ARS SMALL WATERSHED MODEL

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PREFACE

The global population growth and the increasing demand for agricultural products led to the extension of agricultural land and the intensification of land use. Therefore, optimal land use is a very important practical problem of the interaction of agricultural management and the environment, and the mathematical models are useful tools for analyzing this interaction. During 1978-1981 a task "Environmental Problems of Agriculture" within the Resources and Environment Area of IIASA used a complex field level model (CREAMS) for analysis of the problems of soil erosion, nitrogen leaching, phosphorus and pesticide losses. This model (CREAMS) which was developed by U.S. Department of Agriculture was used in Czechoslovakia, England, FRG, Finland, Poland, Sweden and USSR. The results of this use will be published at IIASA as a CPS (forthcoming).

One of the special questions of the task "Environmental Problems of Agriculture" was the problem of transition of a field level model to a regional one. The SWAM model which is described in this paper is one of the attempts to describe the management of land use within the catchment area. The SWAM (Small Watershed Agricultural Model) uses the dynamic version of the improved CREAMS model (CREAMS II) and may be useful to investigate the effect of agricultural management and evaluate the hydrologic sediments and chemicals from a small watershed.

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Land and Landcover Resources

ACKNOWLEDGEMENTS

The development of SWAM is an ARS team effort to which a large number of people are contributing. Dr. Roger Smith is developing much of the dynamic version of the CREAMS II model and is responsible for much of the material presented in that section of this report. He has received a lot of support from other members of the CREAMS team. They are Drs. Walter Knisel, Chairman; Ralph Leonard, George Foster, Arlin Nicks, Jimmy Williams and Virginia Ferreira. Dr. Keith Saxton has participated actively in discussions of plant growth modeling and will be aiding in evaluation. Dr. George Foster contributed much to the development of sediment routing on source areas through numerous discussions of overland erosion processes. Dr. Carlos Alonso is responsible for development of the channel routing of both water and sediments. He will also be playing a major role in assembly and testing of the entire SWAM model. Dr. Harry Pionke has been responsible for coordinating development of the chemistry components' behavior and transport through the channel system. Drs. Bill Gburek and Yui Liong are responsible for development of the groundwater component. Drs. Frank Schiebe and Ron Menzel are responsible for the reservoir model. Dr. Myron Molnau contributed to the development of the snow accumulation and melt routines. Dr. Wade Nutter was responsible for adopting the model to timbered areas. Dr. Clarence Richardson developed the models being used to generate the synthetic climatological inputs. Mr. J.B. Burford has assembled the many data sets needed for testing. Others such as Drs. Harry Kunishi, Leonard Lane, Ken Renard, Ronald Schnabel and John Schreiber have also aided in its development. When the final document is completed, these and many others will have contributed.

ABSTRACT

In this paper I have attempted to describe the SWAM development by ARS. It began several years ago with the work on CREAMS. The Small Watershed Model uses the dynamic version of CREAMS II as its core. The outputs from all source areas within a small watershed are routed through the channel and impoundment systems to the downstream point. The dynamic version of CREAMS II provides a continuous record of water, sediment and chemicals from each field in the watershed. A dynamic channel routing scheme routes the water and sediments, by particle size fraction, calculating both aggradation and degradation; bed armoring is also included. The reservoir model calculates profiles of temperature and sediment concentration as well as the effects of biological activity on nutrient levels. Most of the significant chemical balances and changes are considered as the flow moves from reach to reach. However, much remains to be done to make the combined program useful to a wider range of applications. This consists of sensitivity analyses to reduce the model complexity in insensitive regions and to find efficient ways to aggregate areas such that a basin scale model can be developed.

TABLE OF CONTENTS

ARS SMALL WATERSHED MODEL

D.G. DeCoursey

INTRODUCTION

A group of Agricultural Research Service (ARS) scientists met in Arlington, Texas, in 1980 to discuss the ARS response to expressed needs for information and analytical tools that planners could use in responding to questions on nonpoint source pollution (Section 208 of Public Law 92-500, The Clean Water Act). We felt that the ARS could respond to these needs of action agencies and planners because we had been doing research in this area for many years.

At the meeting three levels of involvement were identified. The first of these to receive attention was the development of a model to simulate runoff, erosion and chemical movement from an agricultural field. A state-of-the-art mathematical model of Chemical, Runoff and Erosion from Agricultural Management Systems known as CREAMS (Knisel, 1980) was published by USDA as Conservation Research Report No. 26, in May, 1980. At this time, the model is being updated and improved. The dynamic version of this improvement is the core of the second model, that of a small watershed (SWAM). The purpose of this model development is to simulate the response of a small watershed (2000 hectares) to alternative land use or management changes within its catchment area. It is limited in size because responses from all the unit areas within the watershed are routed downstream through the channel and any impoundments; and only a few such areas can be handled effectively. The third model, identified at the meeting, was one designed to simulate the response from a basin scale area (several hundred square kilometers). It will be designed to aggregate areas such as those addressed by CREAMS and identified individually in SWAM. The small watershed model will be used in a simulation mode to help identify the best way to aggregate these areas.

This paper, the first of a series of papers describing SWAM, describes the various subroutines that are being combined into the first version of the model. Future papers will describe the sensitivity analyses, more refined versions of the model and sample applications. A USDA publication is being planned that describes the model in detail, provides a users manual and technical papers supporting various components.

INITIAL CONCEPTS

The small watershed model is being designed to show the effect of changes in land use or management on the hydrologic, sediment, and chemical response of a small watershed. Since it uses CREAMS as a base, it is applicable to conservation tillage, crop rotation, double cropping contouring, strip cropping, terraces and grassed waterways. The emphasis of the model is evaluation of management alternatives, thus the response should be reasonably accurate for both absolute and relative estimates of a specific practice at a site. The model is being designed to use on engaged areas, thus it is intended to be used without calibration. For most purposes charts, tables, graphs and maps will provide parameter value guidance for those situations where on-site estimates or previous experience are not available to aid in their selection. Because of the wide variety of situations to which it is likely to be applied, three typical site conditions were considered in its development, i) small watersheds in which the flow is dominated by surface flow in the channel system, ii) small watersheds in which the flow is dominated by surface water impoundments, and iii) small watersheds in which the flow is dominated by subsurface flow. By considering all three situations in the development of the model we should be able to address most site problems that are combinations of these three.

In its initial form, the model will be very comprehensive and will probably be more of a research than a management tool. It was developed this way because we felt that such a model could be used in more situations than simpler models. It is also much easier, through sensitivity analyses, to simplify a comprehensive model where it is least sensitive, than to take a simple model and make it more comprehensive. Because it is comprehensive, at least in its initial configuration, it is not practical for long term (20 years or more) simulations. It will be a continuous simulation model of watershed response to individual events for a period of several years. As it is refined, through sensitivity analyses to both simplify it and develop methods to aggregate areas, it will become more useful for long term simulation.

Because of the many physical processes that are being simulated, it is difficult to grasp a picture of the whole model and all the interaction that takes place. Figure 1 is a schematic of the entire model showing all of the processes that are to be included. Each of these is discussed in more detail in later parts of this paper. Inputs for a model as comprehensive as this are extensive. Figure 2 is an expansion of the major input groups at the top of Figure 1. In the next section of the report I will describe the dynamic version of CREAMS II that serves as the source area and is the core of SWAM. Essentially it is the center part of Figure 1, noted as source area processes.

Subroutines have been developed to provide sequences of daily rainfall, temperature and solar radiation for use at sites where these data are not readily available (Richardson, 1981). Similar subroutines are being developed for wind and pan evaporation. Techniques are also being investigated to disaggregate these to provide the hourly or breakpoint type inputs required of the more comprehensive model. As many data sets as possible are being assembled to test the model. However, no one data set has been found that is complete enough to cover all aspects of the model.

WATERSHED DELINEATION AND CLIMATIC INPUTS

In order to use the model, the entire watershed must be divided into source areas. These areas are as uniform in soils and land use as possible. Response from each of these areas is simulated by defining the source areas as a system of planes and V-shaped channels (a minimum number are used). At this point, there is no aggregation of areas; the response of each area is calculated individually. Methods of aggregation by similar crops, soils or small mixed land use watersheds will be studied by using the model in a simulation mode, looking at typical responses from a variety of different watershed configurations. A future paper will report on these evaluations.

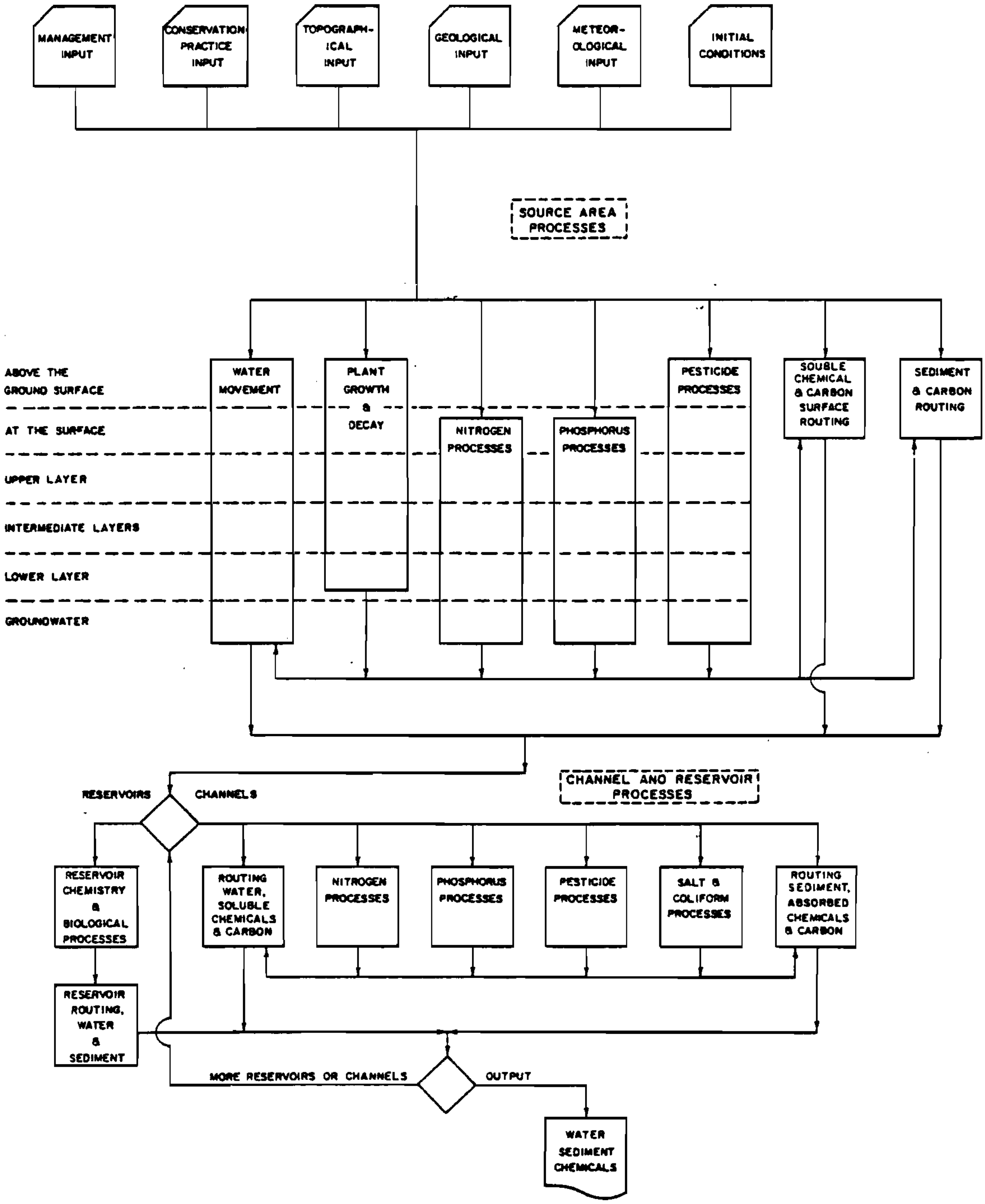

Figure 1. Small Watershed Model (SWAM)

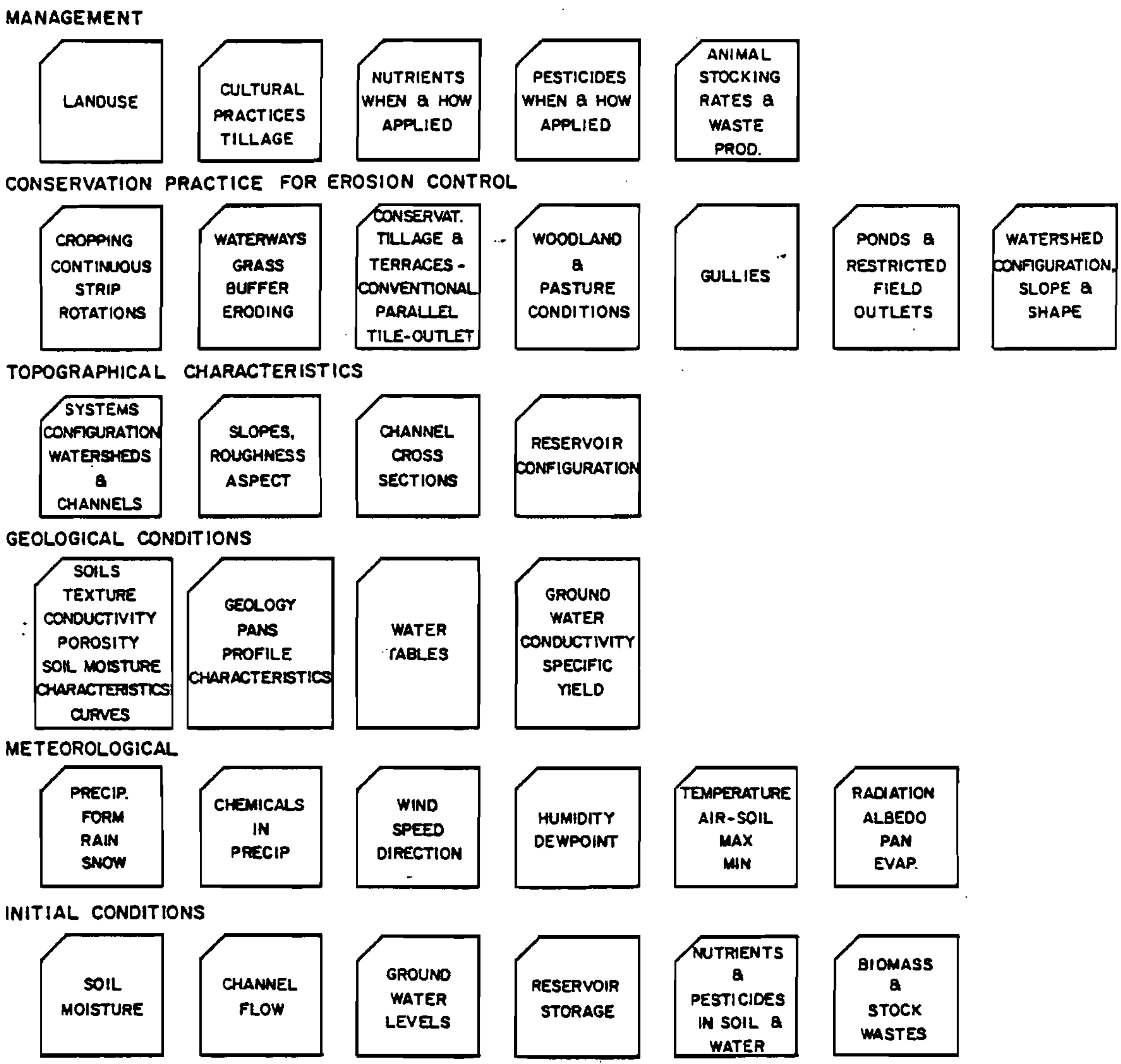

Figure 2. SWAM Inputs

Output from the source area watersheds (water, sediments and chemicals) will be routed through the channel and impoundment systems to the outlet of the watershed. Thus the channels must be described by cross section, bank and bed materials and vegetative cover at representative nodal points; such as at channel confluences and major change in cross section, slope, radius of curvature or bed and bank conditions. The depth-area-capacity curve and outlet structure of all impoundments are also needed or must be estimated. Points of groundwater return to the channel or losses from the channel to groundwater must be identified.

Climatic input to the model consists of breakpoint rainfall, maximum and minimum daily air temperatures and solar radiation. Alternative ET computations use pan evaporation and wind speed. At the present time we are concentrating on development of the model using breakpoint rainfall because we have much more confidence in the hydrologic response of the model with this input rather than daily values. When we start work on the version designed for long term simulation we will probably use daily inputs.

SOURCE AREA RESPONSE

The dynamic version of CREAMS II, which forms the nucleus of the SWAM model, is a significant revision of the CREAMS model. The three independent components of CREAMS (hydrology, erosion and chemicals) have been combined to enable the interactions that exist to operate properly. Many of the processes have been updated and new ones added e.g. precipitation interception by the plant canopy, the effects of tillage on infiltration and a dynamic soil erosion component. Figure 3 is a conceptualization of the movement of water in the model. The following discussion refers to the processes shown in Figure 3.

Precipitation

Precipitation input is divided into snow or rainfall as a function of the maximum and minimum daily air temperature. If weighted air temperature is less than or equal to 0° C (32° F) the precipitation is assumed to be snow. Snow accumulation is in the form of mm. of water equivalent. Snowmelt (Khanjani and Molnau, 1982)is a function of incoming solar radiation, albedo, shading and maximum and minimum air temperature, rainfall, aspect and slope of the site, and heat gain from the soil surface. Snow evaporation is a function of the maximum and minimum air temperature, solar radiation and albedo, which changes with age of the snow and is a function of accumulated degree hours.

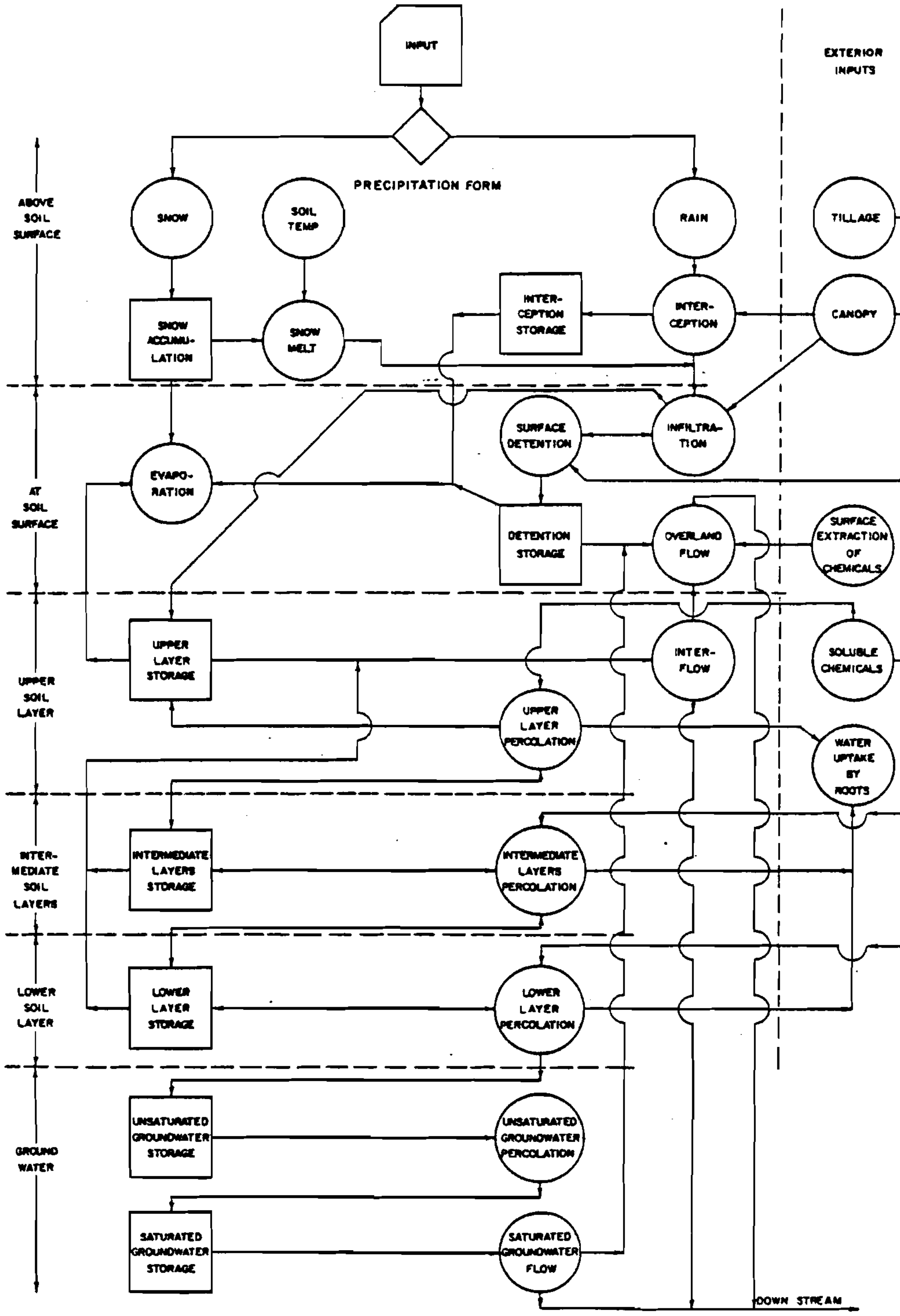

Figure 3. Water movement on source areas

Interception

Before rainfall reaches the soil surface, some of it is intercepted by the plant canopy. A multi-story canopy, such as trees over an understory, is possible. Litter on the ground under a row crop or other canopy is also considered to intercept rainfall. Interception is calculated as a linear function of the leaf area index. Mulch is described as percent cover and its interception treated the same as leaf area. Evaporation is assumed to come first from interception storage before that from the soil surface. Any deficit in interception storage is filled by rainfall in the next precipitation event.

Infiltration

Precipitation that passes through the canopy and litter infiltrates into the soil. Two alternative methods are available to estimate infiltration; the Smith and Parlange (1978) and the Green and Ampt (Moore, 1981) equations. Parameters of the equations are estimated by using the Brooks-Cory (Corey et al., 1965 and Laliberte et al., 1966) relations and the soil properties. Since tillage affects the macro pores, it is considered in calculating infiltration rate. The size of the macro pores are a function of relative surface roughness and the soil type. The depth of tillage depends upon the implement and its use. Both the surface roughness and macro pore size decay with precipitation following a tillage operation.

Moisture Flow in the Root Zone

The soil in the root zone can be described by as many as 10 horizons or layers. Each of these layers is characterized by its porosity, pore size distibution index, 15-bar water content, 0.3-bar water content and effective saturated hydraulic conductivity. Each of the layers is further divided by the computer subroutine into as many as 15 layers for computational purposes. Routing of water between the layers is accomplished by a linearized step-wise solution of the Richards equation in which the gravity and diffusion terms are treated separately to insure stability and lengthen both the allowable time and the distance increments. Roots extract water from the soil layers in proportion to the soil moisture potential in each layer (see section on plant growth).

Surface Detention

Surface detention is a function of roughness, soil type, tillage and amount of precipitation since the last tillage event.

Surface Runoff

Surface runoff occurs only after ponding has occurred and surface detention is filled. Using rainfall breakpoints, surface water is routed, with a kinematic approximation, of flow over a plane/channel cascade. It can provide for convergent or divergent flow, furrow geometry, and recession infiltration. The roughness parameter is a function of tillage, the effects of precipitation energy since the last tillage operation and litter or plant density in the case of range or pasture land conditions.

Erosion

Sediment eroded from the soil surface is calculated using time intervals determined by the rainfall and infiltration rates. A schematic of the processes involved is shown in Figure 4. The transport subroutines have been adapted from Kineros (Smith, 1976a and b and Smith, 1981 a and b). Sediment particles are assumed to be detached by both rainfall and flowing water and transported by the water. Interrill detachment of soil particles by rainfall occurs whether or not there is surface runoff. However, since they cannot be transported, rainfall detachment is not considered until runoff begins. It is a function of rainfall intensity and a soil erodibility factor related to soil type. Detachment in rills by flowing water is a function of the excess transport capacity.

A bookkeeping scheme enables us to calculate all of the above for a range of particle sizes and densities. Since both rill and interill erosion are considered, the concentrations of both surface applied and incorporated chemicals, that are attached to soil particles, can be identified and calculated. The topography is considered to be made up of cascades of planes and channels, all of the many conservation practices such as strip cropping, terraces, grass waterways, convex, concave, complex slopes and small impoundments can be simulated and both aggradation and degradation rates determined. Output consists of the quantities of each of several classes of sediment particle sizes in transport during each time interval. Both organic matter and any attached chemicals are also defined.

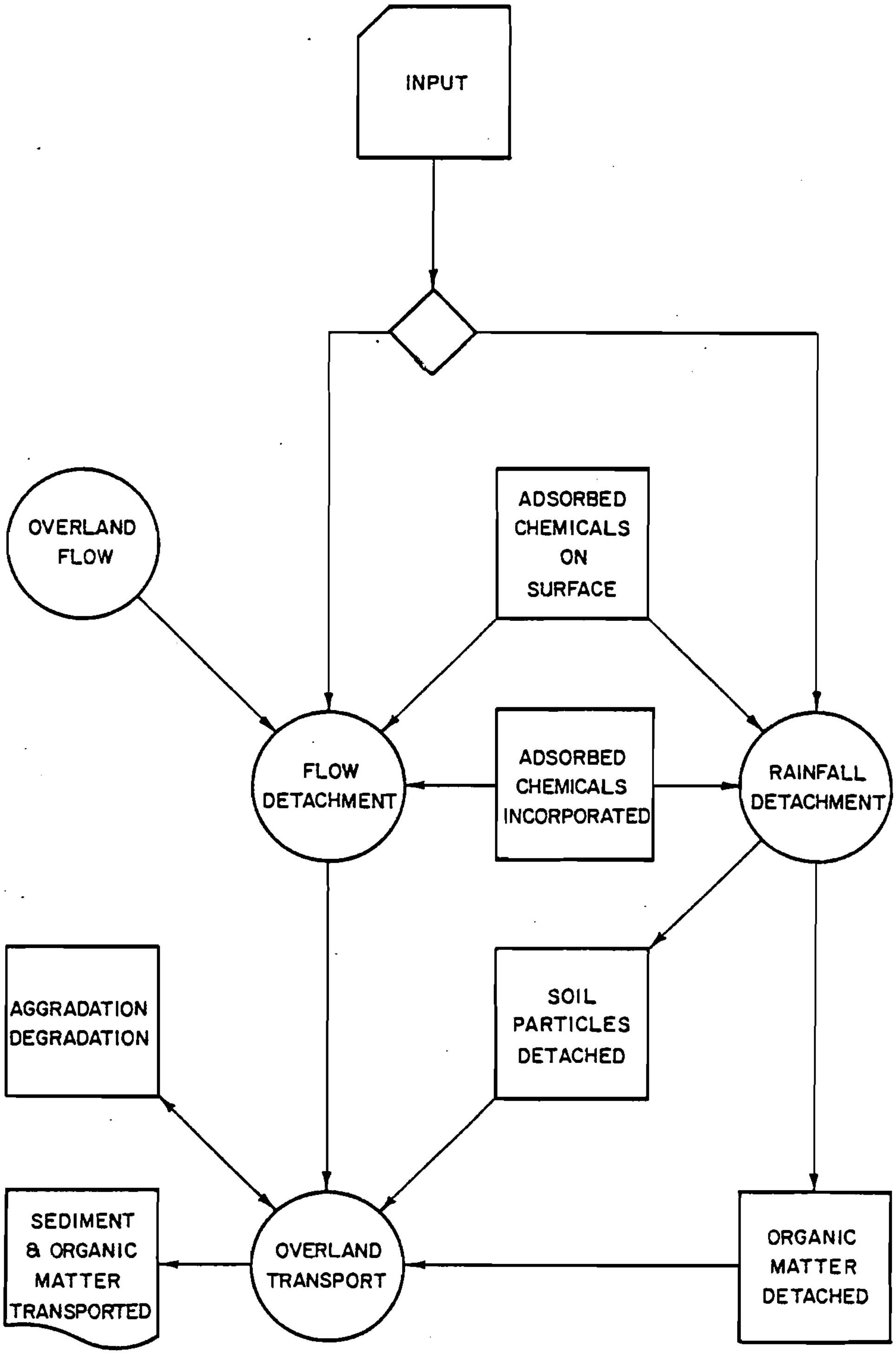

Figure 4. Sediment eroded on source areas.

Evapotranspiration

Incoming energy dissipation is split between soil surface evaporation and evapotranspiration. Evaporation from the exposed soil surface is influenced by any mulch that may be present and is a modified form of the Penman-Montieth method (Ritchie, 1972). Evapotranspiration from the plant surface during interstorm periods is assumed to occur at potential rate until it cannot be provided by water from the root zone. Limiting conditions in any layer begins at a moisture condition 20 percent above the 15 bar tension value. No water is available from soil with a moisture tension of 15 bars or greater. If net soil layer water is less than the 20 percent value, the amount provided is a function of the remaining water above the 15 bar tension value. Plant growth is limited by regions of soil that are completely saturated or have a moisture tension greater than 15 bars. Potential evapotranspiration rate can be calculated by Ritchie's method (Ritchie, 1972) or using pan evaporation with a coefficient. If the interstorm period is less than a day, potential evapotranspiration is distributed between dawn and dusk in a sinusoidal pattern. Dawn and dusk times are calculated by an algorithm from Mohler and Gifford (Khanjani and Molnau, 1982).

Plant Growth and Decay

The extent of protection provided by the canopy is calculated by a plant growth model (see Figure 5). Actual plant growth is a modification of potential growth; with potential growth being a function of three input variables defined for each crop. They are i) the energy efficiency of biomass production, ii) maximum potential dry mass production and iii) average degree-days to maturity. Water, temperature and nitrogen stress modify the potential growth curve. This form of growth model can very easily show regrowth response to harvesting, such as for alfalfa or other grass crops. However, yield of the crop is not a primary objective of the model at present, thus it is assumed to be a function of the dry matter produced. Die back after reaching maturity converts the leaf area to standing dry matter which then begins to fall and becomes surface residue. Papers describing these processes will be prepared by the team working on revision of the CREAMS model in the next few months.

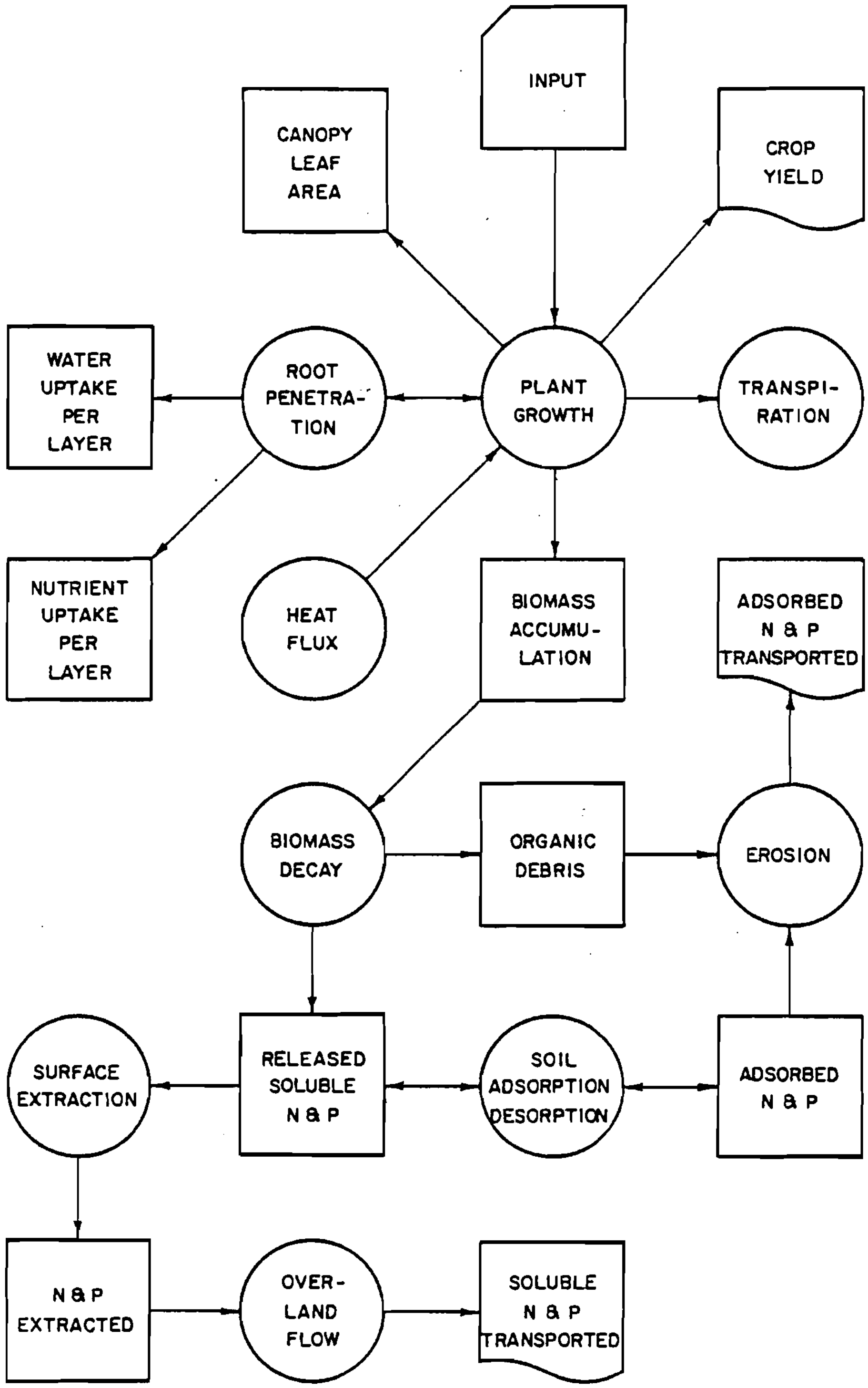

Figure 5. Biomass growth and decay

Decomposition of surface residue is a function of contact area with the soil. If the field is plowed, the surface biomass is incorporated and decomposes at a rate determined by mineralization rate in the nitrogen cycle. If the field is not plowed, only the material in contact decomposes by mineralization. As it decomposes additional material comes in contact with the soil until eventually all is decomposed. At the present time, the nutrients considered in the decomposition are phosphorus and nitrogen. Both the nutrients and carbon accumulations are based on the carbon-nitrogen ratios of the plant and average nutrient content.

The concentration or density of plant roots in any one soil layer is assumed to be great enough to provide that fraction of the water that the hydrostatic pressure gradient indicates should come from that layer. Thus, only the penetration depth of the roots is needed. It is assumed to be a nonlinear function of plant growth, i.e. root penetration is faster early in the season. Nutrient uptake by the roots is assumed to be sufficient to meet the plant's needs. Nutrient stress occurs only when the nutrients in the soil profile are insufficient.

Heat Flux: Since many of the nutrient processes as well as snowmelt are dependent upon soil temperature, a heat flux model is provided. It solves the second order differential equation for heat flow using the same soil layers as those used for water movement, but with the nodes assumed to be at the layer boundaries. The temperature, several cm. below at the base of the root zone, is assumed constant. Only daily average temperatures are used for the soil surface boundary--no daily fluctuations are considered.

Nitrogen Cycle

The nitrogen cycle in the soil is very complex. Figure 6 shows those components considered. Inputs of nitrogen are assumed to be fertilizer, manure, plant residues, nitrogen fixation and rainfall. Microorganisms in the soil convert the organic forms of nitrogen to ammonia and nitrate; the rate of conversion is a function of the soil moisture and temperature conditions. The nitrification of ammonia to nitrate is not considered as a separate process; it is incorporated in mineralization. Nitrate in soil solution is taken up by the plants, redistributed with the soil water, leached below the root zone into ground water,

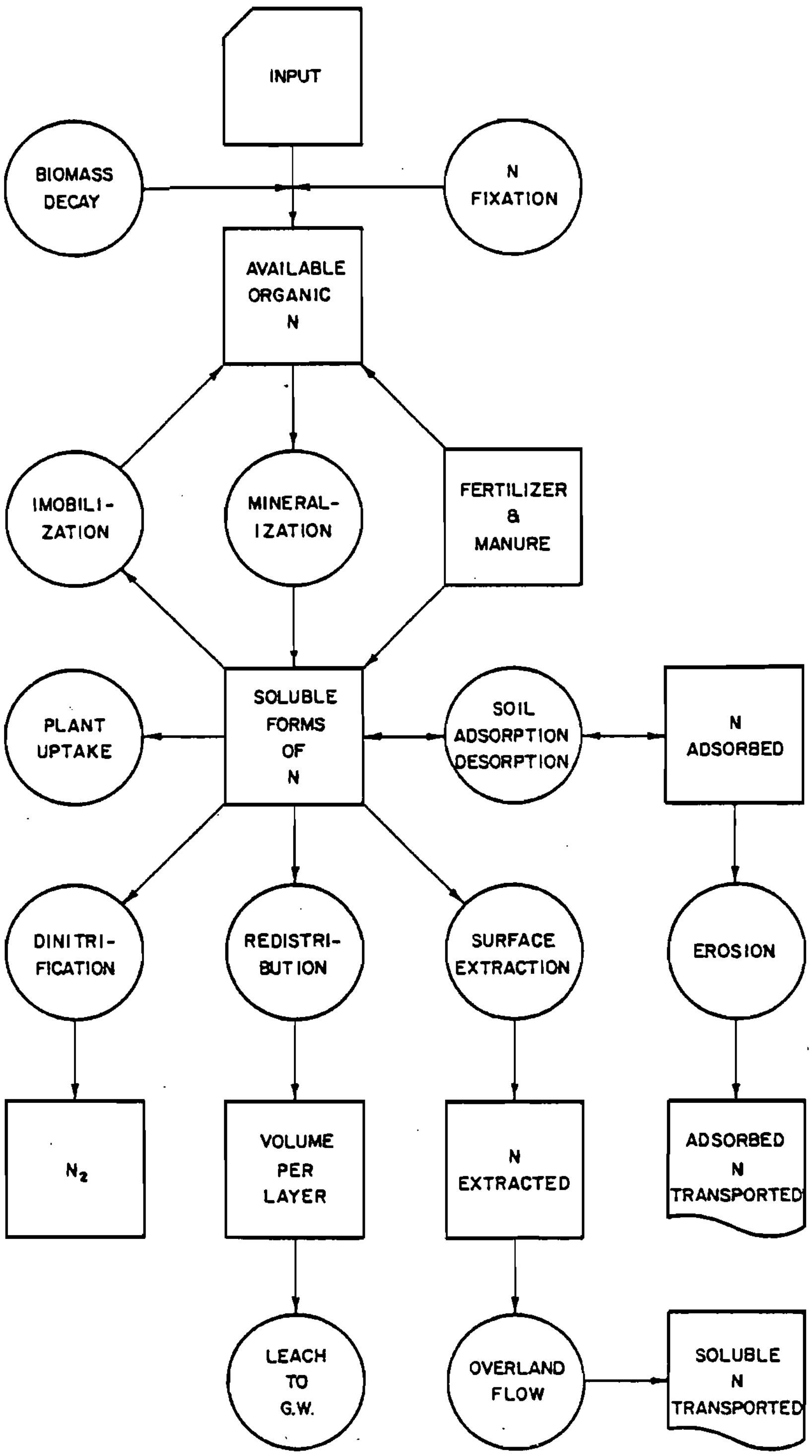

Figure 6. Nitrogen cycle on source areas

extracted from surface soil layers by surface runoff, immobilized and denitrified. Adsorption-desorption isotherms relate the soluble ammonia to that adsorbed on soil particles. The adsorbed ammonia plus other sediment associated nitrogen is subject to erosion with the soil. Expressions for the nitrogen cycling processes are based on the Phoenix and EPIC models (McGill et al., 1981 and Williams, 1982).

Phosphorus Cycle

The phosphorus processes are shown in Figure 7. Inputs consist of plant residues and fertilizer or manure in the form of soluble phosphates. Within the soil, mineralization of organic forms to the inorganic or immobilization of inorganic to organic are not considered. Soluble PO_4 is strongly adsorbed on soil particles thus the soil can act as a scavenger. Phosphorus can be leached from the soil surface, but is not considered to move through the soil profile except in certain circumstances. The amount extracted from the surface by runoff is a function of an extraction coefficient, the phosphorus concentration in the soil solution and flow rate. Adsorbed PO_4 is subject to loss as erosion removes the soil particles. Plant uptake is a function of demand.

Pesticide Processes

The movement of pesticides on source areas is shown in Figure 8. The method of application is considered; it can be either surface applied or incorporated in the soil. The amount of a surface applied pesticide reaching the soil surface is a function of the canopy cover and, after reaching the soil, is treated much the same way as incorporated pesticides. Decay rates, appropriate for the specific pesticides, are applied to calculate, from day to day, the amount of the pesticide remaining in or on the soil surface. Appropriate adsorption/desorption isotherms are provided to show what part of the pesticide is adsorbed and what part is in solution. The soluble forms are routed with the water through the soil zones or extracted in surface runoff. Extraction is a function of the concentrations in an assumed mixing depth, the flow rate and an extraction coefficient. The adsorbed pesticides are subject to erosion with the soil particles.

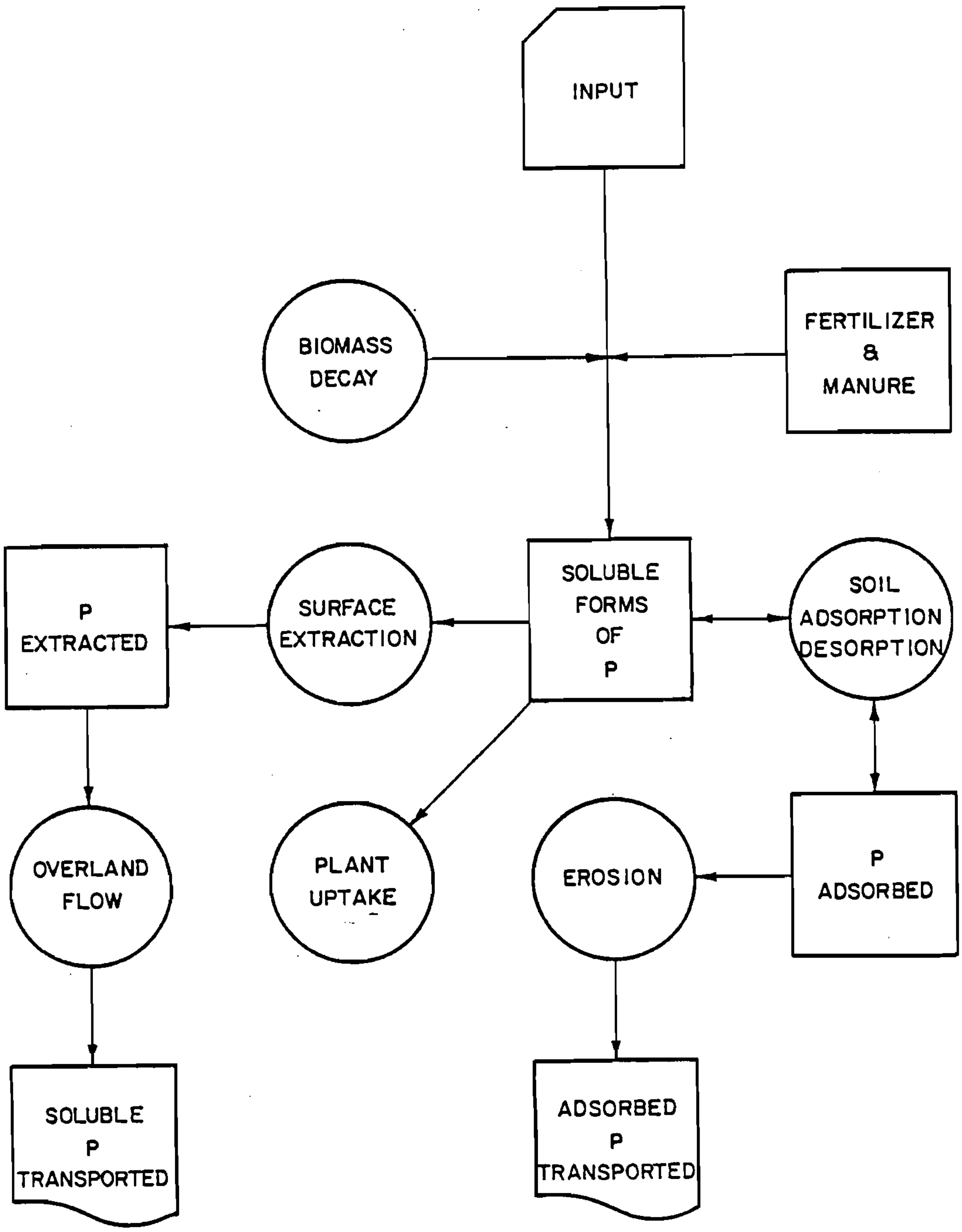

Figure 7. Phosphorus cycle on source areas

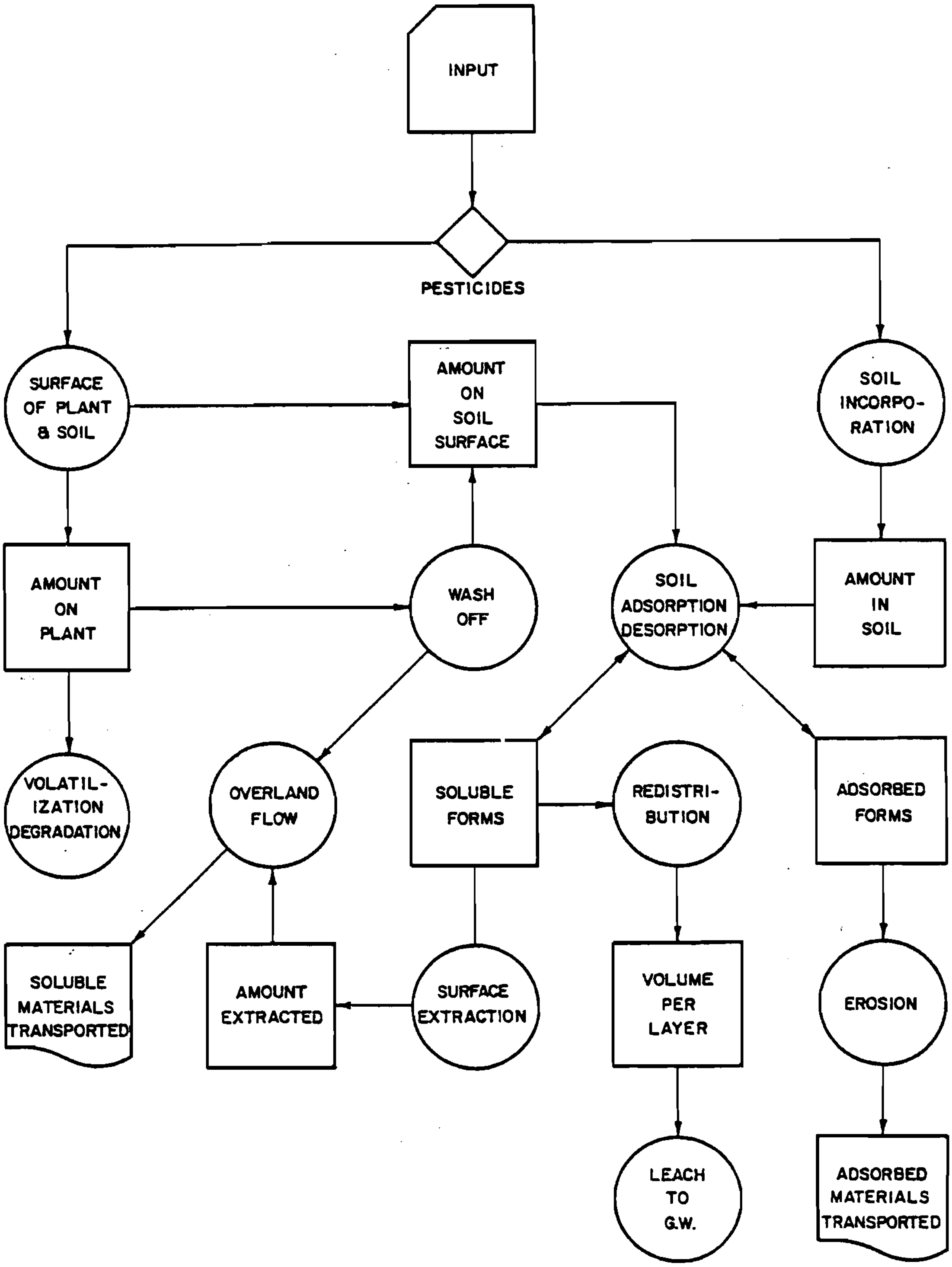

Figure 8. Pesticides on source areas

The amount of pesticide that reaches the plant surface is subject to volitalization, degradation and wash-off. The amounts that are volitalized or degraded are a function of the specific pesticide. The amount that is washed off is a function of the crop to which it is applied and its adsorption into the wax on the plant surface. A mass balance plus a decay factor is used to determine the amount washed off. The fate of that which washes off is dependent upon the size of the event and whether or not there is surface runoff. See the previous discussion of pesticides on the soil surface.

Timbered Areas

The rate of movement of water, sediment and chemicals from timbered areas will be handled by modifications in parameter values of the equations of flow, erosion and sediment transport; and changes in the evapotranspiration subroutine. Changes in the ET subroutine allow the relative contributions of soil surface evaporation and plant transpiration to follow a non-linear rate as a function of leaf-area-index without restriction of a maximum LAI of three. The influence of the forest floor as a diffusion barrier to soil evaporation is accounted for by modification of the soil-water transmission and crop residue-soil cover parameters. Interception algorithms identify four different vegetative types; long-leafed conifers, short-leafed conifers, mature hardwoods and mixed hardwood-pine. A different interception pattern is defined for each.

CHANNEL, RESERVOIR AND GROUNDWATER PROCESSES

The previous sections are a description of the source area response, that is the core of SWAM. The balance of this presentation is a description of the routing of water, sediment and chemicals through the channel system; the groundwater flow; and the movement of water sediment and chemicals through reservoirs.

Routing Water and Sediments in the Channel System

Water: Characteristics of the channel that are needed for routing water through the channel system were described briefly in the section of this paper that described the Watershed Delineation and Climatic Inputs. Using these descriptions of the channel system and the hydrographs of all inputs to a given point (node) in the channel system (upstream channel, lateral inflows, reservoir outflow, and groundwater), routing to the next node is shown in Figure 9. Within the channel, water can move either into or out of the channel banks, channel losses are calculated as a function of the channel permeability. Out-of-bank flow is subject to evaporation and infiltration. Infiltrated water moves back into the channel, after the storm, as groundwater or it goes into deep storage. If the reach is upstream from a reservoir or in a backwater situation, then solution of the flow equations is based on the diffusive wave approximation. If the flow is unosbtructed, solution is based on the kinematic wave approximation. Output from the reach is input to the next reach downstream.

Sediment: The composition of sediment transported through the channel reach is dependent upon the characteristics of the bed material, the transported load, flow conditions and channel configuration. Processes considered in routing sediments are shown in Figure 10; they are based on the USDA Sedimentation Laboratory Model (Alonso et al, 1981). Residual transport capacity, which determines whether the channel reach will agrade, degrade or remain in equilibrium is based on the carrying capacity of the flowing water, the sediment load that it receives and the particle size distribution of the sediment load. If the sediment load is in balance with the carrying capacity, the load passes through the reach unchanged. If it is greater than the capacity, deposition will occur. Particles are deposited, starting with the largest size fraction, until transport capacity is reached. Composition of the bed is then determined and a new bed elevation established. If the sediment load is less than transport capacity, erosion of the bed occurs. The smallest size fractions available in the bed are then removed until transport capacity is achieved or the remaining surface layer is composed of material too large to be transported. This then becomes the armor layer and the bed composition and elevation are determined. The sediment load and its composition is then passed on to the next reach.

The Groundwater Component

Groundwater movement into the channel system is based on the flow line or stream tube concept. Low flow conditions in the watershed are used to identify those reaches where groundwater enters the channel system. Groundwater wells are used to establish the groundwater divide then representative flow paths are drawn. See Figure 11 (Liong and DeCoursey, 1982 and Liong et al. 1981). The flow paths are then grouped

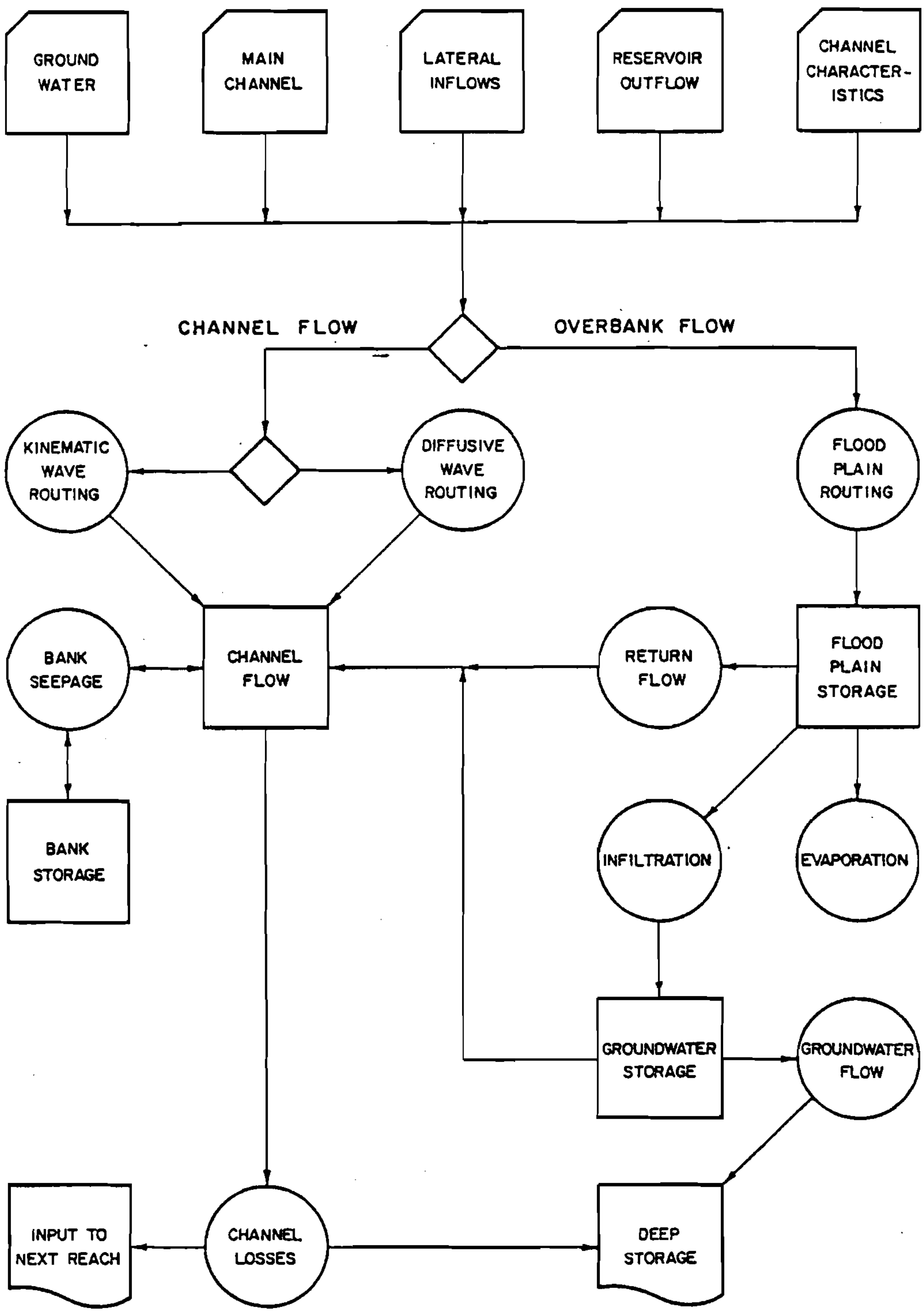

Figure 9. Stream flow routing within a channel reach

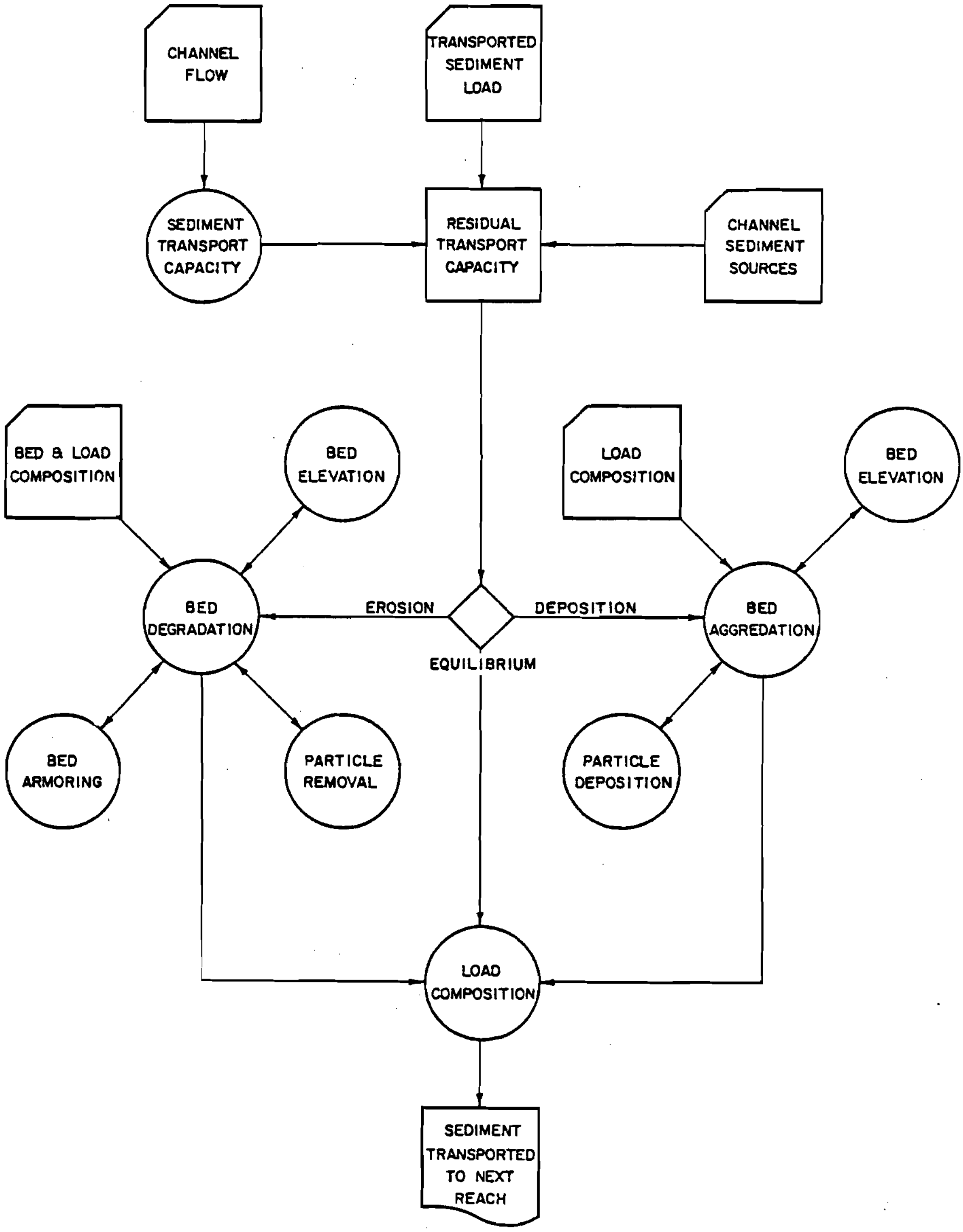

Figure 10. Sediment transport within a channel reach

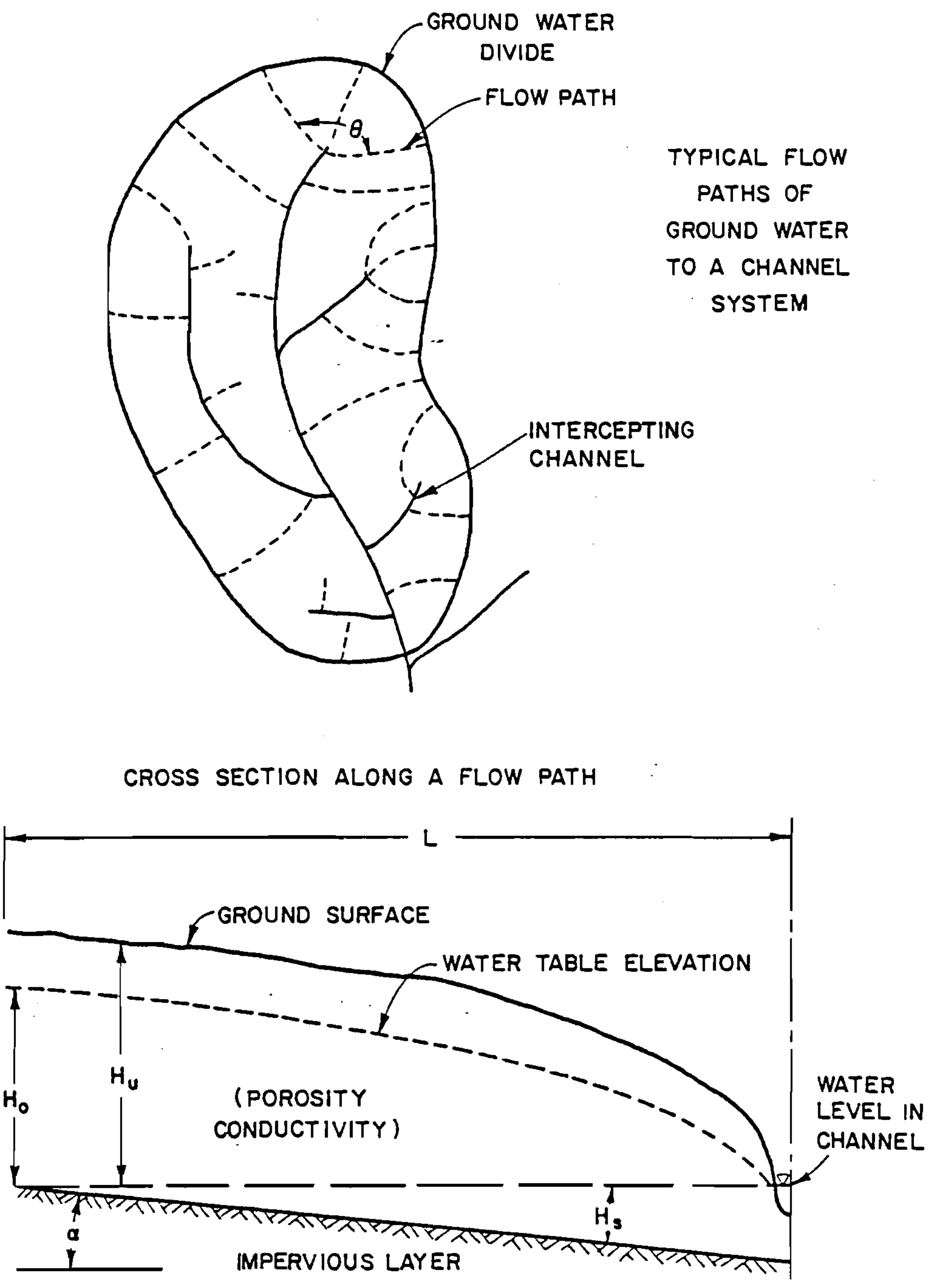

Figure 11. Groundwater processes

into representative lengths for each of the channel reaches and the input calculated on a daily basis. Flow into the channel is a function of the saturated hydraulic conductivity, the porosity, the length of the flow path, the hydraulic head of the water surface elevation at the divide over water elevation in the channel, and the thickness of the aquifer at the channel. Both convergent and non-convergent flow are considered. A kinematic routing scheme moves water that passes below the root zone, through the unsaturated zone above the water table, to the water table. This raises the elevation of the groundwater, thus changing the flow rate and rate of groundwater flow recession. If a flow path crosses several fields or response areas, total flow, through the root zone from all fields is averaged across the entire length of the path to get a single weighted average increase in the water table level. Any chemicals, such as nitrate, that the percolating water may carry into the groundwater are assumed to be uniformly mixed with the groundwater below the field. These concentrations are mixed with inflowing water from gradient and down-gradient in the same way. This simplified approach to estimating the quantity and chemical concentrations of groundwater provides reach inputs that can be added to surface runoff and routed through the channel system.

Reservoir Processes

Reservoirs and small impoundments such as farm ponds probably have more impact on the quality of water in a channel system than any other structural or land use conservation practice. Therefore, this component of the model has received considerable attention. It is presented in a very simplified form in Figure 12. Given the following physical characteristics of the reservoir; initial temperature, suspended sediment, dissolved solids profiles; chemical structure; hydrologic and meteorologic data; morphometric data; inflow data; and outflow relationships--a series of subroutines calculates changes that take place in the temperature, suspended sediment and dissolved solids profiles. These subroutines take into consideration density currents that develop as inflow enters the reservoir (Dhamothran and Stefan, 1980). After changes in the profiles are calculated, chemical and biological process changes are simulated. Phosphorus processes include macrophyte and plankton uptake and decay and sediment sorption-desorption isotherms in both the epilimnion and hypolimnion. The sedimentation of detritus and effects of rooted macrophytes are also considered in the phosphorus structure.

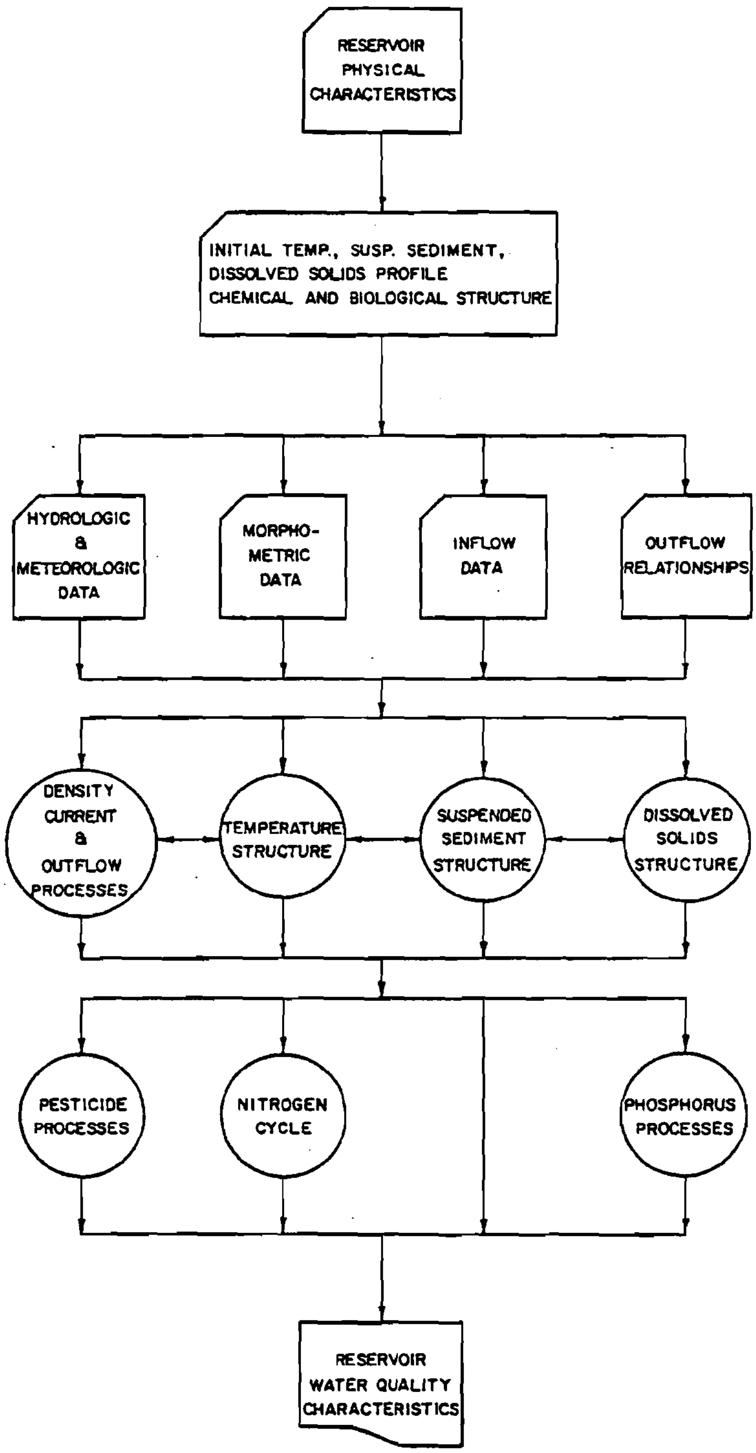

Figure 12. Reservoir Processes

At the present time, the nitrogen cycle is handled in a very simple way taking into consideration the organic matter level and nitrate concentration in the reservoir as compared to the inflowing water, the residence time and temperature. The model will be refined, comparable to that of phosphorus, in the near future.

The pesticide processes simulated include a sorption-desorption isotherm balance between the soluble fraction and that adsorbed on the suspended sediments in both the epilimnion and hypolimnion. Outflow from the reservoir at the end of each day (if there is any) includes the suspended sediments and associated water quality constituants. These values are input to the channel system downstream. Subroutines provide a mechanism for calculating the tray efficiency of the sediments, nutrients and pesticide components of flow (see Figure 13).

Movement of Chemicals through the Channel System

Nitrogen: The nitrogen compounds of most concern in channel flow are nitrates and sediment associated N (see Figure 14). For practical purposes, nitrates are not adsorbed, but move only in solution. The sediment associated N is considered to move primarily with the organic fraction of the sediment. The NH_4, which is computed as part of the sediment associated N, is mostly adsorbed. An alogrithm for NH_4 transport, determined by a partitioning coefficient based on ion exchange equilibrium is being developed for those special situations where NH_4 is important. Because flow through the channel system is relatively rapid, changes due to N incorporation, nitrification or denitrification are assumed to be insignificant. If travel time through some channel systems is sufficiently long so that these processes should be considered, the reservoir N cycling model could be incorporated. Outputs of the nitrogen routing process include the concentrations and masses of nitrate in solution and the sediment associated N.

Phosphorus: The phosphorus output from the source areas are soluble inorganic PO_4 and adsorbed PO_4 (see Figure 15). The other P fractions such as soluble organic, organic matter or mineral P forms are not modeled. Equilibrium is assumed between the soluble and adsorbed PO_4. These two fractions comprise roughly 20-40 percent of the total P and are the most biologically active P fractions. the technique used is a mass balance based on the Equilibrium Phosphorus Concentration (EPC) published by Kunishi and Taylor, 1977; and Taylor and Kunishi, 1971. Merging flow

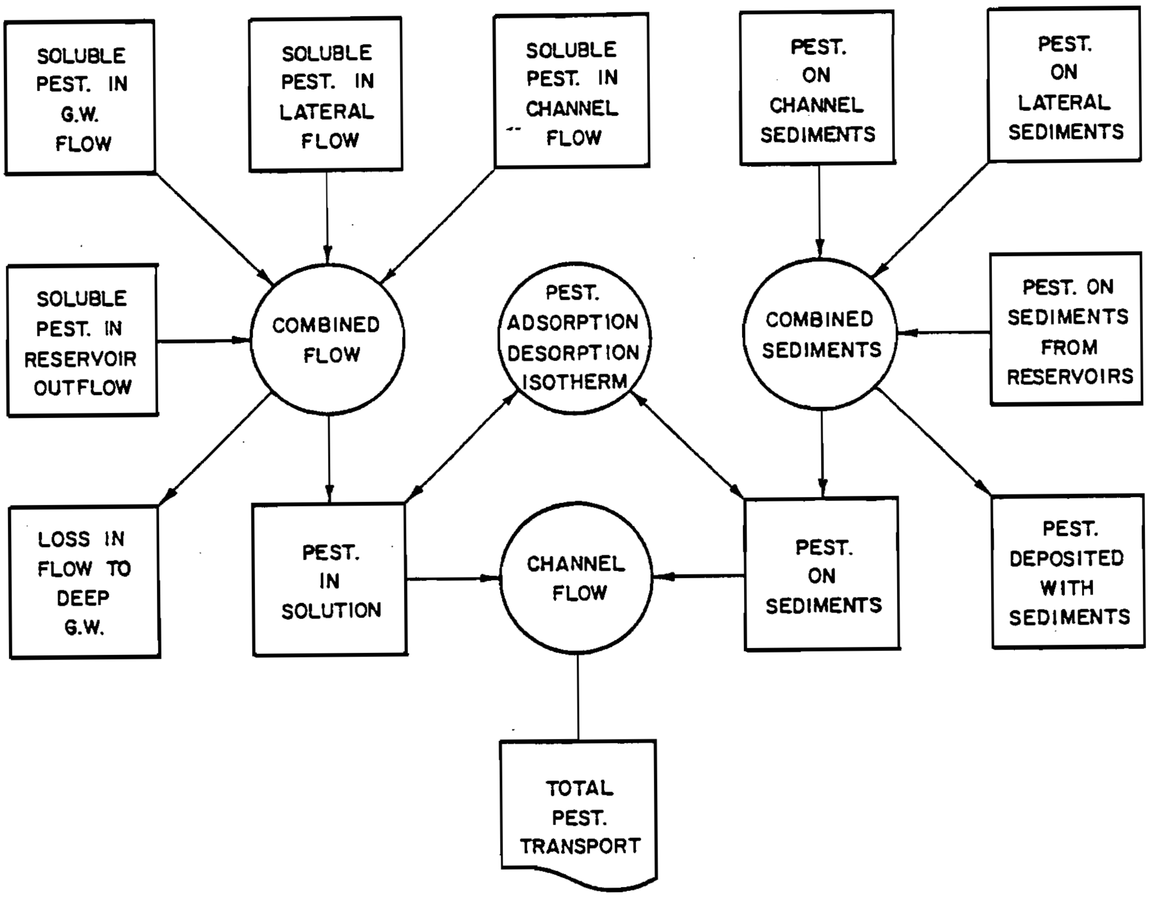

Figure 13. Pesticides movement within a channel reach

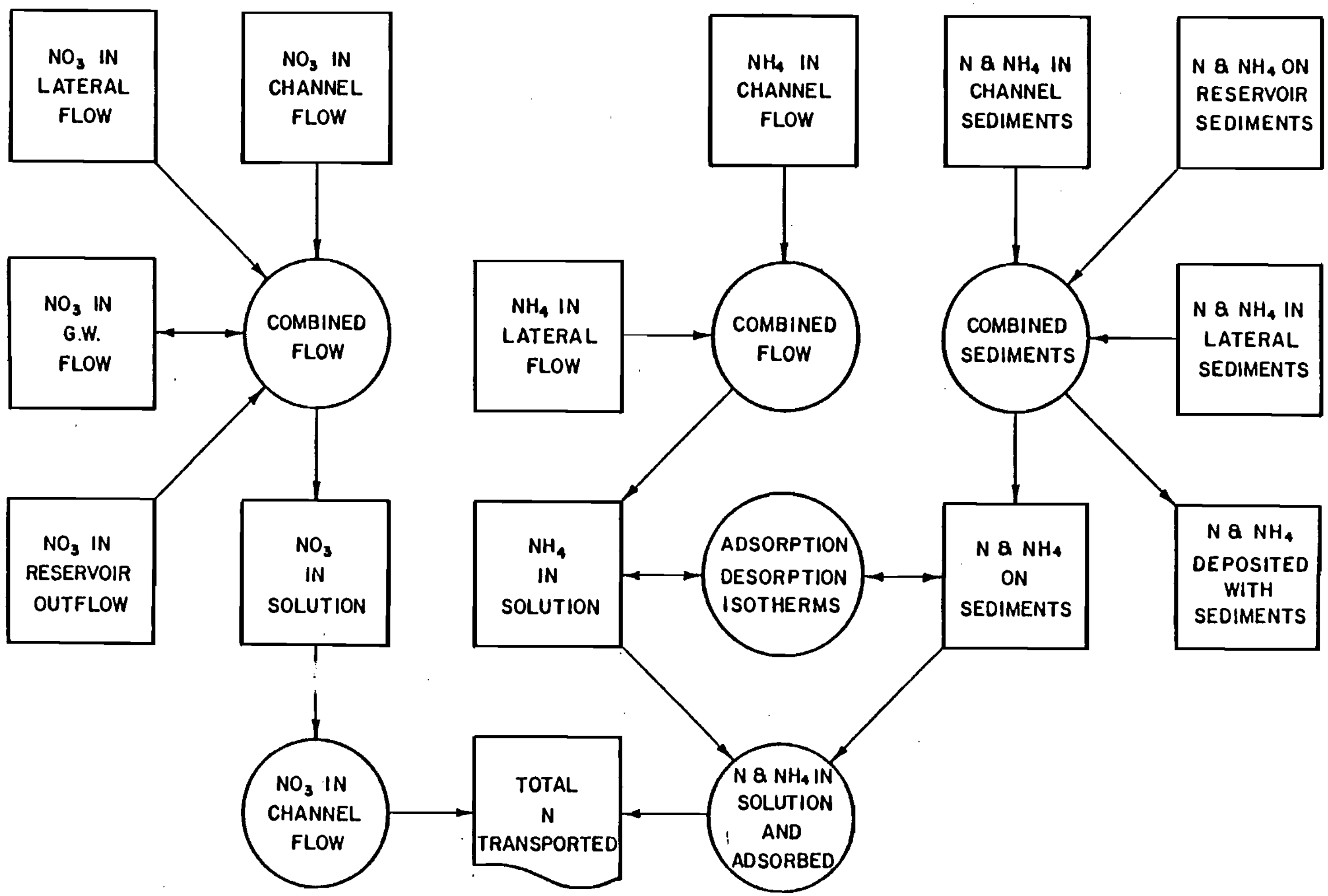

Figure 14. Nitrogen movement within a channel reach

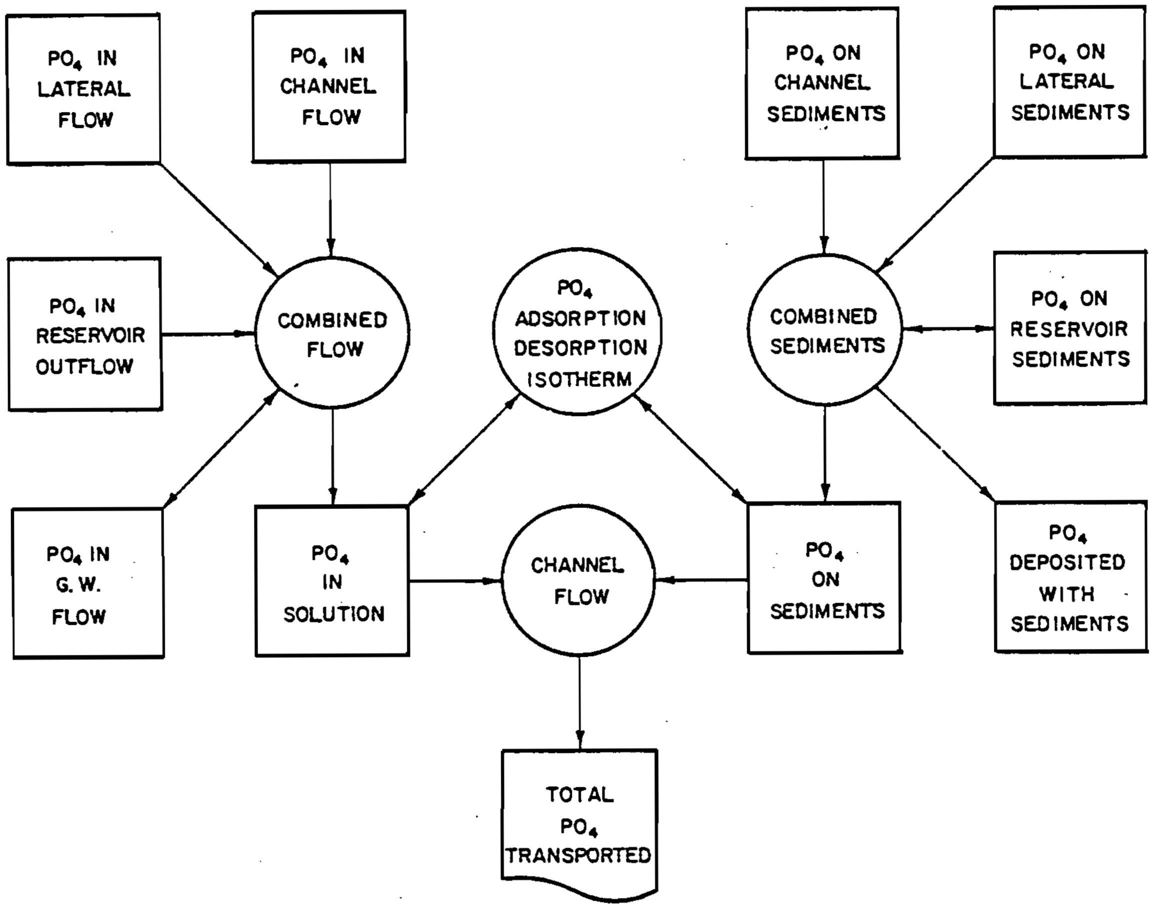

Figure 15. Phosphorus movement within a channel reach

or sediments are each characterized by a linear buffer curve which is then recomputed for the combined mass, minus that PO_4 transformed to unavailable P forms (fixation). The direct loss of soluble PO_4 is computed on the basis of water loss to groundwater recharge. Soluble PO_4 sources include field runoff, groundwater and later inflow. It can move into the groundwater or be adsorbed on sediments deposited in the channel. Adsorbed PO_4 sources are channel and lateral inflows from fields and residual sediments in the channel. PO_4 fixation is computer as a PO_4 loss.

Carbon: The primary source of carbon is soil organic matter and eroded organic matter transported in the sediment phase. It is computed as a mass balance with field inflows being the primary source. Erosion and deposition of carbon associated with stream bottom sediments is estimated (see Figure 16). Carbon is required as input to the reservoir model and pesticide adsorption calculations.

FUTURE EFFORTS

Most of the subroutines described in the discussion have been developed and tested and some of them have been combined. In the near future all of them will be assembled into one large program and sensitivity analyses and testing begun. However, there are several agricultural practices, applications, or consequences that have not been addressed. As time permits, we will attempt to incorporate them into the model. These include tile drainage, irrigation, groundwater inflow to ponds or reservoirs, erosion from concentrated sources such as gullies, bacterial and biological activity, point sources of pollution, a complete treatment of temperature, adequate coverage of organic matter decomposition, nutrient leaching and surface extraction of chemicals. After sensitivity analyses, methods of aggregating areas will be developed and efforts to develop a basin scale model begun.

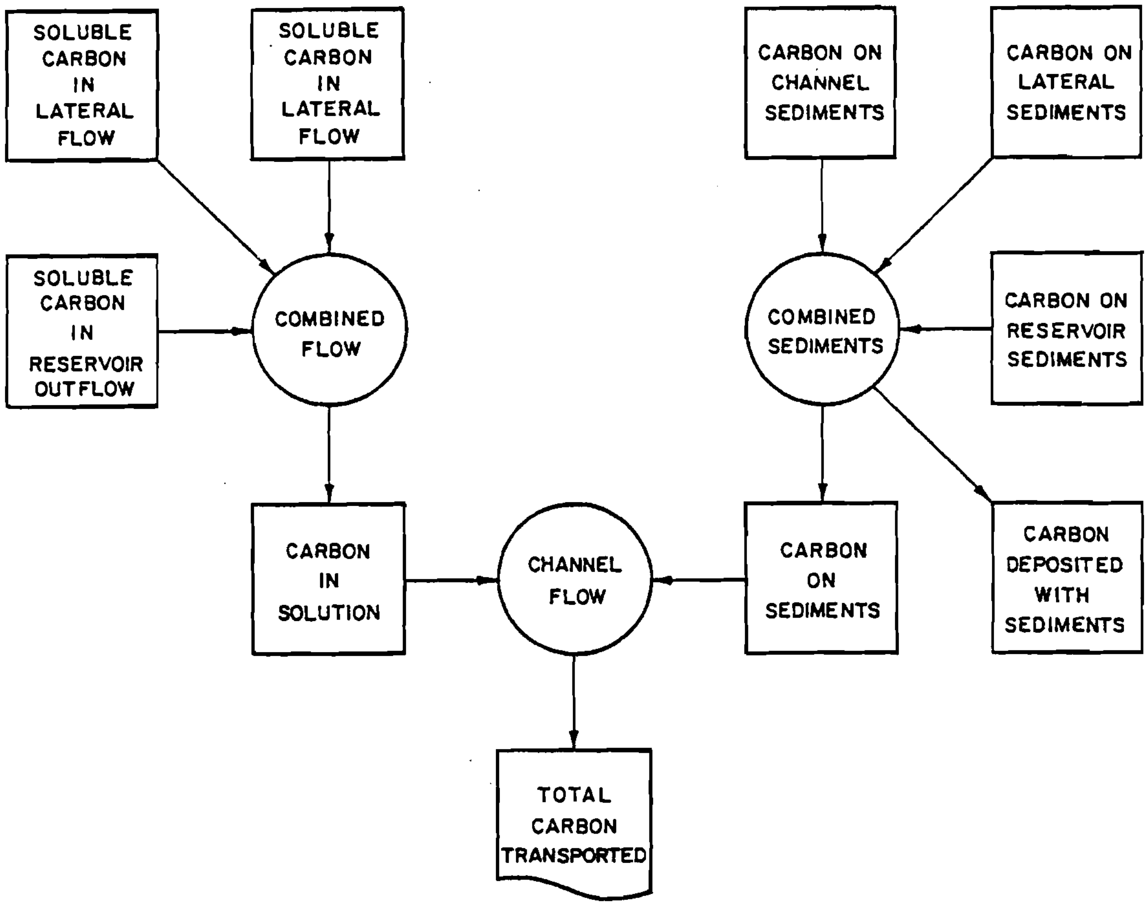

Figure 16. Carbon movement within a channel reach

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