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INTERNAL REPORT 20

HYDROLOGIC MODEL FOR WATERSHED 10, ANDREWS EXPERIMENTAL FOREST Round 1

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BACKGROUND

Watershed 10 is selected for the prototype hydrologic model for the Coniferous Biome. This report is the result of the first round of discussions of the hydrology modeling group at Oregon State University. This group consists of persons in the hydrology area and those in the modeling area. It is the result of four 2-hour working sessions by an average of six people. At the end of this series of work sessions we benefited from a visit by Paul Riley, who discussed hydrologic modeling for hydrograph simulation. His objectives and ours are sufficiently different that his models are not useful to us at this stage. We anticipate, however, that he can provide submodels that we can use at the next round of modeling.

PERSPECTIVE AND OBJECTIVES

Water is viewed in its three ecosystem functions: as environmental component, transport medium for nutrients, and nutrient. Against this general perspective, the objective was identified as development of a <u>hydrologic model with the capacity to describe the state of the system at any desired time in any desired place</u>, and where <u>state</u> is yet to be defined by the input needs of the other submodels of the system, particularly by the producer, decomposer, and nutrient-cycling submodels.

The essential nature of the hydrologic model is that of a cascade. Water (in the form of precipitation) impinges on the system, is temporarily stored in various compartments (or places) and cascades through the system, ultimately leaving the area of interest by (1) evaporation or transpiration, (2) stream flow or (3) deep ground water flow.

To account for the intermittent pulsing nature of the hydrologic system, we have adopted a two-phase model. The first phase is a recharging model. This accounts for the nature of precipitation and adjusts the states of all the compartments to account for the inputs during a storm. The second phase is a decay model. This is evoked when the storm stops and is in effect until the next storm starts. The decay model is a cascade with water flowing down and out, except for certain instances of capillarity that require movement upwards in the soil.

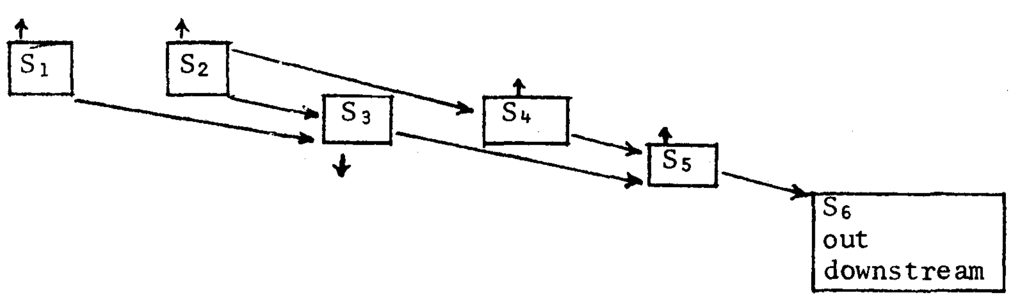
Both phases of the model will be imposed on the system in terms of a specific organizational and spatial resolution. Temporal resolution will vary between the phases. Organizational structure is depicted in Figure 1. A detailed description of the compartments and transfer functions appears in Appendix I. This follows the general organizational structure agreed upon for the overall coarse resolution model. The only likely refinement in this structure might be in soil depth: additional information exists in terms of location in the soil column, but at this stage, soil will be treated as a homogeneous compartment in the vertical dimension.

Spatial structure is in the form of strata defined by physiographic and geologic features. Criteria are essentially location, elevation, soil depth, and soil moisture capacity. Preliminary soils data are tabulated in Tables 1 and 2. These edaphic and physiographic features are translated into Figures 2 and 3, a soil depth and type map and a contour map. The intersection of these two maps constitutes the essential stratified structure of the fine spatial resolutions of Watershed 10. In practice, some coarse stratification will be used, at least in the beginning.

Temporal structure of the phase 1 model is not determined, although the current consensus is that it will be between 30 minutes and 2 hours. This resolution must be fine enough for accurate representation of the recharging process. No work was done on this phase beyond the attempt to identify the problems.

Temporal resolution of the phase 2 model has been fixed at one day. That is, variables of interest will be defined in terms of daily quantities and daily means and instantaneous values at specified times of a day. Updating of the model system by simulation would proceed from day to day. As details of the external state variables (outputs) have not been specified for the other subsystems, we can not now specify the particulars of this daily updating or of the processes that must be modeled in translating "water content" into the desired state characterization. For this round, we will treat water volume as the sole state variable, and we will follow water volume through time by the specified spatial and organizational structure as it changes under the specified cascade model.

The basic model for phase 2 may be conceptualized as a compartment model in which the compartments are defined by the intersection of the organizational structure and the spatial structure. If we consider only the spatial dimension, the form can be approximated by:



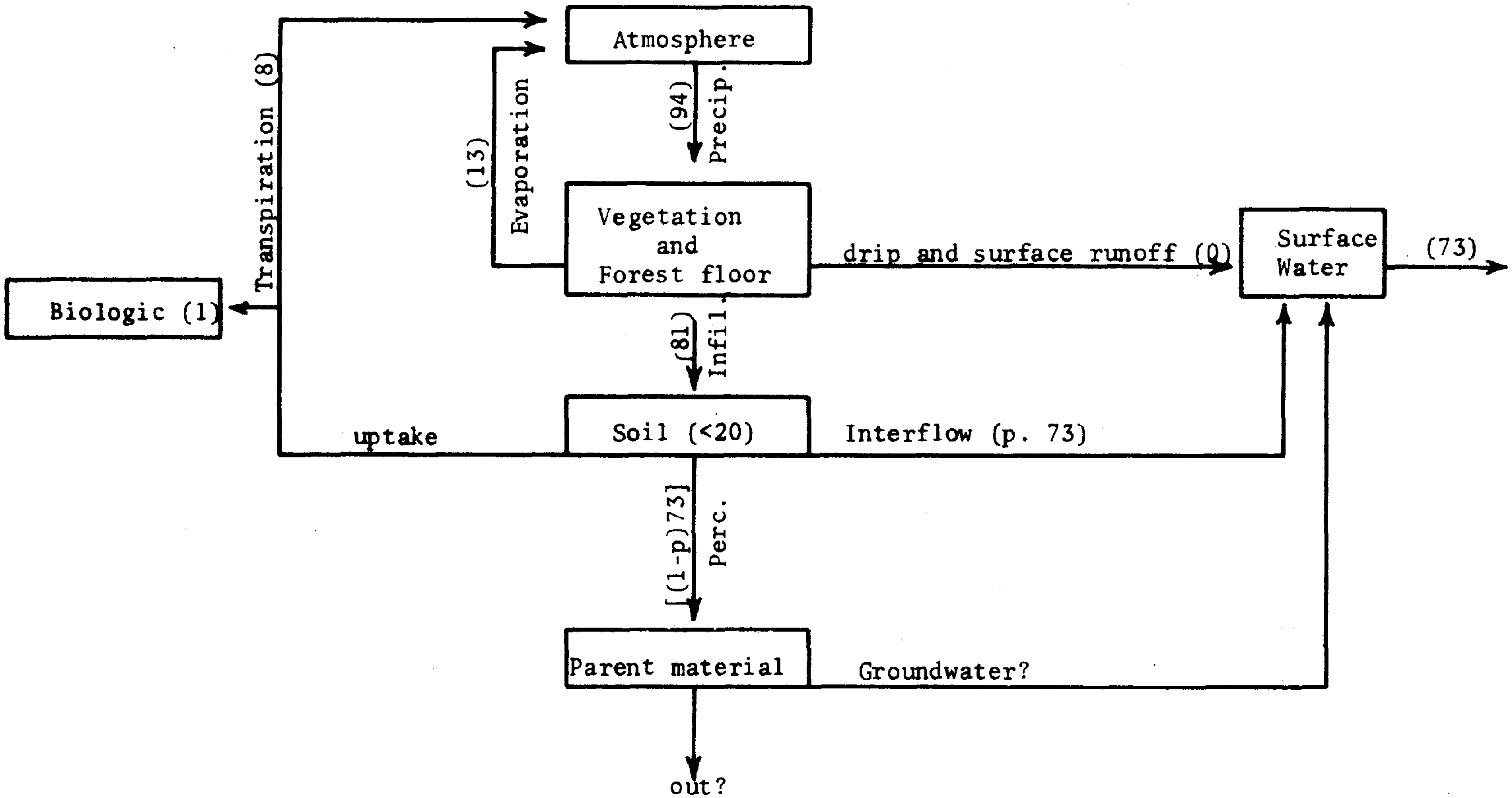


Figure 1. Organizational structure and approximate annual hydrologic budget for Watershed 10. Numbers in parentheses describe water <u>stored</u> in compartments, <u>transfer rates</u> between compartments, or <u>proportion</u> (p) of flow in any pathway.

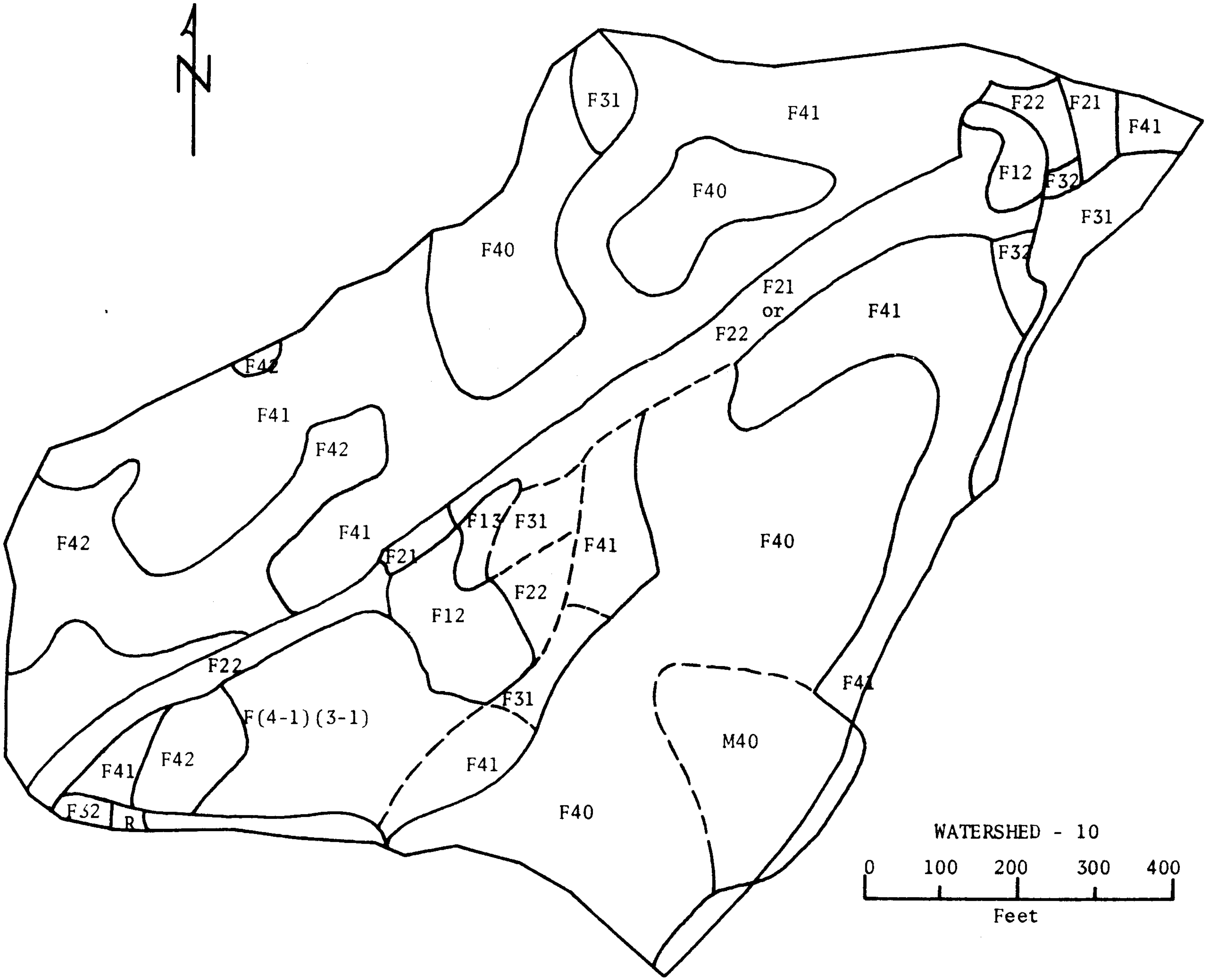


Figure 2. Soil compartments for Watershed 10. Area, depth, stone content, and water storage in upper 40 inches are given by type in Tables 1 and 2.

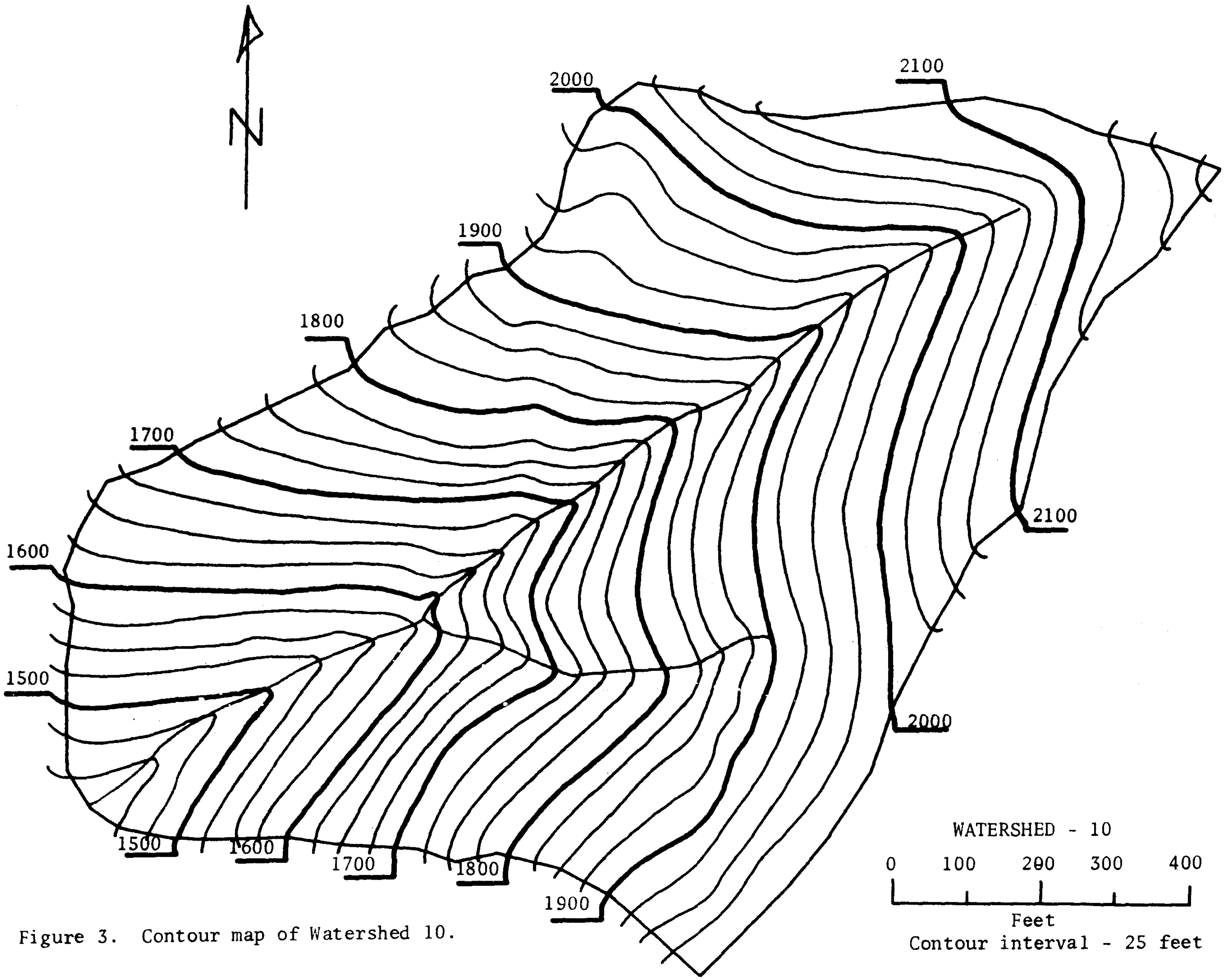


Figure 3. Contour map of Watershed 10.

Table 1. Soil Compartment Designations for Frissel (F) and McKenzie River (M) Soil Series, Watershed 10[1].

Numeric designator	Depth	Stone content
	Inch	*Percent*
0	Rock	0-10
1	0-10	10-35
2	10-20	35-75
3	20-40	75 +
4	40 +	

[1]Designator consists of Series, Depth, and Stone Content. For example, F40 is Frissel, 40 + inches depth, 0-10% stones.

Table 2. Preliminary Water Storage Computations in Soils of Watershed 10[1].

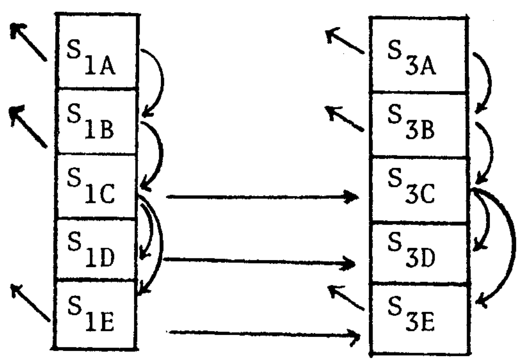
Soil compartment	Area	Storage in upper 40 inches	Storage by type (SxA)
	Acres	*Inches*	
M40	1.9	8.3	15.8
F40	4.8	8.3	39.8
F41	9.7	6.5	63.0
F42	2.4	3.7	8.9
F31	1.4	4.9	6.9
F32	0.2	2.8	0.6
F21	0.8	2.4	1.9
F22	1.2	1.4	1.7
F12	0.7	0.8	0.6
F13	0.4	0.4	0.3
Complex	1.7	2.2	3.7
	25.2		143.2

[1]Mean storage for Watershed 10 $= \frac{143.2 \text{ acre inches}}{25.2 \text{ acres}} = 5.7$ inches.

which diagram can be represented by an adjacency matrix, where a

$$\begin{bmatrix} 0 & 1 & 2 & 3 & 4 & 5 & 6 \\ 1 & & & 1 & & & \\ 1 & & & 1 & 1 & & \\ 1 & & & & & 1 & \\ 1 & & & & & 1 & \\ 1 & & & & & & 1 \end{bmatrix}$$

1 in the ij^{th} position signifies a flow from compartment i to compartment j, and where compartment 0 is the atmospheric sink and compartment 6 the downstream sink. Now each of these compartments can be elaborated by organizational structure so that we would visualize, for example:



etc.

When we attempt to structure this, problems apparently arise in terms of biologic water. Water that enters biological material creates great complexity but represents a minute part of the total water budget. For this reason, such water will be considered a nutrient, and once taken up by living tissue will not be considered further in the hydrologic cycle. The single (and important) exception is water of the plant transport mechanism. Water of transpiration will continue to be treated in the hydrologic model, but metabolic and cellular water will not.

(Question: Does this get us into trouble?)

If we model the phase 2 hydrologic model as a system of first-order linear differential equations, then the output y will be of the form,

$$y = \sum_{i-j}^{k} \beta_{1i} \, e^{\beta_{2i} t}$$

when β_{1i} and β_{2i}, i=1, ---, k are functions of the coefficients of the system of equation. We anticipate that by analysis of prior records of streamflow, we can get a clue as to required level of spatial resolution to represent adequately at least that particular output variable.

The hydrologic modeling effort will continue with: (1) Elaboration of the phase 1 model; (2) Examination of existing flow records from Watershed 10; (3) Formulation of level of spatial resolution as indicated by analysis of flow records and consideration of other subsystems (particularly primary producers); and, (4) Elaboration of external (output) variables.

Generalized procedures for model construction, some features of the hydrologic modeling effort, and the contribution of the hydrologic modeling effort to other discipline groups within the Biome are summarized in Appendix II.

APPENDIX I
DETAILED DESCRIPTION OF THE ORGANIZATIONAL STRUCTURE
OF THE ANDREWS HYDROLOGIC MODEL

A diagramatic representation of the hydrologic cycle is presented in Figure 4. The basic diagram should apply to any forest system. The diagram contains three elements: storage compartments where water resides (shown by boxes), transfer functions for water flow between compartments (shown by arrows), and numerical values which denote estimates of water stored or moving. The estimates are made using data obtained from the work of Rothacher, Fredriksen, and Dyrness (1967). The values shown are annual estimates and are in units of depth/unit area.

Description of the Storage Compartments

The atmosphere is the source of water for the system and is global in extent. Measuring the water in the atmosphere above the ecosystem of concern is unimportant on a macroscale.

Vegetation surfaces form a temporary storage site for precipitation during storm.

The forest floor or duff layer is a temporary storage site for precipitation. The amount of water stored is generally quite small. The principal hydrologic function of the forest floor is to cushion the impact of rain drops and facilitate rapid infiltration of precipitation.

The soil consists of the unconsolidated material beneath the forest floor or duff. Its ability to store water is a function of depth, texture, and structure and is thus highly variable. Measurements indicate a value of 17-20 inches for most Andrews soils.

The parent material consists of the consolidated rock strata beneath the soil. No geologic surveys have been made that will provide accurate data about these strata.

Biologic water is water stored within the biomass. Assuming about 7,000 cubic feet of wood per acre and about 25 pounds of water per acre, one can estimate that the biomass stores 175,000 pounds of water per acre, or about 3,000 cubic feet. This is equivalent to 0.07 feet of water per acre or about 0.84 inches. Being generous with this biological compartment, we have assigned it 1 inch of storage.

The surface water is water stored within the stream very temporarily. In reality, it is synonymous with runoff for our Andrews watersheds.

Description of the Transfer Functions

Precipitation is the amount of rain and snow falling on the watershed. The annual increment is about 94 inches and is rather uniformly distributed across the watershed with little orographic deviation.

Drip is the volume of intercepted water that falls to the forest floor after contact with the vegetation. The magnitude of this value has not been determined. It has been measured together with

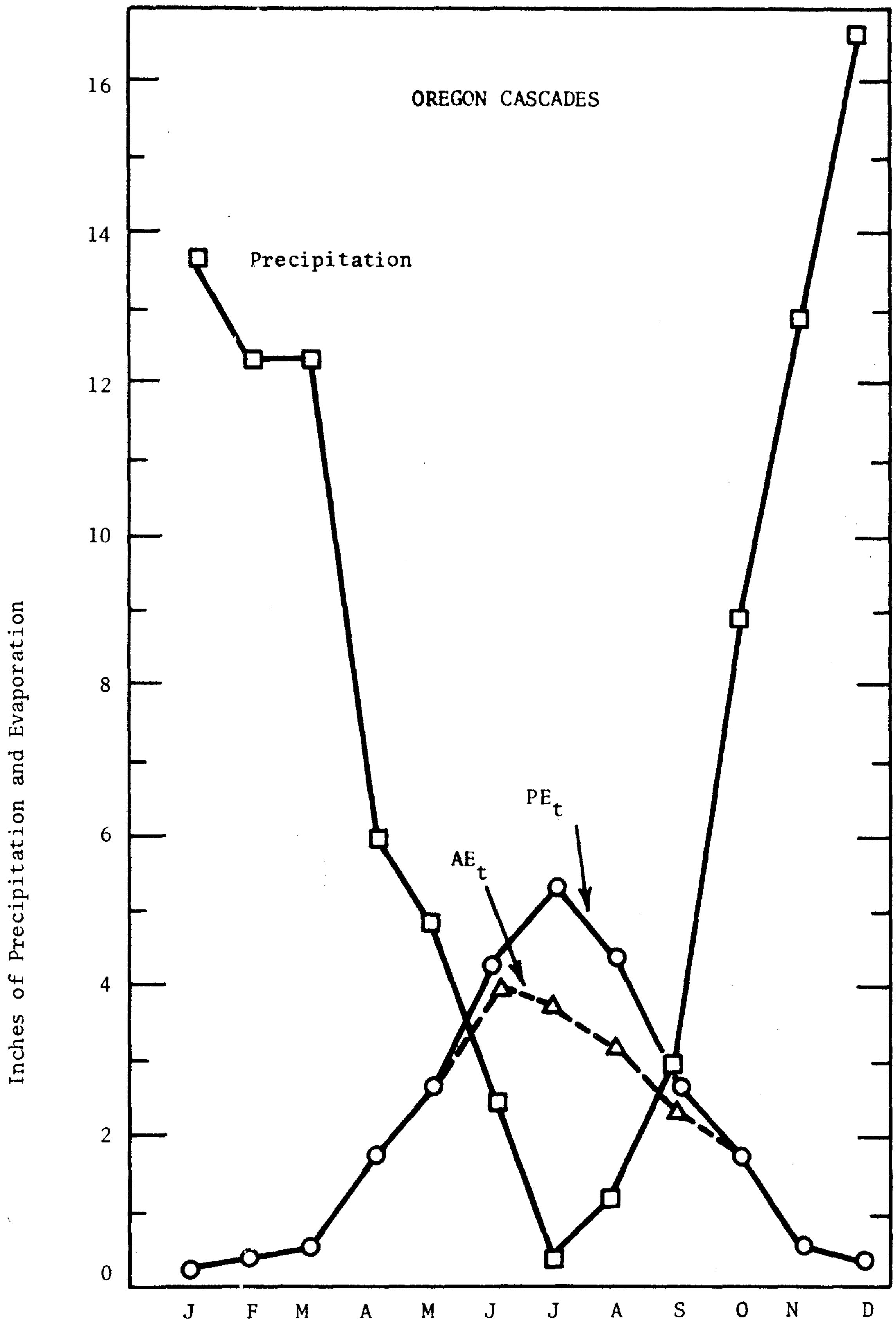


Figure 4. Approximate monthly water balance for H. J. Andrews Watershed 3. AE_t is actual evapotranspiration; PE_t is potential evapotranspiration.

precipitation passing through the canopy without striking vegetal surfaces. These two components are generally lumped together and termed throughfall. Drip into the stream channel is negligible.

Stemflow is the volume of water intercepted by the vegetation which eventually finds its way to the forest floor by running down the stem. Hydrologically, this value is negligible.

A portion of the precipitation that is intercepted by vegetation and the forest floor evaporates. The estimated value for this loss is 13 inches annually. Most of this direct evaporation occurs from the vegetative surfaces.

Transpiration is that loss of water from the system produced by the vegetated surface. This value is about 8 inches per year. It varies with the vegetative density, species composition, and energy availability, but the potential variation between watersheds 1, 2, and 3 is probably small.

Infiltration is the rate at which water moves downward through the duff into the soil. This value can be regarded as nearly infinite on the Andrews soils. Rates of over 250 inches per hcur have been measured. As a result, surface runoff on these watersheds never occurs.

Capillarity is the upward movement of water in the soil. It is dependent upon soil texture and structure.

Percolation is the downward movement of water through the soil or parent material. It differs from infiltration in that it is a subsurface phenomenon in the soil and geologic strata. As a result, the rate of movement is much less.

Interflow or seepage is the lateral movement of water through the soil mantle to the stream. This occurs in both saturated and unsaturated soil systems. Little is known about this process in steep topography. It is a key research area for the hydrology group.

Groundwater flow is also a lateral movement of water. Because it is in the consolidated rock strata, the movement is generally slow.

Evaporation from the stream water surface is likely to be quite small on these streams and probably insignificant.

Uptake by the biological community can be regarded as equaling transpiration.

APPENDIX II
PROCEDURES FOR MODEL CONSTRUCTION

Data input

Basic data for the comprehensive hydrologic model will come from several sources. Process studies of water movement through forest soils will contribute data on this predominant flow mechanism in forest watersheds. These studies are located in Washington at the Cedar River site, in Oregon at the H. J. Andrews site, and on a set of watersheds in northern California. The goal is to develop a subsurface flow "subroutine" for the comprehensive model through these efforts.

A wide range of hydrologic information is available for Watershed 10 on the Andrews. Streamflow, precipitation, and soil moisture will be monitored. As described earlier, good soils descriptions are also available on this watershed.

A snow-melt "subroutine" has been developed and tested by the modeling group at Utah State and will be incorporated in the comprehensive model.

Streamflow and precipitation records have a 15-minute resolution on the H. J. Andrews Watershed 10. At the northern California study site, where subsurface flow processes will be studied in detail, the resolution for streamflow, precipitation, and groundwater level will be about 5 minutes.

Calibration

The first step in preparation of a comprehensive hydrologic model for coniferous watersheds is to model successfully the daily hydrographs for Watershed 10 given the several basic data inputs available. Existing records for precipitation and streamflow will be utilized to make a first approximation of the system. As better information becomes available, for example from the subsurface flow studies, the Andrews model will be refined such that daily hydrographs may be predicted accurately with given inputs of precipitation.

Validation

Validation of the hydrologic model will be a two-phase process. The first validation will be for the Andrews model and will, of course, be conducted with different data than those used to construct the model. After verification, this model will be used to predict the response of other coniferous watersheds to precipitation inputs. This second, or extrapolation phase, is the ultimate test of the validity of the model.

FEATURES OF THE HYDROLOGIC MODELING EFFORT

The strongest feature of the hydrologic modeling effort is the modeling experience of the project leaders. The modeling efforts of the Utah State group are particularly well known. This project has the added advantage of an analog-digital computer for hydrograph simulation.

The Utah State group has developed a workable snow-melt model that will be a subroutine in the comprehensive model. The snow-melt routine will be tested again on the Andrews watershed. It is noteworthy, however, that a workable model is available and will not need to be constructed from scratch.

A distinctive feature of the modeling studies is the watershed selected for study. Watershed 10 on the H. J. Andrews Experimental Forest contains moderately deep soils that are nearly stone free and are fairly uniform. These characteristics will be helpful in attempting to model subsurface flow on steep terrain. This watershed is small enough (25 acres) so that variation in soil and topography can be described easily and variation in precipitation inputs will be minimal. This small watershed also will permit a high intensity of instrumentation.

The study of subsurface flow processes at Davis, California, also is noteworthy. Precipitation, streamflow, and water table fluctuation will be monitored with a 5-minute level of resolution on a highly instrumented, well-described watershed. This will permit the hydrologists to follow precipitation pulses through the system in a manner seldom achieved in other watershed studies.

HYDROLOGIC SUPPORT FOR OTHER BIOME GROUPS

The hydrologic modeling effort will contribute to the efforts of the nutrient cycling, meteorology, primary producer, and aquatic working groups.

Water is the principal carrier of nutrients through the forest system. Understanding subsurface flow processes and the mechanisms for routing precipitation through the soil-plant system will serve as a basis for routing and understanding nutrient flow. Scientists interested primarily in nutrient cycling have been included in discussions of the hydrologic model. Further, the Utah State group has had some experience in simulating salt outflow from agricultural watersheds concurrently with their efforts at simulating stream flow.

The obvious link between hydrology and meteorology is evapotranspiration (ET). Independent estimates of ET by both groups will permit checking of water balance and energy balance methods. This joint effort should contribute significantly to the understanding of this complex process in steep, densely forested terrain. Likewise, estimates of transpiration by the primary producer group will add to the construction of a comprehensive hydrologic model. Such a model will form a valuable feedback to the producer group by providing soil moisture status reports necessary in modeling the life processes of plants. This information also will be of value to the decomposer group.

Outflow hydrographs and attendant nutrient concentration graphs will provide valuable information to the aquatic group. These data are important parameters for defining the status or condition of the aquatic habitat.

REFERENCE

ROTHACHER, J., C. T. DYRNESS, and R. L. FREDRIKSEN. 1967. Hydrologic and related characteristics of three small watersheds in the Oregon Cascades. U.S. Dep. Agric., For. Serv., Pac. Northwest For. and Range Exp. Stn. 54 p.