Paper No. 97-2209
An ASAE Meeting Presentation

USING APEX TO INDENTIFY ALTERNATIVE PRACTICES FOR ANIMAL WASTE MANAGEMENT

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**Written for Presentation at the
1997 ASAE International Meeting
Sponsored by ASAE**

Minneapolis Convention Center
Minneapolis, Minnesota
August 10-14, 1997

Summary:

This paper describes the analyses of alternative management practices for animal waste application areas using a hydrologic/water quality model, Agricultural Policy Environmental eXtender (APEX). Two micro-watersheds with intensive dairy operations were the study areas for this work. Initially, the model was calibrated and validated using observed stream monitoring data from three monitoring stations (Part I). The model was found suitable for long-term analysis of alternative management practices. In Part II we analyzed five alternative management practices with six manure-application rates for each scenario in one of the micro-watersheds. The aim of these analyses was to maximize the nutrient uptake by the crops, and to match the manure application to the crop uptake of nutrients. From the results we conclude that through proper agronomic management and adopting a watershed management approach, sustainable water quality can be achieved with minimal hauling of surplus manure out of the watershed.

Keywords:

nonpoint source pollution; hydrologic/water quality model; animal waste management; water quality

USING APEX TO IDENTIFY ALTERNATIVE PRACTICES FOR ANIMAL WASTE MANAGEMENT: PART - I: MODEL DESCRIPTION AND VALIDATION [1]

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Abstract

Proper waste management of confined animal feeding operations is critical to the sustained health of the water bodies. This work describes the analysis of alternative management practices for waste application areas using a hydrologic/water quality model, Agricultural Policy Environmental eXtender (APEX, Williams et al., 1997), and a watershed management approach. Two micro-watersheds with intensive dairy operations in the Upper North Bosque River watershed in Texas were the study area. In this first part of a two-part paper, we calibrated and validated the model using observed stream monitoring data from three monitoring stations. We used graphical (time series plot and scattergram) and statistical (mean deviation, correlation coefficient and modeling efficiency) techniques with a set of acceptance criteria for model evaluation. Simulated flows matched fairly well with the observed flow at all three monitoring points, but showed temporal discrepancies at some instances. Spatial variability of rainfall could have been a major reason for these discrepancies. The sediment and nutrient simulations at several instances showed temporal discrepancies between observed and simulated values. However, the mean simulated values matched with the observed values indicating that the model is suitable for long-term simulation experiments. Considering the fact that we were trying to simulate natural processes involving several uncertainties, the model performance was acceptable for long-term experiments that analyze different management scenarios.

Introduction

Phosphorus in the streams of Southern Plains has become an important issue of concern to a rapid increase in the number of confined animal feeding operations (Sharpley and Smith, 1995). U.S. Environmental Protection Agency (EPA) reports nutrient enrichment as the leading cause for impairment of lakes in the United States with agriculture as a major source of these nutrients (USEPA, 1994). Animal manure is often disposed in limited areas near the feeding sites due to the cost of high transportation. Repeated

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applications of manure can lead to soil nutrient accumulation levels higher than crop nutrient uptake rates resulting in surface and ground water pollution (Cooper et al., 1984).

Sharpley and Smith (1995) analyzed long-term soil nutrient accumulations and concluded that long-term application of animal manure can influence the relative fractions and availability of soil P more than soil N, thus increasing the soil productivity and also the potential for P transport in runoff. Therefore, alternative management practices (best management practices) for animal waste management must be tested and implemented for efficient utilization of animal manure to avoid potential nutrient pollution in water bodies.

Computer models that describe the soil-water-plant-nutrients relationships could be cost-effective tools to analyze the relative effectiveness of alternative management practices. In this study, we used a multi-field (micro-watershed scale) model, APEX (Agricultural Policy/Environmental eXtender, Williams et al., 1997) to analyze alternative management practices to reduce nutrient loading to streams from the dairy operations. In this part of a two-part paper we calibrated and validated the model for two micro-watersheds in Upper North Bosque Watershed (Figure 1). In Part II we analyzed the effects of selected alternative management practices on reducing nutrients loading from dairy waste applications in one of the micro-watersheds.

Materials and Methods

Upper North Bosque Watershed

The Upper North Bosque River (UNBR) watershed (Figure 1) is defined as the drainage area of North Bosque River above Hico, Texas, which flows into Lake Waco. Lake Waco served as the drinking water source for City of Waco (about 140,000 people). The UNBR drains approximately 92,500 ha and contains about 94 permitted dairies having approximately 34,000 cows. A majority of the UNBR watershed lies in Erath county. While dairy is a major agricultural enterprise in the watershed, peanut, beef cattle, pecan orchard, and hay operations are also important land uses. There are 40 Natural Resources Conservation Service (NRCS) Public Law 566 (PL-566) flood control reservoirs in the UNBR watershed that provide sediment retention and flood control. The Texas Institute for Applied Environmental Research (TIAER) has monitored agricultural nonpoint source runoff in the UNBR watershed since 1991 (McFarland and Hauck, 1995).

Description of the Study Area

In order to validate APEX for its applicability in the UNBR watershed, we chose two micro-watersheds, (i) North-Fork (NF) and (ii) Goose Branch (GB) (Figure 1). Both these watersheds are about 1,500 ha in area (Figures 2a and 2b). There is a NRCS PL-566 reservoirs at the mouth of each watershed. However, we did not include these reservoirs in our simulations with APEX. In this paper we have given only a brief description of the micro-watersheds. Detailed descriptions can be found in reports by McFarland and Hauck (1995 and 1997).

Land Use

Land uses of the watersheds were determined from Landsat Thematic Mapper (TM) imagery classification supplemented with ground truthing. The land use distribution in both watersheds were fairly similar expect for forest and range land, with major land use as improved pasture (mostly coastal bermuda grass - *Cynodon dactylon (L.)*) (Table 1).

Soils

Soil maps for the watersheds were developed by USDA-NRCS by digitizing the county soil survey maps into a GIS. The soil physical properties were obtained from Soils5 and STATSGO databases of NRCS (NRCS, 1994). Important soil series in these watersheds are Windthorst, Purves, Duffau, Bunyan, Bolar, and Blanket (Table 2). Textural classifications range from clay (Purves) to fine sandy loam (Windthorst, Duffau, and Bunyan). Purves is a shallow soil series with average profile depth of less than 0.5 m. The Windthorst, Duffau, Bunyan, and Blanket have average profile depths of more than 1.5 m.

Dairy Locations and Milking Herd Distribution

There are three major dairies in the NF watershed with a total permitted herd size of 2,050 cows. The average estimated milking herd size is about 1,300 cows. Most of the waste application fields are distributed in the southern portion of the watershed (Figure 2a). The total waste application in the area is about 375 ha. The GB watershed has 7 major dairies with a total permitted herd size of 3,500 cows. Waste generated from the dairy operations is applied over 675 ha within the GB watershed (Figure 2b).

APEX Model

APEX is an extension of the field-scale model Erosion Productivity Impact Calculator (EPIC) (Williams, 1995) that simulates multiple subareas (or hydrologic units) with routing of flow, sediments and nutrients to the outlet of the watershed. The processes within each subarea are similar to the EPIC model, with modifications to incorporate confined animal waste management operations (such as animal waste management options and lagoons). These options can be changed according to user-defined variables. For the sake of brevity, in this paper we are describing only selected components of APEX.

Animal Waste Management Options

The user can define the manure application rate by specifying an application area-animal ratio (ha/hd) for the entire watershed. Then for each subarea the number of animals within the subarea, the annual amount of waste generated per animal, and a typical number of manure applications per year is specified. The model estimates dry-manure load based on 9.3 kg/cow/day (ASAE, 1988). Given these inputs, the model will apply manure automatically. However, the user can choose to manually define the manure application in the model along with other management scheduling for each subarea.

The lagoon operation was simulated by specifying the normal, maximum and minimum lagoon volumes, and the portion of each subarea that drains into the lagoon. The lagoon component of the model allowed only conservative storage of nutrients, and did not consider nutrient transformations and losses during storage. The lagoon dewatering was scheduled automatically by specifying a typical dewatering interval. The lagoons got emptied according to the dewatering interval or if the lagoon became filled to the maximum storage volume.

Channel Routing Components

Flood Routing: Channel routing used a variable storage coefficient method developed by Williams (1969). Channel inputs included the reach length, channel slope, bankfull-width and depth, channel side slope, flood plain slope, and Manning's n for the channel and flood plain. Flow rate and average velocity were calculated using Manning's equation, and travel time was computed by dividing channel length by velocity. Outflow from a channel was adjusted for transmission losses, evaporation, diversions, and return flow.

Sediment Routing: The sediment routing model consisted of two components operating simultaneously (deposition and degradation). The deposition component was based on fall velocity and the degradation component was based on Bagnold's stream power concept (Bagnold, 1977). Deposition in the channel and flood plain from the subbasin to the basin outlet was based on sediment particle fall velocity. Fall velocity was calculated as a function of particle diameter squared using Stokes Law. The depth of fall through a routing reach was calculated as the product of fall velocity and reach travel time. The delivery ratio was estimated for each particle size as a linear function of fall velocity, travel time, and flow depth. Stream power was used to predict degradation in the routing reaches. Bagnold (1977) defined stream power as the product of water density, flow rate, and water surface slope. Williams (1980) modified Bagnold's equation to place more weight on high values of stream power--stream power raised to 1.5. The available stream power was used to scour loose and deposited material until all stream-bed material was removed. Excess stream power caused potential bed degradation. Bed degradation was adjusted by the USLE soil erodibility and cover factors (K and C factors) of the channel and flood plain.

Nutrients and Pesticide Routing: While the soluble portion of nutrients and pesticides was transported with water, the sediment attached portion was allowed to transport or settle along with the sediment. Chemical transformations of soluble and sediment bound chemicals were not simulated in the model. We believe that for small watersheds with small travel times, ignoring the chemical transformations is an acceptable assumption.

Model Input Data Accumulation

Using a digital elevation model (DEM -- 30m horizontal and 1 m vertical resolutions, digitized from 1:24,000 USGS 7.5 minute topographic maps), the subbasins for the micro-watersheds were delineated using a digital terrain model (DTM), TOPAZ (Ver. 1.10; Garbrecht and Campbell, 1995) in conjunction with a GIS, Geographical Resources Analysis Support System (GRASS; Shapiro et al., 1992). Over the subbasins map, the waste disposal fields, soil, and land use map layers were overlaid using GRASS, and the subareas for each micro-watershed were defined (26 and 43 subareas respectively, for NF and GB watersheds). Dominant land use within each subarea was used for the entire subarea, except for manure application areas where actual management scheduling, type of manure (solid or liquid), and crops grown were obtained from the dairy owners through state regulatory agency dairy permit documents. The dominant soil within each subarea was used for the entire subarea. Other model inputs such as average overland slope, channel slope, and USLE slope-length factor (SL) were obtained from standard GIS procedures (*r.watershed* option of GRASS) and by manual procedures using the USGS topographic maps (1:24,000 scale).

Precipitation data for the watersheds were obtained from tipping bucket recording-type(15 min interval) rain gages installed near the PL-566 reservoir (NF035) and by the South Fork of UNBR. Temperature data from a National Weather Service (NWS) weather station at Stephenville were used for both the micro-watersheds. Other meteorological information such as relative humidity and solar radiation were stochastically generated within the APEX model using long-term monthly weather statistics from Stephenville. An analysis of precipitation data from six rain gages in UNBR watershed by McFarland and Hauck (1995) showed significant spatial variability in monthly rainfall particularly during the summer months.

Model Application and Analyses

Stream Flow and Water Quality Monitoring Data

Monthly simulated results from the model were compared with observed stream flow and water quality parameters (Total Suspended Solids—TSS, organic and mineral N and P) from the sampling sites in the two micro watersheds (Figures 2a and 2b). Each site had an automated sampler with an ISCO™ 3230 bubbler-type meter and an ISCO™ 3700 automatic sampler. The ISCO 3230 meter initiates the pre-set sampling programs for the ISCO 3700 sampler when a threshold water stage (36.5 mm in our case) is exceeded. Once triggered, the samplers were programmed to take 24 one-liter sequential samples. A typical sampling sequence was (i) one initial sample, (ii) three samples at one-hour intervals, (iii) four samples at two-hour intervals, and (4) remaining samples at six-hour intervals. Samples were flow-integrated and the total loading of each constituent was estimated. McFarland and Hauck (1995) have given a detailed description of the automated sampling protocol, list of monitored constituents, and analytical and statistical methods for constituent load estimation.

Model Calibration and Validation

Daily stream flow and water quality measurements for two sites in NF watershed (NF010, and NF020 – Figure 2a) for the period September 1993 through December 1996, and one site for GB watershed (GB020 – Figure 2b) for the period May 1995 through December 1996 were available. We used the data from the period September 1993 through August 1994 of the NF010 and NF020 for calibrating the stream flow at NF010 and NF020 by adjusting the soil hydraulic conductivity, carrying capacity of streams, and stream hydraulic conductivity. The remaining period of the data (September 1994 through December 1996) was used for validating the model. We did not adjust the parameters of the model that affect sediment yield or water quality predictions. Therefore we considered the period September 1993 through December 1996 as the validation period for sediment and nutrient predictions for the NF watershed. Since the stream flow and water quality monitoring data were available only for 20 months for the GB watershed, we did not calibrate the model, but used the calibrated parameters from NF watershed.

Model Evaluation

For evaluating the model performance, we used visual techniques (time-series plot and scattergram) and statistical parameters of comparison – mean deviation (M_d) which is the difference between mean observed and simulated monthly values, correlation coefficient (r), sorted prediction efficiency (E_S), and unsorted prediction efficiency (E_{NS}) (Nash and Suttecliffe, 1970). The prediction efficiencies (sorted and unsorted) were calculated using

$$E = \frac{\sum_{i=1}^{n}(O_i - \overline{O})^2 - \sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \tag{1}$$

where E is the prediction efficiency, O_i and P_i are the observed and predicted values, respectively, $\overline{O}$ the mean of the observed values, and n is the number of samples. The value of M_d may range from $-\infty$ to ∞; r from -1.0 to 1.0; and E from $-\infty$ to 1.0.

The r value is an indicator of the strength of the linear relationship between the observed and simulated values, with zero indicating no linear relationship, and the extremes (-1.0 and 1.0) indication strong positive or negative relationships. The E_S value indicates the model's ability to describe the probability distribution of the observed results and the E_{NS} value indicates how well the plot of observed versus simulated is close to the 1:1 line. The desired values of M_d are 0, and r, and E_{NS} are 1.0. We used a *paired t-test* to check if the values of M_d are significantly different from zero at 95% confidence level.

There are no standards or a range of these comparison statistical parameters established that will adjudge the model performance as acceptable (Loague and Green, 1991). In this paper, we set a few new standards for evaluating the model performance. If the r and/or E_{NS} values are less than or very close to zero, we deemed the model performance as unacceptable or poor. If the values of r, E_{NS}, and E_S are greater than 0.5, 0.4, and 0.75, respectively, we judged the model performance as satisfactory. If the M_d value was not significantly different from zero at 95 % confidence level, the model's average predicted value during the simulation period was deemed to have corresponded acceptably with the observed values.

Results and Discussion

NF Watershed

Flow Calibration

The times series plot of observed and simulated stream flows at NF010 and NF020 (Figure 3) show that the simulated magnitudes and trends of runoff volumes match very well with the observed flows. Low M_d values for NF010 and NF020 that are significantly not different from zero at 95 % confidence level (Table 3) indicate the total flow simulated by the model at these locations during the calibration period matches well with the observed flows. The scattergrams (Figure 4) and the linear regression results (Table 3) show strong linear relationship between the observed and simulated values. The E_S and E_{NS} values are greater than 0.8, further indicating that the simulated results match very well with the observed ones.

Flow Validation

The time series plot for sampling site NF010 (Figure 5a) shows that the model predictions matched considerably well with the observed flow volumes for the period September, 1994 to July 1995. The model predicted insignificant flows from August 1995 through April 1996, whereas the observed data at NF010 shows significant flows during the same period (Figure 5a). The flows patterns look similar to base flows because runoff volume was equal to or greater than precipitation volumes. Stream flows at sampling location NF020 (Figure 5b) did not show such flow patterns and at this time we do not have adequate information on what exactly happened during that time period to make any conclusions. Further, the high flows observed during August 1995 and September 1996 (Figure 5a) were not explained by the model adequately. A positive M_d value for monthly flow volume that is significantly different from zero at 95% confidence level indicate that the model underestimated the total stream flow during the validation period (Table 3). The scattergram (Figure 6a) and linear regression results (Table 3) show a significant linear relationship between observed and simulated flows ($r = 0.65$). The slope of the regression and the E_{NS} values are significantly less than one (Table 3), indicating that the model underestimated flow. However, an E_S of 0.75 (Table 3) indicate that the model explained the probability distribution of the observed values to an acceptable extent.

The model underestimated stream flow at NF020 and the M_d value was significantly different from zero (Table 3). The statistical parameters of comparison, r, E_{NS}, and E_S (Table 3), as well as the scattergram (Figure 6b) are similar to that of NF010. However, the time series plot (Figure 5b) shows that the predicted magnitude and trends of flow were closer to the mean observed values than NF010. The observed stream flow data showed differences in flow trends between NF010 and NF020 (October 94, December 94 to May 95, September 95 to June 96, and October 96), which may be due to the spatial variability of rainfall. Such differences were not captured by the model because weather data from a single location was used for the entire watershed.

Water Quality Parameters

The model underestimated all the water quality parameters for NF010 (linear regression slope less than 1.0 – Figure 8). The M_d values for all parameters except mineral-N ($NH_4 + NO_2 + NO_3$) were significantly different from zero (Table 3). For NF010 the sediment yields (Figure 7c) during May 1995 to July 1995 showed a marked peak that was not captured by the model, and the Organic-N and P predictions, which depend on the sediment yield showed similar trends during that period. This could have been caused by bank sloughing, which was not considered in the model. The scattergrams (Figure 8) and statistical parameters for the comparisons (Table 3) show poor agreement between the observed and predicted results.

The time series plots for NF020 (Figure 9) show that the model explained the general trend of the observed values in all the cases. The scattergrams (Figure 10) show that the model generally underestimated the water quality parameters, slightly in some cases (Organic-N, and P) and more in other cases (mineral-N, mineral-P and total suspended solids). This is further confirmed by the E_{NS} values (Table 3). The average nutrient and sediment monthly loads at NF020 predicted by the model were close to the observed values (M_d values that are not different from zero at 95% confidence level for all the parameters – Table 3). The model also explained the variation in observed monthly sediment and nutrient loads satisfactorily (r value ranged from 0.61 to 0.88 – Table 3). The E_S values ranged from 0.76 to 0.96 showing the model's ability to describe the probability distributions of the observed water quality parameters.

GB Watershed

Flow Volume

The time series for GB020 (Figure 11a) show that the simulation results of flow from 14 of the 20 months were close to the observed results (including the 6 months being in the dry spell of 1995-96 – December 95 to April 96). The few discrepancies shown are probably due to the spatial variability of rainfall. A M_d value (Table 3) that is not significantly different from zero suggest that the average monthly observed and simulated results correspond well. The scattergram and slope of the linear regression line (Figure 12a) show that there is significant linear relationship between the observed and predicted values, and the model underestimates stream flow. The E_S value suggests that the model adequately described the probability distribution of the observed runoff volumes, and with E_{NS} value being greater than 0.4 and from Figure 12a, we conclude the observed Versus simulated plots are fairly close to the 1:1 line.

Total Suspended Solids

Although the M_d value between the observed and simulated sediment loads is -0.02 Mg/ha and not significantly different from zero, the correlation coefficient values (Table 3) do not show a strong linear relationship between the observed and simulated values . The E_S and E_{NS} values are both negative showing that the simulated trends do not correspond very well with the observed trends. The mean simulated results from this 20-month period corresponding well with the observed values indicates that the model is good for long-term simulation experiments even though temporal variations may not been explained very well.

Nutrients

The M_d values from the comparison of observed and simulated mineral-N and mineral-P (Table 3) are not different from zero at 95% confidence level. However, the scattergrams (Figures 12b and 12c) show that the model generally underestimated both these fractions. The mineral-N predictions do not show a strong linear relationship with the observed data (r = 0.33), but the observed and simulated mineral-P shows fairly strong linear relationship (r = 0.58). The observed Versus simulated plots are not close to the 1:1 line (E_{NS} = -0.12 and 0.20, respectively, for mineral N and P). The E_S values (Table 3) indicate that the model explains the probability distribution of the observed mineral N and P values very well.

The average monthly organic nutrient load predictions are close to the observed values (M_d values are not significantly different from zero). The scattergrams and the slopes of linear regressions (Figure 12e and 12f) show that the model underestimated organic-N and P. A negative E_{NS} value for organic-N (-0.43) indicates that the observed and simulated plots are not acceptably close to the 1:1 line, but for organic-P observed and simulated plots are fairly close to the 1:1 line (E_{NS} = 0.44). The E_S values (Table 3) show that the model explains the probability distribution of the observed values to an acceptable extent.

Overall, the model shows temporal discrepancies when compared to the observed results, but the mean monthly predictions for the 20-month period are fairly close to the observed values.

Conclusions

APEX, a hydrologic/water quality model for small watersheds/whole farms, was applied to simulate the hydrology and water quality within two micro-watersheds (NF and GB watersheds) in UNBR watershed. Monthly flow volumes, sediment, and nutrient fractions (organic and mineral), simulated by the model were compared at three monitoring locations (two within NF watershed and one in GB watershed). The following conclusions were drawn from the results of this study

1. The simulated flow volumes matched fairly well with the observed flow at two out of three monitoring points.

2. We believe that spatial variability of rainfall is the main reason for flow discrepancies, particularly during the summer and fall months.

3. The model did not predict the temporal variations of TSS load very well at two monitoring sites (NF010 and GB020). However, the mean observed and simulated values agreed fairly well at all the three locations.

4. The nutrient simulations at some instances showed temporal discrepancies between the observed and simulated values. However, the mean simulated values matched with the observed values.

5. The model simulated the average runoff volumes, TSS, and nutrient loads close to the observed results. The model also explained the temporal variation of flow and water quality parameters at several instances. Hence we conclude that the model performance is acceptable for long-term management scenario experiments.

References

ASAE. 1988. Manure production and characteristics. ASAE Standard, ASAE Data: ASAE D384.1. St. Joseph, MI: ASAE.

Bagnold, R. A. 1977. Bed load transport in natural rivers. *Water Res. Res.* 13(2):303-312.

Cooper, J.R., R.B. Reneau, Jr., W. Kroontje, and G.D. Jones. 1984. Distribution of nitrogenous compounds in a Rhodic Paleudult following heavy manure application. *J. Environ. Qual.* 13:189-193.

Garberecht, J., and J. Campbell. 1995. An automated digital landscape analysis tool for topographic evaluation, drainage identification, watershed segmentation and subcatchment parameterization. Report # NAWQL 95-3. Durant, OK: National Agricultural Water Quality Laboratory, USDA-ARS.

Loague, K. and R. E. Green. 1991. Statistical and graphical methods for evaluating solute transport models: overview and application. *J. Contaminant Hydrology* 7:51-73.

McFarland, A.M.S., and L.M. Hauck. 1995. Livestock and the environment: Scientific underpinnings for policy analysis. TIAER Report # PR95-01. Stephenville, TX: Texas Institute for Applied Environmental Research.

McFarland, A.M.S., and L.M. Hauck. 1997. Livestock and the environment: A national pilot project. TIAER Report # PR97-02. Stephenville, TX: Texas Institute for Applied Environmental Research.

Nash, J. E., and J.E. Suttecliffe. 1970. River flow forecasting through conceptual models, Part I - A discussion of principles. *J. Hydrol.* 10(3):282-290.

USDA-NRCS, 1994. State Soil Geographic (STATSGO) database. USDA-NRCS Miscellaneous Publication Number 1492. Fort Worth, Texas: USDA-NRCS National Cartography and GIS Center.

Shapiro, M., J. Westervelt, D. Gerded, M. Larson, and K.R. Brownfield, 1992. Geographic Resources Analysis Support System (GRASS) Reference Manual. Champaign, IL: US Army CERL.

Sharpley, A.N., and S.J. Smith. 1995. Nitrogen and phosphorus forms in soils receiving manure. *Soil Science.* 159(4):253-258.

USEPA. 1994. The quality of our nation's water: 1994. Executive Summary of the National Water Quality Inventory: 1994 Report to United States Congress. EPA841-S-94-002. Washington, DC: USEPA.

Williams, J. R. 1969. Flood routing with variable travel time or variable storage coefficients. *Trans. ASAE* 12(1):100-103.

Williams, J. R. 1980. SPNM, a model for predicting sediment, phosphorus, and nitrogen from agricultural basins. *Water Res. Bull.* 16(5):843-848.

Williams, J.R. 1995. The EPIC model. In *Computer Model of Watershed Hydrology*, ed. V.P. Singh, 909-1000. Highlands Ranch, CO: Water Resources Publication.

Williams, J. R., J. G. Arnold, R. Srinivasan, and T. S. Ramanarayanan. 1997 (*in press*). APEX: A new tool for predicting the effects of climatic changes and CO2 changes on erosion and water quality. In *Modeling Soil Erosion by Water, NATO-ASI Global Change Series*, eds. J. Boardman and D. Favis-Mortlock. Heidelberg, Germany: Springer-Verlag.

Tables

Table 1. Land use in North Fork (NF) and Goose Branch (GB) micro-watersheds

Description	NF		GB	
	Area (ha)	Percent Coverage	Area (ha)	Percent Coverage
1. Forest	243.8	15.8	332.7	21.3
2. Range	503.5	32.6	302.5	19.4
3. Pasture	606.5	39.2	692.4	44.4
4. Sudan/Winter Wheat	151.1	9.8	185.0	11.9
5. Water	19.6	1.3	22.1	1.4
6. Urban/Barren Land	21.2	1.4	25.0	1.6
Total	1545.7	100.0	1559.8	100.0

Table 2. Distribution of major soils in North Fork (NF) and Goose Branch (GB) micro-watersheds

Soil Series Name	Soil Taxonomic Name	Textural Classification	NF		GB	
			Area (ha)	%	Area (ha)	%
Windthorst	Fine, Mixed, Thermic, Udic Paleustalfs	Fine Sandy Loam	1,005	65.0	581	38.4
Purves	Clayey, smectitic, thermic Lithic Calciustolls	Clay	160	10.4	160	10.6
Bolar	Fine-Loamy, Carbonatic, Thermic Udic Calciustolls	Clayey Loam	96	6.2	44	2.9
Bunyan	Fine-Loamy, Mixed, Nonacidic, Thermic Typic Ustifluvents	Fine Sandy Loam	90	5.8	110	7.3
Blanket	Fine, Mixed, Thermic Pachic Argiustolls	Clayey Loam	85	5.5	61	4.1
Duffau	Fine-Loamy, Siliceous, Thermic Udic Paleustalfs	Fine Sandy Loam	30	1.9	438	29.0
Waurika	Fine, Montmorillonitic Thermic Typic Argialbolls	Silty Loam	13	0.8	88	5.8

Table 3: Statistical results from comparison of model results with observed values

Variable	N	M_d	r	E_{NS}	E_S
Flow Calibration - NF010					
Flow Volume (mm)	12	-0.260	0.90	0.81	0.9
Flow Calibration - NF020					
Flow Volume (mm)	12	-2.590	0.94	0.85	0.89
Flow Validation - NF010					
Flow Volume (mm)	28	4.030*	0.65	0.27	0.75
Flow Validation - NF020					
Flow Volume (mm)	28	2.868*	0.66	0.30	0.76
Water Quality Parameters - NF010					
Mineral- N (kg/ha)	40	-0.015	0.43	-0.92	0.61
Mineral-P (kg/ha)	40	0.024*	0.82	0.32	0.40
Sediment Load (Mg/ha)	40	0.130*	0.30	0.04	0.34
Organic-N (kg/ha)	40	0.280*	0.84	0.05	0.11
Organic-P (kg/ha)	40	0.048*	0.42	0.19	0.15
Water Quality Parameters - NF020					
Mineral- N (kg/ha)	40	-0.004	0.61	0.13	0.94
Mineral-P (kg/ha)	40	0.013	0.65	0.35	0.77
Sediment Load (Mg/ha)	40	0.002	0.88	0.77	0.96
Organic-N (kg/ha)	40	0.040	0.78	0.48	0.84
Organic-P (kg/ha)	40	0.003	0.79	0.47	0.84
Flow and Water Quality - GB020					
Flow Volume (mm)	20	-0.133	0.69	0.41	0.97
Mineral- N (kg/ha)	20	0.005	0.33	-0.12	0.85
Mineral-P (kg/ha)	20	0.003	0.003	0.21	0.93
Sediment Load (Mg/ha)	20	-0.020	0.46	-0.12	-0.85
Organic-N (kg/ha)	20	-0.050	0.47	-0.43	0.69
Organic-P (kg/ha)	20	0.043	0.69	0.44	0.77

* significantly different at 95 % confidence level

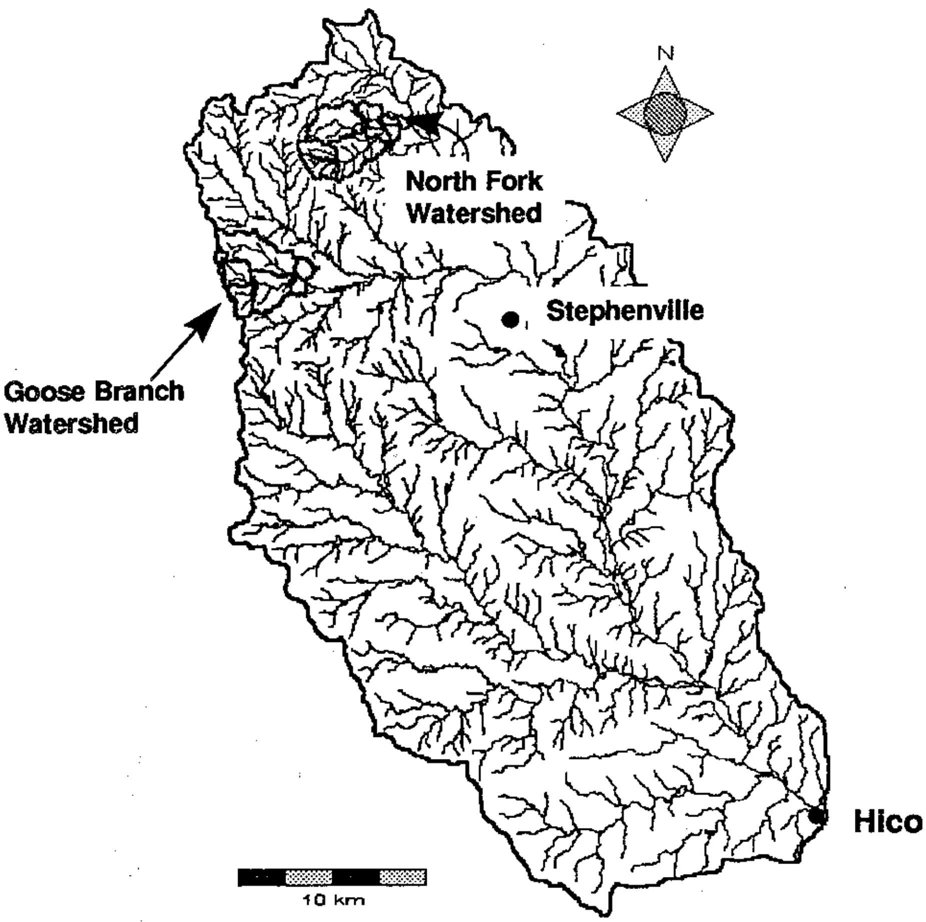

Figure 1. Upper North Bosque Watershed

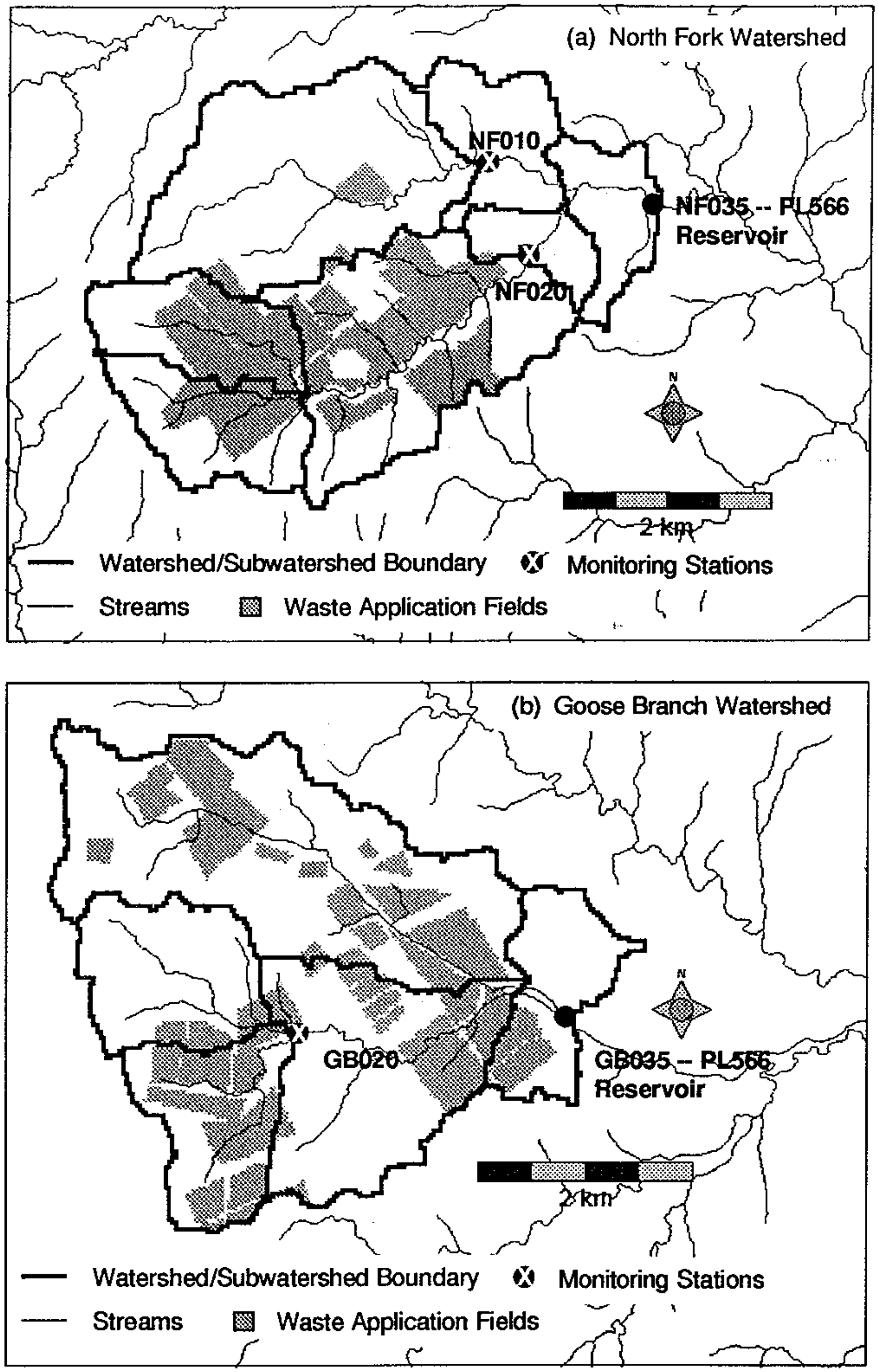

Figure 2. Micro-watersheds with sampling sites and waste application fields

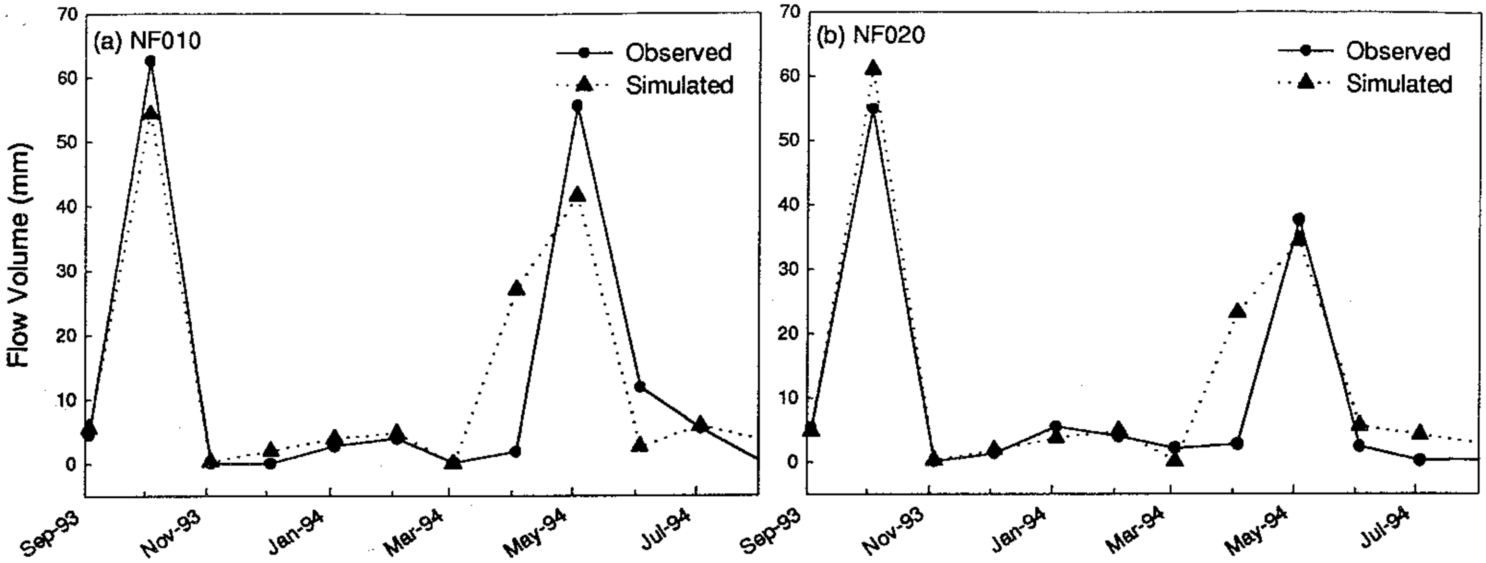

Figure 3. Time series of observed and simulated monthly flow during the calibration period (Sep-93 to Aug-94)

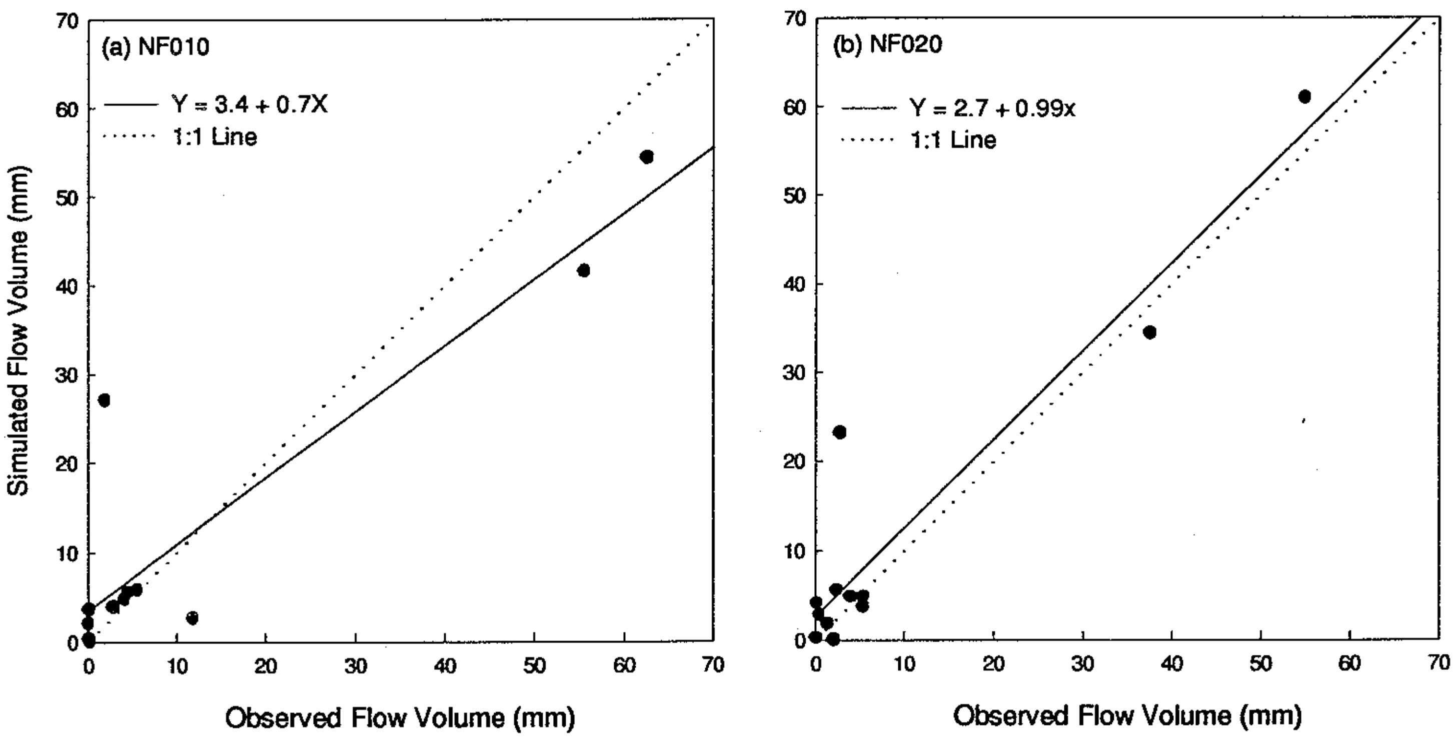

Figure 4. Scattergram of observed and simulated monthly flow during calibration period (Sep-93 to Aug-94)

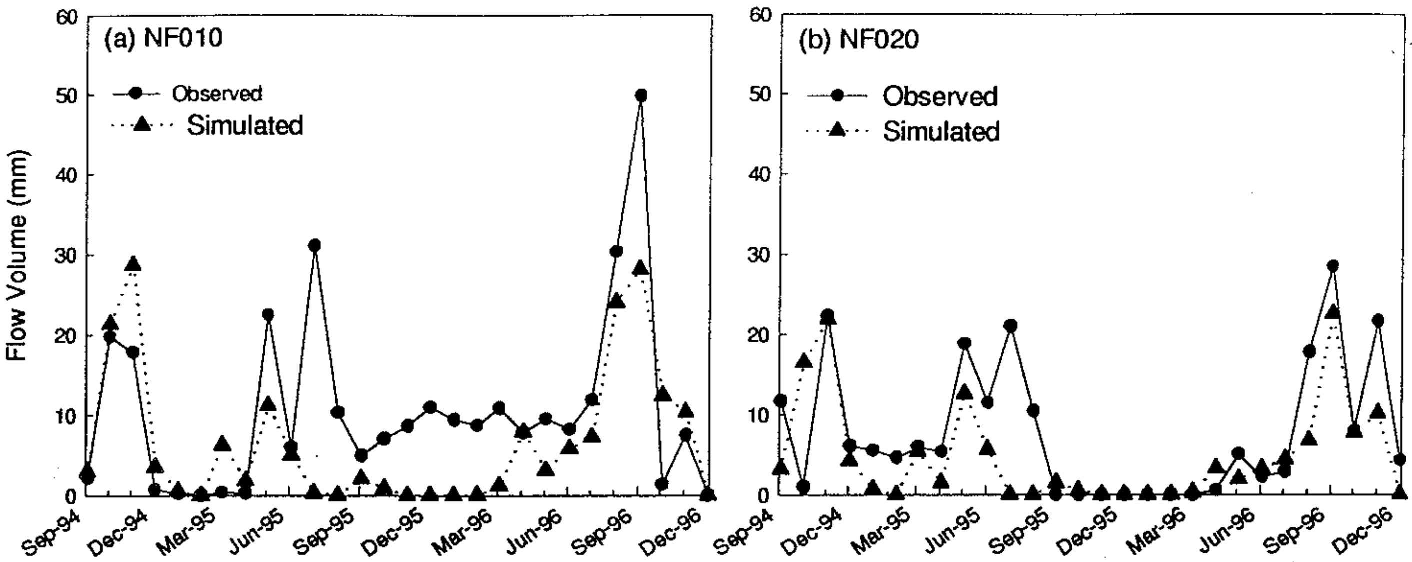

Figure 5. Time series of observed and simulated monthly flows in the North Fork watershed during the validation period (Sep-94 to Dec-96)

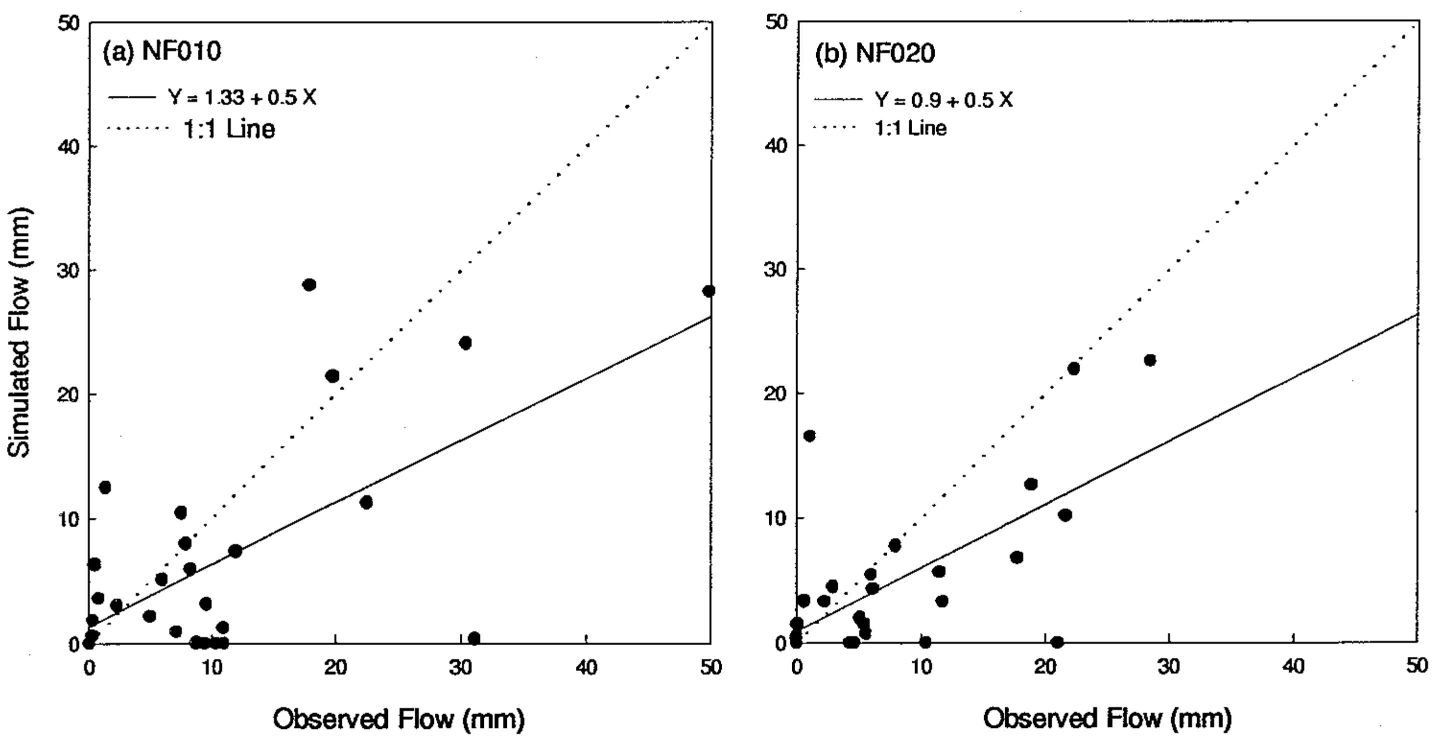

Figure 6. Scattergram of observed and simulated monthly flows in the North Fork watershed during the validation period (Sep-94 to Dec-96)

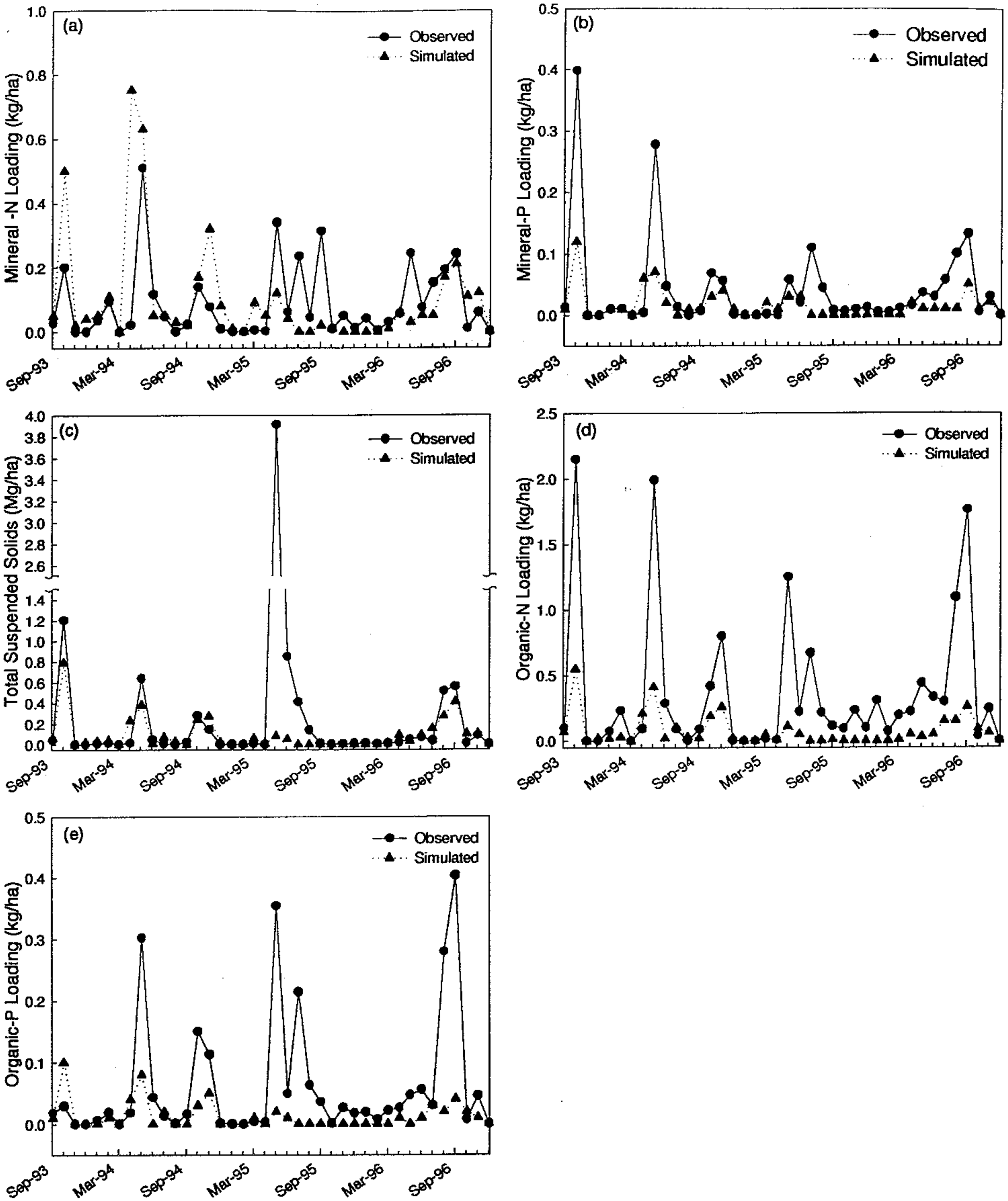

Figure 7. Times series of observed and simulated monthly water quality parameters at sampling site NF010

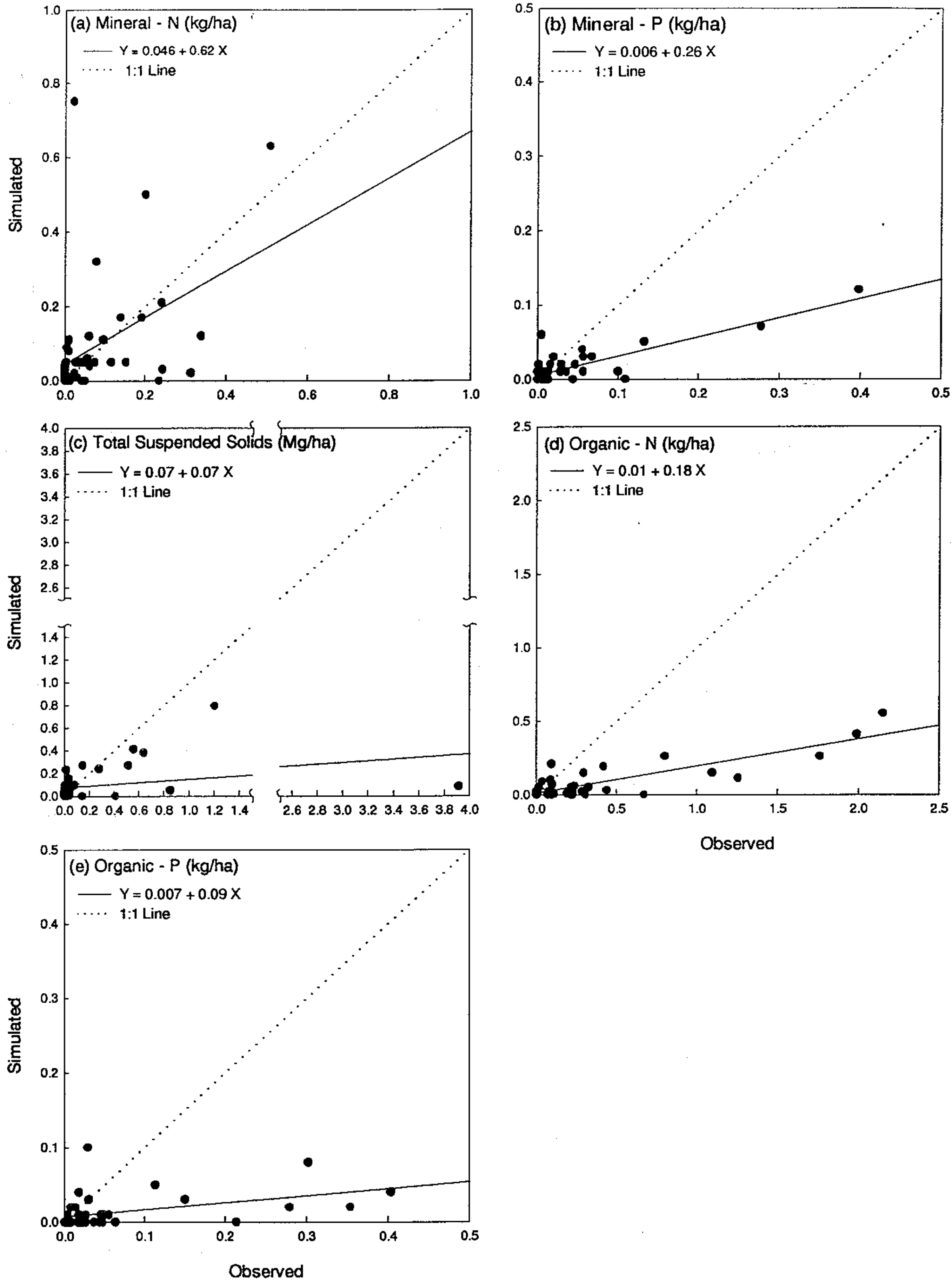

Figure 8. Scattergram of observed and simulated monthly water quality parameters at sampling site NF010 for the period Sep-93 to Dec-96.

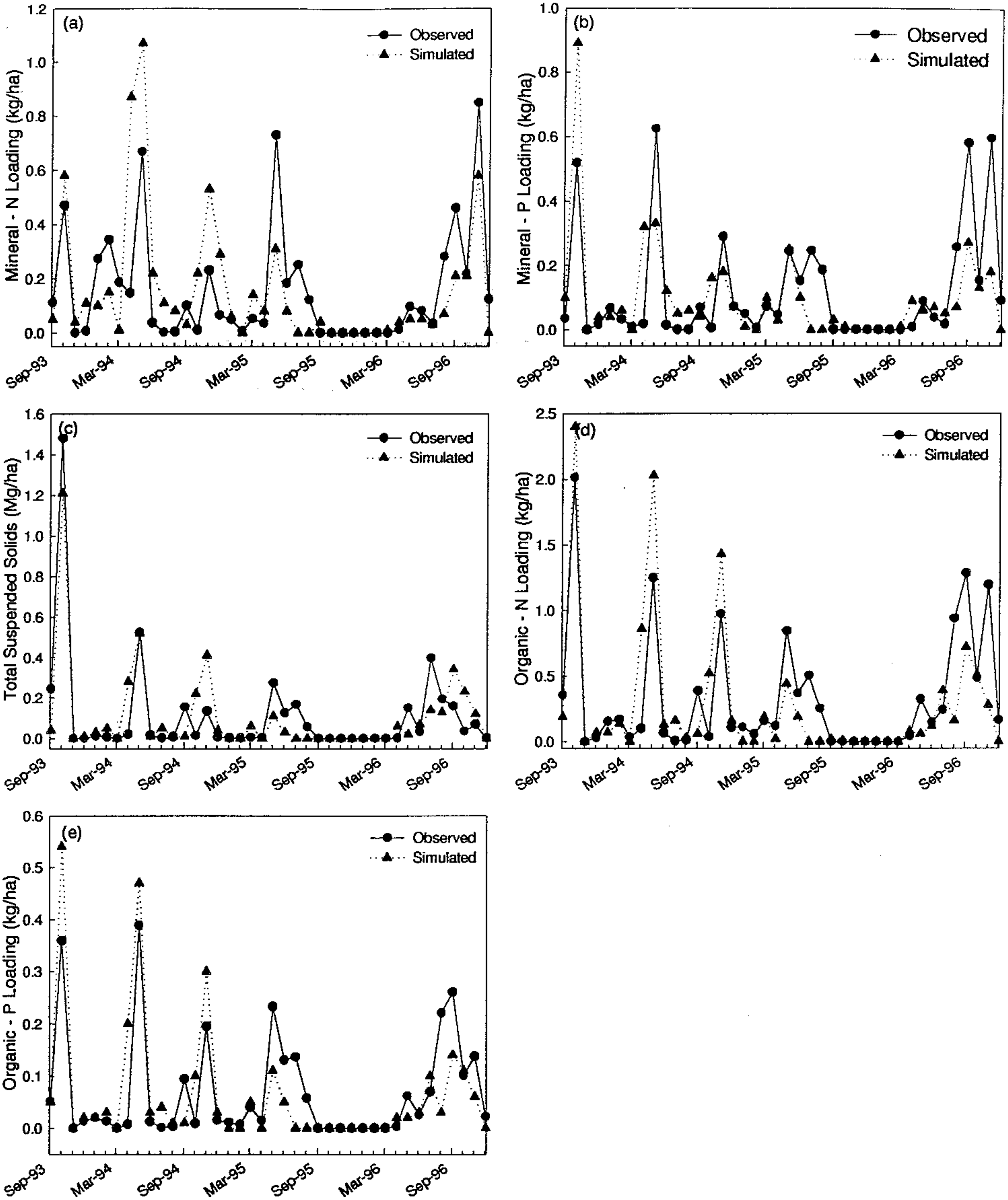

Figure 9. Times series of observed and simulated monthly water quality parameters at sampling site NF020

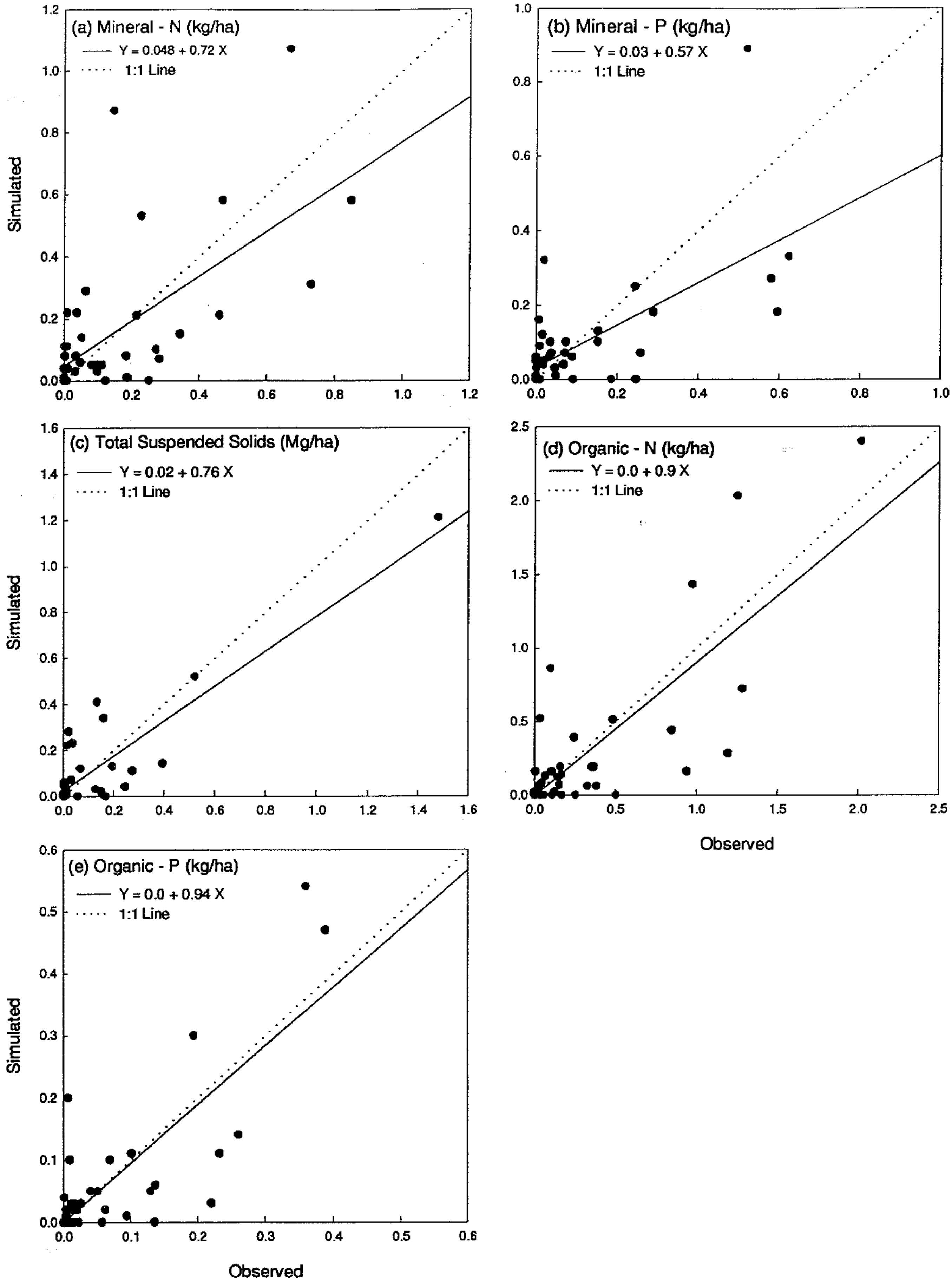

Figure 10. Scattergram of observed and simulated monthly water quality parameters at sampling site NF020 for the period Sep-93 to Dec-96.

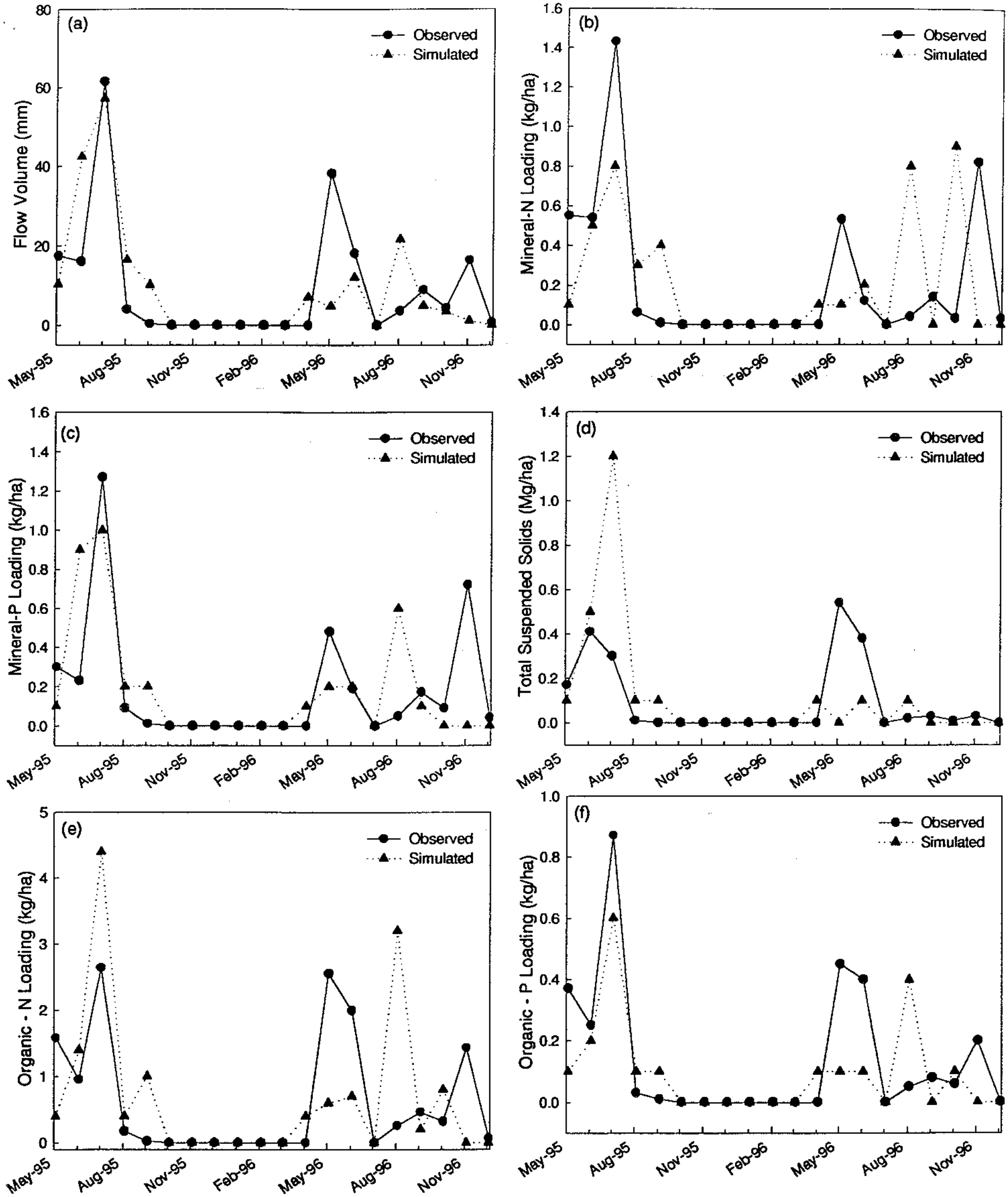

Figure 11. Times series of observed and simulated monthly water quality parameters at sampling site GB020

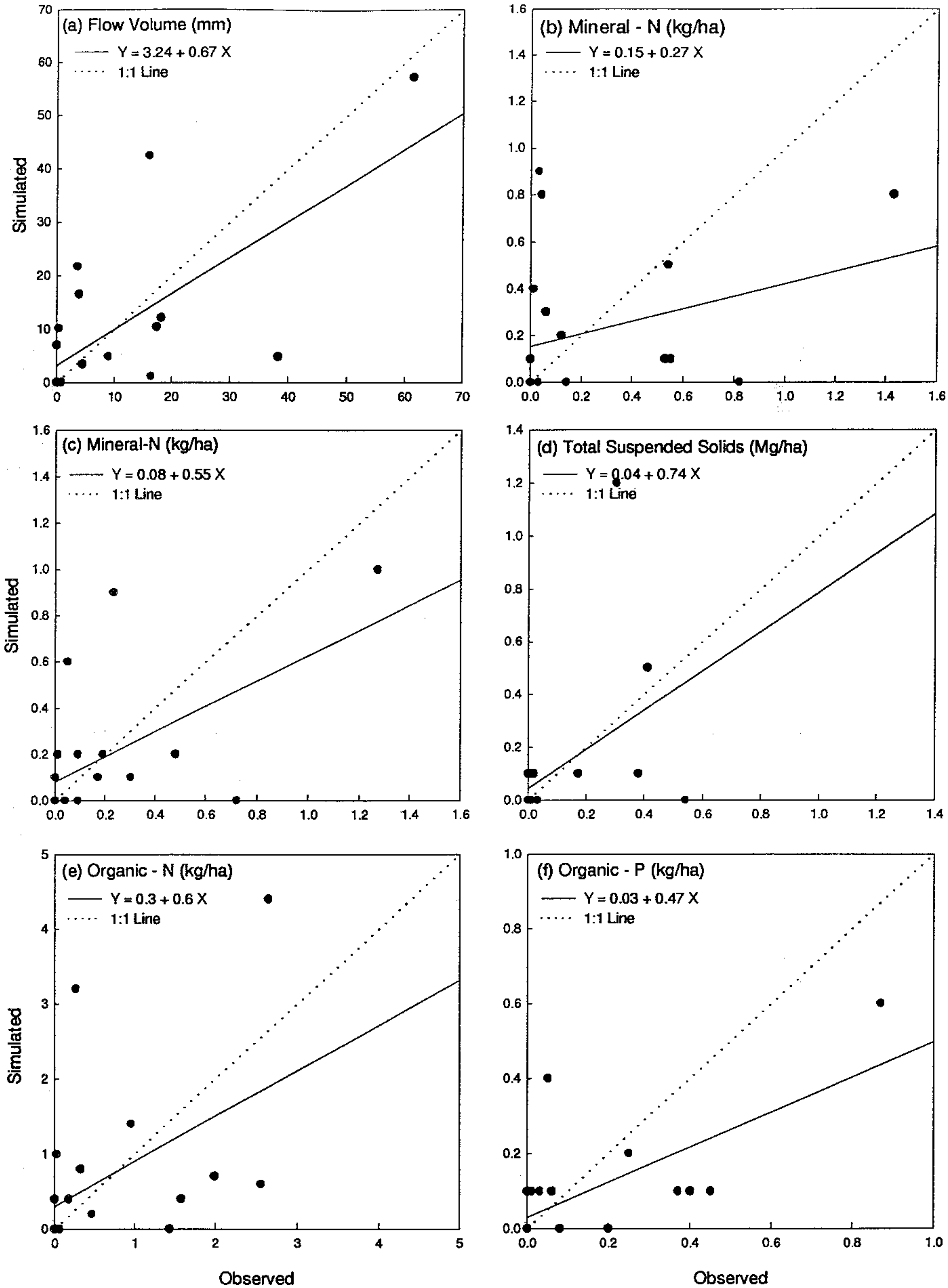

Figure 12. Scattergram of observed and simulated monthly flow volume and water quality parameters at samplingsite GB020 for the period May-95 to Dec-96.

USING APEX TO IDENTIFY ALTERNATIVE PRACTICES FOR ANIMAL WASTE MANAGEMENT: PART - II: ALTERNATIVE MANAGEMENT ANALYSES[1]

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Abstract

In the first part of this paper a small-watershed/whole farms scale model, APEX was calibrated and validated for two micro-watersheds in Upper North Bosque River Watershed (Figure 1 - Part I) In this second part of the paper the effect of alternative management practices for dairy manure disposal in runoff, total suspended solids (TSS), and nutrients loading in the Goose Branch micro-watershed (Figure 2b - Part I) using APEX. We analyzed five alternative management options with six application rates for each scenario. Of the five options, four were agronomic practices that promoted increased nutrient uptake by the crops and reduce nutrient loss to the streams, and the other fifth option involved hauling surplus manure off the watershed. From the results we conclude that through proper agronomic management and adopting watershed management approach, sustainable water quality can be achieved with minimal hauling of away from the watershed.

Introduction

In Part-I of this paper, we described calibration and validation of a small watershed/multi-field scale model, Agricultural Policy Environmental eXtender (APEX) to simulate the hydrology and water quality in two micro-watersheds with concentrated dairy manure application fields. In this part, we present the results for the application of APEX to analyze the effects of alternative management practices of dairy manure disposal on runoff, sediment and nutrient loading in the Goose Branch micro-watershed (Figure 2b - Part I). The scenarios we considered were alternative agronomic practices for the dairy manure application fields, surplus manure distribution to non-application areas, and surplus manure haul-off.

There have been only a limited number of watershed-scale studies on identifying alternative management practices for animal waste management, most of them involving implementation and monitoring studies (Edwards et al., 1996). Brown et al. (1989) reported

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that in the barnyard areas P reductions of about 50% to 90% were achieved by implementing runoff reduction practices such as lagoon storage, whereas in the cropped lands scheduling of manure application and the rate of application reduced P loading to as high as 35%. Walker and Graczyk (1993) noted that best management practices (BMPs) such as conservation reserve, contour strip cropping, minimal tillage, change in crop rotation and barn yard treatment led to reduced mass transport of ammonium-N (NH_4-N) and total suspended solids (TSS). Park et al. (1994) while presenting stream monitoring results before and after BMP implementation in a 1,500 ha basin in eastern Virginia, reported that BMPs such as no-till, critical area treatment and structural practices reduced N and P concentrations by about 20% to 40%. Edwards et al. (1996) used non-parametric analysis of variance (ANOVA) to identify the changes in the trends in stream water quality after the implementation of animal waste BMPs in a Northwestern Arkansas watershed. They reported significant decreasing trends in NH_4-N, total Kjeldahl nitrogen (TKN), and chemical oxygen demand (COD). Nitrate-N (NO_3-N), total phosphorus (TP) and TSS concentrations showed decreasing trends at isolated instances, but soluble P failed to show any significant decreasing trends.

Vegetative filter strips were found to be effective in trapping sediment and sediment-bound nutrients and to some extent in reducing total runoff and soluble nutrients (Dillaha et al., 1989; Chaubey et al., 1994). Several research studies have documented the role of wetlands (natural and constructed) in serving as a sinks for nutrients and solids from NPS pollution (Engler and Patrick, Jr., 1974; and Mitsch, 1992). Costello (1989) observed a 98% decrease in biochemical oxygen demand (BOD), 95% decrease in ammonium and nitrate-nitrogen and about 95% increase in dissolved oxygen when dairy effluent was passed though a natural wetland. Cronk (1995) evaluated constructed wetlands as a BMP for a dairy operation using experimental wetland cells (9m × 61 m) and reported substantial trapping (50% to 90%) of nutrients and suspended solids in the wetland cells.

Materials and Methods

We analyzed five alternative management scenarios with six application rates for each scenario. All the analyses were based on 30-year simulation results using APEX.

Management Scenarios

Alternative agronomic management scenarios such as tillage and crop rotation that will increase the crop uptake of soil available nutrients were analyzed. In addition to the present conditions, we analyzed the following scenarios:

1. Summer Crops grown on Application Areas (S): Existing summer crops (Coastal Bermuda Grass—*Cynodon dactylon* (L.) and Sudan Grass—*Sorghum vulgare*) that are presently grown on the application areas.

2. Summer Crop Overseeded with Winter Crop (SW): Existing summer crops with winter wheat—*Titicum aestivum* growing during the winter. It should be noted that the winter crop was overseeded (grown simultaneously with the summer crop). This option was

recently incorporated in the Erosion Productivity Impact Calculator (EPIC) model, and subsequently introduced in the APEX model also.

3. Summer Crops with Winter Tillage (ST): After the harvest of summer crops and before the onset of winter (December) a tillage operation (chisel and an offset plow) was introduced, which was same as # 1 plus winter tillage.

4. Summer Crops Overseeded with Winter Crop—tilled before winter planting (WT): This strategy was same as # 2 plus a tillage operation (chisel and offset plow) introduced before planting wheat (October).

5. Surplus Manure Haul-off (SH): In this strategy, the surplus manure from the application areas was hauled out of the watershed.

Manure Application Rates

The annual manure application rate, AA (Mg/ha) was calculated as

$$AA = \frac{P \times 365}{AAC^{*} \times 1000} \tag{1}$$

and

$$AAC^{*} = \max\left[AAC, \frac{WSA}{HS}\right] \tag{2}$$

where P is the daily manure production rate per cow (kg/hd/d), and AAC is the application area-animal ratio (ha/hd) that can be set by the user in the model, WSA is the application area (ha), and HS is the present herd size for application area (hd). A default value of P, 9.3 kg/cow/d (ASAE, 1994), was used in this study.

There are seven major dairies operating in the Goose Branch watershed and the herd size of all the dairies was obtained. Each dairy owns application areas (hereafter referred as base application areas) distributed within and outside the watershed. The subarea configuration of the watershed was made such that each base application area under each ownership is a separate subarea (hydrologic unit) within the model. The land use and soil allocations within each subarea and subarea parameterization are explained in Part-I of this paper. We assumed the manure produced by a certain dairy was applied uniformly over its entire base application area. Thus, for each base application area we estimated the number of cows contributing to that area. The annual application rate was compared with the manure production rate from the estimated herd size for the application area in order to determine if manure surplus exists.

Surplus Manure Distribution

Options exist in the model whether to apply the surplus manure to the existing non-application areas (here after referred as non-application areas) or to haul it outside the watershed. All of the strategies listed in the previous section except SH considered the possibility of applying the surplus manure to the non-application areas. The lower limit for Application Area-Animal Ratio for the non-application areas (AAC_{NAA}) was fixed at 0.5 ha/hd. The surplus manure from a base application area gets applied to the non-application area available immediately downstream from the base application area. If the AAC_{NAA} of that non-application area equals 0.5, the surplus is carried over to the to the next available downstream non-application area. The application series follow the water routing structure of the watershed. If, at the end of the watershed, there exists some surplus manure, the model checks all the non-application areas iteratively and applies the manure to those that were not applied to capacity, and the rest of the manure, if available, gets hauled out of the watershed. All of the non-haul strategies (S, ST, SW, and WT) allowed manure haul off only if all of the non-application area capacity was exceeded. In any case, the allowed application rates for base and non-application areas were never exceeded.

The manure application distribution for various levels of Application Area-Animal Ratio for base application areas (AAC_{BASE}) for Goose Branch watershed is illustrated Figure 1. The base application area for the watershed is 440 ha and the non-application area is 1,560 ha. The estimated herd size and manure production are 3,280 and 11,200 Mg/yr, respectively. At 0.05 ha/hd AAC_{BASE}, all the manure produced is applied only to the base application areas. As the AAC_{BASE} increases, the application rate (Mg/ha) gets decreased. At the same time, the surplus manure from the base application areas gets applied to the non-application areas. Therefore, as AAC_{BASE} is increased, the application rate for the non-application areas increases in order to accommodate the surplus manure from the base application areas. At AAC_{BASE} of 0.3 ha/hd for the base application areas, all the non-application areas in watershed get utilized to some extent for manure application. At AAC_{BASE} of 0.5 ha/hd for base application area, the application rates for the base and non-application areas are same. For Goose Branch watershed when AAC_{BASE} was set to 0.5 ha/hd, about 550 Mg of manure had to be hauled out of the watershed every year. The existing AAC_{BASE} values for the manure application of different dairy ownership in Goose Branch watershed range from 0.06 to 0.15 ha/hd.

Results and Discussion

We analyzed six outputs—runoff, sediment, and inorganic and organic forms of nitrogen and phosphorus, from the model in response the scenarios outlined in the previous section.

Runoff

The runoff response for the alternative management scenarios are shown in Figure 2. There were no significant changes in annual runoff volume with respect to changes in AAC_{BASE} values. Also introduction of winter tillage or fall tillage (ST and WT) did not produce significant changes in runoff volume when compared to S and W scenarios, respectively. However, the introduction of a winter crop (W and WT) reduced the annual runoff by about 20 mm, when compared to the S and ST scenarios. The summer crops with manure haul-off scenario (SH) produced a slightly higher runoff volume compared to the S and ST scenarios, because lesser biomass was production in the non-application areas when the surplus manure is hauled out of the watershed.

Total Suspended Solids (TSS)

The sediment load response (Figure 3) to the management scenarios is similar to the runoff response. The tillage scenarios (ST and WT) produced a slightly increased sediment load when compared to the S and W scenarios, respectively. Similar to the runoff response, introduction of a winter crop reduced the sediment load by about half. The SH option produced slightly higher sediment loads when compared to S and ST scenarios.

Organic Nitrogen

The organic nitrogen response to the management scenarios is shown in Figure 4. Similar to runoff and sediment response the management strategies did not change significantly with change in AAC_{BASE}, except for the SH strategy where the organic-N load declines sharply with increase in AAC_{BASE}. When a winter crop was introduced by overseeding (W and WT strategies), an annual reduction of about 0.5 kg/ha of organic-N load was achieved when compared to the S and ST strategies. The ST strategy showed a slightly increased organic-N load compared to S, whereas the WT strategy did not show significant difference when compared to the W strategy. From Figure 4 it is also evident that by introducing of winter overseeding a lower or equal organic-N load is achieved when compared to the haul-off strategy (SH) over the range of AAC_{BASE} values tested.

Mineral Nitrogen

Mineral-N response to the management scenarios is shown in Figure 5. In general, the mineral-N response is sensitive to AAC_{BASE} values. For the summer cropping strategies (S, ST, and SH), the mineral-N loading decreases when AAC_{BASE} values were increased until 0.3 ha/hd. Beyond 0.3 ha/hd any increase in AAC_{BASE} did not produce a significant change in mineral-N loading. Similarly for winter cropping strategies (W and WT) as the AAC_{BASE} value is increased, the mineral-N loading decreases until AAC_{BASE} = 0.2 ha/hd, beyond which no significant changes were observed in mineral-N loading. The tillage strategies, ST and WT, did not yield significantly different results when compared to S and W strategies, respectively. The mineral-N response to AAC_{BASE} for haul-off strategy (SH) is almost same as the S and ST strategies until AAC_{BASE} = 0.3 ha/hd, beyond which the mineral-N response in SH strategy is only marginally different from S and ST strategies.

Organic Phosphorus

The organic-P response trends (Figure 6) are very similar to organic-N because the organic N and P loading are dependent on sediment load and the corresponding enrichment ratio for N or P. As in organic-N and sediment response, the winter cropping strategies (W and WT) produced a reduction of 48 % to 59 % of organic-P loading when compared to S and ST strategies. In the haul-off strategy (SH), as the AAC_{BASE} values are increased the organic-P loading kept reducing for the range of AAC_{BASE} values tested in this study. For an increase of AAC_{BASE} from 0.05 ha/hd to 0.5 ha/hd, about 60 % reduction in organic-P loading was achieved in the SH strategy.

Mineral Phosphorus

The mineral-P loss from all the strategies was sensitive to change in AAC_{BASE} (Figure 7). There was a sharp decline in mineral-P loading with the increase in AAC_{BASE} until 0.2 ha/hd for all strategies. The W and WT strategies produced lower mineral-P loading when compared to both S and ST strategies for the entire range of AAC_{BASE} values. Comparing the response of W and WT strategies with SH strategy, for AAC_{BASE} values less than 0.3 ha/hd the W and WT strategies showed lower mineral-P loads. The ST strategy produced significantly less mineral-P load (14 % to 35 %) when compared with S strategy, whereas the WT strategy response showed only a slight difference in mineral-P loading compared to the W strategy.

Conclusions

In this study the role of alternative agronomic practices in reducing nutrient enrichment in the streams from animal waste application fields was studied. The aim of the management practices tested in this study was to properly manage the nutrients, particularly phosphorus, so that the enrichment of nutrients in the runoff was controlled by increased uptake by the vegetation grown. We approached the problem of phosphorus enrichment in the runoff with a watershed management approach, where the surplus manure from the application fields was distributed within the watershed to previously non-application areas. Hauling the surplus manure out of the watershed was also tested and compared with other strategies. The following conclusions were drawn from this study:

1. Introducing a winter crop by over seeding the summer crop increased the uptake of water and nutrients, thus reducing the runoff and nutrient loads by about 40% to 60%.

2. The winter crop also provided increased ground cover thereby decreasing the sediment loss by about 50%.

3. For summer-crop-only strategies, the winter tillage operations marginally increased sediment loads, but significantly decreased mineral-P loading.

4. When considering organic N and P loading, only the haul-off strategy showed reductions when the base application rate was reduced.

5. In case of mineral N and P loading, the winter cropping strategy produced lower or equal loading over the range of AAC_{BASE} values tested when compared to the haul-off option.

6. The CAFOs manure management can be effectively accomplished by adopting a watershed management approach. By spreading the manure judiciously within a

watershed and inducing higher plant uptake of nutrients, a more expensive haul-off option can be avoided to a significant extent.

References

ASAE. 1988. Manure production and characteristics. ASAE Standard, ASAE Data: ASAE D384.1. St. Joseph, MI: ASAE.

Brown, M.P., P. Longabucco, M.R. Rafferty, P.D. Robillard, M.F. Walter, and D.A. Haith. 1989. Effects of animal waste control practices on nonpoint-source phosphorus loading in the West Branch of the Delaware River watershed. *J. Soil and Water Cons.* 44(1):67-70.

Chaubey, I., D.R. Edwards, T.C. Daniel, P.A. Moore, Jr. And D.J. Nichols. 1994. Effectiveness of vegetative filter strips in retaining surface-applied swine manure constituents. *Trans. ASAE* 37(3):845-850.

Costello, C.J. 1989. Wetlands treatment of dairy wastes in Irish Drumlin landscape. In *Constructed Wetlands for Wastewater Treatment*, ed. D.A. Hammer, 702-709. Chelsea, Michigan: Lewis Publishers.

Cronk, J. 1995. Wetlands as a best management practices on a dairy farm. In *Proc. Of Versatility of Wetlands in the Agricultural landscape*, ed. K.L. Campbell, 263-271. St. Joseph, Michigan: ASAE.

Dillaha, T.A., R.B. Reneau, S. Mostaghimi, and D. Lee. 1989. Vegetative filter strips for agricultural nonpoint source pollution control. *Trans. ASAE* 32(2):513-519.

Edwards, D.R. T.C. Daniel, H.D. Scott, J.F. Murdock, M.J. Habiger, and H.M. Burks. 1996. Stream quality impacts of best management practices in a Northwestern Arkansas basin. *Wat. Res. Bull.* 32(3):499-509.

Engler, R.M. and W.H. Patrick, Jr. 1974. Nitrate removal from floodwater overlying flooded soils and sediments. *J. Environ. Qual.* 3:409-413.

Mitsch, W.J. 1992. Landscape design and the role of created, restored, and natural riparian wetlands in controlling nonpoint source pollution. *Ecological Engineering*. 1:27-47.

Park, S.W., S. Mostaghimi, R.A. Cooke, and P.W. McClellan. 1994. BMP impacts of watershed runoff, sediment, and nutrient yields. *Wat. Res. Bull.* 30:1011-1023.

Walker, J.F. and D.J. Graczyk. 1993. Preliminary evaluation of effects of best management practices in the Black Earth Creek, Wisconsin, Priority Watershed. *Wat. Sci. Tech.* 28:539-548.

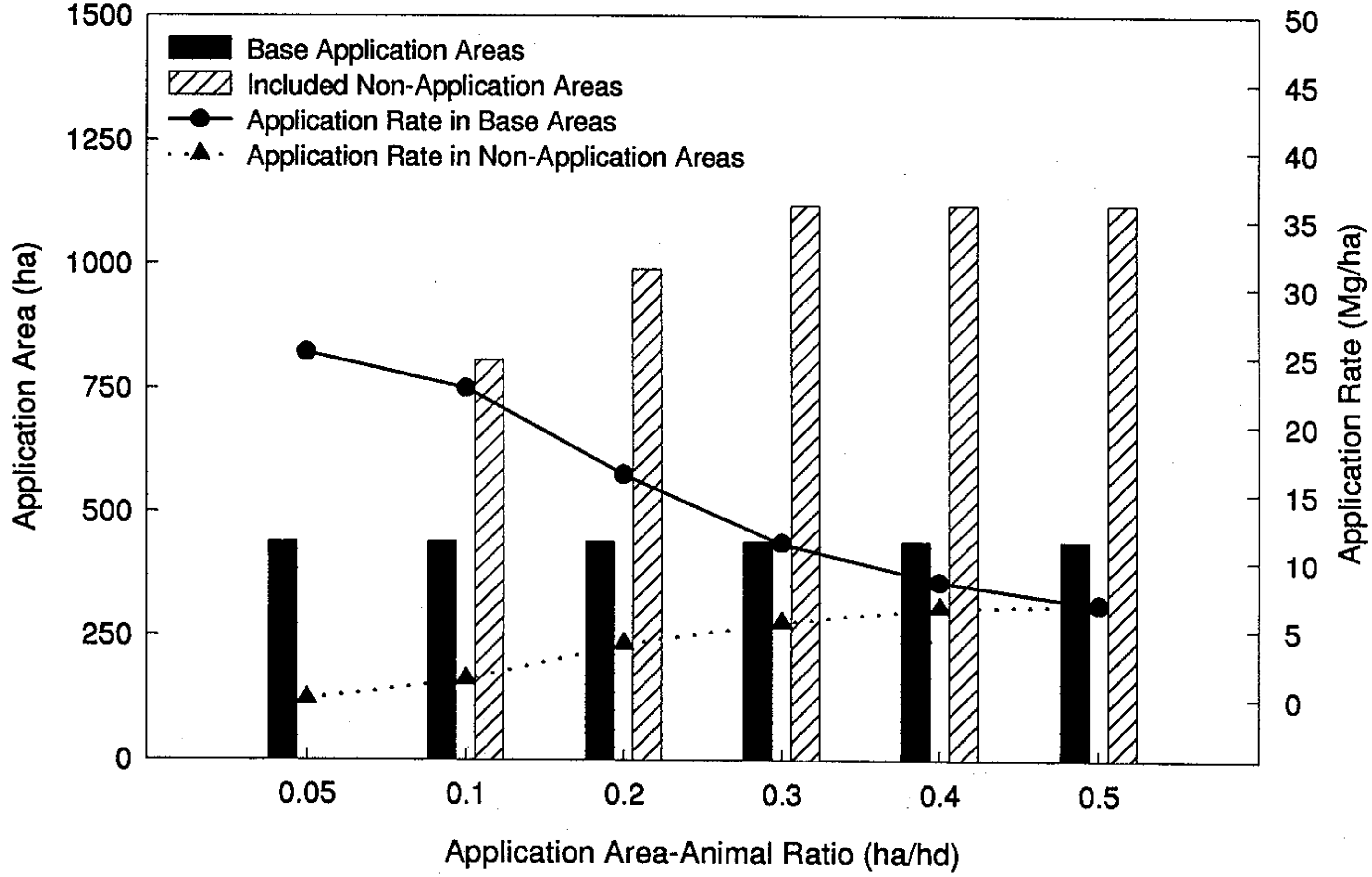

Figure 1. Application areas for base and non-application areas, and application rates for various application area-animal ratios

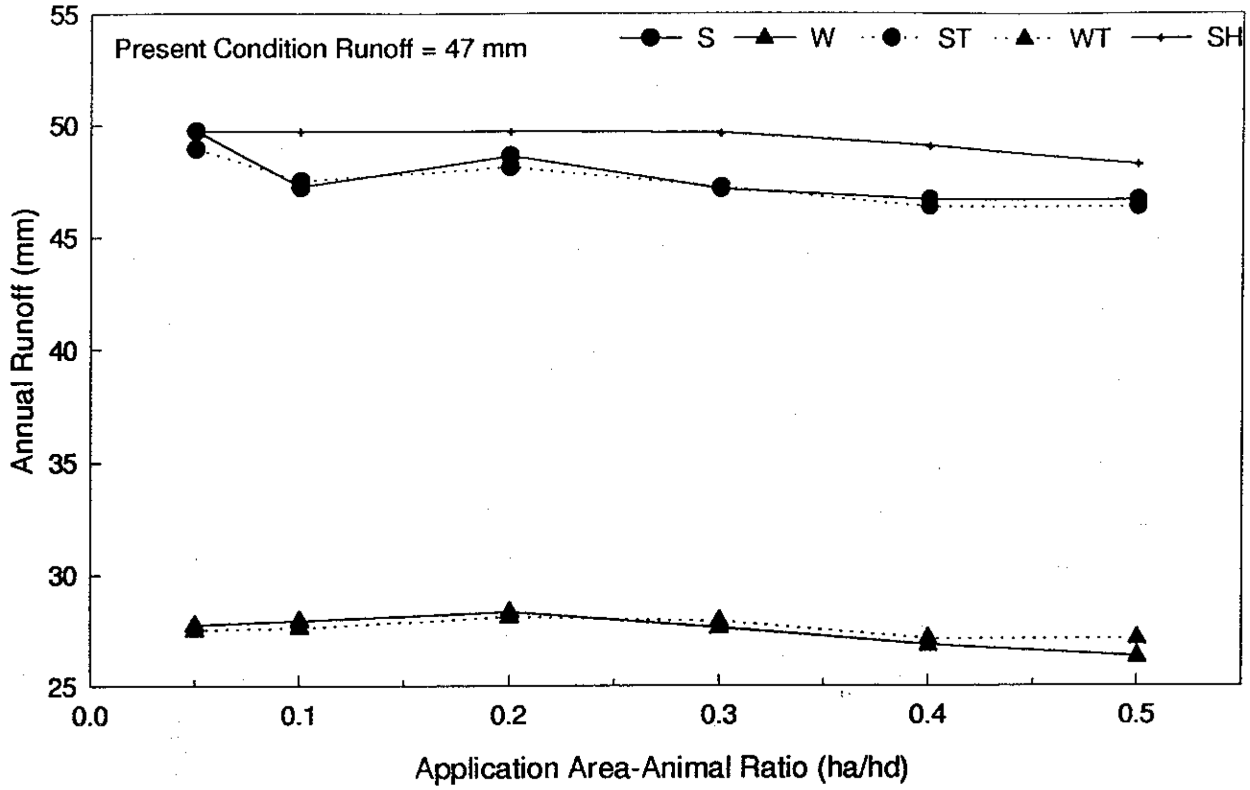

Figure 2. Runoff response to management scenarios

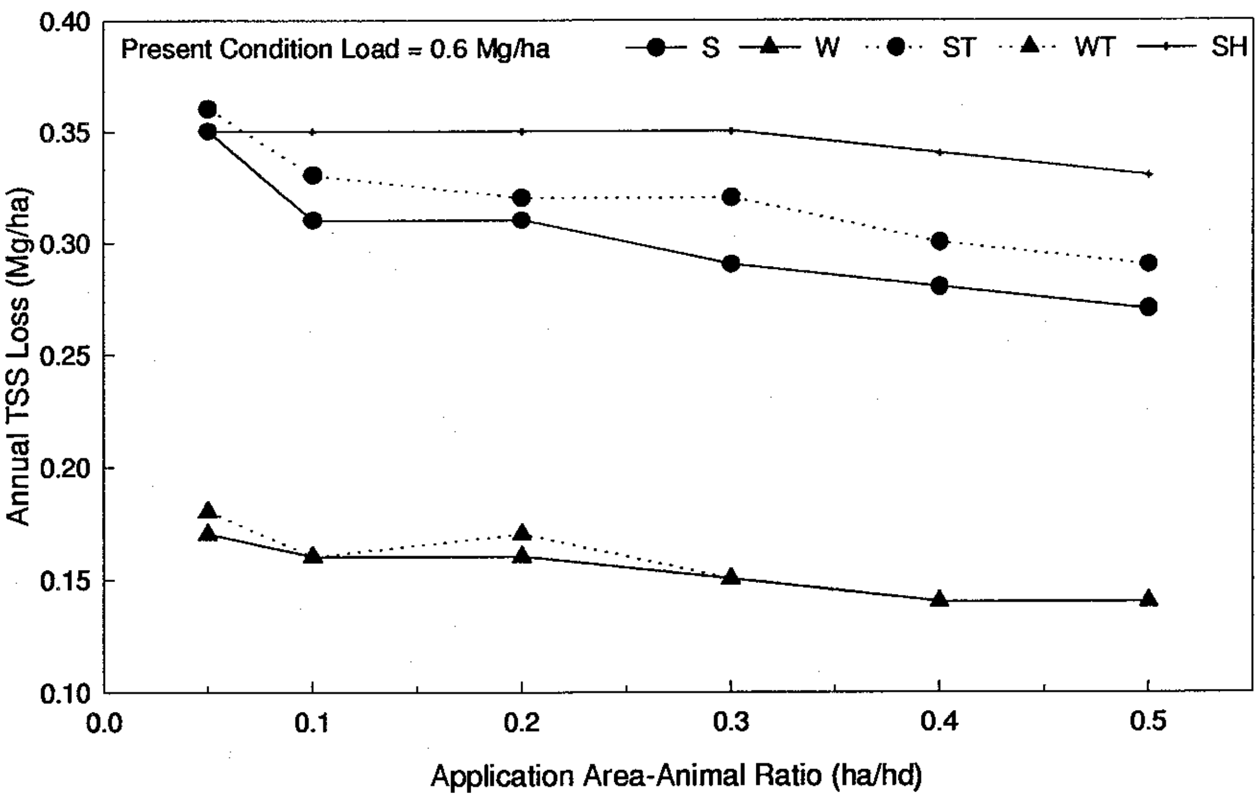

Figure 3. Total suspended solids (TSS) response to management scenarios

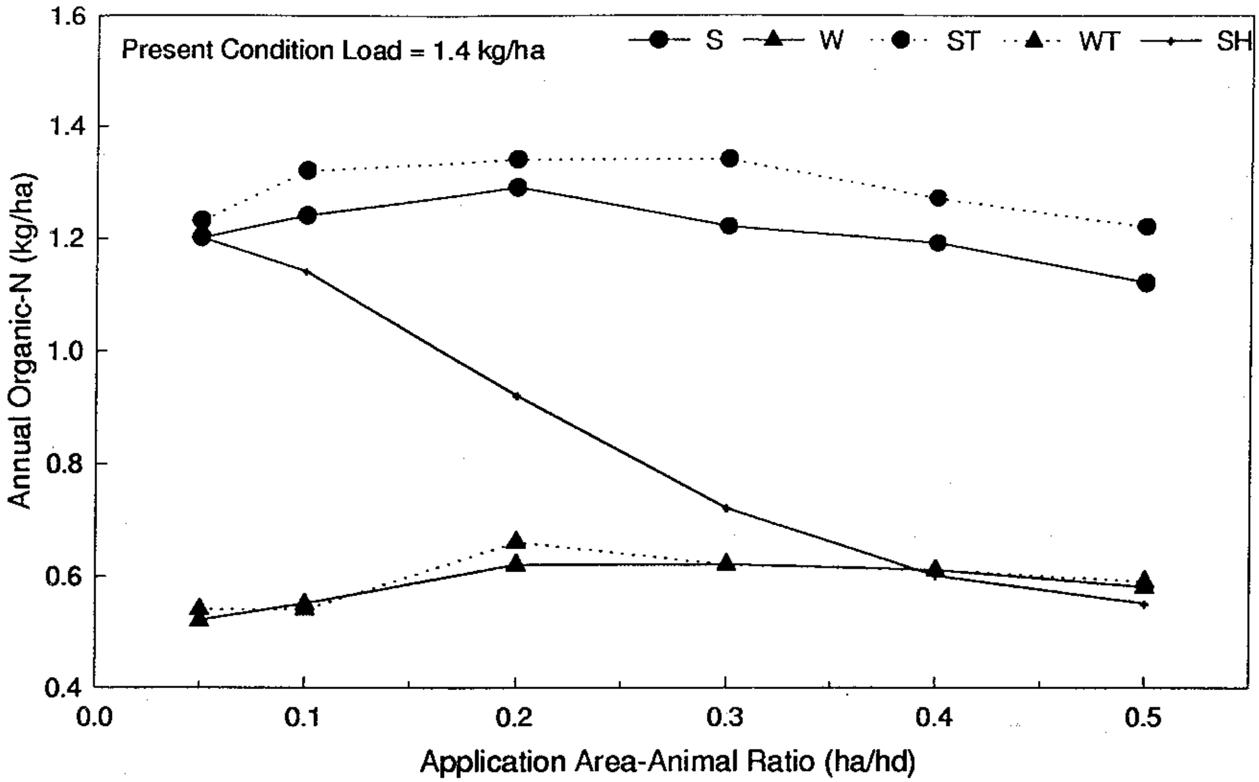

Figure 4. Organic-N response to management scenarios

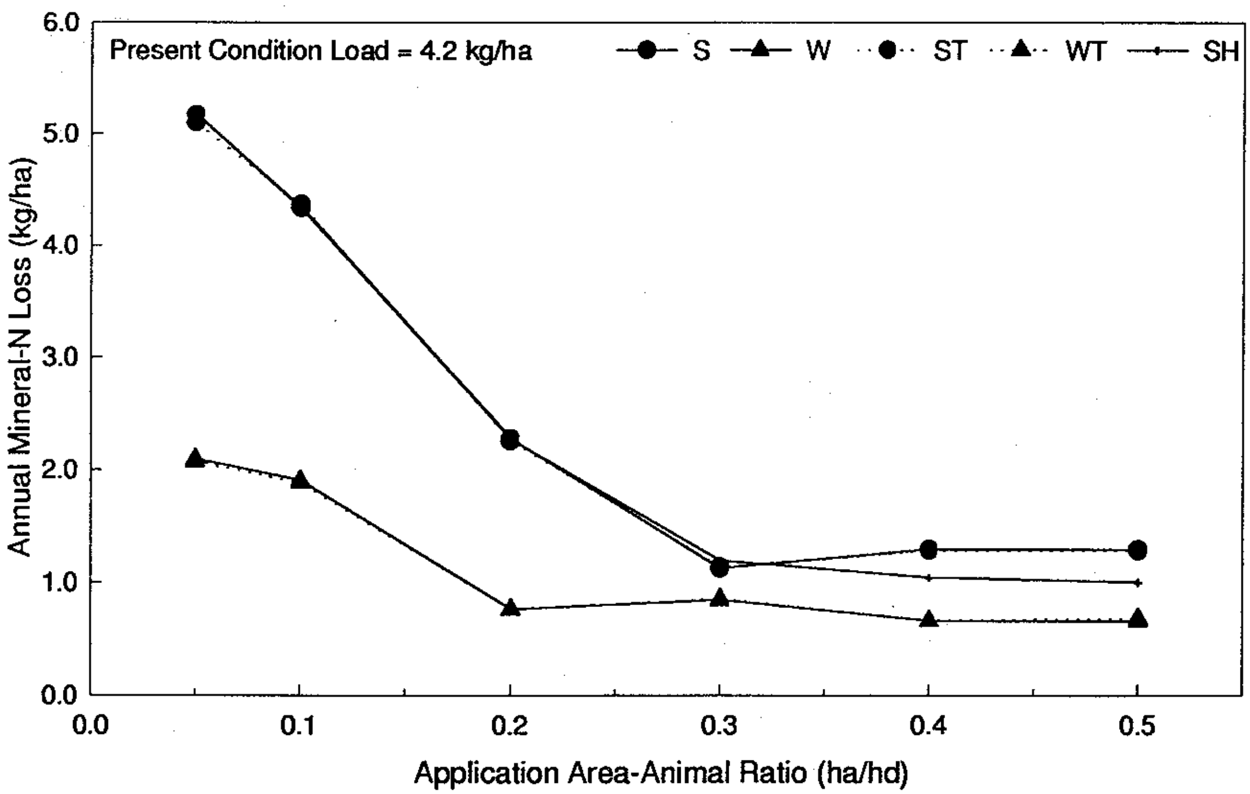

Figure 5. Mineral-N response to management scenarios

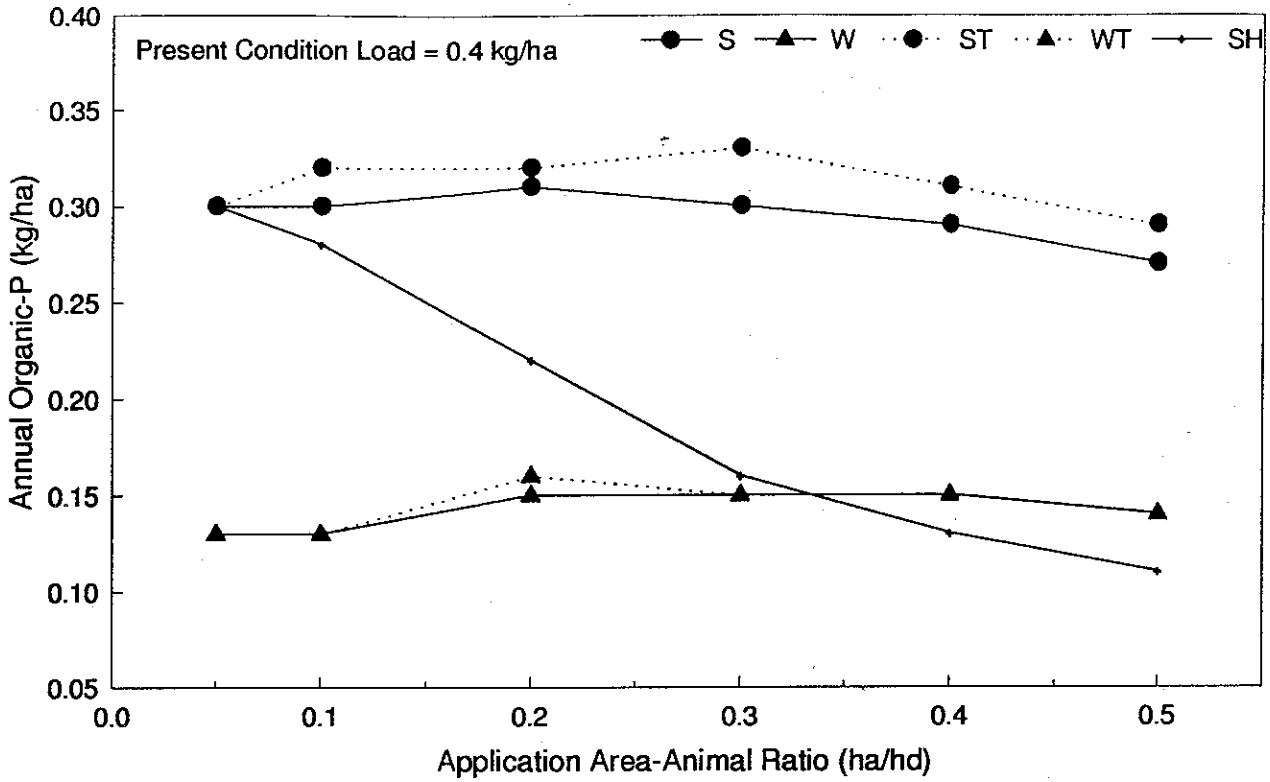

Figure 6. Organic-P response to management scenarios

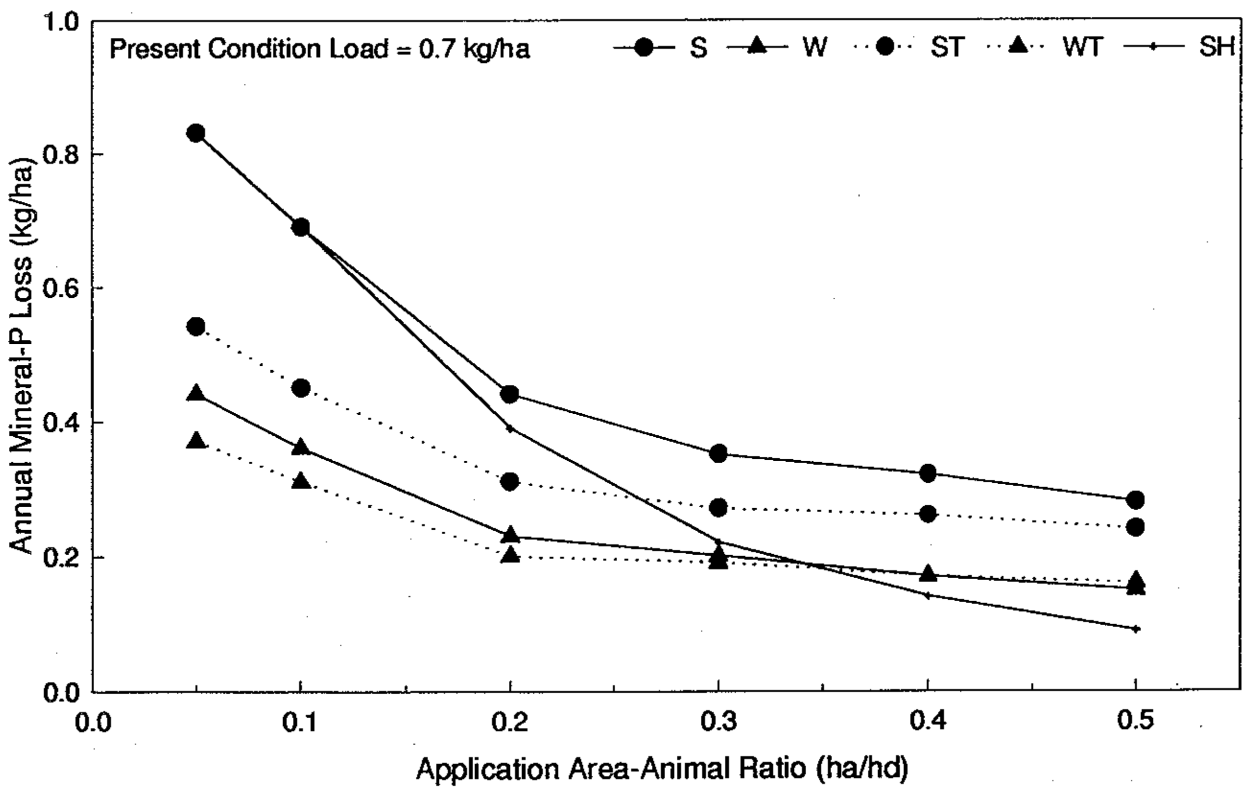

Figure 7. Mineral-P response to management scenarios