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Hydrologic and Chemical Budgets on Walker Branch Watershed — Observations and Modeling Applications

Richard J. Raridon
David E. Fields
Gray S. Henderson

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COMPUTER SCIENCES DIVISION

HYDROLOGIC AND CHEMICAL BUDGETS ON WALKER BRANCH WATERSHED — OBSERVATIONS AND MODELING APPLICATIONS

Richard J. Raridon

David E. Fields

Gray S. Henderson*

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*Environmental Sciences Division

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HYDROLOGIC AND CHEMICAL BUDGETS ON WALKER BRANCH WATERSHED OBSERVATIONS AND MODELING APPLICATIONS

R. J. Raridon, D. E. Fields, and G. S. Henderson

ABSTRACT

Data collected on Walker Branch Watershed for a six-year period have been analyzed and used for validation studies of the ORNL version of the Wisconsin Hydrologic Transport Model. In addition to hydrologic budgets, chemical budgets for dissolved potassium and cadmium were studied. Measurements of wetfall and dryfall, together with hourly rainfall and daily evaporation data, provided the input for the computer program. Comparisons of simulated water and material transport on a monthly basis show good agreement with measured land runoff values. A discussion of parameter selection and sensitivity analysis for the model is included.

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1. INTRODUCTION

This report is one in a series (Mills and Reeves, 1973; Patterson et al., 1974; Fields and Watson, 1975; Culkowski and Patterson, 1976) which documents the development and application at the Oak Ridge National Laboratory of a Unified Transport Model (UTM) for environmental contaminants. This work was sponsored by the National Science Foundation's RANN (Research Applied to National Needs) program and constituted the modeling task of the Ecology and Analysis of Trace Contaminants (EATC) project. Several EATC progress reports have been issued (Fulkerson et al., 1973; 1974a; 1974b; Van Hook and Shults, 1976) which include discussions of the UTM.

This report is limited to the application of a portion of the UTM, namely, the Wisconsin Hydrologic Transport Model (WHTM). The WHTM was evolved from the Stanford Watershed Model (Crawford and Linsley, 1966) and a version of the code was obtained from D. D. Huff (1968) at the University of Wisconsin. The code was implemented locally to operate on an IBM 360 computer. The WHTM is a lumped parameter simulation code that represents water and trace contaminant movement and storage on a watershed basis. Some of the parameters, such as average slope, can be evaluated from physical measurements on the watershed. Other parameters, such as those regulating soil moisture storage terms, can be determined only through calibration studies. Required input data include rainfall, material deposition, and meteorological conditions. The simulated runoff of water and material (contaminant) from the land surface can be compared with measured streamflow values. A user's manual for WHTM (Patterson et al., 1974) and a report describing an optimization procedure for choosing model parameters (Fields and Watson, 1975) have been published. Some preliminary validation studies of WHTM have been reported (Fields and Raridon, 1974; Raridon and Fields, 1974; Raridon et al., 1975; Raridon and Andren, 1976). This report deals with parameter selection for and validation of WHTM using data collected on Walker Branch Watershed by the ORNL Environmental Sciences Division.

2. WATERSHED DESCRIPTION AND DATA COLLECTION

The Walker Branch Watershed (WBW) has been described in detail elsewhere (Nelson, 1970; Peters et al., 1970; Elwood and Henderson, 1975). The study site (Fig. 1) is a 97 hectare (ha) forested catchment

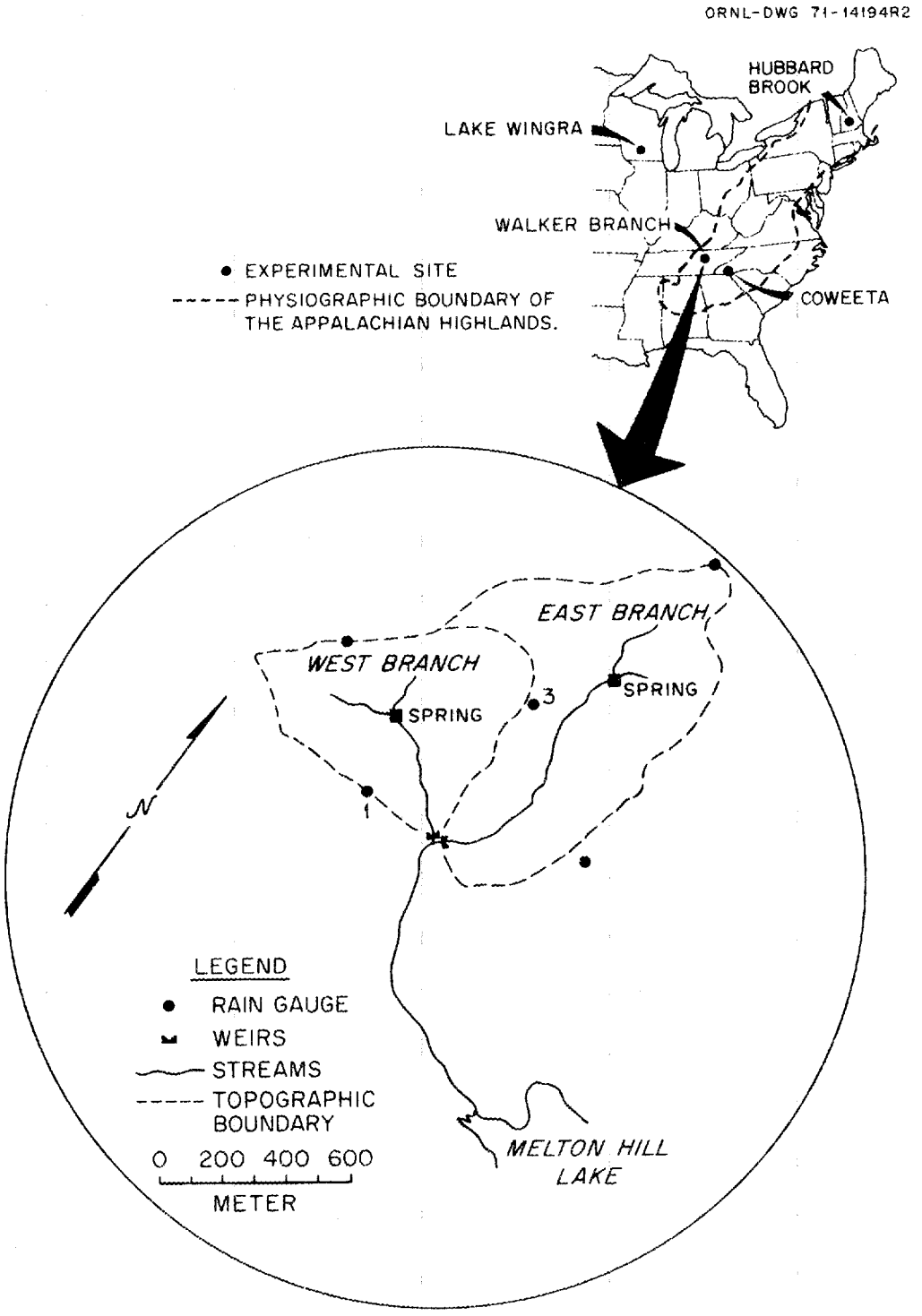

Fig. 1. Location of Walker Branch Watershed Indicating Stream and Precipitation Sample Sites.

located on the Oak Ridge ERDA Reservation about 3 km east of ORNL. It consists of two gaged subcatchments, the east and west forks, which contain 59 and 38 ha, respectively. The elevation ranges from 265 to 365 m. Both basins are underlain by Knox dolomite (McMaster, 1963) and contain several sink holes. Soils of the Fullerton and Bodine series occupy over 90% of the catchment area (Peters et al., 1970). Saturated hydraulic conductivities through the A_1 horizon (0 to 5-8 cm) range from 15 to >140 cm/hr with the higher conductivities reflecting the high chert content of the soil.

Both catchments are drained by small, perennial spring-fed streams. On the east fork, perennial flow emits from springs approximately 760 m upstream from the weir. The mean stream bed slope over this reach is 3.4%, while above the springs the slope ranges from 6.4 to 7.2%. On the west fork the limit of perennial flow is only 370 m upstream from the weir. The mean stream bed slope below this point is 4.3% while above the west spring the slope ranges from 6.2 to 28%.

The collection of hydrologic data on WBW, which started in 1969 as part of the International Biological Program, has been described previously (Nelson, 1970; Elwood and Henderson, 1975). Precipitation monitors are located at five sites on the watershed (see Fig. 1). At each of these stations, modified Wong collectors are used to obtain samples of both precipitation and dryfall for chemical analysis. Composited stream samples were also collected at each weir. Initially, analyses were made weekly only for the nutrients Na, K, Ca, Mg, P, and N. Starting in 1973, under NSF-RANN funding, monthly analyses of wetfall and stream samples were also made for some trace elements, including Cd.

Descriptions of the analytical techniques are described elsewhere (Elwood and Henderson, 1975, Andren et al., 1975). This report is limited primarily to the discussion of water, potassium, and cadmium budgets.

The measured budgets for water and potassium on WBW for a six-year period are given in Table I. Listed are monthly and yearly totals for precipitation, water runoff, and potassium deposition and discharge. Also included in Table I are the simulated evapotranspiration values which will be discussed later. The annual precipitation ranged from 123 to 190 cm, for an average of 146.4 cm. The annual runoff ranged from 45 to 121 cm, with an average of 83 cm which is ca. 57% of the average precipitation. The difference between rainfall and runoff of 63 cm would be attributed to evapotranspiration. McMaster (1967) reported average yearly rainfall and runoff values for the Oak Ridge area of 130 cm and 57 cm, respectively, for a 44% runoff and a difference between the values of 73 cm. One possible explanation for the apparently high runoff from Walker Branch is that WBW is gaining water from outside the boundaries of the watershed, of the order of 10 cm a year. Another possibility is that area-wide estimates such as given by McMaster, which are averages over all topographic situations, do not represent the actual evapotranspiration taking place in extreme positions, such as ridges, where seasonal water deficiencies can develop.

The annual potassium budgets listed in Table I appear reasonable when compared to concentrations in rainfall and streams measured by other investigators (Likens et al., 1967; Pearson and Fisher, 1971). The amount transported from the watershed anually is about twice the input, indicating a substantial loss of potassium.

TABLE I

WATER AND POTASSIUM BUDGETS FOR WALKER BRANCH WATERSHED

(ET VALUES CALCULATED BY WHTM)

		WATER				POTASSIUM		
MO	YEAR	PRECIP (CM)	STREAM (CM)	DIFF (CM)	ET (CM)	WETFALL (KG/HA)	DRYFALL (KG/HA)	STREAMFLOW (KG/HA)
JAN	69	10.90	3.81	7.09		0.150	0.275	0.351
FEB	69	13.21	10.90	2.31		0.117	0.224	0.557
MAR	69	5.41	4.62	0.79		0.057	0.266	0.275
APR	69	7.62	5.23	2.39		0.123	0.249	0.342
MAY	69	7.11	2.03	5.08		0.169	0.259	0.159
JUN	69	12.95	1.65	11.30		0.144	0.210	0.112
JUL	69	7.37	1.50	5.87		0.121	0.360	0.094
AUG	69	15.29	1.55	13.74		0.150	0.386	0.119
SEP	69	10.21	1.42	8.79		0.079	0.175	0.104
OCT	69	5.08	1.35	3.73	6.07	0.204	0.254	0.126
NOV	69	7.06	1.55	5.51	3.71	0.126	0.486	0.151
DEC	69	21.34	9.32	12.01	2.16	0.360	0.267	0.570
TOTAL	69	123.55	44.93	78.61		1.800	3.411	2.960

RUNOFF = 36.4%

TABLE I (CONT.)

MO	YEAR	WATER PRECIP (CM)	WATER STREAM (CM)	WATER DIFF (CM)	WATER ET (CM)	POTASSIUM WETFALL (KG/HA)	POTASSIUM DRYFALL (KG/HA)	POTASSIUM STREAMFLOW (KG/HA)
JAN	70	8.03	7.14	0.89	1.75	0.202	0.259	0.500
FEB	70	7.98	8.46	-0.48	2.87	0.215	0.190	0.606
MAR	70	9.25	8.81	0.43	5.28	0.106	0.139	0.941
APR	70	21.29	21.51	-0.23	9.22	0.204	0.177	1.622
MAY	70	2.84	6.10	-3.25	13.03	0.138	0.176	0.581
JUN	70	14.02	3.99	10.03	11.33	0.375	0.250	0.332
JUL	70	4.72	3.15	1.57	8.41	0.084	0.195	0.273
AUG	70	17.83	3.84	14.00	9.65	0.184	0.134	0.325
SEP	70	5.49	2.82	2.67	7.90	0.045	0.088	0.243
OCT	70	17.27	3.73	13.54	5.18	0.026	0.108	0.344
NOV	70	5.08	3.66	1.42	2.59	0.030	0.187	0.333
DEC	70	10.62	6.91	3.71	1.73	0.055	0.137	0.500
TOTAL	70	124.41	80.11	44.30	78.94	1.664	2.040	6.600

RUNOFF = 64.4%

TABLE I (CONT.)

MO	YEAR	WATER				POTASSIUM		
		PRECIP (CM)	STREAM (CM)	DIFF (CM)	ET (CM)	WETFALL (KG/HA)	DRYFALL (KG/HA)	STREAMFLOW (KG/HA)
JAN	71	12.42	14.02	-1.60	1.52	0.081	0.102	0.920
FEB	71	12.42	8.79	3.63	2.54	0.077	0.079	0.591
MAR	71	11.68	9.14	2.54	5.08	0.103	0.149	0.573
APR	71	10.92	7.14	3.78	9.50	0.128	0.214	0.492
MAY	71	15.75	10.19	5.56	9.78	0.120	0.198	0.781
JUN	71	8.48	2.16	6.32	11.40	0.034	0.150	0.176
JUL	71	23.44	3.02	20.42	9.52	0.053	0.194	0.322
AUG	71	6.20	3.25	2.95	11.02	0.042	0.108	0.267
SEP	71	8.00	1.55	6.45	7.59	0.117	0.064	0.145
OCT	71	6.38	1.47	4.90	5.87	0.034	0.125	0.154
NOV	71	5.54	1.65	3.89	3.33	0.024	0.206	0.175
DEC	71	15.98	5.87	10.11	2.16	0.034	0.194	0.417
TOTAL	71	137.21	68.25	68.96	79.32	0.847	1.783	5.013

RUNOFF = 49.7%

TABLE I (CONT.)

MO	YEAR	WATER				POTASSIUM		
		PRECIP (CM)	STREAM (CM)	DIFF (CM)	ET (CM)	WETFALL (KG/HA)	DRYFALL (KG/HA)	STREAMFLOW (KG/HA)
JAN	72	18.54	16.71	1.83	2.39	0.085	0.057	1.124
FEB	72	11.51	10.95	0.56	2.95	0.051	0.085	0.811
MAR	72	14.86	13.97	0.89	5.92	0.048	0.112	0.532
APR	72	7.19	7.67	-0.48	8.81	0.120	0.220	0.541
MAY	72	11.53	5.71	5.82	10.64	0.028	0.244	0.445
JUN	72	7.80	2.21	5.59	12.06	0.095	0.225	0.190
JUL	72	14.86	1.96	12.90	11.05	0.201	0.194	0.192
AUG	72	6.10	1.57	4.52	10.39	0.039	0.234	0.159
SEP	72	9.88	1.22	8.66	7.01	0.163	0.115	0.128
OCT	72	19.28	2.64	16.64	4.88	0.083	0.150	0.283
NOV	72	11.68	4.57	7.11	2.49	0.129	0.180	0.379
DEC	72	24.08	20.85	3.23	1.55	0.087	0.135	1.459
TOTAL	72	157.30	90.04	67.26	80.14	1.129	1.951	6.643

RUNOFF = 57.2%

TABLE I (CONT.)

		WATER				POTASSIUM		
MO	YEAR	PRECIP (CM)	STREAM (CM)	DIFF (CM)	ET (CM)	WETFALL (KG/HA)	DRYFALL (KG/HA)	STREAMFLOW (KG/HA)
JAN	73	11.13	9.80	1.32	2.39	0.223	0.080	0.699
FEB	73	9.83	10.87	-1.04	2.72	0.040	0.100	0.676
MAR	73	28.42	24.36	4.06	4.55	0.045	0.118	1.633
APR	73	12.65	11.28	1.37	6.02	0.237	0.251	0.803
MAY	73	26.80	17.45	9.35	9.45	0.332	0.303	1.138
JUN	73	14.05	5.74	8.31	10.44	0.131	0.275	0.561
JUL	73	15.14	3.00	12.14	10.49	0.074	0.252	0.291
AUG	73	3.99	3.63	0.36	9.25	0.060	0.200	0.303
SEP	73	7.32	1.70	5.61	7.09	0.072	0.212	0.166
OCT	73	8.66	1.60	7.06	6.53	0.020	0.156	0.161
NOV	73	27.41	13.69	13.72	3.20	0.106	0.426	1.094
DEC	73	24.13	18.14	5.99	1.91	0.143	0.335	1.544
TOTAL	73	189.51	121.26	68.25	74.02	1.483	2.708	9.069

RUNOFF = 64.0%

TABLE I (CONT.)

		WATER				POTASSIUM		
MO	YEAR	PRECIP (CM)	STREAM (CM)	DIFF (CM)	ET (CM)	WETFALL (KG/HA)	DRYFALL (KG/HA)	STREAMFLOW (KG/HA)
JAN	74	24.38	25.86	-1.47	1.75	0.104	0.106	1.554
FEB	74	13.36	14.02	-0.66	3.17	0.069	0.106	0.888
MAR	74	19.71	17.65	2.06	6.20	0.045	0.164	1.191
APR	74	8.99	10.46	-1.47	9.70	0.095	0.266	0.676
MAY	74	17.63	7.14	10.49	9.14	0.125	0.316	0.533
JUN	74	5.00	2.92	2.08	10.67	0.078	0.227	0.223
JUL	74	2.67	1.93	0.74	11.23	0.034	0.281	0.167
AUG	74	14.88	1.70	13.18	7.95	0.045	0.223	0.157
SEP	74	9.52	1.57	7.95	5.54	0.053	0.275	0.137
OCT	74	4.88	1.55	3.33		0.022	0.322	0.153
NOV	74	13.46	2.01	11.46		0.051	0.224	0.198
DEC	74	11.96	7.39	4.57		0.038	0.117	0.458
TOTAL	74	146.46	94.21	52.25		0.759	2.627	6.335
RUNOFF = 64.3%								
6 YR TOTALS		878.44	498.80	379.63		7.682	14.520	36.620
AVERAGES		146.41	83.13	63.27		1.280	2.242	6.103

AVERAGE RUNOFF = 56.8%

Andren et al. (1975) reported concentrations of Cd in wetfall and streamflow for WBW for the period June 1973 through August 1974. These data were combined with the hydrologic data (Table I) to give a partial Cd budget (Table II). Since only dissolved and not particulate Cd was adequately measured in streamflow, the output numbers may be somewhat in error. Recent evaluations of the analytical techniques (Van Hook and Shults, 1976) have led to the conclusion that the Cd concentrations presented earlier may be high by as much as a factor of 7. There were no direct measurements of dry deposition, but Andren et al. (1975) estimated that for Cd it would not exceed ca. 5% of the wetfall.

Application of WHTM to a watershed requires knowledge of the evapotranspiration (ET) which occurs as a function of time. While ET values cannot, in general, be measured directly, they can be estimated from measurements of pan evaporation data or from measurements of daily dewpoint temperature, maximum and minimum air temperatures, wind speed, and solar radiation. These latter meteorological data are used by subroutine EVAPO, an integral part of WHTM, to compute lake evaporation, which is assumed equal to potential ET. Since the appropriate equipment has not been available for collecting meteorological data directly on WBW, we used data from the Oak Ridge townsite weather station (ORATDL, 1972; Culkowski, W. M., private comm.) which is only a few km from the watershed. The average monthly temperatures at this site for the period 1969-1974 ranged from -1 to 8°C in January to 24 to 26°C in July. The mean monthly wind velocities ranged from 1.6 to 2.5 m/sec.

The ET values computed by EVAPO for WBW on a monthly basis for a five-year period are listed in Table I and shown in Fig. 2. The values

TABLE II. MEASURED CADMIUM BUDGET ON WBW FOR THE PERIOD JUNE 1973 — AUGUST 1974

Month	Wet Deposition (G/HA)	Streamflow* (G/HA)
6-73	6.04	0.31
7-73	19.98	0.20
8-73	8.77	0.22
9-73	12.22	0.12
10-73	12.13	0.13
11-73	31.24	0.60
12-73	12.06	0.76
1-74	23.41	1.17
2-74	12.82	0.64
3-74	8.48	0.70
4-74	3.24	0.54
5-74	7.93	0.47
6-74	6.20	0.14
7-74	1.68	0.12
8-74	13.54	0.09
TOTALS	179.74	6.21

*Dissolved Cd only.

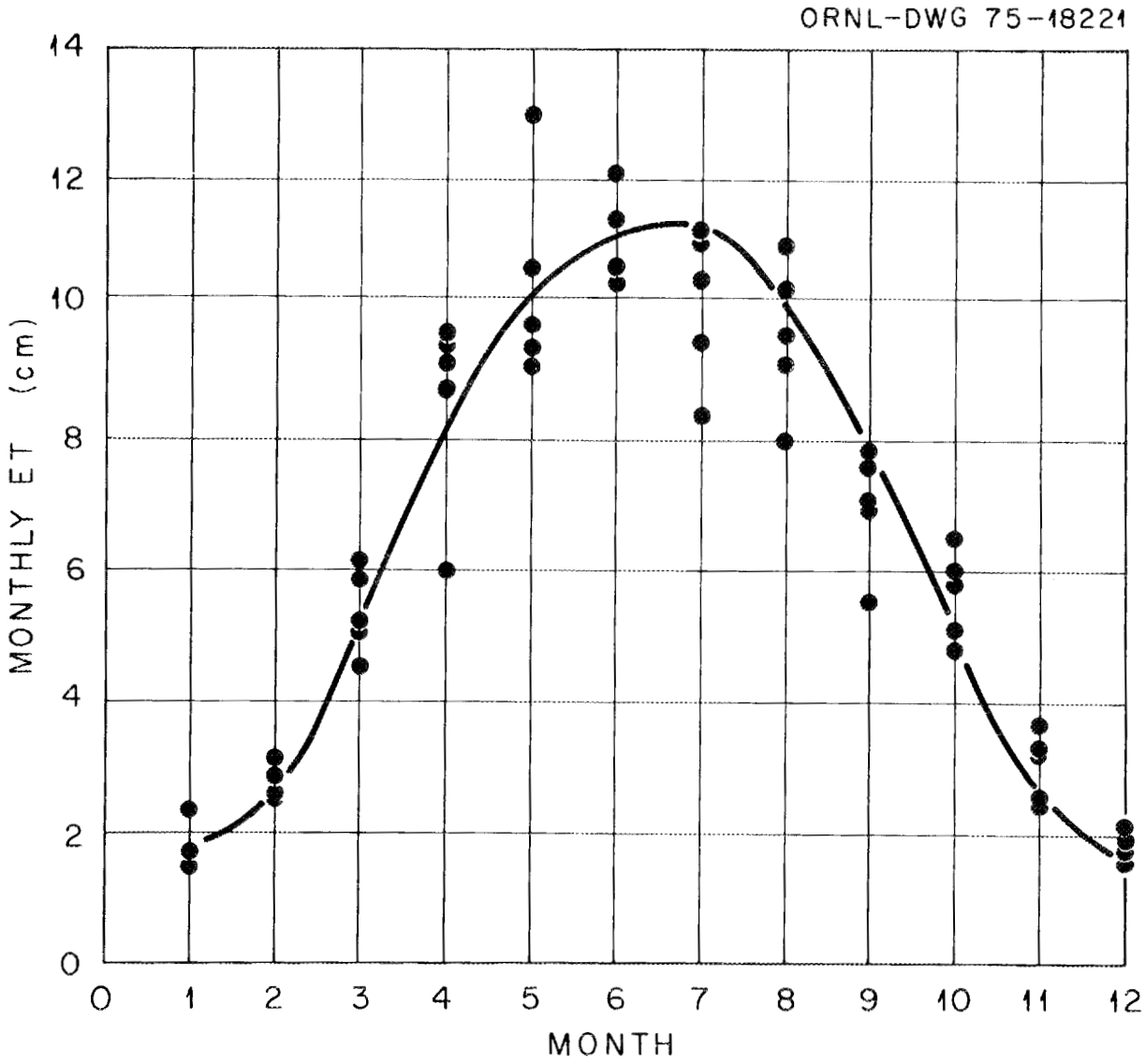

Fig. 2. Simulated Monthly Evapotranspiration on Walker Branch Watershed for Period October 1969 – September 1974 (Solid Line Represents Scaled Pan Evaporation Data).

range from less than 2 cm to about 13 cm. As might be expected, there is more variation from year to year for the warmer months. The computed ET values cannot be compared on a month-to-month basis with the differences between precipitation and runoff. In addition to timing, i.e., rainfall on the last day of one month may result in streamflow recorded the following month, runoff is dependent upon soil moisture conditions and other factors. The average yearly total for these simulated data is 78 cm, only slightly higher than the 25-year average difference of 73 cm between precipitation and runoff given by McMaster (1967). Comparison can also be made with pan evaporation data collected by TVA (1970) at Jefferson City, Tennessee, about 60 km east of WBW. Pan data averaged over a 27-year span were scaled by a factor of 0.75 (Roberts and Stall, 1967) and are included in Fig. 2. Monthly scaled values agree well with simulated values; the annual total of the scaled values is 78.6 cm, in excellent agreement with the simulated yearly totals. It thus appears that the simulated ET values are reasonable for WBW.

3. DETERMINATION OF WHTM INPUT PARAMETER VALUES

In this chapter we define input parameters for the WHTM and indicate how their appropriate values may be determined; the discussion relies heavily on our simulation of transport on the east fork of Walker Branch Watershed. The subsequent validation of WHTM on WBW as a whole resulted in the values of some parameters being changed. In some cases different investigators have suggested alternate methods for determining parameter values. For these cases we compare values obtained with the alternate procedures and indicate the "best" method.

Because results are less sensitive to changes in certain parameters than in others, not all parameters need to be determined with the same accuracy. The sensitivity analysis (Appendix A) indicates which parameters should be determined with the most care, as judged by the change in simulated annual transport for a given percentage change of the parameter value. The sensitivity of the model to a given parameter is, of course, a function of the type of model output under examination; e.g., a change in stream slope for a small watershed produces almost no observable change in the annual simulated streamflow, yet its influence on hourly flows is great. The same may be said for various flow recession parameters.

Types of WHTM Input Parameters

WHTM input parameters may be put in three classes: in the first class are those parameters which are directly measurable or calculable from available measurements. Included here are, for example, watershed area and average slope of land surface. In the second class are those input parameters which are directly related to watershed processes yet cannot be measured easily. Percentage of impervious area and friction coefficient (Manning's n) for overland flow fall into this category. In the third class are those more qualitative parameters having a quantitatively unknown relationship to field measurements. For this class, to which belongs the interflow recession constant, appropriate values can be found only by comparing observed and simulated results.

Application of Digital Topographical Techniques to Parameter Determination

The model parameters identified above as directly measurable or calculable include those available from topographical data. These data

may be expressed in digital form and processed numerically using digital topographical techniques to obtain the model parameter values. Application of these techniques to Walker Branch Watershed is reported elsewhere (Tucker and Fields, 1976).

Application of Parameter Set Optimization

Parameters of the second and third types may be varied within reasonable limits to achieve agreement between observed and simulated transport values. Numerical procedures for parameter set optimization have been developed and applied when observed data have been available (see, e.g., Liou, 1970; James, 1970; Betson, 1972; Fields and Watson, 1975). Our application of this approach to optimization of Walker Branch Watershed parameters is discussed in the latter publication.

Parameters Read by the LAND Link Following 5 LANPAR

Parameters appear here in the order in which they are read by the LAND link of WHTM (Patterson, et al., 1974). We have made liberal use of methods for parameter estimation suggested by others (Crawford and Linsley, 1966; Jacques, 1972; Huff, 1968). Since WHTM currently operates using English units, parameter dimensions will be so defined where appropriate.

K1 — Ratio of Average Segment Rainfall to Average Gage Rainfall. This parameter is normally 1, and should be altered only when data show that the average segment rainfall differs from the gage values read by the PRECIP link. The value for the east fork of Walker Branch is 1.

UZSN — Nominal Upper Zone Storage (inches). For the last year in a series of "typical" water years, this storage parameter should be adjusted so that the value of UZS is approximately the same at the end of the year as at the beginning. Simulation results are quite sensitive to the value of UZSN. Its magnitude may range from 0.4 through 2.0, while a good

estimation of UZSN might be a times LZSN. The multiplier a is watershed-dependent and may vary as follows: for steep slopes, limited vegetation, and low depression storage, $a = 0.06$; for moderate slopes, moderate vegetation, and moderate depression storage, $a = 0.08$; for shallow slopes, heavy vegetation, and high depression storage, $a = 0.14$. Thus for the east fork of Walker Branch, the value 0.86 is predicted for UZSN, which is 0.08 times 10.75, the value chosen for LZSN. The value chosen by OPTRM for UZSN is 2.0, which was the maximum value allowed for the parameter in that optimization execution.

LZSN — Nominal Lower Zone Storage (inches). This parameter, in analogy to UZSN, has a value such that LZS has the same magnitude at the end of the last series of "typical" water years as at the beginning. It may range from 5.0 through 25.0. A reasonable value of LZSN may be estimated by adding 4.0 inches to one eighth of the mean annual precipitation for the site. The value obtained by this method will likely be too small if rainfall is seasonal. It is hoped that sufficient geomorphologic data may become available to allow estimation of LZSN and UZSN from subsurface characteristics. Using the method based upon annual precipitation, LZSN is estimated to be 10.75, which is, probably by accident, very close to the value obtained using parameter optimization. LZSN is a parameter to which WHTM simulation results are sensitive.

K3 — Soil Moisture Evaporation Index. Water loss from lower zone storage is influenced directly by K3. For forested watersheds, most evaporation in wet periods is from interception storage; in dry periods the effect of the value of K3 on model results is large. The value of K3 may range from 0.1 to 0.3. Crawford and Linsley (1966) suggested that K3 should vary with watershed cover; for open land they suggest K3 = 0.2, for grassland 0.23, for light forest 0.28, and for heavy forest 0.3. Our choice for the value of K3 is 0.28.

K24EL — Groundwater Evapotranspiration Index. This parameter may be approximated by the fraction of watershed area with shallow groundwater within reach of vegetation. It obviously should vary seasonally, although similar results may be obtained by varying storage parameters or by weighting pan evaporation input data by the properly normalized leaf index function. For east fork of Walker Branch we estimate the fractional watershed shallow basin area from Walker Branch soils data (Peters, et al., 1970) to be 0.0307. K24EL is assumed equal to this value.

CB — Infiltration Index. This parameter is quite important in structuring watershed response. Its value may range from 0.3 through 1.2. A seasonal change in CB (3.0 in the summer and 0.001 in the winter when soils are frozen) has also been found appropriate (Jacques, 1972). CB and LZSN should be adjusted alternately to "fine tune" hydrologic results. Our initial guess for the value of this parameter is 0.8; the value arrived at through numerical optimization is 0.68.

CC — Time Distribution Parameter for Interflow. This parameter governs the ratio of increment of water added to interflow detention to that increment added to surface detention. It determines the relative amounts of water contributing to the prompt and interflow streamflow components. CC ranges from 0.5 to 5.0. Our initial guess was that CC = 1.8; the value obtained by parameter set optimization was CC = 2.73.

LG — Average Length of Overland Flow (feet). The parameter LG is used in two ways: first, it is needed for the determination of overland hydraulic flow including flow-induced soil mobilization and transport. Here the parameter is used to determine a maximum sheet flow velocity. Secondly, LG is used to determine routing times for overland hydrologic flow. The value of LG appropriate for light rainfall is given by simple geometric constructions which demonstrate that the average distance from a point on an idealized watershed to a single linear channel is of the order of A/(2 L) or A/(4 L), where A is the watershed area and L is the channel length. The value of LG, for Walker Branch Watershed, taking this approach and with reference to topographic maps, is 1590 ft. This value was used for early optimization exercises and for the sensitivity study described in Appendix A.

For periods of heavy rainfall, this method of computing LG gives too large a value. Since the value of LG depends on flow conditions, it may be difficult to determine an appropriate magnitude from simple measurements. This value may, however, be estimated if a representative value of the basin drainage density is known. A discussion of values of drainage density appropriate to various watershed types is given by Chow (1964). This reference indicates that the drainage density of Walker Branch Watershed is probably from 8 to 16 miles/miles^2, suggesting an LG of 165-330 ft. A value of 300 ft was assumed for this application.

SS — Average Slope of Overland Flow Plane. Four methods for determining the average watershed slope are suggested here. Each of these methods has the drawback of yielding a numerical value dependent on the resolution at which the watershed was examined. In the absence of a detailed topographic description of the watershed, several test sites on the

watershed may be randomly chosen for measurement of surface slope. The equipment required may be as simple as a spirit level and a ruler. Should detailed topographic information be available, slopes at the test sites may be computed without recourse to additional field measurements. A better watershed average value is found if numerical digital topographic techniques (Tucker and Fields, 1976) are applied to compute average slopes at a large number of watershed sites. Finally, ERTS satellite data may be processed to provide slope information with relatively low resolution.

In addition to the difficulty of determining a resolution-dependent slope, a second difficulty in finding a value for SS must be considered. In general, the steeper the slope of a given site, the greater its contribution to prompt watershed hydrologic surface runoff and to net watershed eroded soil input to the channel system. Therefore one might wish to sample the watershed in such a way as to emphasize the steeper sloped sites.

The hand computation of overland slope from topographic maps, with some increased emphasis of steeper sites, yielded values of slope from 0.53 to 0.66. The higher value was used for earlier computation and for the sensitivity study discussed in Appendix A. Curlin and Nelson (1968), working in the field, obtained an average value of 0.30, while the application of digital topographic techniques to the entire watershed yielded an average value of 0.1. The value of slope used for simulations described here was 0.3.

IRC — Interflow Recession Constant. This parameter is a daily depletion constant which governs flow from the interflow storage compartment. In the absence of input to interflow storage, IRC is the ratio of discharge from this compartment to that discharged twenty-four hours earlier. IRC should be adjusted to yield good agreement between observed and simulated hydrologic flows over short (daily and sub-daily) periods. Our initial guess was IRC = 0.7 for Walker Branch Watershed; however, use of OPTRM indicated that a more appropriate value is 0.1. In this OPTRM run IRC was restricted to the range $0.1 \leq IRC \leq 0.95$. In another application of WHTM (Munro, et al., 1976) a value of 0.05 for IRC gave good results.

KV — Groundwater Recession Parameter. This parameter is used to compute a variable recession rate for groundwater discharge. It is best determined by examining the computed outflow from groundwater storage for short periods following storms and adjusting KV to improve agreement of simulated and observed flows. The value of KV should be of the order of, but less than, 1.0. Its magnitude influences the groundwater

recession rate when the groundwater recharge rate is large. For the east fork of Walker Branch, a value of 0.5 is assumed for KV. No attempt has yet been made to adjust this value, to which daily and longer term results are relatively insensitive.

A — Impervious Area. A is the fraction of watershed area which instantaneously contributes all precipitation falling upon it to surface runoff. Included in this fraction are portions of roads, large rocks, and streams; the value for an undeveloped watershed is close to zero. The Walker Branch Watershed Soils Report (Peters, et al., 1970) gives the fraction of rocky land on the east fork as 0.03; this is an upper limit, as not all impervious areas on the watershed contribute immediately to runoff. An execution of the OPTRM model, with A restricted to lie between 0.001 and 0.1, yielded a value of 0.013.

EPXM — Interception Storage Parameter (inches). During a storm, precipitation is trapped in interception storage until the accumulated total reaches the value of EPXM. Moisture is lost from interception storage at a rate equal to potential evapotranspiration. The value of EPXM is cover-dependent, and is roughly 0.1 inches for grassland, 0.15 inches for moderate forest, and 0.2 inches for heavy forest. A value of 0.15 was chosen for Walker Branch Watershed. This value of EPXM is probably too large, since recent correlation (Huff, et al., 1976) of observed rainfall and throughfall magnitudes using the Helvy and Patrick throughfall parameterization has indicated that the value of EPXM for Walker Branch varies seasonally from 0.03-0.07 inches.

K24L — Groundwater Loss Parameter. Values of K24L greater than 0.0 cause losses from groundwater storage other than as input to the stream channel or evapotranspiration. Such losses may be ascribed to pumping, underflow, deep seepage, etc., and are suggested by a lack of agreement over several years between precipitation and the sum of measured runoff and estimated evapotranspiration. The value of this parameter for Walker Branch Watershed was chosen 0.0. There exists evidence which suggests that, while there may be subsurface flow from the east fork to the west fork, the total watershed actually has a net annual water gain due to subsurface inputs.

NN — Manning's n for Overland Flow. The parameter NN quantifies surface roughness for the watershed. Its value for smooth asphalt is 0.012; for rough asphalt or concrete paving, 0.014; for packed clay, 0.03; for light turf, 0.20; for dense turf, 0.35, for dense shrubbery and forest litter, 0.4. A value of 0.4 was used for Walker Branch Watershed.

KK24 — Basic Groundwater Recession Rate. The influence of this parameter is seen most directly on the base flow, i.e., that relatively small and slowly varying flow between storms. KK24 becomes decoupled from parameter KV during periods of

low groundwater recharge. The value of KK24 should be very close to, but less than, 1.0. It is used to compute the parameter LKK4. A value of 0.996 was assumed for Walker Branch Watershed. Since our interests were primarily in periods of high flow rates and in the yearly water balances, this parameter has not been reevaluated.

Parameters Read by the LAND Link Following 4 RLNPAR

Some of the parameters required by WHTM to simulate microconstituent transport can be evaluated from data on soil types and compositions. For Walker Branch soils the data of Peters, et al. (1970), were used to compute the amounts of exchangeable potassium, calcium, and magnesium present. Table 57 of that report gives data in terms of milliequivalents per 100 grams of soil for each horizon for several soil types.[1] These data were converted to weight percent using the appropriate equivalent weights of K, Ca, and Mg. The exchangeable fraction of each element was than computed using the data in Table 58 (Peters, et al., 1970) for average total analyses.[2] Results are given in Table III for each of the five soils and for each horizon. In general, the fraction exchangeable is highest for Ca and lowest for K.

Since Fullerton and Bodine soils constitute 90-95% of the WBW soils, an average of the properties for these two soils alone should characterize the watershed with little appreciable error. Exchange is assumed to take place in four thin theoretical plates in the top layer of soil. Therefore, the properties of the A1 horizon were used. For potassium, the following data were used:

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[1]The B22t value for Mg in Claiborne soil should be corrected to 0.36 and the C3 value for Mg in Linside soil corrected to 0.30, since these values appear correctly elsewhere in their report.

[2]One of the values for Ca in Linside A1 is in error; probably the value in Table 58 should be 0.15.

TABLE III

CATION EXCHANGE PROPERTIES OF WALKER BRANCH SOILS

	SOIL	K(T)	K(EX)	%(EX)	CA(T)	CA(EX)	%(EX)	MG(T)	MG(EX)	%(EX)
		WT. PERCENT			WT. PERCENT			WT. PERCENT		
Fullerton										
	A1	0.37	0.0043	1.16	0.06	0.0136	22.71	0.08	0.0021	2.58
	A2	0.45	0.0012	0.26	0.05	0.0018	3.61	0.10	0.0005	0.49
	A3	0.40	0.0016	0.39	0.03	0.0024	8.02	0.10	0.0005	0.49
	B1t	0.56	0.0012	0.21	0.06	0.0016	2.67	0.12	0.0005	0.41
	B2t	0.57	0.0012	0.21	0.04	0.0020	5.01	0.22	0.0013	0.61
	B22t	0.72	0.0020	0.27	0.05	0.0030	6.01	0.23	0.0024	1.06
Bodine	A1	0.36	0.0051	1.41	0.10	0.0242	24.25	0.09	0.0032	3.51
	A21	0.43	0.0016	0.36	0.06	0.0022	3.67	0.09	0.0005	0.54
	A22	0.45	0.0020	0.43	0.05	0.0028	5.61	0.11	0.0006	0.55
	B1t	0.48	0.0016	0.33	0.04	0.0032	8.02	0.13	0.0007	0.56
	B2t	0.61	0.0016	0.26	0.04	0.0032	8.02	0.20	0.0016	0.79
Claiborne										
	A1	0.44	0.0090	2.04	0.15	0.0603	40.21	0.12	0.0080	6.69
	A3	0.72	0.0094	1.30	0.10	0.0459	45.89	0.16	0.0045	2.81
	B1	0.48	0.0027	0.57	0.07	0.0148	21.19	0.12	0.0032	2.63
	B21t	0.53	0.0043	0.81	0.08	0.0501	62.63	0.13	0.0029	2.24
	B22t	0.51	0.0047	0.92	0.08	0.0433	54.11	0.25	0.0044	1.75
	B23t	0.45	0.0016	0.35	0.07	0.0226	32.35	0.12	0.0012	1.01
Linside										
	A1	0.61	0.0051	0.83	0.15	0.0711	47.43	0.44	0.0236	5.36
	A3	0.41	0.0047	1.14	0.11	0.0513	46.64	0.13	0.0226	17.40
	C1	0.50	0.0043	0.86	0.09	0.0345	38.30	0.14	0.0227	16.24
	C2	0.45	0.0031	0.70	0.07	0.0519	74.15	0.15	0.0181	12.08
	C3	0.45	0.0047	1.04	0.06	0.0463	77.15	0.13	0.0036	2.81
Tarklin										
	A1	0.38	0.0063	1.65	0.09	0.0513	57.00	0.08	0.0043	5.32
	A3	0.35	0.0078	2.23	0.09	0.0657	73.03	0.08	0.0044	5.47
	B1	0.35	0.0012	0.34	0.07	0.0106	15.17	0.08	0.0017	2.13
	B2	0.39	0.0023	0.60	0.06	0.0405	67.47	0.08	0.0029	3.65
	B3x	0.46	0.0023	0.51	0.09	0.0435	48.32	0.10	0.0029	2.92

total K = 0.37%

exchangeable K = 0.0047%

density of soil = 1.05 gm/cm^3

median soil particle diameter = 0.5 mm

thickness of theoretical plate = 2.5 mm.

Several of the following parameters (e.g., ANØT and ZERØ) are evaluated per unit area. Since WHTM already uses a unit area of 1 ft^2 and deposition as mg/ft^2, we chose to retain these units here, although any self-consistent set of units can be substituted.

BARE — Fraction of Surface Exposed to Direct Rainfall. The fraction of watershed area subject to erosion due to raindrop impact. Its value was assumed to 0.01 for WBW; this may be high, considering the heavy forest litter. A value of 0.001 might be more appropriate.

ANØT — Residual Microconstituent Distributed on the Land Surface. An initial value, taken arbitrarily to be 0.1 mg/ft^2.

KD — Distribution Coefficient. This parameter is defined as

$$KD = \frac{\left[\dfrac{\text{mass of sediment-associated microconstituent}}{\text{mass of sediment}}\right]}{\left[\dfrac{\text{mass of water-associated microconstituent}}{\text{volume of water}}\right]},$$

and expresses exchange potential of the microconstituent of interest in the soil-water system. Since the net annual flow of potassium is near zero, KD is expected to be close to the "natural value" of 100, i.e., equal to the ratio of exchangeable K in the soil (47 mg/kg) to that in the stream (typically 0.5 mg/liter).

LFTØV — Value of Infiltrating Water Carried Over from Last Period. Initial value taken as 0.0.

ØCRIT — Power Required to Erode Consolidated Soil. A value of 0.014 lb/sec-ft was chosen for WBW. (See Huff, 1968.)

ØNCRIT — Power Required to Erode Unconsolidated Soil. A value of 0.0014 lb/sec-ft was chosen for WBW. (See Huff, 1968.)

AZERØ — Quantity of Microconstituent Contained on Foliar Surfaces and Available for Hydrologic Transport. An initial value, arbitrarily taken as 0.0. mg/ft^2.

SDPM — Amount of Microconstituent in 2" Soil Layer. Calculated value of 230 mg per ft^2 of exchangeable K.

SEDMP — Mass of Detached Soil Particles at Land Surface. An initial value, arbitrarily taken to be 10 gm/ft^2.

SØNE, STWØ, STRE, SFØR — Microconstituent Content of Four Theoretical Plates. Calculated value of 9.8 mg/ft^2 of exchangeable K.

FIXM — Fixed Mass of Soil Available for Ion Exchange at the Land Surface. Taken as 1.2 gm/ft^2.

FF — Empirical Coefficient Relating Stream Power of Overland Flow and Surface Soil Erosion. Value of 50 chosen for WBW, using the OPTRM model.

SGW — Stored Active Groundwater. An initial value, taken to be 0.5 inches.

UZS — Upper Zone Storage. An initial value, taken to be 0.16 inches.

LZS — Lower Zone Storage. An initial value, taken to be 30 inches.

GWS — Active Groundwater Slope. An initial value, taken to be 0.14.

The final four parameters influence the initial stages of hydrologic simulation; they may be adjusted to yield the best agreement between observed and simulated values for the first part of the water year. The values at the end of a water year should be carried over to the start of the succeeding water year, as should the values of all storage terms for water and microconstituents.

4. SIMULATION AND VALIDATION STUDIES

The first application and validation of the ORNL version of WHTM have been completed on Walker Branch Watershed. A previous section discusses the choice of parameter values for the east fork of WBW. Appendix

A describes parameter sensitivity and lists those parameters which need to be specified more accurately. This section considers the watershed as a whole rather than two subwatersheds. This approach avoids the possible problem of dealing with underground transfer of water from one fork to the other (Appendix B). It was necessary, however, to re-evaluate the choice of parameter values which had been picked for the two forks. Since most microconstituent transport through a watershed is water borne, we attempted to obtain a satisfactory simulation of the hydrologic budget first before considering the transport of potassium or any other substance. Most of the initial effort was focused on wateryear 1970 (WY70), which started on October 1, 1969 and ended on September 30, 1970.

For simulation periods of one month, as we have used in this report, it is valid to compare experimental streamflow data with computed flux outputs from the land surface, since time delays introduced by the channel system are very small in comparison with the simulation period. Therefore, simulation of channel dynamics has been omitted in our computer runs; output is taken directly at the end of the LAND link of WHTM. If one wishes to use the CHANL link of the code, a later version called CHNSED (Fields, 1976) is now available. This version accounts for the influence of sediment movement within the stream system on microconstituent transport.

The format of the data sets containing precipitation, climatic, and parametric values for WBW are the same as those described previously (Patterson et al., 1974), with the exception of the channel parameters which were not used in this study. As a result of many individual WHTM computer runs and some optimization runs (Fields and Watson, 1975), a

set of parameters was chosen (Table IV) which yield a reasonably good agreement between simulated and observed monthly transport of water and potassium for WY70 and WY71. They should not be considered the "optimum" set of parameters that could be chosen since it was not feasible to optimize all parameters simultaneously. The computer output for WY70 (Table V) lists both the monthly and yearly totals for measured input (precipitation and total deposition of potassium) and simulated output. Simulated changes in some of the storage compartments are also shown. We have ignored the large discrepancy between simulated and observed runoff for April 1970 since the measured data for that period are admittedly in error (Appendix B).

By using the values of the hydrologic storage terms, such as LZS and UZS, at the end of one water year as input values for the next, we ran the WHTM in a predictive mode and simulated runoff values beyond the time period (one year) used for calibration of the model. The results for four water years (Fig. 3) show the observed and simulated outputs of both water and potassium. The water simulation is reasonably good for all four years, although some of the higher flows are under-simulated. The potassium simulation is not as good, particularly for WY73 where very large discharges were recorded for several months.

An extension of the hydrologic simulation (Fig. 4) covers the period June 73 - August 74 for which dissolved trace metal data were available (Andren et al., 1975). In view of some of the high rainfall and streamflow values which occurred during this period, the discrepancies between observed and simulated values are not great. The simulation of a budget for the dissolved cadmium required different values from those

TABLE IV. PARAMETER VALUES FOR WHTM SIMULATION OF WALKER BRANCH WATERSHED

Parameter	Value	Parameter	Value
K1	1.0	BARE	0.01
UZSN	2.0	ANOT	0.1
LZSN	6.0	KD	50.
K3	0.3	LFTOV	0.0
K24EL	0.029	OCRIT	0.014
CB	2.0	ONCRT	0.0014
CC	4.0	AZERO	0.01
LG	300.	SDPM	230.
SS	0.3	SEDMP	10.
IRC	0.1	SONE*	9.8
KV	0.0	FIXM	1.2
A	0.0052	FF	50.
EPXM	0.06	SGWINV	8.0
K24L	0.0	UZSINV	1.5
NN	0.4	LZSINV	15.0
KK24	0.996	GWSINV	1.0

*Identical in value to STWO, STRE, and SFOR.

TABLE V

WHTM SIMULATION FOR WALKER BRANCH WATERSHED FOR WATER YEAR 1969-70

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
TOTAL RUNOFF	0.97	0.92	3.83	2.88	2.64	2.33	4.14	0.79	0.86	0.62	1.25	0.59	21.82 INCHES
POTASSIUM OUT	0.80	1.29	10.62	6.35	6.46	5.30	9.38	0.37	1.66	0.44	3.11	0.61	46.39 MG/SQFT
POTASSIUM DEP	4.28	5.75	5.85	4.25	3.77	2.34	3.49	2.91	5.79	2.62	2.89	1.24	45.19 MG/SQFT
SURFACE	0.00	0.00	0.14	0.06	0.00	0.01	0.47	0.00	0.00	0.00	0.07	0.00	0.76 INCHES
IMPRV RUNOFF	0.01	0.01	0.04	0.01	0.01	0.02	0.04	0.00	0.03	0.01	0.03	0.01	0.23 INCHES
INTERFLOW	0.01	0.04	2.82	1.94	1.86	1.50	2.87	0.04	0.14	0.00	0.57	0.06	11.86 INCHES
BASE STREAM	0.95	0.87	0.84	0.86	0.76	0.80	0.75	0.74	0.69	0.61	0.57	0.52	8.98 INCHES
PRECIP	2.00	2.78	8.40	3.16	3.14	3.64	8.38	1.12	5.52	1.86	7.02	2.16	49.18 INCHES
EVP/TRAN NET	2.39	1.46	0.85	0.69	1.13	2.07	3.63	5.13	4.46	5.29	3.86	3.11	34.07 INCHES
POTENTIAL ET	2.40	1.46	0.85	0.69	1.13	2.08	3.65	5.16	4.48	5.73	3.88	3.12	34.64 INCHES
STORAGES SGW	7.35	6.92	7.13	6.76	6.59	6.34	6.34	5.69	5.52	4.57	4.50	4.18	
STORAGE UZS	0.72	1.60	4.97	5.03	4.52	3.97	4.55	0.37	0.73	0.26	2.35	1.12	
STORAGE LZS	15.01	15.02	15.05	15.08	15.12	15.15	15.18	15.18	15.20	12.54	12.44	12.45	
SLOPE GWS	0.59	0.47	1.03	0.71	0.64	0.60	0.77	0.37	0.42	0.13	0.32	0.26	
AZERO MONTH	0.08	1.70	0.10	0.19	0.29	0.10	0.12	0.21	0.76	0.34	0.13	0.10	
SEDMP MONTH	10.00	0.06	0.01	0.00	0.01	0.00	0.02	0.04	0.04	0.04	0.01	0.01	
SONE MONTH	10.34	11.05	8.60	7.72	7.10	6.59	5.86	6.60	7.45	8.35	9.24	9.38	

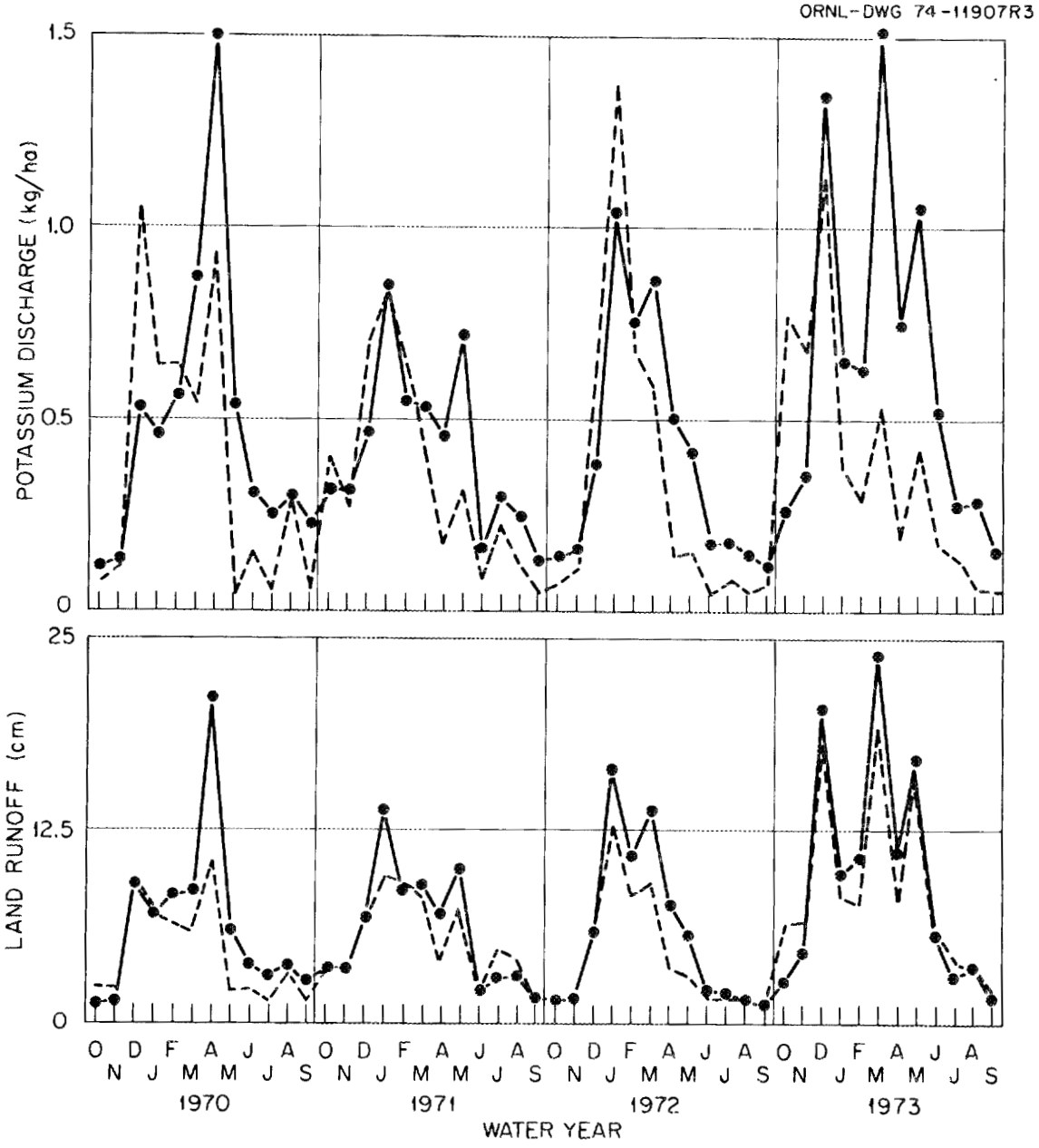

Fig. 3. Discharge of Water and Potassium from Walker Branch Watershed (Dotted Line Represents Simulated Results).

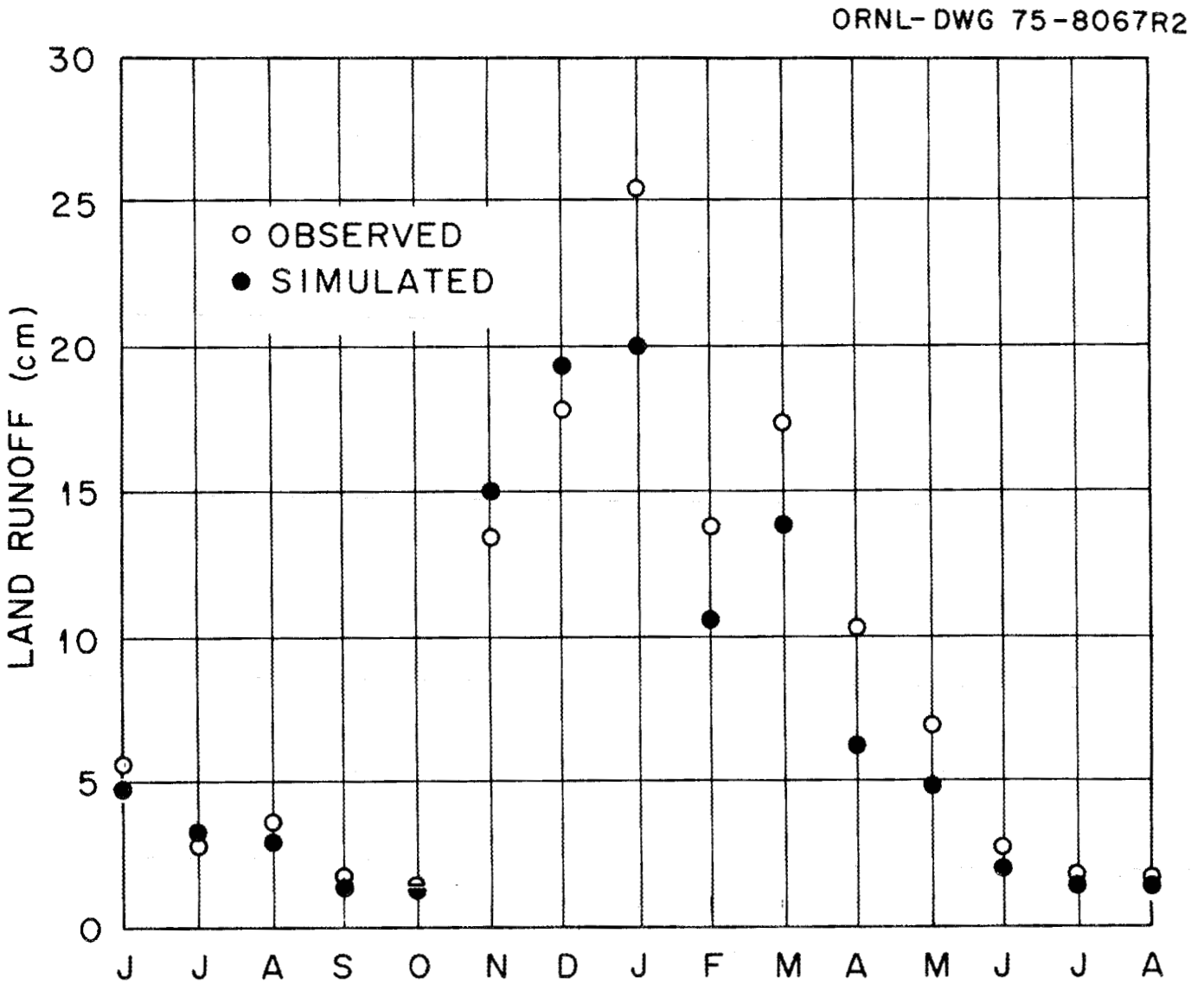

Fig. 4. Hydrologic Transport on Walker Branch Watershed for Period June 1973 — August 1974.

used for potassium for several of the parameters related to microconstituent transport. The new values were: KD = 3500, FIXM = 1000, FF = 300, and SONE, STWO, etc. = 200 $\mu g/ft^2$. These were chosen after making many computer runs but do not necessarily represent the "best" set of values. This is partly because KD, FIXM, and FF are not independent of each other; i.e., nearly identical simulations can be obtained by varying the values of two parameters simultaneously. The agreement of observed and simulated Cd streamflow values (Fig. 5) is quite good. However, it must be emphasized that only dissolved Cd is modelled and that the particulate fraction has not yet been well quantified. Thus, it will probably be necessary to reevaluate the parameters when additional data become available.

5. SUMMARY

The work described in this report demonstrates some capabilities of the ORNL version of the Wisconsin Hydrologic Transport Model and details the process of choosing appropriate parameter values. We have used WHTM to quantitatively simulate the monthly transport of water and dissolved potassium and cadmium on Walker Branch Watershed. The hydrologic budget involved simulation of evapotranspiration in addition to transfer of water from the land surface to the stream through several pathways. Simulation of the chemical budgets required estimation of the mobilities and adsorptive properties of the elements involved. The model may now be used to predict future budgets for K and Cd on the watershed. It is important to continue investigations of this type, not only to "fine tune" the model but also to investigate its limits of validity

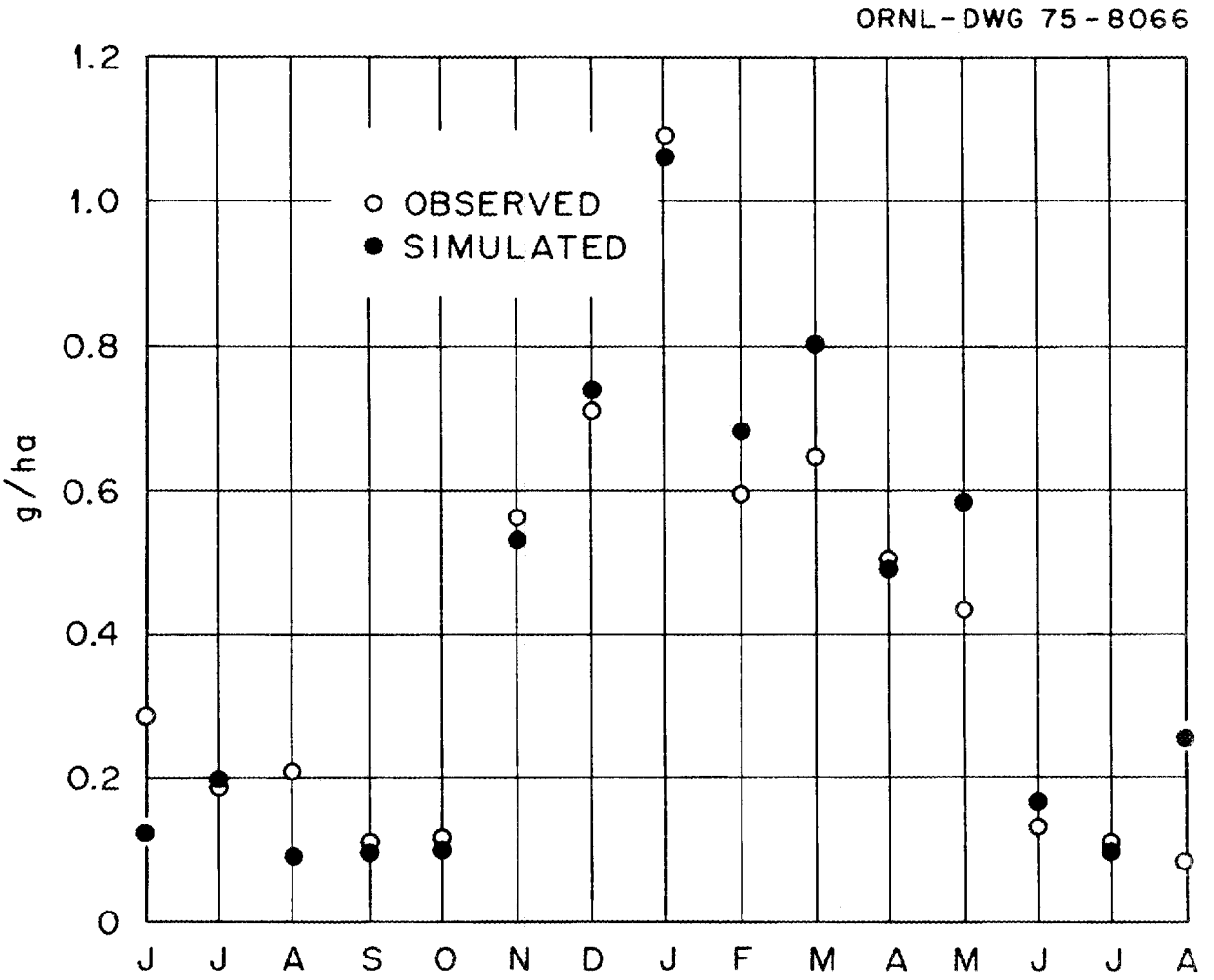

Fig. 5. Transport of Cadmium on Walker Branch Watershed for Period June 1973 — August 1974.

and to demonstrate its capability for dealing with other elements and other watersheds of different size.

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APPENDIX A
SENSITIVITY ANALYSIS OF WHTM PARAMETERS

When WHTM is applied to a new watershed, values for most of the parameters must be determined anew. The description of parameter evaluations in this report is intended to serve as a guide for other investigators. In addition, since the simulated output from the LAND subroutine is more sensitive to changes in certain parameters, it is important to identify these parameters so that they can be specified more accurately. We approached this problem of sensitivity for WBW by making a series of computer runs keeping all parameters constant, save one which was generally changed by a factor of 2, either higher or lower. We chose to look at only yearly totals since our primary interest was in monthly and yearly transport of trace materials. For storm events or daily flows, the list of sensitive parameters would be quite different.

The sensitivity analysis described here was performed on the first set of parameters chosen for the east fork of WBW (Table VI). Since new values were later chosen for some parameters on the basis of optimization (Fields and Watson, 1975) or other procedures, some values in Table VI are different from those used for the validation studies described in the main body of this report. In addition, the sensitivity of some parameters is related to the absolute magnitude of the base value. Nevertheless, we were able to obtain some feeling for the overall effect of changing parameter values on the output. We looked only at the hydrologic parameters, keeping constant the parameters specifically related to material transport.

TABLE VI

SENSITIVITY ANALYSIS FOR WALKER BRANCH EAST FORK PARAMETERS (12-MONTH SIMULATION)

			TOTAL RUNOFF	POTASSIUM OUTPUT	SURFACE FLOW	INTERFLOW	BASE STREAM
	NOMINAL VALUES →		27.45	35.32	2.78	16.87	6.76
PARAMETER	BASE VALUE	NEW VALUE	CHANGE FROM NOMINAL VALUES				
UZSN	1.3	2.6	- 3.11	- 8.81	-1.11	-2.90	+0.91
LZSN	19.2	38.4	-10.15	-18.96	-2.13	-7.76	-0.26
K3	0.28	0.56	- 0.01	- 0.03	-0.01	-0.02	+0.01
K24EL	0.029	0.058	- 0.01	+ 0.01	0.0	0.0	-0.01
CB	0.91	1.82	- 0.91	-15.42	-2.13	-1.37	+2.58
CC	4.00	2.00	- 0.54	+15.32	+3.01	-4.64	+1.10
L	1590.	795.	+ 0.14	- 0.38	+0.88	-0.50	-0.18
SS	0.66	0.33	- 0.07	- 7.34	-0.41	+0.25	+0.09
IRC	0.734	0.367	0.0	- 2.71	0.0	0.0	0.0
KV	0.5	1.0	+ 0.81	0.0	0.0	0.0	+0.82
A	0.024	0.048	+ 0.38	+ 0.51	-0.07	-0.42	-0.18
EPXM	0.15	0.30	- 0.24	- 0.23	+0.02	-0.18	-0.02
K24L	0.0	0.1	- 0.73	+ 0.01	0.0	0.0	-0.72
NN	0.4	0.2	+ 0.14	+ 4.46	+0.88	-0.50	-0.18
KK24	0.996	0.998	- 2.29	0.0	0.0	0.0	-2.28
SGWINV	0.5	1.0	+ 0.43	+ 0.01	0.0	0.0	+0.43
UZSINV	0.16	0.32	+ 0.05	+ 0.27	+0.03	-0.05	-0.04
LZSINV	30.0	15.0	- 7.66	-16.56	+1.83	-6.27	-0.55
GWSINV	0.14	0.28	0.0	0.0	0.0	0.0	+0.01

DATA FOR ALL COMPUTER RUNS

ANNUAL PRECIP = 49.18 INCHES
ANNUAL DEPOSITION = 55.98 MG/FT^2
ANNUAL ET = 17.71 INCHES

The effect on total runoff and material transport (potassium output) from changing each of 19 parameters is shown in Table VI. Total runoff is the sum of surface flow, interflow, base stream, and impervious runoff. Impervious runoff amounted to 1.04 inches with two exceptions: impervious runoff increased by a factor of 2 when the value of A was increased by a factor of 2 (however, total runoff increased by only 0.38 inches) and it decreased by 0.06 inches when EPXM was increased by a factor of 2. Thus, the actual sensitivity of parameter A on total runoff is not as great as might be anticipated.

Several observations can be made as a result of this sensitivity analysis. There are few parameters that do not affect both water and material transport, occasionally with opposite signs. This means that it is difficult to choose a set of parameters to optimize the water simulation without reference to the material transport. Some parameters, such as CC, redistribute water among various compartments without having much effect on the overall total. Nominal and initial values of the water storage terms, UZS and LZS, have large effects on the output. The small initial values of SGW and GWS used here probably account for the relatively small sensitivities to these parameters. The model is only slightly sensitive to the parameters L, KV, EPXM, and K24L, and is relatively insensitive to the parameters K3 and K24EL.

APPENDIX B
CROSS-FEED ON WALKER BRANCH WATERSHED

When WHTM was first applied to WBW, the watershed was treated as two subwatersheds or reaches, the east and west forks. Parameters were chosen for each fork - although for many parameters, the values were the same for the two forks. One parameter, K24L, the fraction of ground water recharge associated with deep percolation (Crawford and Linsley, 1966), was assigned a positive value for the east fork and a negative value for the west fork in an attempt to model the apparent transfer of groundwater from east to west. Elwood and Henderson (1975) pointed out that the annual streamflow per unit area from the west fork of WBW averages 1.9 times more than that from the east fork. This anomaly, which is not uncommon in limestone terrain, may be explained by intrusion of water from outside the topographic divide of the west fork, either from the east fork or from completely outside the boundaries of the watershed or from both. The latter explanation is probably correct since, as was pointed out in the main body of this report, the average annual runoff from WBW as a whole is ca. 25% higher than other nearby areas. The east fork is definitely losing water by other means than streamflow since the flow at the east weir drops as low as 100 m^3/time. In contrast, the flow at the west weir never drops below 2500 m^3/week although the land area of the west fork is only 65% of that of the east fork.

The streamflow at the west weir of WBW may thus consist of two components, runoff from the west fork plus cross-feed (intrusion) of water from the east fork. The amount of cross-feed may be computed if

we assume that, disregarding outside influences, runoff from two reaches should be proportional to the areas of those reaches. The results of this computation are shown in Fig. 6 where computed cross-feed on a weekly basis is plotted versus time for a six-year period. Wide fluctuations from one week to the next are primarily due to timing, i.e., a storm during the final hours of a given week might result in a peak streamflow for the west fork during the remainder of that week while the peak for the east fork might occur just after the next weekly period started. Except for the first two years, the curves for each year are strikingly similar. The values average 3500 m^3/week during the winter and spring, and about 1500 m^3/week during the summer. There is a decided periodicity for years 1971-74 which can be closely approximated by the expression

$$\text{cross-feed} = 2500 + 1000 \sin \left[\frac{\pi}{26} (t-1)\right]$$

where t is the week of the year. Thus, cross-feed could contribute as much as 60% of the flow measured at the west weir during the summer months.

The lack of a peak for cross-feed during 1969 may be due to the fact that rainfall for 1968 was 25% below normal and the water storage compartments required extensive recharging. Rainfall for both 1969 and 1970 was slightly below normal. Not shown on the plot for 1969 is a negative value for week 8 since we felt this was due to an artifact in the recorded streamflow data. Recorded streamflow values at the west weir for weeks 7-9 were 6006, 5811, and 5300 m^3, while at the east weir the corresponding weekly values were 5714, 10210, and 6818 m^3. There is nothing in the precipitation data to justify the 10210 reading. Likewise, there may be artifacts in the data for weeks 11 through 17 in 1970. This was a period

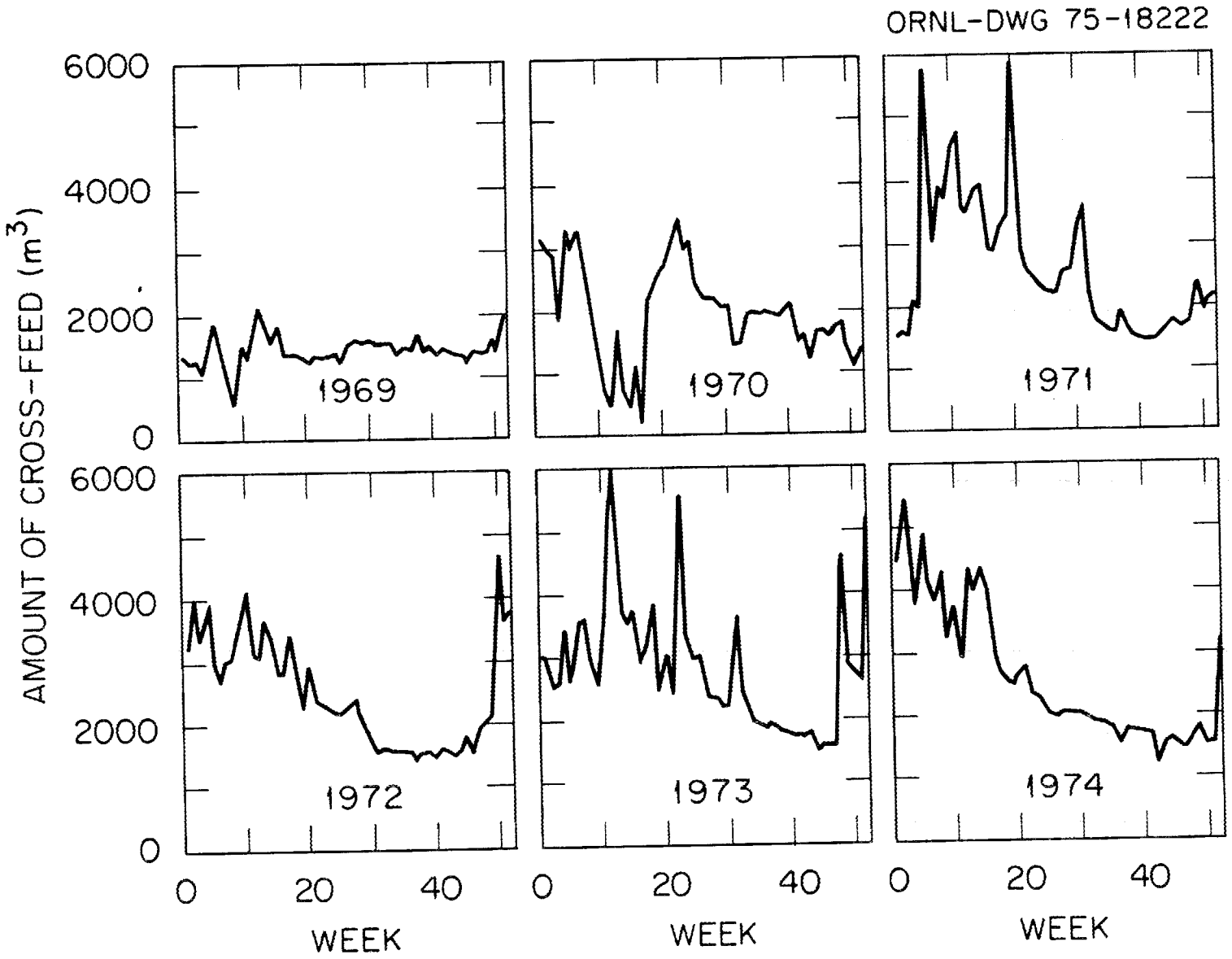

Fig. 6. Hydrologic Cross-Feed (East to West) on Walker Branch Watershed.

of extremely high streamflow. During week 17, for example, a decrease of only 4.4% in the recorded streamflow of 57000 m^3 would increase the calculated cross-feed by 1000 m^3.

Although it may be only coincidental, the flow from the main spring on the west fork changes by a magnitude of ca. 1200 m^3/week with approximately the same cycle exhibited by the computed cross-feed. Since the elevation of this spring is lower than about 90% of the east fork, the spring is probably partially fed by rain falling east of the dividing ridge.

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