Comparisons of simulated and observed labile phosphorus concentrations in the soil on watershed ISU-1 were not as good in the plow layer as comparisons of the nitrogen species (Figs. 40-42). Observed P (Bray test) was low for all depths on all sampling dates compared with simulation results. Even the early season sampling did not show labile P concentrations as high as would be expected from fertilizer application at planting on April 19, 1977. A major erosion-producing storm on the day of fertilization resulted in a concentration of 69 μg available P/g of sediment (Baker et al., 1978). This indicates a high concentration in the surface-active layer of soil, assumed to be 1 cm depth. Between application date and the date of first sampling (May 24), observed available P in the plow layer was extremely low. One explanation of the difference between observed and simulated values might be that the soil chemical characteristics was such that a major portion of the total P tightly bound unavailable mineral form.

Observed and simulated annual runoff volumes and associated nitrogen and phosphorus, and sediment yield data are shown in Table 7. Most of the runoff and sediment and associated N and P losses in 1976 resulted from snowmelt runoff in February and March. A high-intensity rainfall event with 2.9 cm in May resulted in little runoff, but caused most of the observed sediment loss. No runoff was simulated on that date due to the simulated soil water content when using only daily rainfall as input. In 1977, runoff was over-estimated, but the sediment yield for the year compared fairly well. Runoff was over-estimated again in 1978. Nitrogen and phosphorus in runoff and sediment yield data were not readily available for comparison in 1978 (Baker et al., 1978; Johnson, 1978).

Table 7. Observed and simulated annual runoff, sediment yield, and associated N and P losses, watershed ISU-1, Tama County, Iowa, 1976-78.

	Runoff						Sediment Yield	
			Nitrogen		Phosphorus			
Year	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
	cm	cm	kg/ha	kg/ha	kg/ha	kg/ha	t/ha	t/ha
1976	5.84	5.72	2.05	1.50	0.02	0.10	2.62	4.28
1977	0.98	6.92	0.37	2.63	0.08	0.05	3.76	4.36
1978	4.57	8.74	NA	1.58	NA	0.34	NA	3.53

TIFTON, GEORGIA

A 10-yr study was conducted on a 0.35 ha field near Tifton, Georgia, to measure runoff and lateral subsurface flow for wide range of crops and management practices (Knisel et al., 1991). Jackson et al (1973) reported nitrate losses associated with the two flow components during the early part of the study. Hubbard and Sheridan (1983) later reported the results of the complete study. These data were selected for validation of the **GLEAMS** plant nutrient component.

Surface and subsurface flow was sampled for NO_3-N determination, and loads were calculated for the two flow components for the duration of the study, 1969-1978. The cropping system, after about 20 years with only weeds and grass, consisted of: corn 4 years; winter oats-peanuts double crop 1 year; winter oats-soybeans double crop 3 years; corn with rye winter cover 2 years. Inorganic fertilizer was applied at varying rates each year. Although the cropping system included legumes, fertilizer was applied in those double-crop years also.

The soil on the study site, watershed Z, is Cowarts loamy sand (fine-loamy, siliceous, thermic Typic Hapludults) overlying a relatively impermeable mottled clay stratum at about 70-90 cm depth. In an undrained condition, a perched water table fluctuates within the root zone at times each year. An interceptor drain tile was installed at the lower side of watershed Z when the study began, and the flow was routed through a weir for measurement (Knisel et al., 1991). Although the surface and subsurface contributing areas are not coincident, the impermeable layer causes the watershed to act as a natural lysimeter.

GLEAMS does not contain lateral subsurface routing and percolation is assumed to move vertically out of the bottom of the root zone. The model does not simu-late prolonged percolation as measured for extended periods at the tile outlet. Prolonged flow in the real-world system allows additional time for water and nutrient uptake as well as longer time for denitrification. This would tend to over-estimate percolation (compared with tile outflow) and to over-estimate NO_3-N leaching compared with measured values.

Cumulative observed NO_3-N from tile outflow and cumulative simulated NO_3-N leached are shown in figure 43. Simulated leaching is more than twice that observed in subsurface outflow. The magnitude of this difference was not expected but the larger simulated loss was expected. Also shown in figure 43 is the cumulative model-simulated denitrification which is almost as much as the observed tile outflow load.

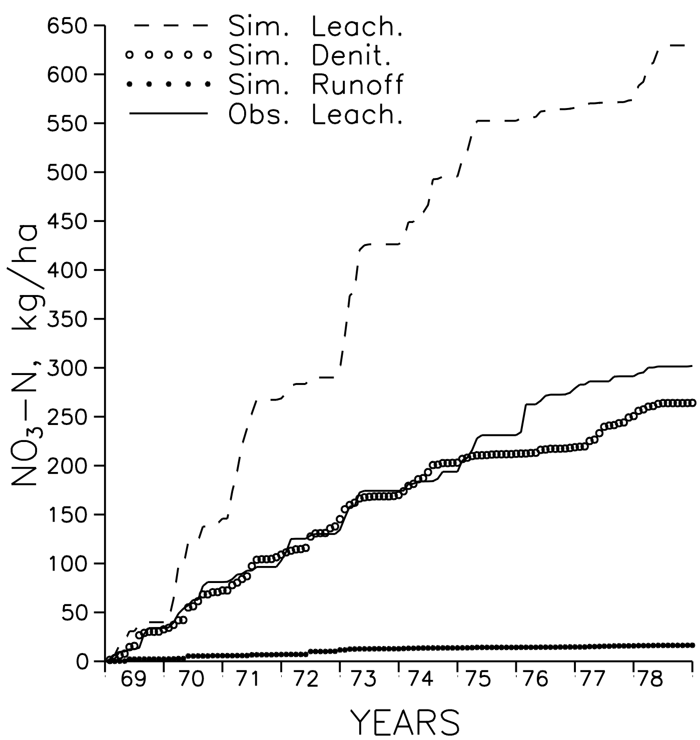

Fig. 43. Simulated and observed NO_3-N leached and runoff nitrogen, and simulated denitrification, watershed Z, Tifton, Georgia, cumulative loads 1969-78.

Observed nitrogen loss in surface runoff was not readily available, but cumulative simulated runoff nitrogen is shown in figure 43 for relative com-parison with the other losses. As expected, surface runoff loss is relatively low because surface runoff duration is short compared with tile drain outflow.

PARAMETER SENSITIVITY

Parameter sensitivity is site-specific. For example, if a sandy soil is being represented, nitrate-nitrogen and labile phosphorus concentrations are sensitive for leaching. The same variables are relatively insensitive for clay soils with a low saturated conductivity and high water retention characteristics. However, those variables may be more sensitive for nutrient uptake on a clay soil in a humid climate. In a semi-arid region without irrigation, precipitation may limit the water balance components (runoff, percolation, and evapotranspiration) such that none of the parameters are very sensitive. For these reasons, it is very difficult to make positive statements about parameter sensitivity that model users will not find erroneous for some particular application. It behooves the user to obtain site-specific data, when available, to aid in fine-tuning model parameters. Even though relative comparison of management alternatives is the primary concern, the model should be expected to produce the best "ball-park" estimate possible. These ideas should be kept in mind when viewing the following discussions.

Initialization of the nitrogen and phosphorus pools in **GLEAMS** may be very sensitive depending upon the simulation. When the model output is being compared with observed data and significant storms occur shortly after simulation, the initial values may be very sensitive for those storms. This is particularly true for NO_3-N (CNIT) and labile P (CLABP). In long-term simulations for management comparisons, these parameters are not sensitive. Particularly CNIT is very dynamic, i. e. changes rapidly due to mineralization, immobilization, leaching, uptake, and denitrification. The model user should make every effort to obtain the best estimate possible for initial values, and rely only on default values as a last resort.

The less dynamic pools TN, POTMN, ORGNW, TP, and ORGPW are less sensitive because of the conceptualized "flow" between pools. The long-term stable pools and their interactions were formulated to represent those fractions that maintain stability of the system. Long-term simulation, e. g. 50 years, may reveal a very significant change in these stable pools due to climate, soil, and management, or due to improper initialization. Default values for these parameters must be highly averaged conditions, because it is impossible for the model developers to know *a priori* what soil or management will be represented.

Crop characteristics may be sensitive depending upon climate and management. Potential yield (PY) and leaf area index (LAI) may be sensitive in climatic regions or with irrigation where water stress is not significant. Current crop rooting depth (CCRD) may be sensitive under potential water stress conditions. Nutrient uptake may be sensitive to the crop coefficient and exponent (C1 and C2, respectively) for intensive, high fertilization, management systems.

Animal waste characteristics (ATN, APORGN, ANH, APHOS, APORGP, and AOM) and the methods of application are sensitive parameters. As discussed in Part III: User Manual (Knisel et al., 1993), model default values for the different animal types basically represent "as excreted" characteristics. Methods of handling and storage, and mixture of bedding or litter significantly affect the characteristics as applied in a management system. The validation with the Watkinsville, Georgia broiler litter data showed that the 4x treatment had significantly higher leaching losses than the 1x treatment, both from the model simulation and observed data. Although the same litter characteristics were used for both treatments, the comparisons indicate the potential sensitivity of constituent elements. The method of application is sensitive for surface-applied versus incorporated or injected due to ammonia volatization losses. Even this loss is less sensitive when considering winter application in cold regions.

Depth of incorporation of animal waste or inorganic fertilizer (DEPIN) may be a sensitive parameter for nitrogen and phosphorus in runoff and leaching, and for ammonia volatization from animal waste. The sensitivity is dependent upon cli-matic conditions, crop uptake, denitrification and time of application relative to runoff- or percolation-producing rainfall.

Nitrogen and phosphorus levels change slightly from year-to-year with changes in fertilization/cropping practices. A long-term management system may result in a balance of the various conceptual pools with negligible change. If a sig-nificant change in management occurs, a gradual change in simulated pools may occur. This probably is real, and little is known about how long the change, either increase or decrease, will last. It is a function of climate and degree of change in management. Initialization of the various pools in the model may be based upon some historic sampling, from pedon data, or default values based upon averages for a range of soils and possibly even climatic ranges. By the very nature of the initialization, a significant change in pool sizes very likely will be simulated with any kind of management system. This is to be expected, and the user should not get alarmed that "the model is wrong". On the contrary, the model may be giving a very realistic result of initialized values, manage-ment, and climatic interactions. These changes do not detract from the objective of the model, that is, to estimate the differences in management practices.

A 50-year simulation was made for a Cecil sandy loam soil at Watkinsville, Georgia to observe the status of the various pools. The first simulation was made for continuous corn for grain with a split application of about 145 kg/ha ammonium nitrate fertilizer, and residue was plowed under. At the end of the simulation, the active and stable soil N pools had increased about 6 kg/ha/yr. Another 50-yr simulation for corn silage (removal of grain + stover) resulted only a slight increase in active soil N pool and a slight decrease in the stable soil N pool. We do not know if these values are correct, but removal of most of the above ground biomass as yield should result in less mineralizable N as indicated by the simulation.

It is readily seen that interactions are very important in estimating sensi-tivity of parameters. Blanket statements about sensitivity cannot be made with absolute certainty.

EVAPOTRANSPIRATION COMPARISONS

Evapotranspiration was calculated with **GLEAMS** at several locations using both the Priestly-Taylor and Penman-Monteith options. Lysimeter data were not avail-able for component validation. Even though proper validation could not be made, the comparative results are shown here for model users' information.

Locations used in the ET comparisons are shown in Table 8 along with the length of simulation at each location. The 10 locations represent a wide range of climatic conditions.

Model simulations were made for continuous corn at each location merely to have the same crop, not that corn would be grown continuously at any location. Representative soils of the areas were used as shown in Table 8. Model-applied irrigation was simulated for all locations except Coshocton, Ohio and Riesel, Texas where irrigation is not normally practiced. Comparative simulations were made without irrigation, also, and the results are summarized in Table 9.

Table 8. Locations and lengths of record for comparing evapotranspiration estimates with **GLEAMS** using Priestly-Taylor and Penman-Monteith methods.

Location	Soil*	Record Period

Orlando, Florida	Lakeland ls	1923-72
Tifton, Georgia	Cowarts ls	1941-90
Tama County, Iowa	Tama sil	1976-78
East Lansing, MI	Spinks lfs	1974-75
Hastings, Nebraska	Hastings sicl	1941-54
Albuquerque, NM	Billings sil	1941-47
Coshocton, Ohio	Keene sil	1939-68
Corvallis, Oregon	Amity sil	1961-89
Riesel, Texas	Houston black c	1941-90
Stevens Point, WI	Plainfield ls	1963-82

*Soil textures are: ls = loamy sand; sil = silt loam; lfs = loamy fine sand; c = clay; sicl = silty clay loam.

Table 9. Evapotranspiration simulated with **GLEAMS** model using Priestley-Taylor (P-T) and Penman-Monteith (P-M) methods.

Location	Years	Rain-fall	Evapotranspiration			
			With Irrigation		Without Irrigation	
			P-T	P-M	P-T	P-M
		cm	cm	cm	cm	cm
Orlando, FL	50	130.58	93.21	91.94	90.23	86.06
Tifton, GA	50	119.65	84.35	80.47	76.62	72.29
Tama Co., IA	3	74.65	74.54	68.35	65.93	59.25
East Lansing, MI	2	81.94	65.30	62.08	61.82	61.43
Hastings, NE	14	58.98	61.01	55.71	49.06	39.56
Albuquerque, NM	7	20.49	42.38	47.43	-.-	-.-
Coshocton, OH	30	89.60	-.-	-.-	62.90	59.25
Corvallis, OR	29	108.74	68.52	69.67	49.36	50.53
Riesel, TX	50	88.21	-.-	-.-	59.31	54.52
Stevens Point, WI	20	74.46	62.97	61.14	53.28	50.34

Average annual evapotranspiration simulated with the Priestley-Taylor method (Priestley and Taylor, 1972) was greater than that using Penman-Monteith (Monteith, 1965) for all locations except Albuquerque, New Mexico and Corvallis, Oregon (Table 9). Jensen et al. (1990) stated that Priestley-Taylor estimates were too high and the method should not be used in irrigated areas [assumed by the present authors to mean "western" irrigated areas] because the P-T method assumes the soil surface is moist. The data in Table 9 refutes this claim for the two most western locations, especially Albuquerque. The data shown in Table 9 are not based upon observed measurements, and therefore no claim can be made about the relative merits of the two methods.

ET estimation is normally made for growing season only (Jensen et al., 1990), but year-round simulation is needed for water quality loading models such as **GLEAMS**. Averaging of data such as in Table 9 is merely for convenience of reporting results that vary in time or space, or both. These data obscure some features that may be significant in water quality implications. Again showing averages for the period of simulation, monthly values of runoff, percolation, ET, and irrigation are shown in Table 10 for the two methods at Albuquerque. Runoff using the Penman-Monteith method was about doubled that using the Priestley-Taylor method. Percolation below the 56-cm root zone was about the same, but the P-M method resulted in 6 cm/yr more irrigation than estimated using the P-T method.

Table 10. Average monthly runoff, ET, percolation, and irrigation for the period of simulation using the P-T and P-M methods at Albuquerque, New Mexico.

Month	Priestley-Taylor				Penman-Monteith			
	Runoff	ET	Perco-lation	Irrigation	Runoff	ET	Perco-lation	Irr-iga-tion
	cm	cm	cm	cm	cm	cm	cm	cm
Jan	0.00	0.49	0.00	0.00	0.00	0.47	0.00	0.00
Feb	0.01	0.80	0.00	0.00	0.01	0.89	0.00	0.00
Mar	0.00	1.61	0.00	0.00	0.00	1.81	0.00	0.00
Apr	0.00	1.19	0.00	0.00	0.00	1.05	0.00	0.00
May	1.20	1.76	0.34	7.53	1.22	1.22	0.54	7.36
June	0.09	2.58	4.03	5.18	0.10	1.28	3.17	3.08
July	0.09	6.05	0.62	4.09	0.09	3.92	1.00	2.28
Aug	0.05	18.56	0.34	11.57	1.45	30.04	0.18	21.69
Sep	0.09	6.28	0.00	0.00	0.09	3.78	0.00	0.00
Oct	0.00	1.66	0.00	0.00	0.00	1.66	0.00	0.00
Nov	0.00	0.70	0.00	0.00	0.00	0.69	0.00	0.00
Dec	0.00	0.70	0.00	0.00	0.00	0.62	0.00	0.00
Total	1.53	42.38	5.33	28.37	2.96	47.43	4.89	34.33

Similar changes in monthly amounts occurred at other locations. More irrigation was simulated using P-T at East Lansing, MI, Tifton, GA, Orlando, FL, Hastings, NE, and Stevens Point, WI. Simulated irrigation was about the same for both methods at Corvallis, OR, and Tama County, IA.

SUMMARY

Results of validation indicate that **GLEAMS** can be used to compare management alternatives in development of resource conservation systems. The broiler litter study at Watkinsville, Georgia provided data for comparing animal waste loading alternate practices. The comparison was relatively good considering the overall treatments, and mineralization of organic nitrogen was in the right order of magnitude for the treatments.

GLEAMS tends to under-estimate the very dynamic NO_3-N late in the season, but during the growing season, simulated soil concentrations were within the range of variability of field data. Simulated runoff losses of nitrogen and phosphorus were in good agreement with observed losses.

The Priestley-Taylor method resulted in more simulated evapotranspiration than the Penman-Monteith method at all locations except Albuquerque, New Mexico and Corvallis, Oregon. Observed ET data were not available, but comparison of the two methods at 10 locations indicate that either method is appropriate for year-round simulation except possibly in semi-arid regions.

GLEAMS is not a predictive model in the sense of absolute quantities, but it can be used for relative comparisons. The validation study made here emphasizes earlier reports by Leonard and Knisel (1990) on validating pesticide transport models.

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