CROPLAND PHOSPHORUS TRANSFORMATION AND LOSS MODELS

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PREFACE

One of the purposes of the joint REN and FAP task, Environmental Problems of Agriculture, is to collect, assess and classify the current agricultural-environmental models. This paper contains a brief description, assessment and classification of eleven models of cropland phosphorus transformations and losses. These models can be used for solving some environmental problems related to the application of phosphorus fertilizers. The present paper serves two purposes. First, it is the second interim report discussing general work on collection, assessment, and classification of existing models. Secondly, this paper can be considered as a modest contribution to the Lake Balaton case study.

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The purpose of this paper is to review selected simulation models describing various mechanisms of cropland phosphorus transformations and transport, as well as to classify existing models and to clarify the main environmental effects related to phosphorus application. For example, phosphorus is one of the nutrients which can accelerate eutrophication of rivers and lakes. Furthermore, heavy application of phosphorus fertilizers to croplands can lead to accumulation of phosphorus in the soil. Both the accumulation of phosphorus in the soil and the acceleration of eutrophication of water bodies are two of the main environmental problems associated with application of phosphorus fertilizers. Figure 1 illustrates the relation between phosphorus application and environmental effects. Both the phosphorus surface runoff and the loss of phosphorus through soil erosion are the main processes responsible for water body phosphorus pollution from croplands. Figure 2 illustrates the cropland phosphorus input-output flow chart. Water soluble phosphorus losses are due to runoff and losses of phosphorus connected to soil particles are due to soil erosion. The forms of phosphorus pollution depend on transformation processes. There are a few reactions which cause transformations of applied phosphorus to several less soluble forms. These reactions lead to a decrease in the phosphorus concentration in the soil solution and accumulation of "fixed" phosphorus in the soil. Figure 3 illustrates the pathway of inorganic phosphorus transformation in the soil. Inorganic forms of soil phosphorus pass through several main phases: soluble phosphorus, physically absorbed phosphorus, immobilized or fixed phosphorus, and phosphorus precipitated from the soil solution. The phosphorus absorption-desorption reaction needs only a few minutes to reach equilibrium, while the precipitation-desolation reaction can require a few days to reach equilibrium, and the immobilization-mobilization reaction will need a few months.

Depending on the specific agricultural and environmental situation, various phosphorus transformation models emphasize different aspects or processes of the transformation processes. The present paper, therefore, is an attempt to collect, assess, and classify current models of cropland phosphorus transformations and losses which were developed in the last 10 years. The eleven models described in this paper are divided into three groups. Figure 4 illustrates the main principles used for the classification. There are four classes: class A contains models necessary for understanding transformation processes at the field level (5 models); class B does not contain models; class C contains models which were developed to predict phosphorus losses from agricultural fields (2 models); class D contains models which were developed to predict phosphorus losses from agricultural watersheds (4 models). It should be noted that a comparative analysis of models which belong to the same matrix cells should be carried out in the future.

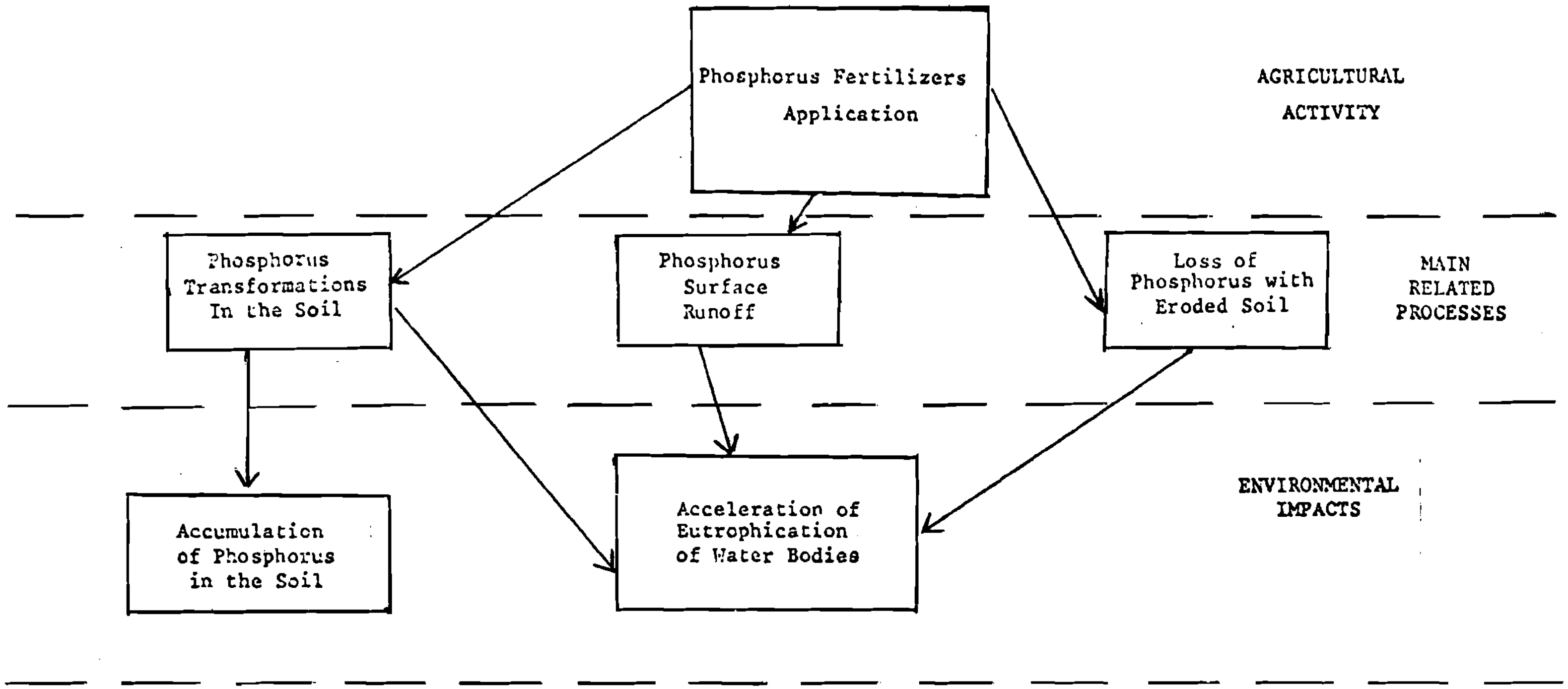

Figure 1. A relationship between phosphorus application and environmental effects.

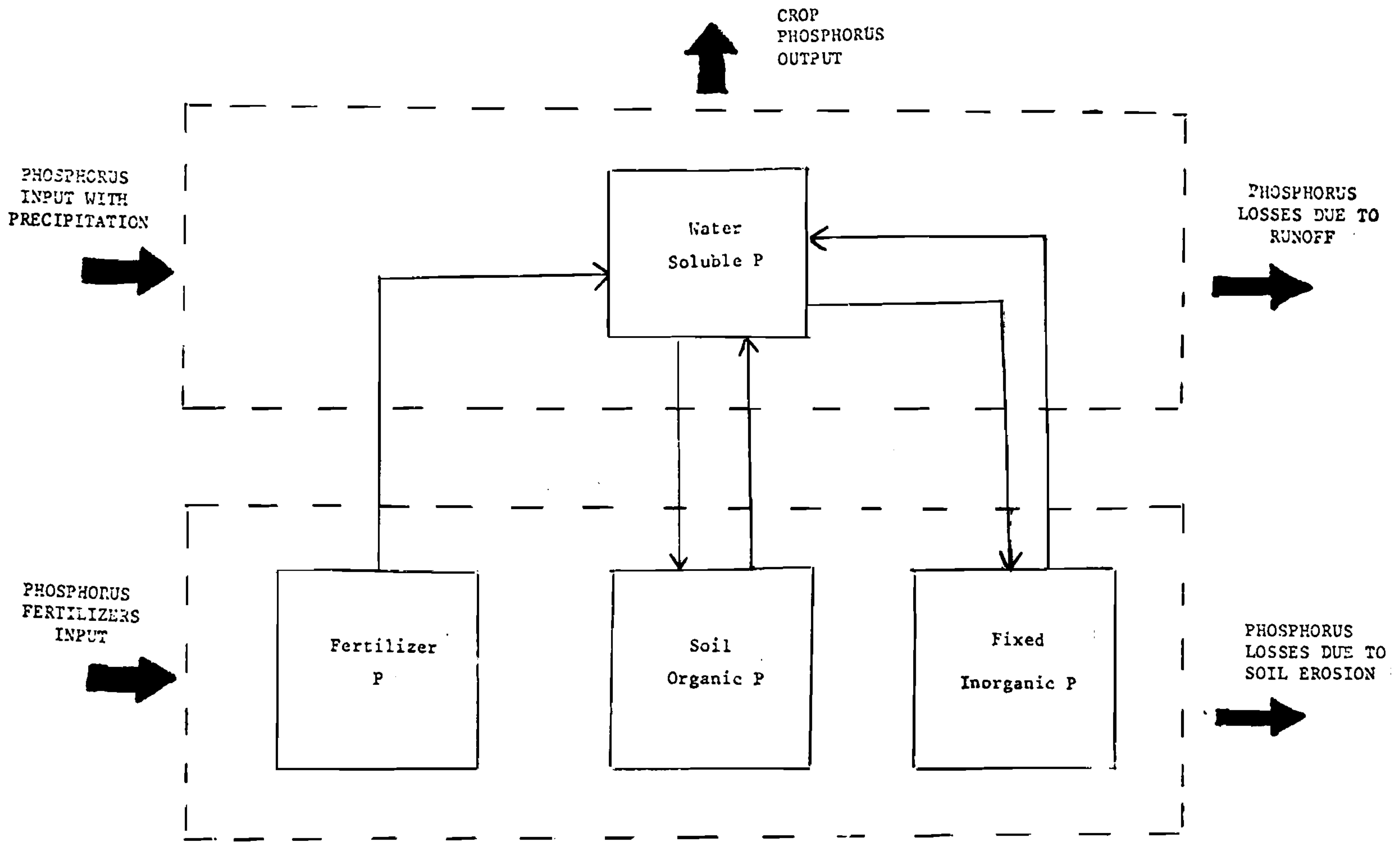

Figure 2. Cropland Phosphorus Input-Output Flow Chart.

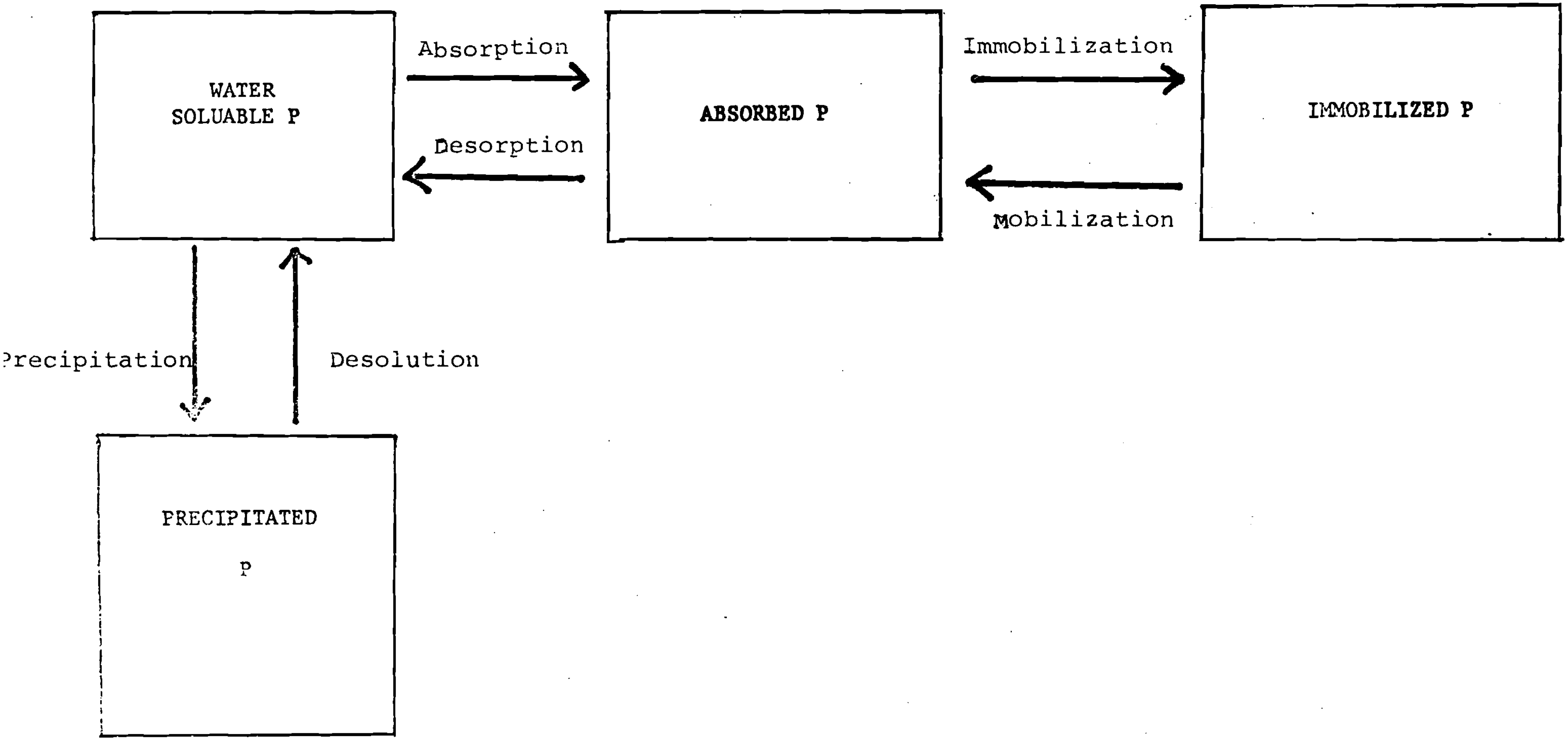

Figure 3. Inorganic Phosphorus Transformation in the Soil.

LEVEL / OBJECTIVE	FIELD LEVEL OF CONSIDERATION	WATERSHED LEVEL OF CONSIDERATION
Modeling and understanding phosphorus transformation processes	Class A (5 models)	Class B (no models)
Prediction of phosphorus losses from croplands	Class C (2 models)	Class D (4 models)

FIGURE 4. Classification of current existing cropland phosphorus models.

LIST OF MODELS

Class A

1. R.S. Mansell, H.M. Selim, P. Kanchanasut, J.M. Davidson, Y.G.A. Fiskell, "Experimental and Simulated Transport of Phosphorus through Sandy Soils," Water Resources Research, v. 13(1) 1977, pp. 189-194.

2. C.G. Enfield, B.E. Bledsoe, "Fate of Wastewater Phosphorus in Soil," Journal of the Irrigation and Drainage Division, v. 101 IR 3, 1975, pp. 145-155.

3. B. Mishra, P.K. Khanna, B. Ulrich, "A Simulation Model for Organic Phosphorus Transformation in a Forest Soil Ecosystem," Ecological Modeling, v. 6, 1979, pp. 31-46.

4. R.S. Mansell, H.M. Selim, J.G.A. Fiskell, "Simulated Transformations and Transport of Phosphorus in Soil," Soil Science, v. 124, No.2, 1977, pp. 102-109.

5. K.R. Helyar, D.N. Munns "Phosphate Fluxes in the Soil-Plant System: A Computer Simulation," HILGARDIA, v.43, No. 4, 1976, pp. 103-130.

Class C

1. L.J. Tubbs, D.A. Haith, "Simulation of Nutrient Losses from Cropland," Paper No. 77-2502 was presented at the 1977 Winter Meeting of the American Society of Agricultural Engineers, Chicago, Illinois, December 13-16, 1977, 34 pp.

2. A. Amberger, J. Hagin, "Contribution of Fertilizer and Manures in the N- and P-load of Waters: A Computer Simulation Model," Final report submitted to the Deutsche Forschungs Gemeinschaft, January 1974, 124 pp.

Class D

1. V. Novotny, H. Tran, G.V. Simsiman, G. Chesters, "Mathematical Modeling of Land Runoff Contaminated by Phosphorus," JOurnal WPCF, v. 50(1) 1978, pp. 101-112.

2. I. Bogardi, L. Duckstein, "Input for a Stochastic Control Model of P loading," Ecological Modeling, v.4, 1978, pp. 173-195.

3. A.S. Donigian, D.C. Beyerlein, H.H. Davis, N.H. Crawford, "Agricultural Runoff Management (ARM) Model," Research Report, EPA-600/3-77-098, 1977, 294 pp.

4. G. Kling, "A Computer Model of Diffuse Sources of Sediment and Phosphorus moving into a Lake," Ph.D. Thesis, 1974, Cornell University, New York.

CLASS A: Model 1

Model reference	R.S. Mansell; H.M. Selin; P. Kanchanasut; J.M. Davidson; J.G.A. Fiskell, "Experimental and Simulated Transport of Phosphorus through Sandy Soils," Water Resources Research, v. 13 (1), 1977, pp. 189-194.
Modelling processes	The orthophosphate movement through the sandy soil, reversible phosphorus absorption-desorption processes, irreversible precipitation and chemical immobilization are taken into consideration.
Modelling techniques	In order to simulate phosphorus movement through soil, a one-dimensional transport equation is used. The solute transport equation is solved numerically for a soil column of fixed length. The explicit-implicit finite difference techniques are used. Three types of reversible absorption are considered. The first is approximated as being linear; the second and third are non-linear.
Model input	The soil water flux in vertical direction and amount of inorganic phosphorus fertilizers applied are the main model input.
Model output	Dynamics of soluble phosphorus concentration in soil water in surface and subsurface soil horizons are the main model output.
Model assessment	The model can be used to understand better the phosphorus transformation processes in the soil. The present model allows us to estimate the role various physical and chemical processes influencing phosphorus transport through sandy soils.

CLASS A: Model 2

Model reference	C.G. Enfield; B.E. Bledsoe; "Fate of Wastewater Phosphorus in Soil," Journal of the Irrigation and Drainage Division, v. 101 IR3, 1975, pp. 145-155.
Modelling processes	The absorption-desorption, precipitation and immobilization phosphorus processes are taken into consideration. The orthophosphate movement through a soil is modelled.
Modelling techniques	In order to simulate phosphorus movement through soil, the one-dimensional transport equation is used. The regression analysis is used to get different Kinetic functions to model absorption-desorption phosphorus processes. Calculations for the solubility of $ACH_2PO_4(OH)_2$; $Ca_5OH(PO_4)_3$ are made. The total phosphorus in solution is calculated as the sum of the different ionic species.
Model input	The amount of inorganic phosphorus applied to the soil and the soil water flux in a vertical direction are the model output.
Model output	The equilibrium residual phosphorus concentration in the soil solution is the main model output.
Model assessment	Using this model one can calculate and predict the equilibrium residual phosphorus concentration in the soil solution. The fate of orthophosphate in soils receives the most attention. Furthermore, the model can be used in a mass balance analysis to assess the capacity of a soil to remove orthophosphate from solution.

CLASS A: Model 3

Model reference	B. Mishra; P.K. Khanna; B. Ulrich, "A Simulation Model for Organic Phosphorus Transformation in a Forest Soil Ecosystem," Ecological Modelling, v.6, 1979, pp. 31-46.
Modelling processes	The decomposition of litter as well as mineralization and immobilization of phosphorus in the humus layer of soil are the main processes considered. Furthermore, the decomposer population growth processes are taken into account.
Modelling techniques	Phosphorus in the humus layer is divided into two components: phytin-like substances and nucleic acid-like substances. Zero-order Kinetic is used to model phosphorus mineralization and synthesis. It is assumed that the rate of litter decomposition is proportional to the growth rate of decomposer organized biomass. The soil moisture and temperature affect the growth rate of decomposer biomass.
Model input	Quantity of litter fall, quality data of litter, monthly amount of phosphorus with precipitation are considered as model input.
Model output	Phosphorus concentration in the effluent of the humus layer, the decomposer biomass, the dynamics of the carbon/phosphorus ratio of litter are the main model output.
Model assessment	The present model can be used to gain an insight into the organic phosphorus transformations and behavior in the soil. Despite the fact that it is a site-specific model developed for a forest soil ecosystem, it is possible to implement the present model, after changes in certain parameters, for agricultural ecosystems.

CLASS A: Model 4

Model reference	R.S. Mansell; H.M. Selin; J.G.A. Fiskell; "Simulated Transformations and Transport of Phosphorus in Soil," Soil Science, v. 124, No.2, 1977, pp. 102-109.
Modelling processes	The transformations and movement of orthophosphate in soil are modelled. The sorption-desorption, mobilization-immobilization, precipitation-dissolution are phosphorus transformation processes taken into account. The transport of solution-phase phosphorus through the soil in the vertical direction is considered.
Modelling techniques	First order differential equations are used to model the dynamics of phosphorus transfer between different phases (adsorbed, soluble, immobilized, and precipitated phases). The explicit-implicit finite difference method is used to solve the phosphorus-transport equation.
Model input	The soil water flux in a vertical direction and the amount of inorganic phosphorus fertilizers applied are the main model input.
Model output	Dynamics of distributions of soluble, adsorbed, immobilized, and precipitated phosphorus in the soil profile are the main model output.
Model assessment	This model can be used for understanding the problem of accumulation of phosphorus in the soil due to heavy applications of municipal wastes and commercial fertilizers to the croplands. The present model provides a detailed description of phosphorus retention and removal processes in the soil.

CLASS A: Model 5

Model reference	K.R. Helyar; D.N. Munns; "Phosphate Fluxes in the Soil-Plant System: A Computer Simulation," MILGARDIA, v.43, No.4, 1976, pp. 103-130.
Modelling processes	The adsorption-desorption, the slow removal of phosphate from the soil solution and adsorbed phases, dissolution of phosphorus fertilizer, and phosphate uptake by plant roots are the main processes considered.
Modelling techniques	The phosphate adsorption and desorption isotherms are used. The slow removal of phosphate from the soil solution and adsorbed phases is modelled by a simple n-th order Kinetic differential equation. The first-order Kinetic is used to model the dissolution of fertilizer. The radial diffusion and convection equation is used to model phosphorus transfer to roots. This equation is solved by a numerical technique, using the Czank-Nicolson finite difference method.
Model input	The amount of phosphate fertilizer applied to the soil is the main model input.
Model assessment	This model can be used to improve the understanding of phosphorus transformation and plant uptake processes in the root zone of soils. The present model can be useful in estimating the role of different factors which affect phosphate transformation and plant uptake.

CLASS C: Model 1

Model reference	L.J. Tubbs; D.A. Haith, "Simulation of nutrient losses from cropland," Paper No.77-2502 was presented at the 1977 Winter Meeting of the American Society of Agricultural Engineers, Chicago, Illinois, December 13-16, 1977, 34 pp.
Modelling processes	Water balance processes: surface and subsurface runoff, snow-melting, percolation, evapotranspiration. Nitrogen balance processes: organic nitrogen mineralization, runoff and percolation losses of nitrogen, crop uptake of nitrogen. Phosphorus balance processes: absorption and desorption of inorganic phosphorus in the soil, soluble phosphorus losses in runoff, absorbed losses of phosphorus with erosion.
Modelling techniques	The hydrological submodel is based on a daily moisture balance for the top layer of soil. Runoff is forecasted using the U.S. Soil Conservation Service's equation. The organic nitrogen mineralization rate is modelled by the Van't Hoff-Azzhnenius relationship. The equilibrium between fixed and soluble phosphorus is described by a linear isotherm. Average soil losses due to erosion are calculated from from the Universal Soil Loss equation.
Model input	Daily weather data (surface air temperature, solar radiation, total precipitation, minimum and maximum daily air temperature), nutrient inputs and crop removals are considered as a main model input.
Model output	Losses of nitrogen and phosphorus in eroded soil, losses of dissolved inorganic phosphorus in runoff, losses of dissolved inorganic nitrogen in runoff and percolation are the main output of the model.
Model assessment	This model can be used to predict losses of fertilizer and nitrogen from an agricultural cropped field. The present model does not provide for the assessment of the effects of changes in manure applications. It should be noted that unlike other existing nutrient simulation models, this model provides reasonable estimates of phosphorus and nitrogen losses.

CLASS C: Model 2

Model reference	A. Amberger; J. Hagin, "Contribution of Fertilizer and Manures in the N- and P-load of Waters. A Computer Simulation Model," Final report submitted to the Deutsche Forschungs Gemeinschaft, January 1974, 124 pp.
Modelling processes	Water balance processes: water flow through the soil, transpiration and evaporation, surface and subsurface runoff. Soil erosion and heat and oxygen transport processes are taken into consideration. Nitrogen balance processes: mineralization of organic nitrogen, immobilization of inorganic nitrogen, nitrification, denitrification. Phosphorus balance processes: phosphorus transport with eroded soil.
Modelling techniques	The calculation of the rate of water flow is based on an extended Darcy equation. Oxygen transport in soil is described by Fick's equation. The soil profile is divided into several layers of equal thickness. The first-order Kinetics are used to model nitrogen transformation processes. With respect to soil erosion modelling, a high permeability for the top layer of soil and a lower one for the second layer is assumed. The equation for the water flow in the permeable layer is based on Darcy's law.
Model input	Daily meteorological data, irrigation intensity and total amount of water applied, the amounts of manure and fertilizer phosphorus and nitrogen applied are the main input of the present model.
Model output	Dynamic of soil moisture and nitrogen concentration in the soil, amount of nitrate leached and amount of phosphorus removed with eroded soil are considered as the main model output.
Model assessment	With respect to phosphorus, the present model can be useful in estimating cropland phosphorus losses due to soil erosion. With respect to nitrogen, this model can be used both to estimate cropland nitrogen losses and to improve our understanding of nitrogen transformation and transport processes in the soil.

CLASS D: Model 1

Model reference	V. Novotny; H. Tran; G.V. Simsiman; G. Chesters. "Mathematical Modelling of Land Runoff Contaminated by Phosphorus," Journal WPCF, v.50 (1), 1978, pp. 101-112.
Modelling processes	The land runoff and sediment, snowpack-snowmelt, infiltration, evapotranspiration, surface soil erosion, phosphorus soil adsorption are the principal processes considered.
Modelling techniques	The phosphorus sorption is described by the Langmuir isotherm. Surface soil erosion is modelled by Universal Soil Loss Equation which includes effects of rainfall energy and sheet runoff. The phosphorus adsorption model is incorporated into a dynamic hydrologic-sediment transport model termed LANDRUN.
Model input	Daily agrometeorological data, watershed characteristics and type of land use are the main model input.
Model output	The soil adsorption submodel output is pollutant distributed between the soil solution and the soil particles. Phosphorus loading on rivers and lakes is the main model output.
Model assessment	The present model can be used to estimate the crop-land phosphorus losses, and to investigate the role of different soil and water protection practices in the nutrient loading of rivers and lakes. Moreover, this model can be used as a phosphorus loading input to water bodies quality models.

CLASS D: Model 2

Model reference	I. Bogardi, L. Duckstein, "Input for a Stochastic Control Model of P Loading," Ecological Modelling, v.4, 1978, pp. 173-195.
Modelling processes	The model consists of two main parts: a submodel of transport of phosphorus into the lake and a submodel of phosphorus accumulation in the lake. The first submodel takes into account the processes of cropland phosphorus removal by runoff and sediment and the second concerns the processes of the phosphorus cycle in the lake.
Modelling techniques	The volume of runoff per event is estimated from the U.S. Soil Conservation Service formula. The sediment yield is calculated by means of the Universal Soil Loss equation. The amount of dissolved phosphorus transported is calculated by multiplying the soluble phosphorus in the soil by runoff volume. The losses of sorbed phosphorus are associated with sediment yield and fixed phosphorus concentration in the soil. The total seasonal P-loading is the sum of random P-loading events. Long-term accumulation of phosphorus in the lake is modelled by a first order difference equation.
Model input	Precipitation and concentration of soluble and sorbed phosphorus in the soil are the main model input.
Model output	The total seasonal P-loading is the main output of the P transport submodel. The dynamics of long-range accumulation of phosphorus in the lake are the main output of the second submodel.
Model assessment	The present model can be used to estimate the seasonal P-loading on the lake from the agricultural watershed and to assess long-range accumulation of phosphorus in lake sediment.

CLASS D: Model 3

Model reference	A.S. Donigian; D.C. Beyerlein; H.H. Davis; N.H. Crawford, "Agricultural Runoff Management (ARM) Model," Research Report, EPA-600/3/77/098, 1977, 294 pp.
Modelling processes	The model simulates: Water balance processes: snow accumulation and melting, runoff, infiltration, percolation, evapotranspiration. Nitrogen balance processes: ammonification, nitrification, denitrification, immobilization, and nitrogen plant uptake, nitrogen leaching. Phosphorus balance processes: mineralization of organic phosphorus, adsorption-desorption, immobilization to organic, plant uptake. The pesticide adsorption-desorption and degradation processes, soil erosion and nutrient runoff and sedimentation are taken into consideration.
Modelling techniques	The model contains five submodels which simulate the hydrologic response of the watershed, sediment production, adsorption-desorption of pesticides, pesticide degradation, and nutrient transformation. The hydrological submodel is a modification of the Stanford Watershed Model. The single-valued reversible and nonsingle-valued irreversible adsorption-desorption equations are used. First-order mechanisms are used to model pesticide degradation and nutrient transformations.
Model input	Hydrometeorological data and amount of fertilizers and pesticides applied are the main model input.
Model output	The losses of phosphorus, nitrogen and pesticides from croplands are the main model output.
Model assessment	The present model can predict the losses of P- and N-fertilizers and pesticides from the agricultural watershed. The model allows for evaluation of the impact of tillage on sediment production and phosphorus losses.

CLASS D: Model 4

Model reference	G. Kling, "A Computer Model of Diffused Sources of Sediment and Phosphorus Moving into a Lake," Ph. D. Thesis, 1974, Cornell University, New York.
Modelling processes	The surface soil erosion and phosphorus sedimentation are the main processes considered.
Modelling techniques	Soil erosion is modelled according to the Wischmeier equation. The linear regression is used to connect total phosphorus losses with sediment yield. Movements of sediment and phosphorus are characterized by separating segments of the landscape from which material should be removed.
Model input	The changes of land use are the main model input.
Model output	The sediment and phosphorus losses from the agricultural watershed are the main model output.
Model assessment	Present model can be used to predict the amount of sediment and phosphorus from non-point sources. The model provides a method to estimate the effects of changes of land use on sediment and phosphorus losses from the agricultural watershed.