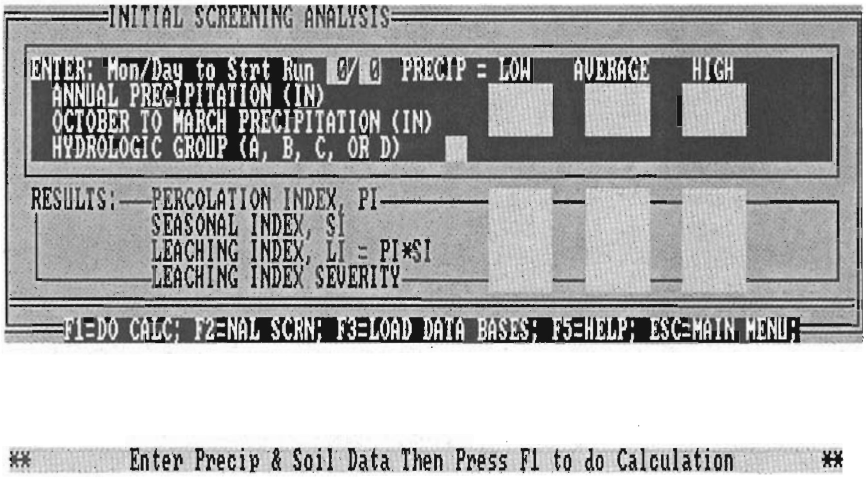


Fig. 13-6. Initial screening screen.

later method is initiated by pressing F3 (CALC N SOUR & SINKS). This will display the remaining Management Data and Soils Data screens shown in Fig. 13-8 and 13-9. Note that management data for a second crop can be entered by pressing the F7 function key while in the Management Data screen. Please complete each screen and proceed foreward by pressing the F1 key. The model will automatically complete the N source-sink calcula-

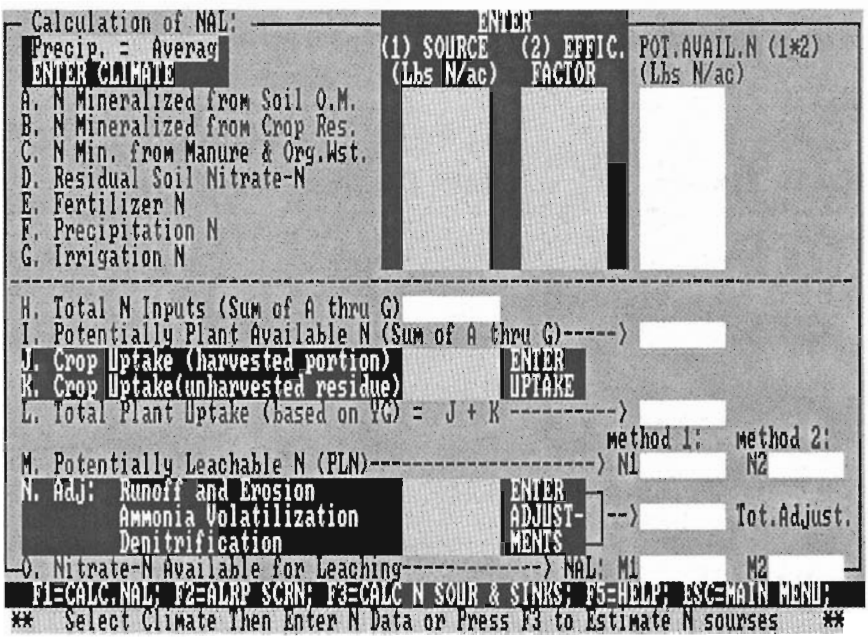


Fig. 13-7. NAL screen (screening analysis).

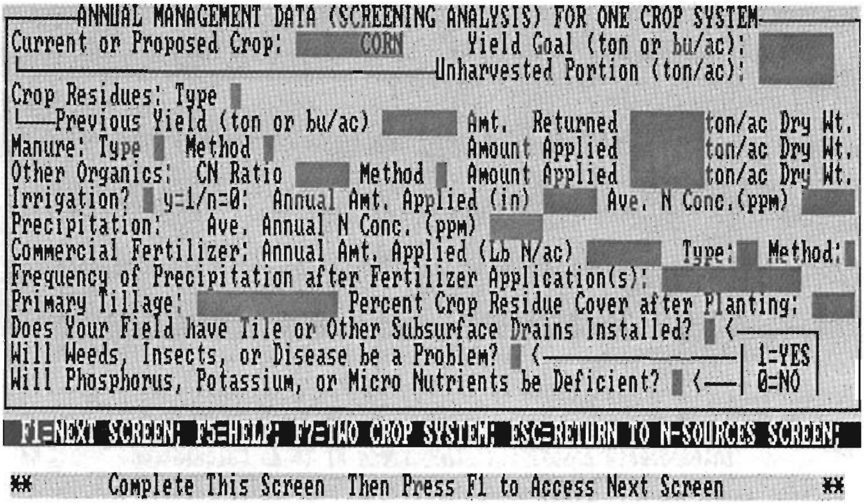


Fig. 13-8. Management screen (screening analysis).

tions upon exit from the soils screens and then return to the NAL screen (Fig. 13-7). The computed source-sink values will be displayed in the appropriate screen locations. Once the N sources and sinks have been entered on the NAL screen (either directly by the user or indirectly by the model), press F1 from the NAL screen to complete the calculation of NAL. Once this is done, press F2 to display the ALRP screen (Fig.13-10). Qualitative

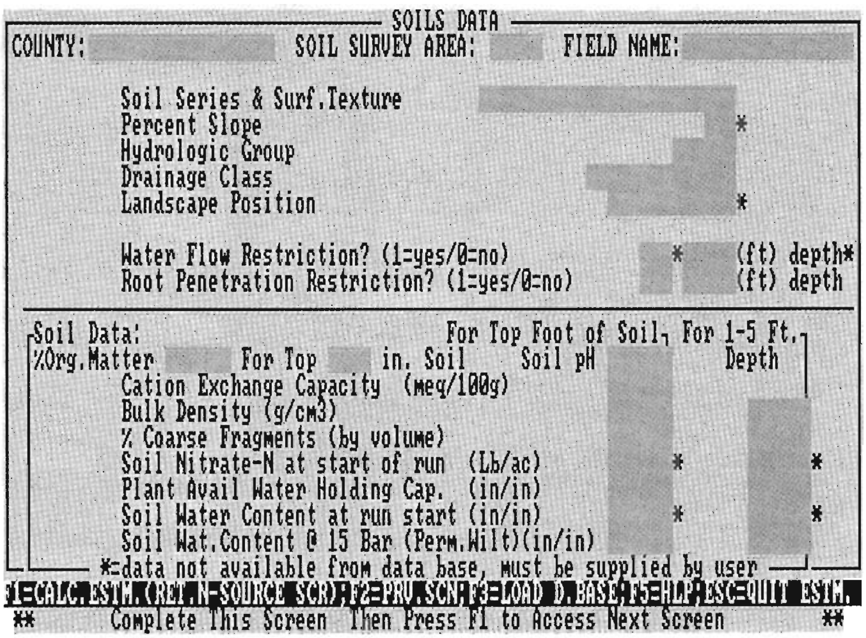


Fig. 13-9. Soils data screen.

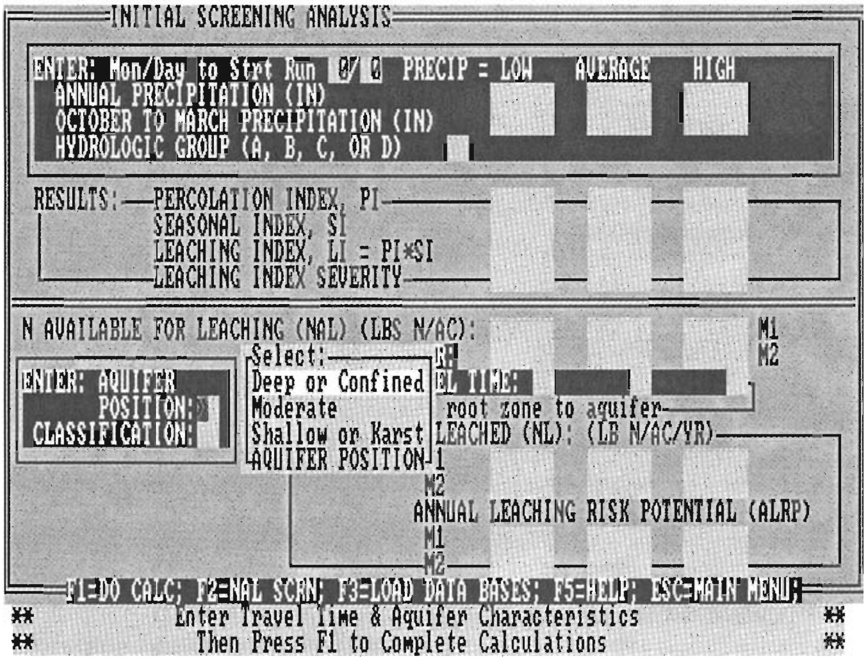


Fig. 13-10. ALRP screen (screening analysis).

information on travel times to the aquifer, aquifer position, and aquifer classification must be entered next. Then press F1 to calculate the ALRP indices. NLEAP will display a message at the bottom of the screen as to what further analyses (if any) may be required. The results obtained from the screening analysis should be considered preliminary and the user should closely follow the recommendations concerning the next steps to follow.

13-2.2.3 Monthly Analysis Option

This option provides a more detailed calculation procedure for LI, NO_3-N available for leaching (NAL), and annual leaching risk potential (ALRP). When the Monthly Analysis option, item (3), is selected from the MAIN menu, NLEAP displays the sequence of screens shown in Fig. 13-11. The Soils Data screens are identical to those previously used in the Screening Analysis (Fig. 13-9). The monthly Management Data screen (Fig. 13-12) prompts the user for historical and current or proposed management information concerning this particular farm field. The user should have access to this information in his local farm production records. The information is needed to help estimate initial conditions and compute the water and N budgets for each climate sequence. Note that management data for a second crop can be entered by pressing the F7 function key while in the monthly Management Data screens. In addition, specific management information on irrigation; crop residue, fertilizer, manure, and organic waste applica-

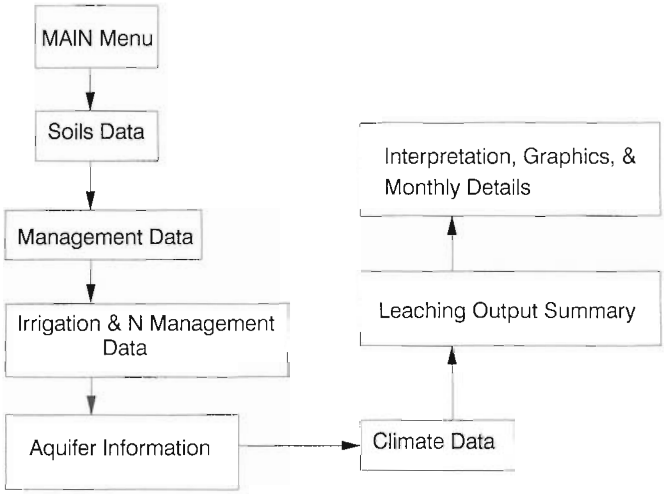


Fig. 13-11. Diagram of monthly analysis sequence.

tions; and nitrification inhibitors are required on the Irrigation and Nitrogen Management screen (Fig. 13-13).

Particular care should be taken in estimating yield goals and crop yields under the various climate scenarios. Please note that NLEAP does not attempt to calculate crop yields as a function of climate (including water supply, temperature, and ET), soil properties, or management inputs. Representative yield values must be supplied by the user. In general, NLEAP will attempt to flag poor management practices associated with N fertilizers, manure, other organic wastes, tillage, and irrigation. Management problems associated with insect, disease, and weed pests; nutrient deficiencies with P, K, and micro-

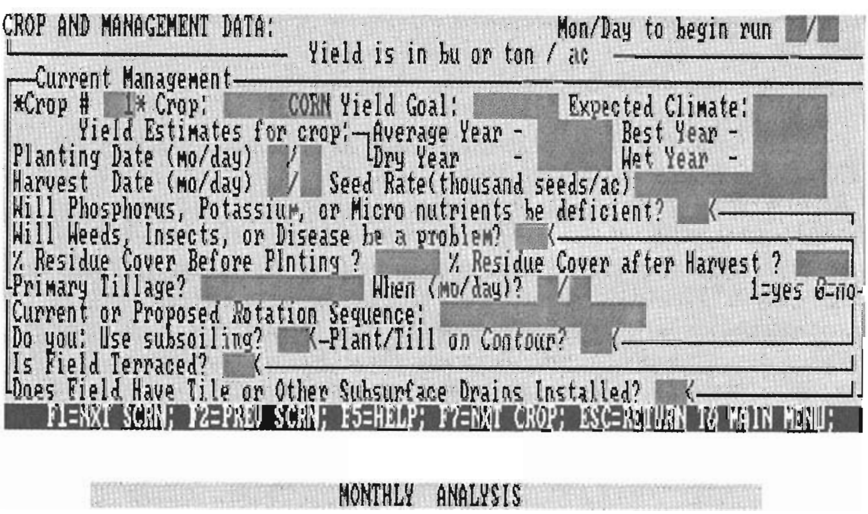


Fig. 13-12. Management screen (monthly analysis).

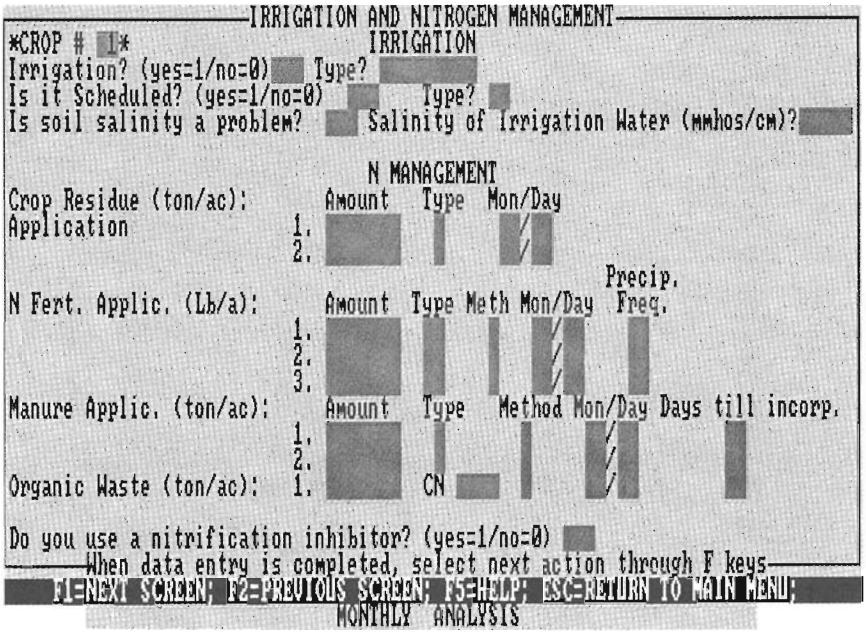


Fig. 13-13. Management screen (irrigation and fertilizers).

nutrients; and other cultural practices such as planting dates and plant populations are not considered. It is the primary responsibility of the user to know when these management problems exist and to avoid misapplication of the model.

After the management screens, an Aquifer Information screen (Fig. 13-14) is displayed that requests the same type of qualitative aquifer data as in the screening analysis. This includes travel times from the root zone to the aquifer, the aquifer position relative to the root zone, and the EPA aquifer classification. This information is used, in part, to compute the ALRP index.

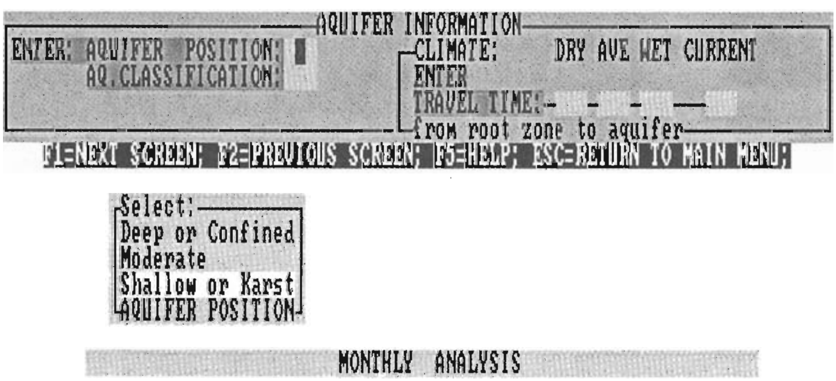


Fig. 13-14. Aquifer information screen.

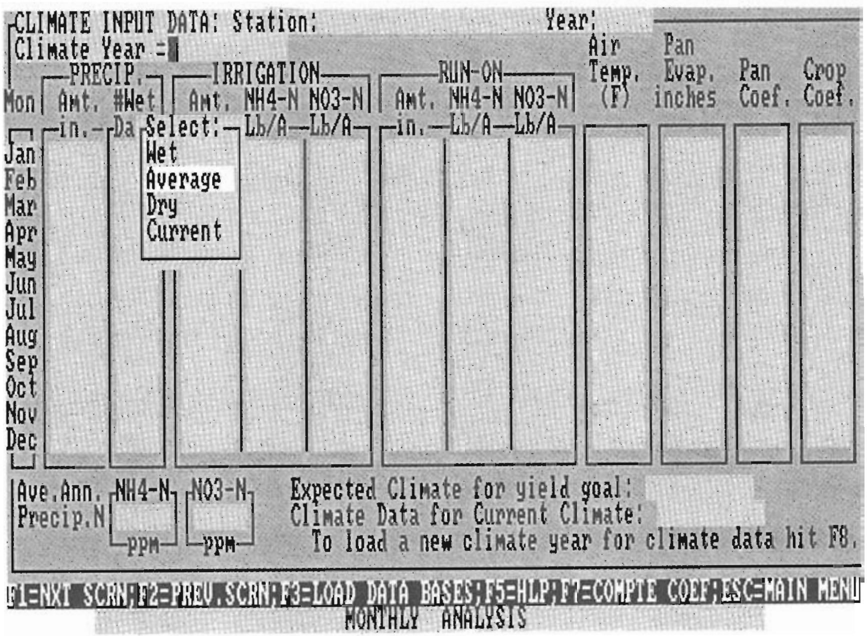


Fig. 13-15. Climate data screen (monthly summary).

The Climate Data screen (Fig. 13-15) asks for monthly values for precipitation, number of wet days, irrigation, run-on, air temperature, pan evaporation, pan coefficient, and crop coefficient. This information can be entered at the keyboard or extracted from the regional Climate Database (with the exception of irrigation and run-on) by pressing the F3 key (LOAD DATA BASES) to get the Database Menu. The pan and crop coefficients are loaded whenever a new crop is specified on the Management Data screen. The user can either accept the database values for the climate information, or make modifications to it. In general, monthly precipitation and average air temperatures are available from the regional database, from local climate records, or can be collected locally on-site using inexpensive measuring devices. Pan evaporation can be obtained from the regional database or elsewhere. Pan and crop coefficients for various crops are available in the NLEAP database or can be derived based on publications such as FAO (1986) or local estimates.

The Leaching Output Summary screen (Fig. 13-16) is displayed by pressing F1 or F4 from the Climate Input Data screen, by pressing F4 from any other monthly input data screens, or by pressing F4 from the MAIN menu when the selection bar is located on item (3), Monthly Analysis. Results are displayed on this screen by pressing F1 (DO CALC) to tell the model to run the monthly calculations and display the output. Crop yield goals are displayed for dry, average, wet, and current climate years as previously specified by the user. Corresponding values for NAL, NO_3-N leached (NL), leaching potential (LP), maximum depth of leaching (MDL), movement risk

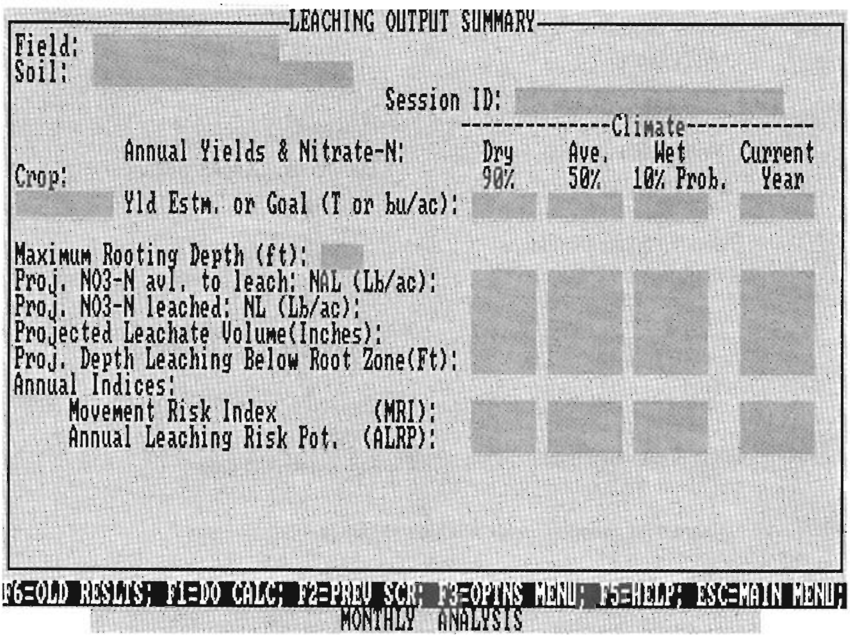


Fig. 13-16. Leaching output summary (monthly analysis).

index (MRI), and ALRP are displayed for each climate scenario. Additional output information can be obtained by pressing F3 (OPTNS MENU) to get the options menu. Details concerning the types of output available from this menu are discussed below under the Event-by-Event Analysis Option.

13-2.2.4 Event-by-Event Analysis Option

This option provides the most detailed analysis of NO_3-N leaching available in the model and also calculates an estimated economic analysis summary of the farming operation. A summary diagram of the screen sequence for the event-by-event analysis is shown in Fig. 13-17. The soils data input requirements are similar to those for the screening and monthly analyses (Fig. 13-9). In addition, general information is required regarding the deep vadose zone, watershed, and aquifer (Fig. 13-18 and 13-19). Note that the aquifer information requested on the Aquifer Risk Index (ARI) Input screen (Fig. 13-19) is used, in part, to compute ARI for each climate sequence.

The event-by-event management data requirements (Fig. 13-20) are slightly more detailed than those for the monthly analysis. Note in particular that the previous cropping history is required along with corresponding crop yields under a range of climate conditions. This information is required by the model to help make suggestions about improvements, if any, in management that might reduce NO_3-N leaching. Please note that management data for a second crop can be entered by pressing the F7 function key while in the event-by-event Management Data screens. The next screen in

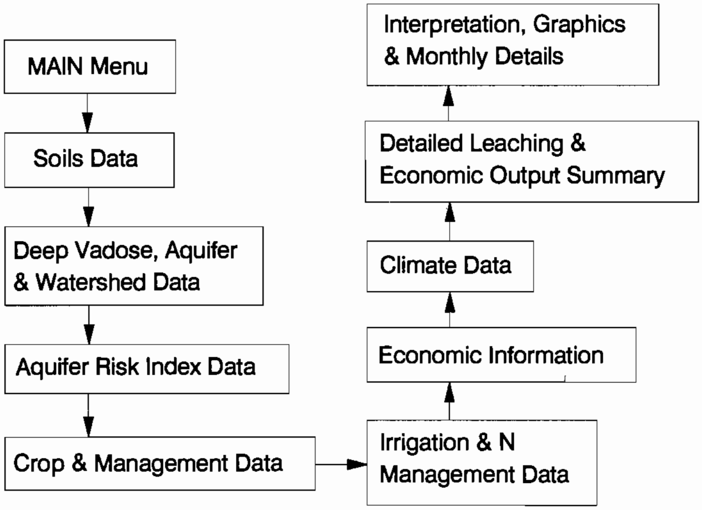


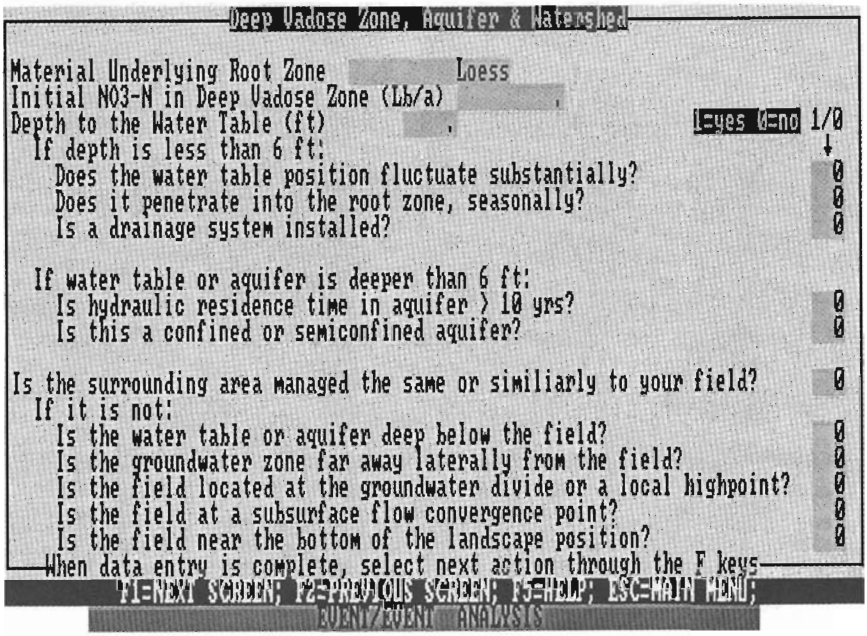
Fig. 13-17. Diagram of event-by-event analysis sequence.

the management sequence requests inputs for irrigation and N management and is identical to the monthly screen shown in Fig. 13-13.

The Economic Information screen (Fig. 13-21) allows the user to enter or modify the dollar values for commodity prices and production costs by scrolling up and down through the entire list. Note that only some of the items are shown in Fig. 13-21.

The Daily Climate Data screen (Fig. 13-22) provides for entry of daily values for precipitation, irrigation, N concentration in the irrigation, and run-on. Monthly values (Fig. 13-15) are required for air temperature, pan evaporation, pan coefficient, and crop coefficient. Note that the summary screens for monthly climate data displays are identical for both the monthly and event-based analyses. The user can select to either load climate data from the regional database or enter his own values directly at the keyboard. Please note that the model requests information for an average or typical year, a wet year, and a dry year (Fig. 13-6, 13-16, and 13-23, respectively). This information has already been selected for each climate station represented in the database. The user must provide values for the current year by entering them at the keyboard or by loading data from the average, wet, or dry year climates. If these are left blank, then calculations cannot be completed for the current year.

Once the input screens have been completed, the Detailed Leaching and Economic Output Summary screen (Fig. 13-23) should be displayed and projected output values computed for a range of annual climates. The move to the summary screen is made by pressing F1 from the Economic Information screen or F4 from the other input screens. Press F1 (DO CALC) from the summary screen to calculate and display the annual results. The F6 key (OLD RESLTS) allows the re-display of results previously computed in an F1 (DO CALC) operation. The crop yield goals supplied by the user for each



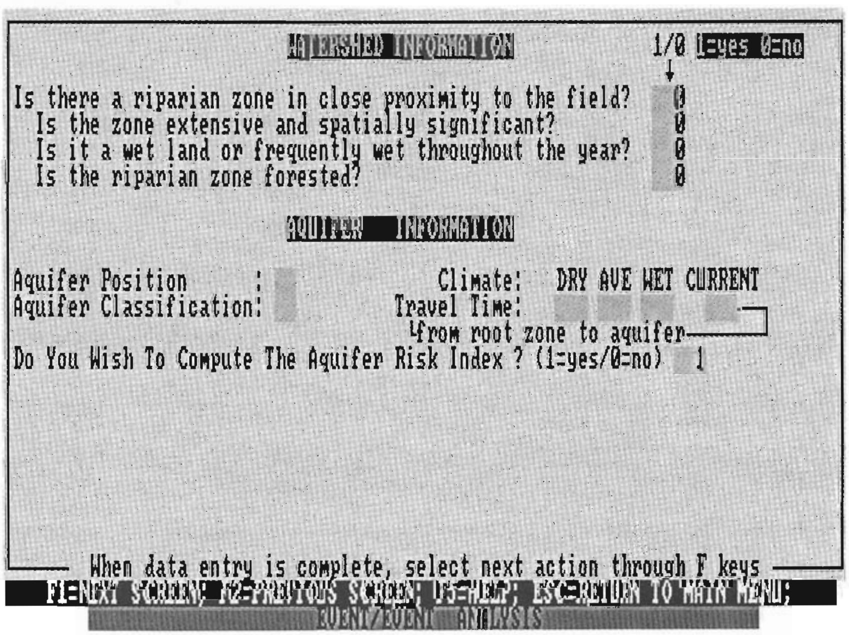


Fig. 13-18. Deep vadose zone and watershed information (event-by-event analysis).

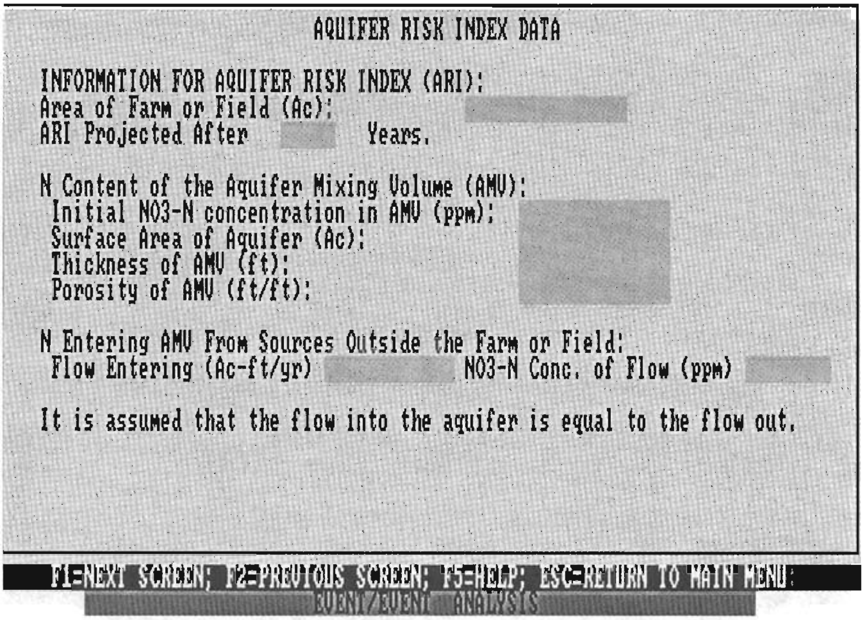


Fig. 13-19. Aquifer risk index (ARI) input screen.

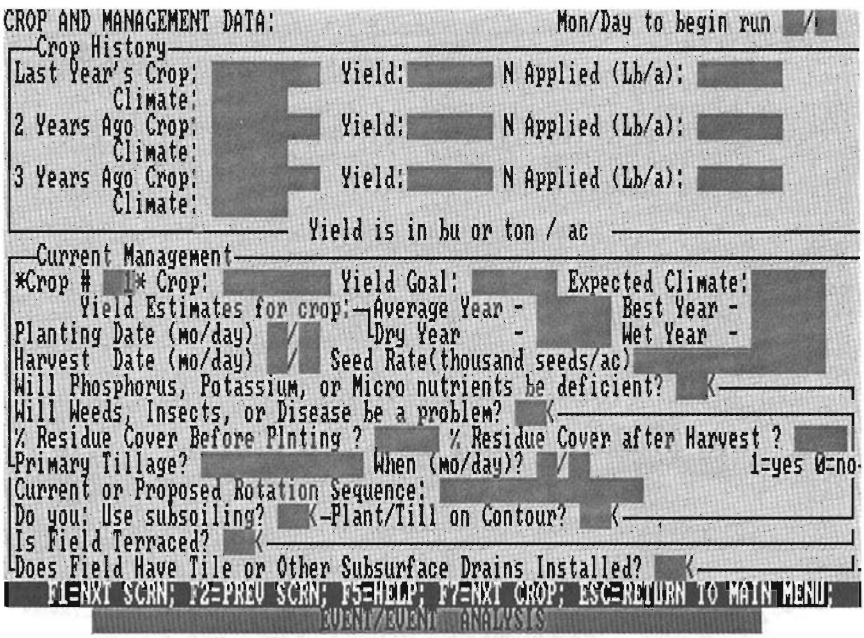


Fig. 13-20. Management data screen (event-by-event analysis).

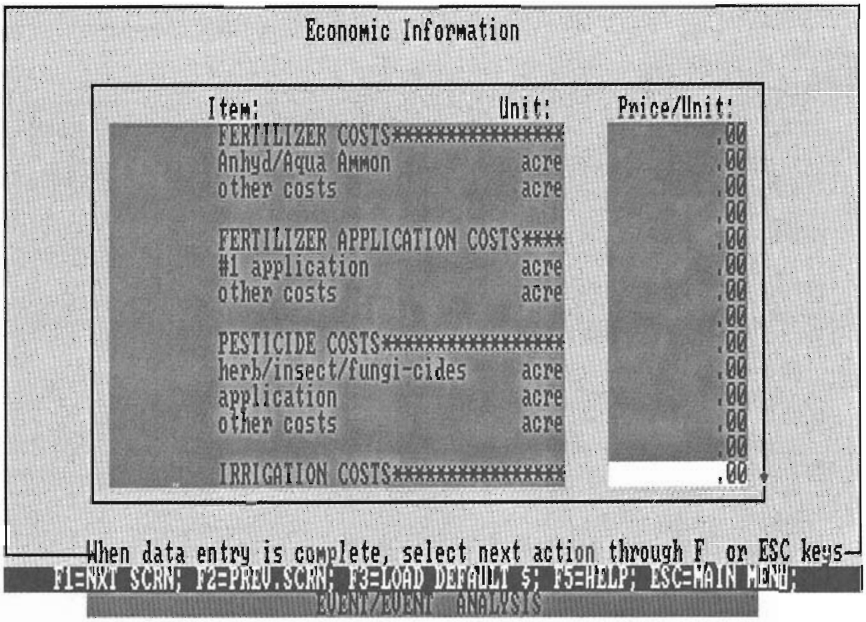


Fig. 13-21. Economics screen (event-by-event analysis).

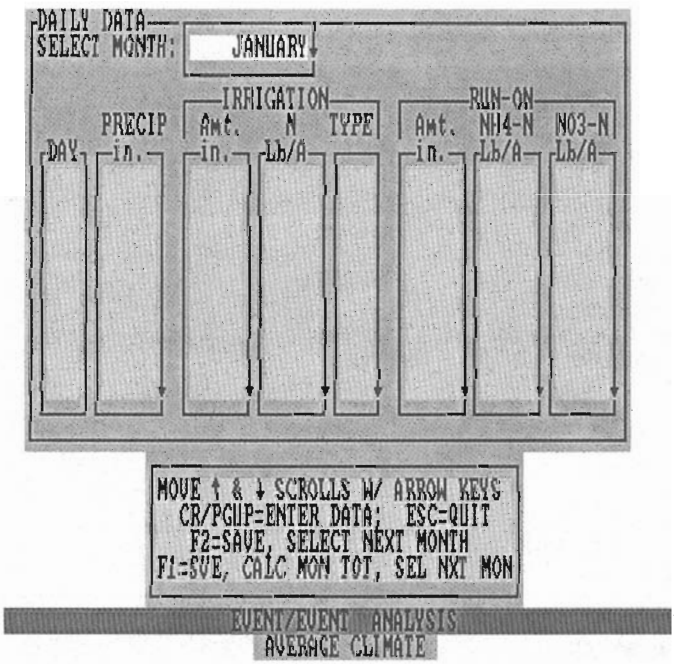


Fig. 13-22. Daily climate inputs (event-by-event analysis).

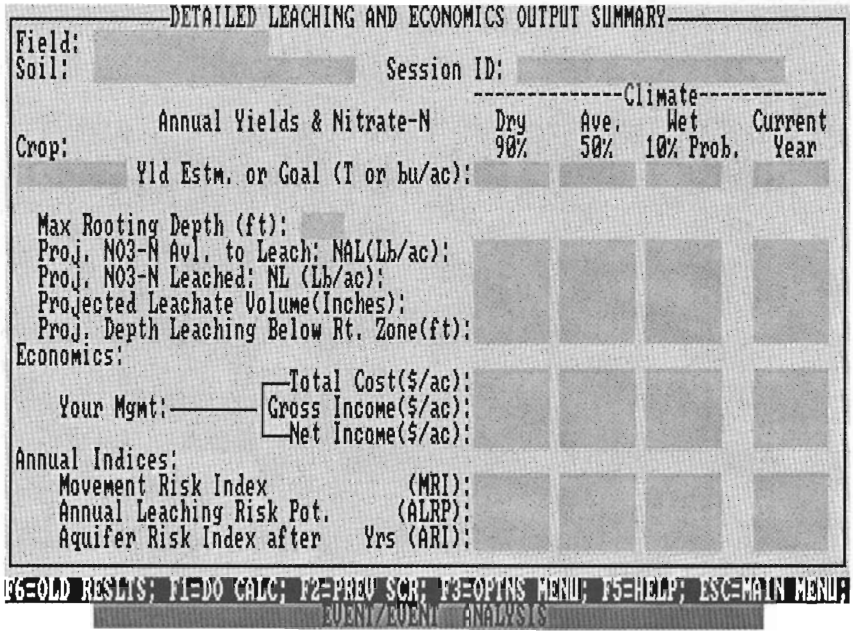


Fig. 13-23. Detailed leaching and economic output screen.

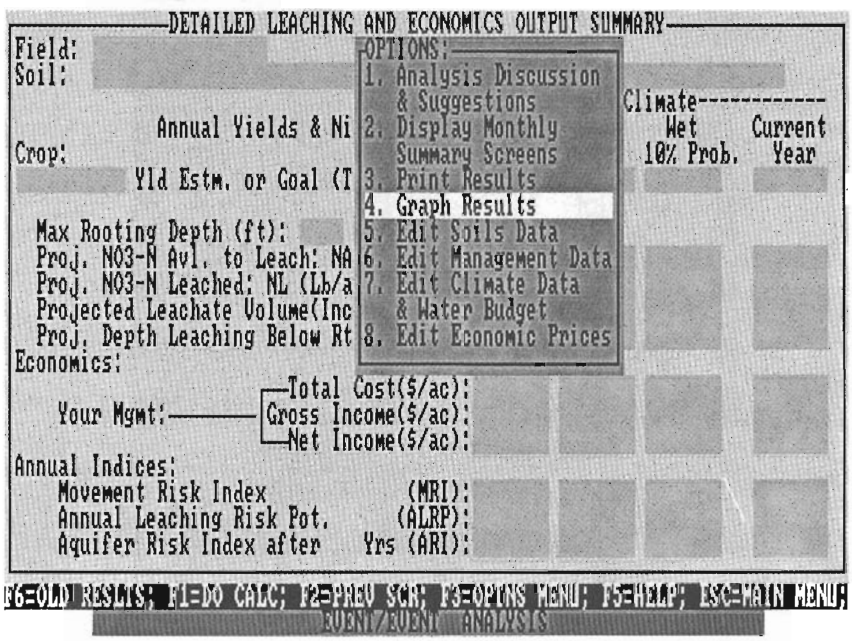


Fig. 13-24. Options menu.

climate scenario are displayed along with projected values for NO_3-N available for leaching (NAL), NO_3-N leached (NL), leaching potential (LP), maximum depth of leaching below the root zone (MDL), annual leaching risk potential (ALRP), movement risk index (MRI), and aquifer risk index (ARI). An economic summary is displayed that includes inputed costs, estimated gross income, and estimated net income (gross − inputed costs) for each climate year.

The Options Menu overlay (Fig. 13-24) is obtained by pressing F3 (OPTNS MENU) (see bottom of Fig. 13-23) and provides access to several additional features associated with model results. Selection of menu item (1) displays a written report that discusses the results obtained from the most recent analysis and makes suggestions concerning possible changes in management that might help reduce leaching of NO_3-N.

Selection of item (2) from this menu displays tabular summaries of monthly results on the Water and Nitrogen Output Summary screen, the Nitrogen Sources screen, and the Nitrogen Sinks and NAL screen; and annual results on the Crop N-uptake Efficiency screen. The first screen displays monthly values for runoff, evapotranspiration (ET), plant available soil water (ASW), effective precipitation (P_e), potential deep percolation (LP), NO_3-N available for leaching (NAL), and NO_3-N leached (NL). The Nitrogen Sources screen shows monthly values for N mineralized from soil organic matter and crop residues (OM and Res.), residual soil NO_3-N, fertilizer N added as NH_4-N and NO_3-N, organic waste N, precipitation N, irrigation N, and NO_3-N produced from nitrification of NH_4. The monthly summary screen for N sinks displays crop uptake of N, runoff/erosion losses, NH_3-N volatilization losses, and denitrification losses; and NO_3-N available for leaching (NAL). The Crop N-Uptake Efficiency screen displays annual uptake efficiencies calculated for various N sources supplied to the system such as N fertilizer, residual NO_3-N, crop residue N, manure N, other organic waste N, soil organic matter N, and irrigation N.

Menu item (3) allows the user to print the tabular results screens and the analysis and discussion file for the current analysis.

Menu item (4) displays the Graphics Setup screen which contains a list of monthly tabular results [same as those in item (2) above plus the monthly climate and irrigation inputs] that can be plotted in the form of bar graphs. The user has the options of plotting one to four graphs on the same screen and one to three sets of monthly results on each graph. A sample graph is shown in Fig. 13-25. Each graphic screen can be ''dumped'' to a *.pcx file that can be viewed and printed through a variety of software packages. Menu items (5) through (8) provide rapid access to the input data screens.

13-4 MODEL TESTING AND VALIDATION

The NLEAP model has been tested for general useability by a team of reviewers, and is being validated against lysimeter and groundwater data obtained from Ohio, Minnesota, Nebraska, Iowa, and Michigan. For exam-

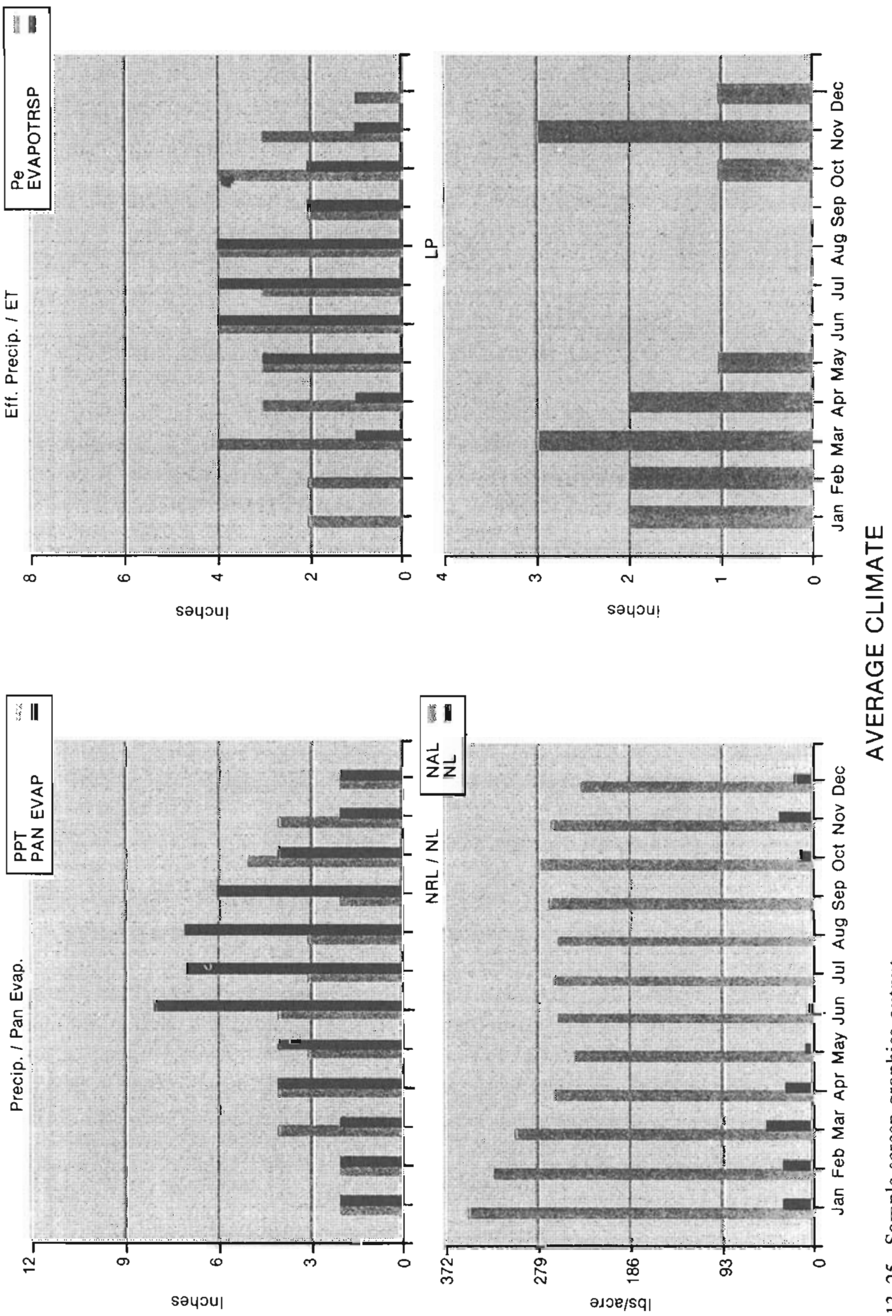


Fig. 13-25. Sample screen graphics output.

ple, we made a 5-yr (1971–1975) comparison of NLEAP estimates with observed values for monthly leachate volumes and NO_3-N leached from USDA-ARS lysimeter Y103 B located at Coshocton,OH, (Chichester, 1977). These results are shown in Fig. 13–26 and 13–27, and indicate that 91 and 86% of the variability in the leachate volumes and mass of NO_3-N leached, respectively, were predicted by the model. NLEAP reproduced the general seasonal trends in the data and correctly selected the leaching indices in each of the 5 yr.

In a second validation study, NLEAP was used to simulate tile drain flows in Boone County, Iowa (Baker et al., 1975). Figure 13–28 shows a comparison of predicted and observed NO_3-N period from 1970 to 1973. NLEAP accounted for 87% of the variability observed in the NO_3-N mass leaving the drains.

13–6 MODEL LIMITATIONS

The NLEAP model was not designed to answer every question regarding potential leaching of NO_3-N. The user must be aware of the limitations of various portions of the model, and decide when another approach or technique within or outside the model might be more appropriate. The screening procedure is designed to give only a general estimate of potential leaching of NO_3-N. The LI portion estimates total annual deep percolation of water without regard to the NO_3-N content. The NAL portion estimates the amount of NO_3-N available for leaching, and the Annual Leaching Risk Potential (ALRP) gives a qualitative estimate of the combined effects of LI and NAL values. However, since leaching of NO_3-N often depends on the relative timing and magnitude of individual precipitation, irrigation, and management events, the more detailed approaches such as the monthly and event-by-event budgets are recommended if the screening analysis indicates a medium to high ALRP or if a domestic water supply is involved.

The monthly budget approach allows the inclusion of seasonal and monthly effects on NO_3-N leaching that include changes in precipitation, temperature, evapotranspiration, and management. The reliability of the results is enhanced by the monthly approach. However, since daily precipitation and irrigation values are accumulated for each month, the user should be careful about using the procedure on sandy or other coarse-textured soils, particularly when they are accompanied by relatively high levels of precipitation or irrigation. The approach is not recommended when an analysis is being made concerning potential NO_3-N leaching to a domestic water supply.

The event-by-event water and N budget tracks the impacts of each precipitation, irrigation, fertilizer, and tillage event on potential NO_3-N leaching. This approach provides the best estimates of NO_3-N leaching available in this model. Its limitations center on cases where proper consideration of rapid water infiltration, leaching, denitrification, and NH_3 volatilization require time steps smaller than 1 d, where complex layering

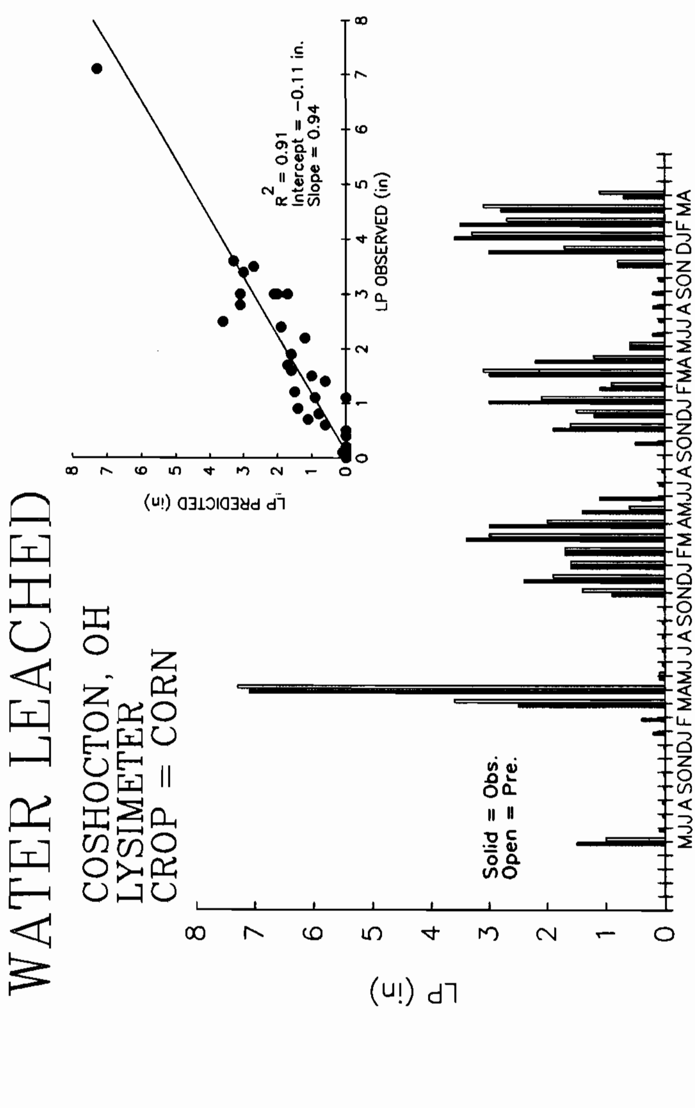


Fig. 13-26. Observed vs. predicted leachate volumes for lysimeter Y103 B, Coshocton, OH.

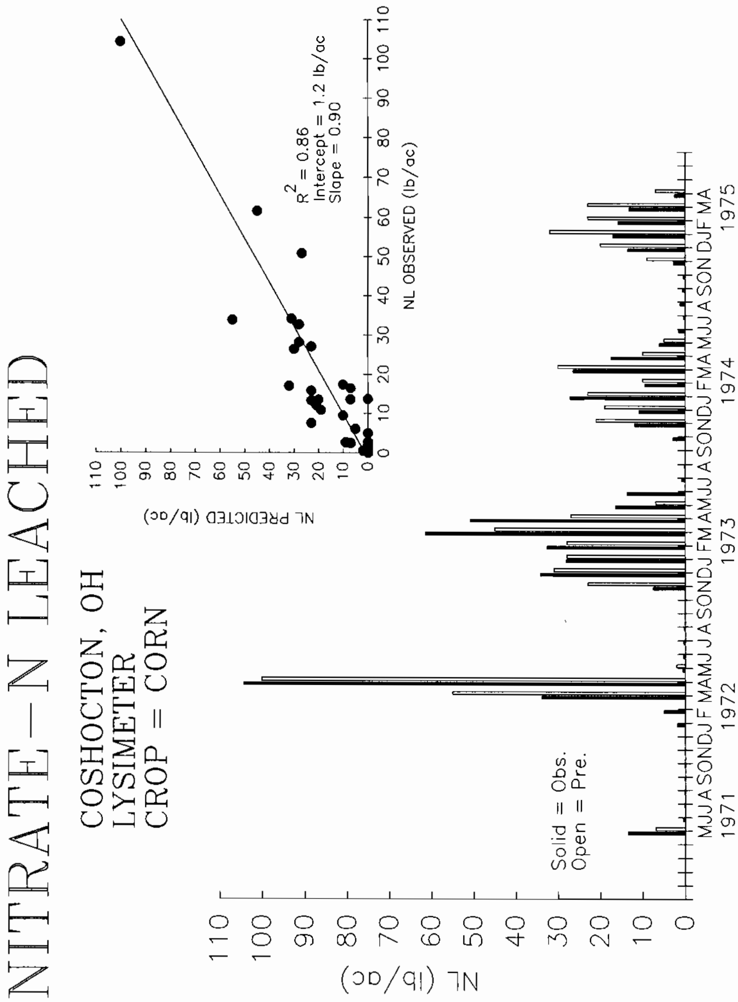


Fig. 13-27. Observed vs. predicted nitrate-N mass leached for lysimeter Y103 B, Coshocton, OH.

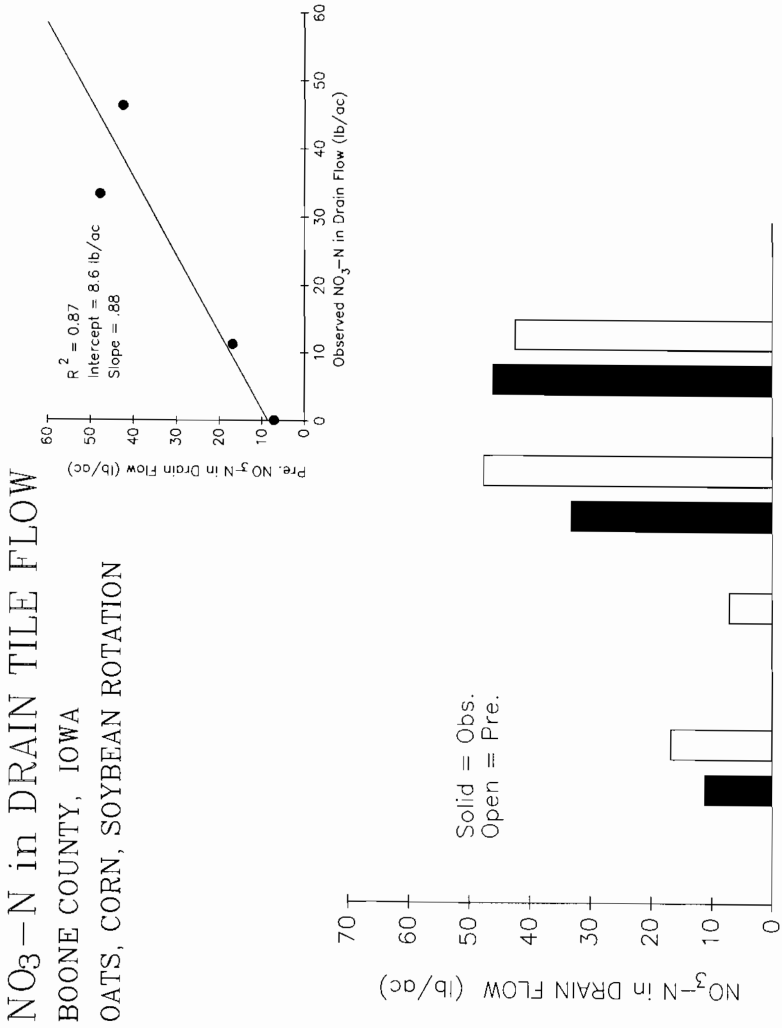


Fig. 13-28. Observed vs. predicted nitrate-N in tile drain discharge, Boone County, Iowa.

is occurring in the soil profile, where a shallow water table is supplying water to the crop, and where water and solute transport in the aquifer are important considerations. In these cases, detailed models such as NTRM, Shaffer and Larson (1987); EPIC, Williams et al. (1984); and CSU-GWFLOW, Warner (1987) are available that are more capable of dealing with these situations.

APPENDIX

Glossary of variables used in the calculation procedure.

Variable	Description
A	Area of field or farm (acre).
AA	Surface area of the aquifer (acre).
ALRP	Annual leaching risk potential.
AMV	Aquifer mixing volume (acre-feet).
ARI	Aquifer risk index.
ASW	Available soil water (in.).
$AWHC_d$	Water-holding capacity of the material below the root zone (in.).
AWHC1	Water-holding capacity of the top foot (in.).
AWHC2	Water-holding capacity of the lower horizon (in.).
CEC	Cation exchange capacity (meq/100 g soil).
CN	Carbon to nitrogen ratio of crop residues, manure, and other organic wastes.
CRES	Carbon content of crop residues, manure, and other organic wastes (lb/acre).
CRESR	Carbon metabolized from crop residue, manure, and other organic wastes (lb/[acre time step]).
Depth	Maximum depth of water penetration below the root zone (ft).
ET	Evapotranspiration (in./time step).
ET1	Potential ET associated with the top foot (in./time step).
ET2	Potential ET from the lower horizon (in./time step).
ET_p	Potential ET (in./time step).
ET_{ps}	Potential evaporation at the soil surface (in./time step).
ET_{pt}	Potential transpiration (in./time step).
EV_p	Average daily pan evaporation during the time step (in./d).
fNU	Fractional N uptake demand at the midpoint of the time step (0–1).
ITIME	Length of time step (days).
K	Leaching coefficient (unitless).
k_{af}	Rate coefficient for ammonia-N volatilization (1/d).
k_{crop}	Crop coefficient (0–1).
k_{det}	Rate coefficient for denitrification (1/d).
k_n	Zero order rate coefficient of nitrification (lb/acre d).
k_{manr}	Rate coefficient for mineralization of manure (1/d).
k_{omr}	Rate coefficient for mineralization of soil organic matter (1/d).
k_{pan}	Pan coefficient (0–1).
k_{resr}	Rate coefficient for mineralization of crop residues (1/d).
LI	Leaching index.
LP	Leaching potential or potential deep percolation (in./time step).

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Appendix continued.

Variable	Description
MDL	Maximum depth of leaching below root zone (ft).
MRI	Movement risk index (0–1).
N	Nitrogen.
NAF	Ammonium-N content of the top foot (lb/acre).
NAF_f	Ammonium-N added from fertilizers (lb/[acre time step]).
NAF_{oth}	Ammonium-N lost to runoff and erosion (lb/[acre time step]).
NAF_p	Ammonium-N added from precipitation and irrigation (lb/[acre time step]).
NAF_s	Ammonium-N content of the surface (lb/acre).
NAF_{rsd}	Residual soil ammonium-N (lb/acre).
NAL	Nitrate-N available for leaching from the root zone (lb/[acre time step]).
NAL1	Nitrate-N available for leaching from the top foot (lb/[acre time step]).
NAL2	Nitrate-N available for leaching from the lower horizon (lb/[acre time step]).
$Navail_1$	Nitrate- + ammonium-N available for uptake in the upper horizon (lb/[acre time step]).
$Navail_2$	Nitrate-N available for uptake in the lower horizon (lb/[acre time step]).
N_c	Initial NO_3-N concentration in the AMV (ppm).
N_{det}	Nitrate-N lost to denitrification (lb/[acre time step]).
N_{dmd}	Nitrogen uptake demand (lb/[acre time step]).
N_f	Nitrate-N added to the soil from fertilizers (lb/[acre time step]).
N1T1	Nitrate-N content of the top foot (lb/acre).
N1T2	Nitrate-N content of soil at 1–5 ft depth (lb/acre).
NL	Nitrate-N leached from the root zone (lb/[acre time step]).
N_l	Nitrate-N leaving the AMV in pumped wells, tile drains, and other flows (lb/time step).
NLEAP	Nitrate Leaching and Economic Analysis Package.
NL1	Nitrate-N leached from the top foot (lb/[acre time step]).
NMANR	Net N mineralization from manure plus other organic wastes (lb/[acre time step]).
NO_3-N	Nitrate-nitrogen
N_n	Nitrate-N produced from nitrification of ammonium-N (lb/[acre time step]).
N_{NH_3}	Ammonia-N volatilization (lb/[acre time step]).
NOMR	Ammonium-N mineralized from soil organic matter (lb/[acre time step]).
N_{oth}	Nitrate-N lost to runoff and erosion (lb/[acre time step]).
N_p	Nitrate-N added from precipitation and irrigation (lb/[acre time step]).
N_{plt}	Nitrate-N uptake by the crop (lb/[acre time step]).
NPLTA	Ammonium-N uptake by the crop (lb/[acre time step]).
NRES	N content of residue, manure, other organic waste (lb/acre).
NRESR	Net mineralization of ammonium N from crop residues (lb/[acre time step]).
N_{sl}	Nitrate-N entering the AMV from sources outside the farm or field (lb/time step).
NWET	Number of days of effective precipitation (precip. > 0.0) during the time interval.
OMR	Soil organic matter (lb/acre).

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Appendix continued.

Variable	Description
P_c	Carbon fraction of residues.
P_e	Effective precipitation (in./time step).
PI	Percolation index.
PLN	Potentially leachable nitrate-N (i.e., the difference between N inputs and plant N uptake).
POR1	Porosity of the top foot (in.).
POR2	Porosity of the lower horizon (in.).
RES	Crop or other organic residues (lb/acre).
SCS	U.S. Soil Conservation Service.
SI	Seasonal index.
SSA	Soil survey area.
SSSA	Soil Science Society of America.
S_{t1}	Available water in top foot at end of previous time step (in.).
S_{t2}	Available water in lower horizon at end of previous time step (in.).
T	Soil temperature (°F).
TFAC	Temperature stress factor (0–1).
TMOD	Soil tempterature (°C).
TNU	Total N uptake (lb/[harvest unit time step]).
USDA	U.S. Department of Agriculture.
W	Thickness of the AMV (ft).
WAL	Water available for leaching from the bottom of the soil profile (in./time step).
WAL1	Water available for leaching from top foot (in./time step).
WFP	Percent water-filled pore space (%).
WFAC	Water stress factor (0–1).
YG	Crop yield goal or maximum yield (units of yield/acre).
YLD	Crop yield (units of yield/acre).

REFERENCES

Baker, J.L., K.L. Campbell, H.P. Johnson, and J.J. Hanway. 1975. Nitrate, phosphorus, and sulfate in subsurface drainage water. J. Environ. Qual. 4:406–412.

Chichester, F.W. 1977. Effects of incresed fertilizer rates on nitrogen content of runoff and percolate from monolith lysimeters. J. Environ. Qual. 6:211–217.

Earthinfo, Inc. 1989. CLIMATE DATA. Summary of the day. Natl. Oceanic and Atmospheric Admin., Natl. CD ROM Disc. Climate Data Ctr., Boulder, CO.

Food and Agriculture Organization of the United Nations. 1986. Early agrometeorological crop yield assessment. FAO Plant Production and Protection Paper 73. FAO, Rome.

Gilmour, J.T. 1984. The effects of soil properties on nitrification and nitrification inhibition. Soil Sci. Soc. Am. J. 48:1262–1266.

Linn, D.M., and J.W. Doran. 1984. Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. Soil Sci. Soc. Am. J. 48:1267–1272.

Marion, G.W., and C.H. Black. 1987. The effect of time and temperature on nitrogen mineralization in artic tundra soils. Soil Sci. Soc. Am. J. 51:1501–1508.

Nommik, N. 1956. Investigations of denitrification in soil. Acta Agric. Scand. 6:195–228.

Shaffer, M.J., and W.E. Larson (ed.). 1987. NTRM, a soil-crop simulation model for nitrogen, tillage, and crop-residue management. USDA Conserv. Res. Rep. 34-1. USDA-ARS. Natl. Tech. Info. Serv., Springfield, VA.

Shaffer, M.J., J.B. Swan, and M.R. Johnson. 1984. Coordinated farm and research management (COFARM) data system for soils and crops. J. Soil Water Conserv. 39:320–324.

U.S. Soil Conservation Service. 1990. Soils-5 and Soils-6 data bases. SCS, Ames, Iowa.

Warner, J.W. 1987. Mathematical development of the Colorado State University finite element 2-dimensional groundwater flow model SCU-GWFLOW version FEM2D3.1. Groundwater Tech. Rep. 2, Colorado State Univ., Fort Collins.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1984. A modeling approach to determining the relationship between erosion and soil productivity. Trans. ASAE 27:129–144.