LA-11851-MS

UC-702

Issued: September 1990

LA--11851-MS

DE91 000061

*Runoff and Sediment Yield Model
for Predicting Nuclide Transport
in Watersheds Using BIOTRAN*

A. F. Gallegos

W. J. Wenzel

MASTER

EP

CONTENTS

ABSTRACT	1
I. INTRODUCTION	2
A. Model Overview	3
B. Model Application	3
1. Watershed Surface	3
2. Watershed Aquifer and Alluvial Plain	7
C. Regions	8
II. MODEL STRUCTURE	9
A. Subroutine CLIMAT	9
B. Subroutine WATFLX	10
C. Subroutine RUNOFF	12
D. Subroutine GEOFLX	14
E. Subroutine AQUIFER	18
F. Subroutine EROSON	21
III. INPUT STRUCTURE	26
A. Input to MAIN	27
1. SC1	27
2. SC2 and SC3	27
B. Input to CLIMAT	27
1. SC1	27
2. SC2 and SC3	45
C. Input to WATFLX	45
1. SC1	45
2. SC2 and SC3	46
D. Input to GEOFLX	46
1. SC1	46
2. SC2 and SC3	48
E. Input to PLTGRO	48
1. SC1	48
2. SC2 and SC3	49
F. Input to UPTAKE	49
1. SC1	49
2. SC2 and SC3	49
G. Input to BIOPLT	49
1. SC1	49
2. SC2 and SC3	50
IV. RESULTS	50
A. Regions, Precipitation	50
B. Regions, Mean Daily Temperature	50
C. Regions, Total Above Ground Biomass	102
D. Regions, Surface Runoff	103
E. Regions, Return Flow	103
F. Regions, Erosion	104
G. Regions, Soil Specific Activity	105
H. Regions, Total Activity Inventory	105
I. Channels, Lateral Runoff	105
J. Channels, Water Transmission	106

Contents (cont)

K.	Channels, Peak Discharge Rate	106
L.	Channels, Return Flow	107
M.	Channels, Aquifer Transport Losses and Aquifer Heights	107
N.	Channels, Aquifer Volumes	108
O.	Channels, Sediment Discharges	107
V.	DISCUSSION	109
VI.	ACKNOWLEDGEMENTS	116
VII.	REFERENCES	116

FIGURES

1.	Sketch of Mortandad Canyon model	6
2a.	Precipitation events for the 10th simulation year for scenario 1, sc1	51
2b.	Precipitation events for the 10th simulation year for scenario 2, sc2	52
2c.	Precipitation events for the 100th simulation year for scenario 3, sc3	53
3a.	Mean daily temperature for the 10th simulation year for scenario 1, sc1	54
3b.	Mean daily temperature for the 10th simulation year for scenario 2, sc2	55
3c.	Mean daily temperature for the 100th simulation year for scenario 3, sc3	56
4a.	Total above ground live biomass for scenario 1, sc1, for annual and perennial grasses and herbs on the 10th simulation year	57
4b.	Total above ground live biomass for scenario 2, sc2, for grasses, shrubs, and trees in niche competition and succession on the 10th simulation year	58
4c.	Total above ground live biomass for scenario 3, sc3, for grasses, shrubs, and trees in niche competition and succession on the 100th simulation year	59
5a.	Regional surface runoff events for the 10th simulation year in scenario 1, sc1. Compare with figure 2a	60
5b.	Regional surface runoff events for the 10th simulation year in scenario 2, sc2. Compare with figure 2b	61
5c.	Regional surface runoff events for the 100th simulation year in scenario 3, sc3. Compare with figure 2c	62
6a.	Subsurface return flow for the 10th simulation year for scenario 1, sc1	63
6b.	Subsurface return flow for the 10th simulation year for scenario 2, sc2	64
6c.	Subsurface return flow for the 100th simulation year for scenario 3, sc3	65
7a.	Regional soil erosion for the 10th simulation year in scenario 1, sc1	66
7b.	Regional soil erosion for the 10th simulation year in scenario 2, sc2	67
7c.	Regional soil erosion for the 100th simulation year in scenario 3, sc3	68
8a.	Mass of soil removed by erosion from regions in 10th simulation year for scenario 1, sc1	69
8b.	Mass of soil removed by erosion from regions in 10th simulation year for scenario 2, sc2	70
8c.	Mass of soil removed by erosion from regions in 100th simulation year for scenario 3, sc3	71
9a.	Regional soil uranium specific radioactivity for 10th simulation year in scenario 1, sc1	72

Contents (cont)

9b.	Regional soil uranium specific radioactivity for 10th simulation year in scenario 2, sc2.....	73
9c.	Regional soil uranium specific radioactivity for the 100th simulation year in scenario 3, sc3.....	74
10a.	Regional total soil uranium radioactivity for 10th simulation year for scenario 1, sc1.....	75
10b.	Regional total soil radioactivity for 10th simulation year for scenario 2, sc2.....	76
10c.	Regional total soil uranium radioactivity for 100th simulation year for scenario 3, sc3.....	77
11a.	Lateral runoff into channels from adjacent regions for 10th simulation year for scenario 1, sc1.....	78
11b.	Lateral runoff into channels from adjacent regions for 10th simulation year for scenario 2, sc2.....	79
11c.	Lateral runoff into channels from adjacent regions for 100th simulation year for scenario 3, sc3.....	80
12a.	Water transmission at end of channel on 10th simulation year for scenario 1, sc1.....	81
12b.	Water transmission at end of channel on 10th simulation year for scenario 2, sc2.....	82
12c.	Water transmission at end of channel on 100th simulation year for scenario 3, sc3.....	83
13a.	Peak channel discharge rates for runoff events in 10th simulation year in scenario 1, sc1.....	84
13b.	Peak channel discharge rates for runoff events in 10th simulation year in scenario 2, sc2.....	85
13c.	Peak channel discharge rates for runoff events in 100th simulation year in scenario 3, sc3.....	86
14a.	Return flow volume entering a channel from adjacent regions on 10th simulation year for scenario 1, sc1.....	87
14b.	Return flow volume entering a channel from adjacent regions on 10th simulation year for scenario 2, sc2.....	88
14c.	Return flow volume entering a channel from adjacent regions on 100th simulation year for scenario 3, sc3.....	89
15a.	Aquifer transport losses at distal face below channels for 10th simulation year for scenario 1, sc1.....	90
15b.	Aquifer transport losses at distal face below channels for 10th simulation year for scenario 2, sc2.....	91
15c.	Aquifer transport losses at distal face below channels for 100th simulation year for scenario 3, sc3.....	92
16a.	Aquifer height below channel for 10th simulation year for scenario 1, sc1.....	93
16b.	Aquifer height below channel for 10th simulation year for scenario 2, sc2.....	94
16c.	Aquifer height below channel for 100th simulation year for scenario 3, sc3.....	95
17a.	Alluvial aquifer volume for 10th simulation year for scenario 1, sc1.....	96
17b.	Alluvial aquifer volume for 10th simulation year for scenario 2, sc2.....	97
17c.	Alluvial aquifer volume for 100th simulation year for scenario 3, sc3.....	98
18a.	Sediment discharge from channels in 10th simulation year for scenario 1, sc1.....	99
18b.	Sediment discharge from channels in 10th simulation year for scenario 2, sc2.....	100
18c.	Sediment discharge from channels in 100th simulation year for scenario 3, sc3.....	101

Contents (cont)

TABLES

1.	Listing of BIOTRAN Subroutines and Their Functions	4
2.	Scenario 1 Input Description.....	28
3.	Scenario 2 and 3 Input Description.....	35
4.	Observed Precipitation Near Mortandad Canyon at Three LANL Sites.....	110
5.	Observed and Simulated Precipitation and Runoff Events in Mortandad Canyon Above Upper Weir (GS-1)	111
6.	Simulated Moisture Runoff from Surface and Return Flow Events.....	112
7.	Simulated Discharge Rates and Other Related Parameters for Mortandad Canyon.....	113
8.	Simulated Sediment Outflow at Weir GS-2 for Scenario 3	115
9.	Annual Water and Sediment Outflows from GS-Z	115

RUNOFF AND SEDIMENT YIELD MODEL FOR PREDICTING NUCLIDE TRANSPORT IN WATERSHEDS USING BIOTRAN

by

A. F. Gallegos and W. J. Wenzel

ABSTRACT

The environmental risk simulation model BIOTRAN was interfaced with a series of new subroutines (RUNOFF, GEOFLX, EROSON, and AQUIFER) to predict the movement of nuclides, elements, and pertinent chemical compounds in association with sediments through lateral and channel flow of runoff water. In addition, the movement of water into and out of segmented portions of runoff channels was modeled to simulate the dynamics of moisture flow through specified aquifers within the watershed. The BIOTRAN soil water flux subroutine, WATFLX, was modified to interface the relationships found in the SPUR model (Wight 1984) for runoff and sediment transport into channels with the particle sorting relationships utilized by Lane (1985) to predict radionuclide enrichment and movement in watersheds. The new subroutines were applied specifically to Mortandad Canyon within Los Alamos National Laboratory by simultaneous simulation of eight surface vegetational subdivisions and associated channel and aquifer segments of this watershed. This report focuses on descriptions of the construction and rationale for the new subroutines and on discussing both input characteristics and output relationships to known runoff events from Mortandad Canyon. Limitations of the simplified input on model behavior are also discussed. Uranium-238 was selected as the nuclide for demonstration of the model because it could be assumed to be homogeneously distributed over the watershed surface.

I. INTRODUCTION

The simulation model BIOTRAN has been used in previous health risk assessments and contaminant migration studies by constructing complex scenarios to estimate the movement of nuclides and nutrients in diverse environments through specified plant and animal pathways to man. The plant pathways simulated by BIOTRAN have involved both natural and irrigated plants used as food by both humans and livestock to predict cancer mortality in a given human population. There is an equal need to predict the surface and subsurface transport of radionuclides and hazardous chemicals within a watershed. Contaminated particles and solutes may ultimately be transported from areas of minimal risk to humans to environments which may pose a health hazard to man by entering his drinking water and foodchain in significant quantities.

A number of factors such as climate, vegetation type and standing crop, soil characteristics, and slope of watershed surfaces and channels all affect erosion processes. A simulation model which can integrate these processes with those involving human landscape modifications such as surface paving and agricultural tillage can become a valuable tool in assessing health risks to man from runoff-generated events. BIOTRAN has the capability of estimating surficial contamination of plant surfaces from global fallout and resuspension of soil particles. In its present version, it is capable of integrating these process with scouring and sediment deposition events. The integration has been possible by use of the relationships developed in the SPUR model (Wight 1984) for overland runoff and sediment yield predictions with the simulation model particle size sorting and channel transport processes developed by Lane (1985) for application in the Los Alamos environment. The development of an aquifer component in BIOTRAN to simulate the subsurface movement of water is complementary to channel transport processes mentioned earlier. The simulation of a riparian ecosystem along the channel segments is also a new feature of the model. As with many simulation models, BIOTRAN previously modeled only one site or region of variable area. In its present version, multiregional simulations are possible to characterize different parts of a watershed to correspond to topographic plant associations and slope effects, thus a wide variety of vegetational zones for the steep E-W trending canyon and mesa watersheds at Los Alamos can be simulated simultaneously. It is also possible to perform simultaneous multinuclide and multinutrient simulations in one run of BIOTRAN.

BIOTRAN has incorporated well-known, validated portions of other ecosystem models such as RANGE (Gilbert 1974), ELM (Cole 1978), and CREAMS (Knisel 1980) in addition to SPUR (Wight 1984) over the last 14 yr. BIOTRAN is internally consistent with units. The units shown in this report retain the English or metric units from the references used to derive input or develop code. BIOTRAN functions primarily in daily time increments and operates generally with difference equations involving regression equations when required. The version presented in this report is limited to modeling physical transport of contaminants and solutes by erosion and excludes adsorption-desorption or chemical processes involving contact by surface or infiltrating water. However, plant uptake and soil leaching of nuclides by these last processes have been modeled previously for other applications, and it is expected that future model development will interface them with runoff simulations.

A. Model Overview

The simulation model BIOTRAN contains a menu program called MAIN to allow the user to set up the scenario sequencing the 16 subroutines listed in Table 1 with an abbreviated function. A detailed description for each subroutine and its intended applications are described in the BIOTRAN User's Manual (Gallegos et al. 1990). The asterisked subroutines in Table 1 are described using FORTRAN algorithms in this report. All or part of the 16 subroutines could be used in any given simulation, depending on the scenarios defined by the user in MAIN. The subroutines used in this report were limited to CLIMAT, WATFLX, GEOFLX, RUNOFF, EROSON, AQUIFER, PLTGRO, and UPTAKE. The subroutines CLIMAT, PLTGRO, UPTAKE, AND BIO-PLT will be described in this report in general terms as they relate to those subroutines of interest. Additional information on these subroutines may be found in another report (Wenzel et al. 1987). The subroutine WATFLX will be described primarily in reference to its importance as an interface to the new subroutines and not as the soil moisture movement simulator, which is its major function.

B. Model Application

1. Watershed Surface. The site for the application of the runoff and sediment transport simulations involved the upper portion of Mortandad Canyon within the confines of the Los Alamos National Laboratory (LANL). Figure 1 shows a sketch of the simulated area. The simulated segments are outlined on the figure. The portion of the canyon simulated extends from its farthest reach at 7300-ft elevation near Diamond Drive to about 6800-ft elevation at the intersection of the main channel with the tributary channel that originates about 1.5 mi west; this channel was not included in the simulation. The main channel segment extends about 2.43 mi and has an average slope of about 0.04 between the markers set for the scenario. About 1.15 mi downstream from the main channel, another tributary channel intersects at about 7100-ft elevation; the channel originates about 0.46 mi up-channel in a westerly direction near the LANL facilities TA-50 and TA-55. This channel is included in the scenario because low-level radioactive effluent is disposed into it from the LANL liquid waste processing facility, TA-50. The main channel segment also receives sanitary and cooling water effluents a short distance above this junction, which is also included in the scenario construct. The total watershed area modeled is approximately 500 acres, consisting of ponderosa pine forest with an admixture of pinyon-juniper and shrub oak vegetation at the lower elevations. For modeling purposes, Figure 1 shows the watershed channels segmented into four drainage areas with associated channels:

- (1) 1.15-mi channel length initiating at 7300 ft along the main channel near LANL facility TA-59 and terminating at 7100 ft at the junction of the first tributary channel draining the TA-50 site. This channel has a slope of about 0.046 and drains approximately 246 acres. The drainage area has an approximate slope of 0.07. Vegetation is ponderosa pine forest and has about 10% of its surface impermeable due to rock outcrops. A shallow aquifer without an alluvial plain is included (Baltz 1963).

TABLE 1. Listing of BIOTRAN Subroutines and Their Functions

<u>Subroutine</u>	<u>Function</u>
AIRAC	Simulates chronic and acute air contamination events.
CLIMAT	Simulates daily temperature, solar radiation, precipitation amounts and pattern, potential evapotranspiration, and other climatic variables.
WATFLX	Simulates moisture movement through the rooting zone of plants, evapotranspiration processes, and irrigation events.
GEOFLX*	Simulates the coordination of runoff and erosion events from specific regions of a watershed to respective channels.
RUNOFF*	Simulates the amount of runoff as a function of antecedent soil moisture and precipitation amount; and the simulation of immediate moisture infiltration into the rooting zone of plants.
EROSION*	Simulates the differential removal of soil or alluvial particles as a function of particle diameter.
AQUIFER*	Simulates the infiltration and movement of alluvial ground water from one channel segment to another.
PLTGRO	Simulates the growth of plants as a function of plant type, solar radiation, ambient temperature, nutrients, frost-free period, and other environmental factors.
FORMAN	Simulates the growth of forest stands by diameter classification and other forest characteristics such as tree height and bole diameter.
FORCUT	Simulates tree harvesting operations and forest fires in conjunction with the FORMAN subroutine.
UPTAKE	Simulates the contamination of plants by root uptake and surficial deposition as the result of resuspension and fallout mechanisms.
ZOOGRO	Simulates the food supply of herbivores, omnivores, carnivores and humans in conjunction with PLTGRO and UPTAKE subroutines. Both internal and external contamination of plants and animal tissues for consumption are estimated for different diet preferences.
ANIMAL	Simulates the growth of mammals including beef and dairy cattle, deer, and rodents. The biological transport of contaminants through the foodchain is also modeled. In addition, an insect model is included to simulate a diet item for insectivorous rodents.
HUMTRN	Simulates the growth of male and female human populations by age group and foodchain transport of contaminants from specific diets.

TABLE 1. (cont)

<u>Subroutine</u>	<u>Function</u>
AQUAT	Simulates the functioning of a lake ecosystem including phytoplankton and zooplankton, and lake chemical and thermal dynamics in conjunction with the CLIMAT subroutine.
BIOPLT	Model-wide variable selector for graphical display modes.

 *New subroutines documented in this report.

- (2) 0.46-mi channel length initiating at about 7200 ft near TA-55 and terminating at 7100 ft at its junction with the main channel. This channel has a slope of about 0.08 and drains approximately 72 acres. The drainage area has an approximate slope of 0.10. Vegetation is ponderosa pine forest and has about 10% of its surface impermeable due to rock outcrops and human pavement. A shallow aquifer without an alluvial plain is included.
- (3) 0.79-mi channel length initiating at 7100-ft elevation along the main channel at its junction with channel (2) and terminating down-channel at about 6900-ft elevation. This channel has a slope of about 0.05 and drains approximately 116 acres. The drainage area has an approximate slope of 0.10. Vegetation is predominantly ponderosa pine forest with some admixture of pinyon pine and about 10% impermeable surface due to rock outcrops. An alluvial plain of about 3.2 acres occurs along the length of the channel coincident with the surface area of the shallow aquifer underlying the channel.
- (4) 0.49-mi channel length initiating at about 6900-ft elevation along the main channel at the terminus of channel (3) and terminating down-channel at about 6800-ft elevation. This channel has a slope of about 0.04 and drains approximately 63 acres. The drainage area has an approximate slope of 0.10. Vegetation is predominantly ponderosa pine forest with an admixture of pinyon pine and juniper and about 10% impermeable surface due to rock outcrops. An alluvial plain of about 6.9 acres runs along the length of the channel coincident with the surface area of the shallow aquifer underlying the channel.

The information presented above was estimated from LANL topography maps of Mortandad Canyon and from information obtained by Onishi (1982) in his watershed study of the canyon. A substantial amount of information concerning the vegetation, radionuclide inventory and movement, soils, and hydrology of Mortandad Canyon has been documented by a number of investigators (Hakonson 1973, Nyhan 1976, and Purtymun 1974), and the reader is referred to these documents for more detail.

Explanation of Symbols

- > = direction of moisture flow
- = regional boundaries
- ch1 = channel(1)
- ch2 = channel(2)
- ch3 = channel(3)
- ch4 = channel(4)
- dr1, dr2, dr3, ..., dr7 = runoff drainage from regions 1, 2, 3, ..., 7
- ac = watershed acreage for specific region

Notes

Channels(1-2) drain directly into channel(3), and the latter drains directly into channel(4). Drainages(1-2) flow directly into their respective channels(1-2); however, drainages(3-4), and dr(5,7) drain into regions(6,8), respectively. That is, runoff drainage runoff into channels(3-4) is from regions(6,8), respectively, which receive direct runoff from the regions indicated.

Fig. 1. Sketch of Mortandad Canyon model.

2. Watershed Aquifer and Alluvial Plain. A shallow aquifer continuous throughout the main and tributary channels in question is included in the scenario. The aquifer is approximated as a series of connected trapezoidal solids with a slope parallel to the corresponding channel slope: the down-channel trapezoidal face has a greater depth and width than the face of the anterior end. The aquifer coincides with the four channel segments described previously with the posterior faces of anterior segments becoming the anterior faces of posterior channels. The slope of the channel is also taken into account in estimating the aquifer volume. Figure 1 shows the top of the four aquifers beneath each channel. The dimensions of the four aquifers below each channel are estimated from observed values (Baltz 1963) as described below:

- (1) Aquifer underlying channel segment 1. This aquifer is estimated to be 6072 ft long with surface slope of 0.046. The anterior trapezoidal face has estimated dimensions of 3.0, 1.5, and 2.0 ft for upper base, lower base, and height, respectively. The posterior trapezoidal face has dimensions of 24.0, 14.0, and 6.0 ft for upper base, lower base, and height, respectively. An alluvial plain is not included for this channel segment.
- (2) Aquifer underlying channel segment 2. This aquifer is estimated to be 2429 ft long with a surface slope 0.08. The anterior trapezoidal face has estimated dimensions of 3.0, 1.5, and 2.0 ft for upper base, lower base, and height, respectively. The posterior trapezoidal face has dimensions of 24.0, 14.0 and 6.0 ft for upper base, lower base, and height, respectively. An alluvial plain is not included for this channel segment.
- (3) Aquifer underlying channel segment 3. This aquifer is estimated to be 4171 ft long with a surface slope of 0.05. The anterior trapezoidal face has estimated dimensions of 24.0, 14.0, and 6.0 ft for upper base, lower base, and height, respectively. The posterior trapezoidal face has dimensions of 43.0, 21.0, and 15.0 ft for upper base, lower base, and height, respectively. An alluvial plain is included for this channel segment with a surface area equal to 3.2 acres as described earlier. Other characteristics of this plain are presented later in this report.
- (4) Aquifer underlying channel segment 4. This aquifer is estimated to be 2587 ft long with a surface slope of 0.04. The anterior trapezoidal face has estimated dimensions of 43.0, 21.0, and 15.0 ft for upper base, lower base, and height, respectively. The posterior trapezoidal face has dimensions of 191.0, 46.0, and 36.0 ft for upper base, lower base, and height, respectively. An alluvial plain is included for this channel segment with a surface area equal to 6.9 acres.

In summary, aquifer and channel segments 1 and 2 enter aquifer and channel 3, which then enters aquifer and channel 4. Alluvial plains are modeled for the last two channel segments (3 and 4).

C. Regions. Eight contributing areas and their associated plant communities that have been defined to model the upland portion of Mortandad Canyon are described below. Figure 1 shows the regions, channels, and underlying outline of the shallow aquifers.

1. This region coincides with the drainage area (canyon walls and watershed) presented for channel 1 and its description: 7100- to 7300-ft elevation, 246 acres, with ponderosa pine, oak shrub, and cool-season annual and perennial grasses as the predominant vegetation.
2. This region coincides with the drainage area (canyon walls and watershed) presented for channel 2 and its description: 7200- to 7100-ft elevation, 72 acres, with ponderosa pine, oak shrub, and cool-season annual and perennial grasses as the predominant vegetation.
- 3 & 4. These canyon wall watershed regions connect to region 6 parallel to channel 3. They are located at 6900- to 7100-ft elevation and are divided equally into two 56.4-acre tracts (for modeling purposes). The predominant vegetation is ponderosa pine, oak shrub, and cool-season grasses.
- 5, 7. These canyon wall watershed regions connect to region 7 parallel to channel 4. They are located at 6680- to 6900-ft elevation and are divided equally into two 28.0-acre tracts (for modeling purposes). The predominant vegetation is ponderosa pine, oak shrub, and cool-season grasses with some pinyon pine and warm-season annual and perennial grasses.
6. This region coincides with the alluvial plain for channel 3 as described previously except that it incorporates the aquifer and extends beyond the aquifer area at the surface. It is located at an elevation of about 7000 ft with an area of 3.2 acres and a riparian plant community consisting of ponderosa pine, deciduous trees and shrubs, and warm- and cool-season grasses. Channel 3 flows through the center of this region throughout its length.
8. The region coincides with the alluvial plain for channel 4 as described previously except that it incorporates the aquifer and extends beyond the aquifer area at the surface. It is located at an elevation of about 6850 ft with an area of 6.9 acres and a riparian plant community consisting of ponderosa pine, deciduous trees and shrubs, and warm- and cool-season grasses as the predominant vegetation along with an admixture of pinyon pine.

A more detailed description of these simulated regions will be presented when input/output structures are considered later in this report.

II. MODEL STRUCTURE

The BIOTRAN subroutines WATFLX, RUNOFF, GEOFLX, and EROSON will be the primary focus of this section. Subroutine CLIMAT will be discussed in relation to evapotranspiration input into WATFLX, and the latter will receive attention with regard to interfacing the newly developed subroutines mentioned above. Other subroutines involved in the watershed simulation using BIOTRAN will receive indirect attention when input requirements are described. The reader is referred to other references for information on BIOTRAN as a whole and specifically for other subroutines not considered here (Gallegos 1980, Gallegos 1984, Wenzel 1985).

A. Subroutine CLIMAT

This subroutine is a stochastic climate simulator of regional temperature, precipitation, and precipitation pattern. CLIMAT also simulates solar radiation intensity, snowfall, snowmelt, and potential evapotranspiration for a given site (Gallegos 1984).

Potential evapotranspiration, mm/day, for a given region is estimated with the following FORTRAN algorithms:

$$PET = (1.28 * DELTT * HO) / (DELTT + APSYC), \quad (1)$$

where DELTT is the slope of psychrometric saturation line, mbars/°C;

$$DELTT = 5304 / (T + 273) ** 2 * \exp(21.255 - 5304 / (T + 273)), \quad (2)$$

where T is the average daily temperature, °C. APSYC is the psychrometric constant, mbars/°C,

$$APSYC = 0.0006595 * PMBAR, \quad (3)$$

where PMBAR is the barometric pressure, mbars;

$$PMBAR = 1013. - 0.1152 * (0.3048 * G1 + 5.44E-06 * (0.3048 * G1) * (0.3048 * G1)), \quad (4)$$

where G1 is the site elevation in feet above sea level, HO is the net daily solar radiation, Langelys;

$$HO = (1 - ALBD) * SOLRAD / 58.3, \quad (5)$$

where ALBD is the albedo (set to 0.2), and SOLRAD is the daily energy insolation, Langelys.

The major difference between this estimate of PET and that obtained using the CREAMS model (Knisel 1980) is that the psychrometric constant is a function of estimated barometric pressure based on site elevation. This PET estimate is used later in the WATFLX subroutine to initially estimate surface water losses and set the upper boundary for transpiration losses from successive rooting soil layers.

Snowfall and snowmelt are bounded to an average daily temperature of 2°C above zero which snowmelt occurs; otherwise, snow accumulation is simulated. This temperature was estimated from tuning of the algorithm to give the best representation of snow accumulation at Los Alamos. At average daily temperatures exceeding 2°C, snowmelt, SNM, mm/day, is estimated as

$$SNM = 11.28 * TMX + 1.128, \quad (6)$$

where TMX is the maximum daily temperature, °C;

$$TMX = T + 0.53 * ABS(T + 1), \quad (7)$$

where T is the average daily temperature, °C. Ten inches of snow is assumed equivalent to 1 in. of precipitation on the average.

B. Subroutine WATFLX

This subroutine contains a substantial portion of the soil hydrology modeling including soil physical properties; nuclide, chemical, and nutrient composition; extent of root penetration into the soil horizon; transpiration by plants; evaporation from the soil surface; and irrigation strategies. WATFLX integrates with other subroutines used in modeling runoff and erosion as well. Transpiration, evaporation, and an abbreviated discussion of soil moisture movement will be described in this report; other modeling efforts within this subroutine were discussed elsewhere (Wenzel 1987, Gallegos et al. 1990).

Plant transpiration is estimated as the total amount of water evaporated from successive soil layers of a given plant type (each type, such as cool-season grass or ponderosa pine, is simulated separately for each layer) from a given region where TP_i is the transpiration from the i th soil layer, mm/day, $i=2,3,\dots,n$;

$$TP_i = ((WA_i - W1_i) / (H_i - W1_i)) * (WA_i - W1_i) * ZFF_i * TLAI, \quad (8)$$

where WA_i is the i th soil layer soil moisture content, mm; H_i is the i th soil layer moisture content at holding capacity (moisture in total pore space), mm; $W1_i$ is the i th soil layer moisture content at wilting point; mm, ZFF_i is the i th soil layer root penetration fraction; and $TLAI$ is the plant leaf/needle area index, m^2/m^2 . The TP_t is the total daily transpiration from the plant rooting zone, mm/day:

$$TP_t = TP_1 + TP_2 + TP_3 + \dots + TP_n. \quad (9)$$

The upper boundary for TP_t is set by PET, Eq. (1), and moisture is removed from each successive layer until PET is reached or until the last layer is reached, whichever is realized first. If a given layer cannot satisfy demand, then the excess demand is removed from the next layer. Also, a moisture withdrawal boundary from any soil layer is set by the amount of moisture in excess of the moisture content at wilting point. Root penetration is set at twice the estimated actual

fraction of a soil layer occupied by plant roots at any simulated time, but it is not allowed to exceed 1.0 for that layer. The actual rate of root penetration varies with plant types: annuals, perennials, woody, herbaceous, time of year, ..., etc. (Wenzel and Gallegos 1987).

The leaf area index, TLAI, of a specific plant type based on its leaf biomass, is modeled to have a significant impact in affecting moisture withdrawals from unsaturated soils. In the current BIOTRAN model, TLAI is based on live (green) leaf biomass, WND in g/m² dry weight, for each plant type:

$$TLAI = 0.013 * WND \quad (10)$$

For plant type-specific surficial dust deposition modeling in BIOTRAN, TLAI includes both live (WND) and dead standing leaf biomass (WD1) (Wenzel and Gallegos 1987).

Evaporation of moisture from the soil surface is modeled to affect the top 20-mm thick soil layer exclusively. This layer is also used for resuspension and deposition modeling of particulates in the same manner. Evaporation in mm/day from the soil surface is modeled from the top soil layer as

$$EVAP = 0.5 * WAV * EXP(-0.4 * TLAI), \quad (11)$$

where WAV is the potential moisture withdrawal from top layer, mm/day;

$$WAV = (PET - TP_n) \quad (12)$$

The amount of potential moisture withdrawal from the top layer, WAV, is bounded by that in excess of 5% volumetric wetness and also by transpiration, TP_i, losses which are allocated beforehand. The strategy is similar to that of the CREAMS model except for the boundary conditions imposed and the order of allocation. This adjustment is required because BIOTRAN structures more than one soil layer for moisture allocation and because of the steep moisture gradient created at the surface by evaporation (Hillel 1976). Finally, the leaf area index in the soil evaporation calculation uses only the green leaf biomass densities mentioned previously.

Soil moisture remaining after adjustment for evaporation, transpiration, and surface runoff losses is modeled as infiltration moisture, before modeling of unsaturated soil moisture movement within the soil profile with an approximation of Darcy's equation (Hillel 1976). Both surface runoff and infiltration will be considered later in this report along with subsurface return flow. The relationship used to estimate Darcian soil moisture movement is modeled separately for the top layer as

$$MFLX1 = CZ1 + 0.5 * CZ1 * YM2, \quad (13)$$

where MFLX1 is the soil moisture movement from the top layer, mm water/mm soil per day; CZ1 is the weighted soil water conductivity, mm water/mm soil per day, based on sand, silt, or clay soil

composition for the top soil layer; and YM_2 is the weighted matric potential, mm/mm soil for the second soil layer (matric potential at the surface of the soil is assumed to be zero). Note that units are consistent with Hillel's definition when multiplied by soil layer depth in mm. The relationship for soil moisture movement, $MFLX_i$, in the i th layer, mm water/mm soil per day, is represented as

$$MFLX_i = CZ_i + 0.5 * CZ_i * (YM_{i+1} - YM_{i-1}), \quad (14)$$

where CZ_i is the weighted soil conductivity, mm water/mm soil per day, for i th soil layer; YM_{i+1} is the weighted matric potential, mm/mm soil for the $i + 1$ soil layer; and YM_{i-1} is the weighted matric potential, mm/mm soil for the $i - 1$ soil layer.

Moisture movement direction is determined as downward ($MFLX_i > 0$) or upward ($MFLX_i < 0$) within a given soil layer. Both soil moisture conductivity and matric potential are estimated by regression analysis ($p = .01$, $r > .9$) as power functions of volumetric wetness from information for sand, silt, and clay soil columns provided by Hillel (1976). The values of $MFLX_i$ are maximum estimates which assume adequate soil moisture is present in a given soil layer. Beginning with the top layer and proceeding to the bottom layer, a cumulative boundary moisture flux is estimated for each layer, and moisture flux is adjusted to lower values if inadequate moisture limits the maximum flux estimates. Also, moisture flux is adjusted to prevent any but the top soil layer from exceeding the holding capacity of that layer; this adjustment is accomplished by sequentially downward adjustment of moisture fluxes beginning with the bottom soil layer and proceeding toward the second layer. Lower-limit boundaries are set at 5% volumetric wetness for all soil layers, and moisture exports are adjusted to disallow soil moisture excursions below this value. A final adjustment is made on upward moisture fluxes (WATAKU) described previously if the addition of moisture to an upper layer from this source results in a volumetric wetness which exceeds the adjacent lower layer. In such cases, the export flux is reduced to balance volumetric altogether wetness in both layers or is excluded altogether. The latter was determined by tuning of experiments to stabilize model operation when relatively large volumetric wetness differences exist between adjacent soil layers.

The loss of moisture from the soil profile below the rooting zone is set at 0.5% of the bottom-layer available moisture daily; however, when subsurface return flow is operational in BIOTRAN, this loss is set to 0.0. The former loss is modeled as a sink, whereas the subsequent return flow process is integrated with channel hydrology simulations to be described in a subsequent section of this report.

C. Subroutine RUNOFF

This subroutine deals with both surface runoff and infiltration modeling events as a result of precipitation. The infiltration modeling is primarily a mass-balance accounting of residual moisture. This approach is made necessary by lack of precipitation duration information required for this purpose and the consequent necessity of having to model surface runoff on the basis of total precipitation for a given event independent of its intensity (Knisel 1980, Branson 1981, Haan

1982). Surface runoff is estimated by use of "curve numbers," a technique which takes into account soil type, plant cover, vegetative type, and antecedent soil moisture (Branson 1981). The data presented by Branson were used to formulate regression equations ($p = .01$, $R^2 \sim .8$) to estimate CNII, the normal soil moisture condition curve number:

$$CNII = ACN2 - BCN2 * AKOND - BCN3 * HFAV, \quad (15)$$

where ACN2 is the plant crown cover factor;

$$ACN2 = 96 - 16 * CCVV \quad (16)$$

and

$$BCN2 = 9.0 + 5.9 * CCVV, \quad (17)$$

where CCVV is the plant crown cover fraction, BCN2 is the plant crown cover-conductivity interaction, and BCN3 is the plant crown cover-vegetation type interaction:

$$BCN3 = 0.8 + 0.04 * CCVV. \quad (18)$$

AKOND is the moisture infiltration rate, in./h, and HFAV is the mean lifespan of vegetation type in years.

Mean lifespans for specific plant types are estimated in BIOTRAN as are daily crown cover values. Moisture infiltration rates are supplied as input to the model. Also, plant types with mean lifespans less than or equal to 15 yr are treated as 15-yr mean lifespans. This strategy places all annual and perennial grasses and herbs into one category, all shrubs into a second category, all shorter-lived trees into a third category, and all long-lived trees into a fourth vegetation-type category. More study of these relationships is suggested to obtain a more accurate formulation of the curve number.

An estimate, CNI, of the dry antecedent soil moisture condition curve number from the normal soil moisture condition was obtained from the CREAMS model:

$$CNI = -16.91 + 1.348 * CNII - 0.01379 * CNII^2 + 0.0001177 * CNII^3. \quad (19)$$

This curve number is further corrected for the presence of impervious material such as exposed bedrock or pavement by the relationship (Lane 1985)

$$CNI = (100 * CNI * (1 - BDRK) + 99 * BDRK * 100) / 100, \quad (20)$$

where BDRK is the fraction of site covered by impervious material.

The corrected dry antecedent soil moisture curve number is used to estimate a maximum soil moisture retention parameter, SMX, in mm:

$$SMX = 25.4 * ((1000/CNI) - 10). \quad (21)$$

The estimated soil moisture retention parameter SIR_n over n soil layers for a given day at a given site for a given vegetation type is estimated as

$$SIR_n = SIR_{i-1} + SMX * WIS_i * ((UL_i - SW_i) / UL_i) \text{ for } i = 2, \dots, n, \quad (22)$$

where SIR_n is the i th cumulative moisture parameter for a given soil layer and WIS_i is the i th soil-layer weighting factor for $i=1, 2, \dots, n$:

$$WIS_i = CWIS * \exp(-4.16 * SLC_i / SDPTH), \quad (23)$$

where $CWIS$ is a constant such that the sum of all WIS_i 's equals 1.0; $SDPTH$ is the depth of soil profile, mm; SLC_i is the ratio of depth to bottom of the i th layer to the bottom of the soil profile or n th layer; UL_i is the soil moisture content at holding capacity for i th soil layer; and SW_i is the daily estimated soil moisture content of i th soil layer.

The SPUR model (Wight 1984) criteria were used for estimating the soil-layer moisture weighting factors as well as the algorithm for estimating the weighted soil moisture parameter (SIR_n).

If precipitation exceeds 20% of the weighted soil moisture, then daily surface runoff, $RNOFD$, mm (Soil Conservation Services, SCS), is estimated as

$$RNOFD = (PRCP - 0.2 * SIR_n) ** 2 / (PRCP + 0.8 * SIR_n), \quad (24)$$

where $PRCP$ is the precipitation event, mm/day.

The difference between precipitation and surface runoff is treated as infiltration moisture, mm:

$$WSRP = (PRCP - RNOFD). \quad (25)$$

Beginning with the upper soil layer, each successive soil layer is increased to holding capacity until $WSRP$ is totally accounted for. "Ponding" occurs when the soil moisture content of the top layer is increased above holding capacity should lower layers become saturated to the holding capacity before $WSRP$ is accounted for. Ponding is treated as surface runoff on the following day (which increases available water for transpiration) until mass balance is accomplished.

D. Subroutine GEOFLX

This subroutine is primarily an interface between surface runoff, return or subsurface flow, particle erosion, and channel and aquifer flows in BIOTRAN. All of the data input required for execution of these processes is located in this subroutine, and regional integration is also included for specific land areas and channels.

Subsurface or return flow is modeled for each watershed region specified on a daily basis by use of a modification of Darcy's equation. Only those soil layers with the soil moisture content equaling or exceeding the field capacity for that soil type will contribute to return flow from a given vegetation type of a given region:

$$RFLW_v = RFLW_{p-1} + WATV_{Ap} \quad (26)$$

RFLW_v is the integral average subsurface return flow, ft³/day, from all layers (greater than or equal to field capacity) for all vegetation types (v) of a given region, where p = 2,..., v. WATV_{Ap} is the total daily flow, ft³, from the pth vegetation type along the receiving channel:

$$WATV_{Ap} = 2.0 * ARR_{Xp} * AKOND * 0.1, \quad (27)$$

where AKOND is the soil conductivity, in./h, for the region. ARR_{Xp} is the weighted cross-sectional area, ft³, of the pth vegetation type along the receiving channel into which regional return flow enters:

$$ARR_{Xp} = 5280 * SCVR_p * DPX * XCHAN, \quad (28)$$

where XCHAN is the length of receiving channel, mi, receiving regional return flow and DPX is the thickness of the soil horizon, ft. SCVR_p is the fraction of total crown cover due to the pth vegetation type. A mean slope of 0.1 is assumed from the center of the mesa tops to the channel segment in question.

BIOTRAN models soil hydrology for all vegetation types in a given region. Each region generally exhibits different water use patterns and may have different soil characteristics (edaphic); hence, return flow is weighted to reflect the vegetation composition of the region as described above. Finally, the upper boundary for RFLW_v is set by the cumulative sum of each conducting soil layer for each vegetation type of a given region:

$$WATV_{Xv} = WATV_{xp-1} + (SW_i - FC_i) * AR_{Xp}, \quad (29)$$

WATV_{Xv} is the available soil moisture above field capacity for all conducting soil layers of all vegetation types in a given region; FC_i is the moisture holding capacity, ft, of ith soil layer at field capacity; and SW_i is the moisture content, ft, of ith soil layer; where SW_i ≥ FC_i. AR_{Xp} is the area of pth vegetation type, ft²:

$$AR_{Xp} = SCVR_p * RAREA * 43564, \quad (30)$$

where RAREA is the surface area of the region, acres.

After the flow of moisture from each region by surface runoff and return flow has been established, the next process modeled in GEOFLX is a channelization of this moisture to an appropriate drainage system. The assignment of drainage from a given region to a specific channel

or from an upper to another lower region is supplied as input to the model. The corresponding interconnections of specific channels or channel segments to form the drainage pattern are also supplied as input in GEOFLX. If a given lower region is receiving surface runoff from another upper region(s), then the water runoff increment to the lower region is treated as additional precipitation and processed by the RUNOFF subroutine described earlier. Although this regional apportionment appears awkward from the mass-balance perspective, the code appears to operate properly. Similarly, return flow water increments are added to the soil layers (from bottom to top) below specific vegetation types in proportion to the number of vegetation types in the receiving lower region. Each consecutive soil layer incremented in this manner is allowed to reach the holding capacity before allowing moisture to enter the upper layers within the same profile. Residual moisture remaining, after all soil layers for each vegetation type are at holding capacity, is allocated to the surface layers proportionately and are allowed to exceed holding capacity or to "pond" as described earlier. Other parameter estimates such as mean temperature, mean precipitation, and total area of combined regions are also determined in this section of the subroutine.

The volume of water entering specific channels from specific regions, other channels, or channel segments must be adjusted for transmission losses before downslope channels or channel segments are incremented. The outflow volume of water, VTRND, from a specific channel or channel MCfd segment is modeled after Lane (1985) as

$$VTRND = ATRN*43654 + BTRN*VTRNX + FTRN*VLATX/XCHAN, \quad (31)$$

where BTRN is the regression slope, day, and WCHAN is the width of channel, ft.

$$BTRN = \text{EXP}(-AKDCF*XCHAN*WCHAN), \quad (32)$$

ADKCF is the decay factor for transmission loss, mi/ft,

$$ADKCF = -1.09*n(1-ALNC), \quad (33)$$

where ALNC is the decay factor coefficient, in./acre-ft,

$$ALNC = 0.00545*AKOND*DUHR/(VMEAN*RAREA/12), \quad (34)$$

DUHR is the duration of a given runoff event, h:

$$DUHR = C1HR*(RAREA/640)**(C2HR), \quad (35)$$

where C1HR and C2HR are constants supplied as input or default values.

VMEAN is the potential mean runoff volume into channel, in.:

$$VMEAN = 0.05*(RAREA/640)**(-0.2). \quad (36)$$

ATRN is the regression intercept, acre-ft,

$$ATRN = (AUCI/(1-BCTR))*(1-BTRN), \quad (37)$$

where BCTR is the unit channel regression slope for transmission loss,

$$BCTR = \text{EXP}(-AKDCF). \quad (38)$$

AUCI is the unit channel intercept for transmission loss, acre-ft:

$$AUCI = -0.00465*ALOND*DUHR. \quad (39)$$

FTRN is the lateral flow parameter for transmission, acre-ft:

$$FTRN = (1-BTRN)/(AKDCF*WCHAN). \quad (40)$$

VTRNX is the total volume of water, ft³/day, added to channel from other channels, channel icemelt, and the aquifer, if present. VLATAX is the total volume water, ft³/day, added to channel from surface runoff. Subsurface return flow is included if an aquifer is not modeled below the channel bed (AQUGAT = 0.0).

The upper boundary for moisture flow [(VTRND, Eq. (31))] is set by the total inflow from all sources. If an aquifer is present below the specific channel, then the moisture surplus (VTRNX+VLATX-VTRND) is added to the aquifer; otherwise, it is lost to a sink. Finally, mean channel drainage, daily average temperatures, and average precipitation amount per event are estimated as described previously for interconnecting regions.

In the event that an ephemeral or perennial flow of moisture enters a given channel, then ice formation deletions and icemelt additions to channel flow must be taken into consideration. If the average daily temperature is less than or equal to zero, then ice formation occurs:

$$AICE = AICP+(VTRNDP/CHAREX)*12.*25.4, \quad (41)$$

where AICE is the ice thickness, mm, as water above the channel bed, and AICP is the previous ice thickness, mm, as water. VTRNDP is the daily water increment to channel, ft³/day; and CHAREX is the area of aquifer surface specified for ice deposition, ft².

$$CHAREX = 0.5*(TCH+TBCH)*XCHAN*5280, \quad (42)$$

where TCH is the width of the proximal end of the aquifer, ft; and TBCH is the width of distal end of aquifer, ft. Similarly, icemelt is modeled at average daily temperatures above zero as

$$AMELT = (11.28*TCHAN+1.11280)*CHAREX/(25.4*12), \quad (43)$$

where AMELT is the maximum moisture production from ice, ft³/day, and TCHAN is the mean channel drainage temperature, °C.

The actual amount melted is bounded by the available ice on a given day:

$$AVMLT = AICE \cdot CHAREX / (25.4 \cdot 12), \quad (44)$$

where AVMLT is the moisture, ft³, in ice thickness above the channel.

The moisture resulting from icemelt is used to increment VTRNX of a specific channel: as the magnitude of VTRNDP increases, the model becomes less accurate as not all moisture would be expected to be retained as ice; a fraction of such flow would then be required for this process.

Other modelling aspects of GEOFLX will be discussed in conjunction with subroutines AQUIFER and EROSON.

E. Subroutine AQUIFER

This subroutine models the flow of moisture into a confined alluvial aquifer(s) from transmission losses of the overlying channel and gains from up-slope subsurface return flow through vertical cross sections. All of the dimensions for constructing the specified aquifers are supplied as input to BIOTRAN in subroutine GEOFLX together with articulation instructions. The aquifers are all specified as trapezoidal solids incorporating two trapezoidal vertical cross sections at the proximal and distal ends that are connected by the channel segment length, XCHAN, described previously. Furthermore, each aquifer is tilted from the proximal to distal ends at a specified inclination. Consequently, it is modeled as a "tipped-bucket" volume into upper and lower portions to accommodate height variations at both ends due to channel slope. Also, it is possible to model a riparian plant community by specifying as input a riparian region on the non-channel portion of the upper aquifer lateral surface. This surface is then modeled to intercept drainage into its soil layers before the water enters the associated channel. It is important to note that the specified channel width is not generally of the same magnitude as are the specified dimensions of the upper lateral surface of the aquifer, which makes the modeling of a riparian or other terrestrial plant community on this surface possible.

The total volume of a specific aquifer (transverse slice method) is estimated as

$$VAQT = A1C \cdot hpx^3 + A2C \cdot hpx^2 + A3C \cdot hpx, \quad (45)$$

where VAQT is the maximum volume of aquifer, ft³; and hpx is the maximum linear distance connecting the bottom portions of the aquifer, ft:

$$HPX = (HOH^2 + h_x h^2)^{1/2}, \quad (46)$$

where HOH is the vertical height to the bottom of the aquifer at the proximal end of the aquifer, ft, relative to the bottom of the aquifer at the distal end, HXH is the quadratic coefficient, ft, and A1C is the perpendicular distance between the distal and proximal ends at the aquifer segment, ft:

$$A1C = ((TBCH-TCH)*(HBT-HTP)+(BBCH-BCH)*(HBT-HTP))/(6.0*HPX**2), \quad (47)$$

where TCH and TBCH are the widths of the top of the aquifer at the proximal and distal ends, ft, respectively; BCH and BBCH are the widths of bottom of aquifer at the proximal and distal ends, ft, respectively; and HTP and HBT the vertical heights, ft, at the aquifer segment at the proximal and distal ends, respectively. Further,

$$A2C = (HBT*(TCH+BCH-2.0*(BBCH+TbCH))+HTP*(TBCH+BBCH))/(4.0*HPX). \quad (48)$$

A3C is the coefficient

$$A3C = (TBCH + BBCH)*HBT/2.0. \quad (49)$$

VAQf is the total volume of a specific (vertical slice method) of aquifer at a given height above the bottom, ft:

$$VAQf = A1CC*HPX*HTX**2+A2CC*HPX*HTX, \quad (50)$$

where HTX is the height, feet of water above aquifer bottom,

$$A1CC = (TBCH-BBCH)/(4.0*HBT)+(TCH-BCH)/(4.0*HTP), \quad (51)$$

$$A2CC = (BBCH+BCH)/2.0, \quad (52)$$

and

$$HTX = HTXn, \quad (53)$$

where HTXn is the iterated height determined by Newton's approximation method.

The total volume of water in the aquifer before adjustment for daily loss through its distal vertical cross section is estimated as

$$VAQF = VAQFP+VTRNX+VLATX-VTRND+VLOSSP+VRFLX, \quad (54)$$

where VAQF is the aquifer water content, ft³; VAQFP is the previous day volume, ft³; VLOSSP is the water increment from the up-slope aquifer, ft³; and VRFLX is the return flow water increment from the region drained.

The distal vertical cross section through which moisture exits depends on the aquifer porosity (currently set at 0.25), the maximum vertical cross section itself, and the estimated moisture volume within. If the water volume in the aquifer after adjustment for porosity does not exceed VAQT, then Newton's approximation method is applied to Eq. (46) to obtain the height of the fluid in the bottom portion contained within VAQT, where HTX_b is the height of fluid at the distal vertical aquifer cross section:

$$HTX_n = HTX_n \cdot FXX / FXD, \quad (55)$$

$$FFX = A1CC \cdot HPX \cdot HTX_n^{**2} + A2CC \cdot HPX \cdot HTX_n \cdot VAQF, \quad (56)$$

and

$$FXD = 2.0 \cdot A2CC \cdot HFX \cdot HTX_n + A2CC \cdot HPX. \quad (57)$$

HTX_n is the height estimate of the distal vertical cross section, ft, from Newton's approximation algorithm when the aquifer volume $\leq VAQT$. This routine is repeated until convergence to HTX_b is approximated.

If the volume of fluid adjusted for aquifer porosity exceeds VAQT, then surplus moisture is added to runoff as shown below, and

$$VAQF = A1CC \cdot HPX \cdot HTX_b^{**2} + A2CC \cdot HPX \cdot HTX_b; \quad (58)$$

$$HTX_b = HTX_n \quad (59)$$

after convergence.

Surplus moisture above the aquifer will occur when the unadjusted fluid volume estimate including aquifer porosity exceeds the total volume [VAQT, Eq. (45)]. This model treats them as separate processes:

$$VQDX1 = 0.25 \cdot (4.0 \cdot VAQF - VAQT), \quad (60)$$

where VQDX1 is the surplus water above aquifer, ft, due to moisture exceeding the maximum aquifer volume (VAQT):

$$VAQF = VAQT. \quad (61)$$

When a region is modeled above the aquifer's lateral surface, then the surplus moisture from the regions is converted to a depth in mm over the surface and is added sequentially to each layer, beginning at the bottom until its soil moisture reaches holding capacity. Then, the next upper layer is incremented and so on until all surplus moisture is used, or until all soil layers are saturated. The residual remaining after all soil layers are saturated is used to increment moisture

loss from the aquifer itself in the down-slope direction. All of the surplus moisture is used to increment moisture loss from the aquifer if a region has not been modeled above the aquifer.

The loss of moisture from the distal vertical cross section VLOSS, in ft³/day, is estimated by a modification of Darcy's equation described previously through the cross-sectional area:

$$VLOSS = 2.0 * ATX * AKOND * SLOPX; \quad (62)$$

$$ATX = HTXb * (BBCH + WTX) / 2, \quad (63)$$

where ATX is the cross-sectional area, ft², of the distal vertical cross section of aquifer, and SLOPX is the slope of the channel to the distal end of the segment. WTX is the width of the aquifer, ft, at water level in the aquifer:

$$WTX = BBCH + ((TBCH - BBCH) / (HBT * HTXb)). \quad (64)$$

The modeling strategy for construction of the aquifer volumes was taken from the work of Baltz (1963) at Mortandad Canyon to be described later in this report.

F. Subroutine EROSON

This subroutine models the transport of sediment particles from regions using surface water runoff as a vector. The strategies employed in the SPUR model (Wight 1984) for estimating total sediment yield (lbs/acre, etc.) from a given land surface as a result of surface runoff are coupled with the differential erosion rate strategies as a function of particle diameter developed by Lane (1985) to produce the overall modeling of particle movement into channels. The movement of particles within and between channels, channel segments, and regions are also adaptations from Lane. This subroutine is highly integrated with the other subroutines described previously, and hence is very sensitive to information flow from these sources, particularly with respect to surface runoff volume estimates determined in the RUNOFF subroutine.

The peak discharge rates from channels and regional surface moisture flows are estimated as

$$CFS^{\circ}D = (C5HR / C1HR) * QFLOW * (RAREA / 640) ** (1 - C2HR) \quad (65a)$$

for regions where CFSPD is the peak discharge rate of surface runoff from a given region or channel, ft³/s,

$$CFSPD = C5HR * QFLOW / DUHR \quad (65b)$$

for channels, where C5HR is the peak discharge coefficient supplied as input or as a default value for regions and channels. QFLOW is the surface runoff, in./day, from a specific region,

$$QFLOW = RNOFD / 25.4, \quad (66a)$$

and QFLOW is the transmitted volume, ft³, from a specific channel,

$$QFLOW = VTRND. \quad (66b)$$

Regional erosion is modeled as a function of peak discharge and the MUSLE equation of the Agricultural Research Service (ARS) as

$$TONFLW = 95*((QFLOW*CFSPD)**0.56)*K*C*P*LS*SCVR, \quad (67)$$

where TONFLW is the weight of sediment eroded from a specific region for a given surface runoff event, ton/acre/day, for a given vegetation type. The depth of surface runoff flow from a given region or channel, ft, is given as

$$DCHAN = QFLOW/12 \quad (68)$$

for regions and

$$DCHAN = QFLOW/(12.*DUHR*3600) \quad (69)$$

for channels.

Similarly, the width of surface flow for a given region or channel, ft, is estimated as

$$WCHAN = XCHAN*5280 \quad (70)$$

for regions and

$$WCHAN = 2.17*(CFSPD/3)**0.5 \quad (71)$$

for channels if not supplied as input.

The mean velocity of surface flow, ft/s, for both regions and channels is estimated as

$$VCHAN = (1.49/RCHAN)*(SCHAN**0.5)*(RHYRC**(0.66)), \quad (72)$$

where RCHAN is the roughness or Manning coefficient, dimensionless, for regions and channels, which is supplied as input or estimated as

$$RCHAN = 0.0301*(CFSPD/3)**(-0.05). \quad (73)$$

SCHAN is the regional and channel slope, fraction, which is supplied as input or estimated as

$$SCHAN = 0.000771*(CFSPD/3)**(-0.3).$$

RHYRC is the hydraulic radius of surface moisture flow for regions and channels, ft:

$$RHYRC = WCHAN \cdot DCHAN / (WCHAN + 2 \cdot DCHAN). \quad (75)$$

The hydraulic roughness of the fluid bed for channels and regions is estimated as

$$RCHANB = (RCHAN^{**}(0.66) + (2 \cdot DCHAN / WCHAN) \cdot (RCHAN^{**}(1.5) - 1.2 \cdot RCHAN^{**}(1.5)))^{**}0.66, \quad (76)$$

where $RCHANB \geq 0.63 \cdot RCHAN$ and $RCHANB \leq RCHAN \cdot ((WCHAN + 4 \cdot DCHAN) / (4 \cdot DCHAN))^{**}(0.66)$. The upper boundary is estimated to be the roughness coefficient of the area of the channel perpendicular to the direction of fluid flow.

The hydraulic radius for resistance of particles on the surface of regions or channels is estimated as

$$RHYRG = RHYRB \cdot (RCHANG / RCHANB)^{**}1.5, \quad (77)$$

where RHYRB is the hydraulic radius for bed resistance, ft,

$$RHYRB = RHYRC \cdot (RCHANB / RCHAN)^{**}1.5,$$

and RCHANG is the grain or particle resistance coefficient,

$$RCHANG = 0.132 \cdot D50^{**}(0.166), \quad (78)$$

where D50 is the median particle diameter, mm, supplied as input.

The shear stress, SSTRES in lbs/ft², for sediment transport associated with surface runoff from regions and channel beds is estimated as

$$SSTRES = 62.43 \cdot RHYRG \cdot SCHAN. \quad (79)$$

The model developed by Lane (1985) for differential erosion of particles as a function of diameter size is based on the assumption that the sum of the transport capacities of the different particle size fractions is equal to the transport capacity estimated by using the median particle diameter size (D50). The transport capacity for the median particle diameter size, mm, is estimated as

$$GSBD50 = BSD50 \cdot SSTRESS \cdot (SSTRES - SSTR50), \quad (80)$$

where GSBD50 is the particle transport capacity per unit width of channel or region, for median particle diameter (D50), lbs./s ft. BSD50 is the particle transport coefficient for median particle diameter, cubic ft³/lb-s, of a given channel or regional surface:

$$BSD50 = 40 / D50^{**}1.5. \quad (81)$$

SSTR50 is the critical shear stress for median particle diameter of a given channel or regional surface, lbs/ft²:

$$\text{SSTR50} = 0.0022 + 0.01 \cdot \text{D50}, \text{ when } \text{D50} < 1.0 \text{ mm};$$

$$\text{SSTR50} = -0.0078 + 0.02 \cdot \text{D50}, \text{ when } \text{D50} \geq 1.0 \text{ mm}. \quad (82)$$

The model of Lane also discriminates between whether the particles are carried along the surface (bed load) or whether the particles are carried in the fluid (suspended load). Particles less than 0.063 mm in diameter are assumed to be suspended; all other particles are considered bed load. An estimate of the suspended load transport capacity is given as

$$\text{GSBDS} = 2 \cdot \text{DSFS} \cdot \text{SSTRES} \cdot \text{VCHAN}^2, \quad (83)$$

where GSBDS is the particle transport capacity per unit width of channel or region, for particles less than 0.063 mm in diameter, lbs/s-ft; and DSFS is the mass fraction of particles in that diameter class.

The transport capacities of all other diameter classes in the soil or channel alluvium is presented as

$$\text{GSBDI} = \text{DSFI} \cdot \text{BSDI} \cdot \text{SSTRES} \cdot (\text{SSTRES} - \text{SSTR}_i), \quad (84)$$

where GSBDI is the particle transport capacity per unit width of channel or region, the for i th particle in bed load, lbs/s-ft, $i=2, \dots, n$, and DSFI is the mass fraction of particles in i th diameter class.

BSDI is the sediment transport coefficient for i th diameter class, cubic ft³/lb-s:

$$\text{BSDI} = 40 / \text{DSI}^{1.5}, \quad (85)$$

where DSI is the specific diameter of i th particle class, mm. SSTR _{i} is the critical shear stress for i th particle size class, lbs/ft²:

$$\text{SSTR}_i = 0.0022 + 0.01 \cdot \text{DSI}_i, \text{ when } \text{DSI}_i < 1.0 \text{ mm};$$

$$\text{SSTR}_i = -0.0078 + 0.02 \cdot \text{DSI}_i, \text{ when } \text{DSI}_i \geq 1.0 \text{ mm}. \quad (86)$$

The sum of all particle transport capacities, GSBDI, is identified as GSBDT, or the total bed load particle transport capacity over all diameter classes greater than 0.063 mm. The effective particle transport capacity for each diameter class in this range is estimated by a constant which will make GSBDT equal to GSBD50:

$$\text{GSBDI} = \text{GSBDI} \cdot (\text{GSBD50} / \text{GSBDT}). \quad (87)$$

In estimation of particle erosion from a regional surface, the estimates of sediment yield by particle diameter are initially made by "strapping" overall sediment yield for a runoff event, TONFLW, for a given vegetation type with a weighting factor and then summing over all vegetation types; for channels the process is straightforward. Both events are estimated as

$$\text{GSBDWI} = 2000 * \text{TONFLW} * \text{RAREA} * \text{GSBDI} / (\text{GSBD50} + \text{GSBDS})$$

for a given vegetation type of a specific region and

$$\text{GSBDWI} = 3600 * \text{GSBDI} * \text{DUHR} * \text{WCHAN} \quad (88)$$

for a given channel, where GSBDWI is the weighted sediment yield, lbs/day, for the i th particle diameter class, $i = 2, \dots, n$, for a given channel or vegetation type (bedload).

GSBDWS is the weighted sediment yield, lbs/day, for the suspended load particle diameter class from a given region of a specific vegetation type or specific channel (suspended load):

$$\text{GSBDWS} = 2000 * \text{TONFLW} * \text{RAREA} * \text{GSBDS} / (\text{GSBD50} + \text{GSBDS})$$

for a given vegetation type of a specific region and

$$\text{GSBDWS} = 3600 * \text{GSBDS} * \text{DUHR} * \text{WCHAN} \quad (89)$$

for a given channel. The total inventory for a given particle diameter is adjusted for erosion losses:

$$\text{DSMSI} = \text{DSMSP} - \text{DSMI}, \quad (90)$$

where DSMSI is the soil inventory of channel or region for suspended and bed load particles of the i th diameter class, assuming a 20-mm thickness for regions and 200-mm thickness for channels, pounds, $i = 1, 2, \dots, n$; where DSMSP is the previous-day soil inventory, lbs, for the i th diameter class, and DSMI is the cumulative daily regional removal from all vegetation types, or daily channel removal, lbs, of the i th diameter class.

A total soil loss over all particle diameters is also inventoried, DSMT, by summation of the losses [see Eq. (92)] and subtraction from the total soil mass inventory, SEDMNS.

The nuclide content of specific diameter classes and the overall diameter class is obtained in a similar manner by use of the specific activity of each particle diameter class:

$$\text{DSMAI} = \text{DSMAIP} - \text{DSACI}, \quad (91)$$

where DSMAI is the soil inventory of channel or region for suspended and bed load particle nuclide content of the *i*th diameter class, assuming a 20-mm thickness for regions and a 200-mm thickness for channels, μg , pCi, etc. DSMAIP is the previous-day activity inventory, μg , pCi, etc., for the *i*th diameter class. DSACI is the cumulative daily regional removal from all vegetation types or daily channel removal, μg , pCi, etc., of the *i*th diameter class:

$$\text{DSACI} = \text{GSBDWS} * \text{DZASI} * 454$$

for suspended load particles and

$$\text{DSACI} = \text{GSBDWI} * \text{DZASI} * 454 \quad (92)$$

for bed load particles, where DZASI is the nuclide concentration or activity, ppm, pCi/g, etc., of the *i*th particle diameter.

A total activity inventory, SDMNSA, is maintained for a given region or channel by subtraction of Eq. (91) for each diameter class specified, and the specific activity of the surface soil or alluvium is obtained by the ratio

$$\text{SDMNCT} = \text{SDMNSA} / \text{SEDMNS} * 454, \quad (93)$$

where SDMNCT is the specific activity, $\mu\text{g/g}$, act/g, etc., for surface soil over all diameter classes for channel surface alluvium or regional surface soil.

The specific activity for any channel or regional surface may be affected by the deposition of soil particles from another channel or region as the model may specify in its interconnections. Hence, a new value of the nuclide concentration, DZASI, must be estimated whenever an erosion event occurs that may in fact reflect both deposition of soil particles from another channel or region and a scouring of particles from the region or channel in question.

III. INPUT STRUCTURE

Three scenarios were developed as input for testing the hydrological simulations:

1. Mortandad Canyon with only warm- and cool-season annual and perennial grass growth in all 8 regions (10-yr simulation called sc1).
2. Mortandad Canyon with ponderosa and/or pinyon-juniper, shrubs, and associated annual and perennial grasses in all 8 regions (10-yr simulation called sc2).
3. Same as (2) above, but extended to 100-yr simulation called sc3.

The first scenario (sc1) was used to test and verify subroutine interfacing and economize on computer time required for tuning and debugging of the newly developed subroutines. BIO-TRAN simulates the serial development of vegetation through the climax stage and also places

plants with similar growth strategies into niche competition for available soil moisture. Consequently, the first scenario can reach climatic climax within 4 to 10 yr if the advanced succession strategy, ADSUC, is employed. However, between 80 and 120 yr of simulation time were required to reach climax when ponderosa and/or pinyon-juniper tree simulations are included. The first scenario also serves as a runoff and erosion comparison between forested and nonforested regions in the canyon watershed of interest. Other minor differences between scenario input specifications will be noted later in this report. Input requirements together with variable identifications are presented in Tables 2-3 for the three scenarios. However, the description to follow will address sc1 only in Table 2; input for the second and third scenarios (sc2 and sc3) will be discussed insofar as they differ from sc1. Further detail on scenario setup and input is described in the BIOTRAN Users Manual (Gallegos 1990).

A. Input to MAIN

1. **SC1:** The number of simulation years (y2) was set to 10. Two elements and four chemical compounds are modeled (anz): uranium, nitrate-nitrogen, ammonia-nitrogen, labile phosphate, soluble phosphate, and potassium. The four chemical compounds and potassium are obligatory nutrients necessary for plant simulation to the model in all simulations. Additional non-obligatory elements and chemicals can be included in addition to potassium if desired. Eight land regions (apx) and four vegetation types (ap l = 4) are modeled as described previously. Optional subroutines accessed by MAIN are BIOPLT (pbx = 1), and WATFLX (watx = 1); calls to CLIMAT and PLTGRO are obligatory to MAIN.

2. **SC2 and SC3:** Input to the main subroutine is identical to input for sc1 with one exception: the value of the simulation time (y2 = 100) for sc3 is the only difference in input for the three simulations.

B. Input to CLIMAT

1. **SC1:** Input for separate regions (apx = 8) is entered sequentially, beginning with region 1 and terminating with region 8. Minimum (t1 = 270) and maximum (t2 = 723) insolation together with the lag to maximum (l1 = 90) are entered with minimum and maximum (t4 = 68.4) temperature and lag-to-maximum temperature (l2 = 120). Included is the monthly temperature standard deviation (tmxv = 2) and the precipitation event coefficient of variation for each region (prcv = .2). The elevation (relv = 7000) and the temperature lapse rate (alpsr = 0.005) for each site is entered next as well as the number of precipitation events for each month (tre). Also, the fractions of annual rainfall (x) for each month are specified together with the annual precipitation (r = 18), reference elevation (g1 = 7000), and latitude correction (l = 0) for the site. The frost-free period (ffp = 138) and latitude of the region (alatd = 37) are also entered. A reference site is required if climatic data are not available for the regions in question. Finally, a random number (randn = 136), day (dmod = 0), and year (ymod = 0) modules are entered. The random number resets the random number generator to produce a different set of numbers for a given run. The day and year moduli are required for CLIMAT output purposes (a value of 0 for either module negates output from that subroutine). The climatic data for all eight regions of sc1 are identical.

TABLE 2. Scenario 1 Input Description

10.	6.0	8.0	0.0	0.0	0.0	1.0	
Y2	ANZ	APX	ZOOX	ANIX	HUMX	BPX	
4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0 APL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AIRX
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0 WATX
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 FRMNX
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AQUAX
							MAIN
0.0	0.0	0.0	0.0	0.0	0.0	0.0	CLIMAT
							0.0 CLM
270.	723.	90.	33.9	68.4	120.		
T1	T2	L1	T3	T4	L2		
2.0	.2	7000.	.005	136.	0.0	0.0	
TMXV	PRCV	RELV	ALPSR	RANDN	DMOD	YMOD	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
TRE(1,1)	TRE(2,1)	TRE(3,1)	TRE(4,1)	TRE(5,1)	TRE(6,1)	TRE(7,1)	TRE(8,1)
4.0	4.0	3.0	4.0				
TRE(9,1)	TRE(10,1)	TRE(11,1)	TRE(12,1)				
.046	.038	.062	.046	.064	.059	.178	.216
X(1,1)	X(2,1)	X(3,1)	X(4,1)	X(5,1)	X(6,1)	X(7,1)	X(8,1)
.094	.085	.053	.058				
X(9,1)	X(10,1)	X(11,1)	X(12,1)				
18.	7000.	0.0	138.	37.			
R	G1	L3	FFP	ALATD			REGION 1
270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
18.	7000.	0.0	138.	37.			REGION 2
270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
18.	7000.	0.0	138.	37.			REGION 3
270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
18.	7000.	0.0	138.	37.			REGION 4
270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
18.	7000.	0.0	138.	37.			REGION 5
270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
18.	7000.	0.0	138.	37.			REGION 6
270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				

TABLE 2. (cont)

18.	7000.	0.0	138.	37.	REGION 7		
270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	178	.216
.094	.085	.053	.058				
18.	7000.	0.0	138.	37.	REGION 8		
CLIMAT							
1.0	10.	1.0	0.0	0.0	4.0	3.0	WATFLX
DMOD	YMOD	PHEFF	CLAYEF	CALEFF	CHNNU	SEDGAT	1.0
1.0	1.0	1.0	1.0	1.0	1.0	1.0	AQUGAT
0.1	0.1	0.1	0.1	0.1	0.0	0.1	1.0 WTF
							0.0 BDRK
GEOFLX							
0.0	0.0	0.0	0.0 AKOND (CHANNELS)				
0.0	0.0	0.0	0.0 C1HR				
0.0	0.0	0.0	0.0 C2HR				
0.0	0.0	0.0	0.0 C5HR				
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
DSZ(1,1)	DSZ(2,1)	DSZ(3,1)	DSZ(4,1)	DSZ(5,1)	DSZ(6,1)	DSZ(7,1)	DSZ(8,1)
.015	.005	.05	.12	.39	.37	.05	
DSF(1,1)	DSF(2,1)	DSF(3,1)	DSF(4,1)	DSF(5,1)	DSF(6,1)	DSF(7,1)	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 1
DZAS(1,1)	DZAS(2,1)	DZAS(3,1)	DZAS(4,1)	DZAS(5,1)	DZAS(6,1)	DZAS(7,1)	
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
.015	.005	.05	.12	.39	.37	.05	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 2
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
.015	.005	.05	.12	.39	.37	.05	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 3
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
.015	.005	.05	.12	.39	.37	.05	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 4
0.0	0.0	2.0	1.0 ENTCHN				
1.0	1.0	1.0	1.0 RNCHN				
9.0	10.0 CHNE						
11.0	CHNE						
1.0	CHLAT						
2.0	CHLAT						
6.0	CHLAT						
8.0	CHLAT						
0.0	0.0	6.0	8.0 CHNAQ				
3.0	3.0	24.	43. TCH (AQUIFER)				
1.5	1.5	14.	21. BCH				
2.0	2.0	6.0	15. HTP				
6.0	6.0	15.	36. HBT				
24.	24.	43.	191. TBCH				
14.	14.	21.	46. BBCH				
0.0	0.0	0.0	0.0 VAQF				
0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0 REGENT
3.0	4.0 REGX						
5.0	7.0 REGX						
246.	72.	56.4	56.4	28.	3.2	28.	6.9 RAREA
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
DSZ(1,1)	DSZ(2,1)	DSZ(3,1)	DSZ(4,1)	DSZ(5,1)	DSZ(6,1)	DSZ(7,1)	DSZ(8,1)
.42	.09	.10	.12	.16	.10	.01	
DSF(1,1)	DSF(2,1)	DSF(3,1)	DSF(4,1)	DSF(5,1)	DSF(6,1)	DSF(7,1)	
4.60	2.22	1.0	0.83	0.1	0.01	.001	REGION 1
DZAS(1,1)	DZAS(2,1)	DZAS(3,1)	DZAS(4,1)	DZAS(5,1)	DZAS(6,1)	DZAS(7,1)	

TABLE 2. (cont)

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 2

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 3

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 4

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 5

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 6

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 7

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 8

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 C1HR
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 C2HR
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 C5HR
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AKSOIL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 CSOIL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 PSOIL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 ALSOIL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AKOND
.07	.10	.10	.10	.10	.048	.10	.039 SCHAN
1.0 SCHXI							
.03	.03	.03	.03	.03	.03	.03	.03 RCHAN
1.0 RCHXI							
1.152	.461	.788	.788	.485	.788	.485	.485 XCHAN
1.152	.461	.788	.485	XCHAN (CHANNELS)			
3.0	3.0	3.0	3.0	1.0	WCHAN,WCHI		
.046	.082	.048	.039	1.0	SCHAN,SCHI		
.03	.03	.03	.03	1.0	RCHAN,RCHI		
5929.	4524.	0.0	0.0 VTRNDP				GEOFLX

WATFLX							
92.	7.0	7.0	15.	15.	19. ATND (NUCLIDES)		
238.	14.	14.	30.98	30.98	39.1 AWT		
0.0	0.0	0.0	0.0	0.0	0.0 HFLIF		

0.0	0.0	0.0	0.0 YZF (PLANTS)				
1.0	0.0	0.0	0.0	0.0	0.0 YAZ (NUCLIDES)		
1.0	0.0	0.0	0.0	0.0	0.0 YSRT		
1.0	0.0	0.0	0.0	0.0	0.0 DSRT		
0.0	0.0	0.0	0.0	0.0	0.0 WATCH		
0.0	0.0	0.0	0.0	0.0	0.0 YUP		
3.0	-1.	-1.	-1. RCODE (PLANT)				
420.0	420.0	420.0	420.0 SDPTH (PLANTS)				
20.	150.	250.	SLICE (SOIL LAYERS)				
.10	.10	.10	ROCK				
.39	.39	.43	SAND				
.36	.36	.30	SILT				
.15	.15	.17	CLAY				
13.	13.	13.	W1				
38.	38.	32.	H				
33.	33.	28.	F1				
6.1	6.6	6.1	PH				
2.000E+01	1.000E+01	0.500E+00	Z1 (NUCLIDE CONC.,ACTIVITY)				
2.000E+01	1.000E+01	0.500E+00	Z1				
2.000E+01	1.000E+01	0.500E+00	Z1				
2.000E+01	1.000E+01	0.500E+00	Z1				
							REGION 1

TABLE 2. (cont)

0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
420.0	420.0	420.0	420.0		
20.	150.	250.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			

REGION 2

0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
420.0	420.0	420.0	420.0		
20.	150.	250.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			

REGION 3

0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
420.0	420.0	420.0	420.0		
20.	150.	250.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			

REGION 4

0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0

TABLE 2. (cont)

0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
420.0	420.0	420.0	420.0		
20.	150.	250.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			

0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
820.0	820.0	820.0	820.0		
20.	300.	500.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			

0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
420.0	420.0	420.0	420.0		
20.	150.	250.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			

0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
820.0	820.0	820.0	820.0		

TABLE 2. (cont)

20.	300.	500.						
.10	.10	.10						
.39	.39	.43						
.36	.36	.30						
.15	.15	.17						
13.	13.	13.						
38.	38.	32.						
33.	33.	28.						
6.1	6.6	6.1						
2.000E+01	1.000E+01	0.500E+00						
2.000E+01	1.000E+01	0.500E+00						
2.000E+01	1.000E+01	0.500E+00						
2.000E+01	1.000E+01	0.500E+00						
								REGION 8
								WATFLX
								PLTGRO
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 PGR
0.0	0.0	0.0						
ADSUC	DMOD	YMOD						
1.0	1.0							
RSCDE	AICHE							
7.0	8.0	19.	18.	PLTID				
0.0	0.0	0.0	0.0	ARIG				
0.0	0.0	0.0	0.0	AHRV				
1.	1.	1.	1.	RGCPLT				
1.0	1.0	1.0	1.0	RGC				
0.0	0.0	0.0	0.0	RIRRC				
1.0	2.0	1.0	2.0	RSS				
246.	246.	246.	246.	ACRES				REGION 1
1.0	1.0							
7.0	8.0	19.	18.					
0.0	0.0	0.0	0.0					
0.0	0.0	0.0	0.0					
1.	1.	1.	1.					
1.0	1.0	1.0	1.0					
0.0	0.0	0.0	0.0					
1.0	2.0	1.0	2.0					
72.	72.	72.	72.					REGION 2
1.0	1.0							
7.0	8.0	19.	18.					
0.0	0.0	0.0	0.0					
0.0	0.0	0.0	0.0					
1.	1.	1.	1.					
1.0	1.0	1.0	1.0					
0.0	0.0	0.0	0.0					
1.0	2.0	1.0	2.0					
56.4	56.4	56.4	56.4					REGION 3
1.0	1.0							
7.0	8.0	19.	18.					
0.0	0.0	0.0	0.0					
0.0	0.0	0.0	0.0					
1.	1.	1.	1.					
1.0	1.0	1.0	1.0					
0.0	0.0	0.0	0.0					
1.0	2.0	1.0	2.0					
56.4	56.4	56.4	56.4					REGION 4
1.0	1.0							
7.0	8.0	19.	18.					
0.0	0.0	0.0	0.0					
0.0	0.0	0.0	0.0					
1.	1.	1.	1.					
1.0	1.0	1.0	1.0					
0.0	0.0	0.0	0.0					
1.0	2.0	1.0	2.0					
28.	28.	28.	28.					REGION 5

TABLE 2. (cont)

1.0	1.0						
7.0	8.0	19.	18.				
0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0				
1.	1.	1.	1.				
1.0	1.0	1.0	1.0				
0.0	0.0	0.0	0.0				
1.0	2.0	1.0	2.0				
3.2	3.2	3.2	3.2				REGION 6
1.0	1.0						
7.0	8.0	19.	18.				
0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0				
1.	1.	1.	1.				
1.0	1.0	1.0	1.0				
0.0	0.0	0.0	0.0				
1.0	2.0	1.0	2.0				
28.	28.	28.	28.				REGION 7
1.0	1.0						
7.0	8.0	19.	18.				
0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0				
1.	1.	1.	1.				
1.0	1.0	1.0	1.0				
0.0	0.0	0.0	0.0				
1.0	2.0	1.0	2.0				
6.9	6.9	6.9	6.9				REGION 8
							PLTGRO
0.0	0.0						
DMOD	YMOD						
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 UPK UPTAKE
0.0	0.0	2.0					
GMT (1)	GMT (2)	REC					
29.	19.	20.	21.	22.	23.	24.	25. XPTC
26.	27.	28.	302.	1.0 XPTC			
PREC	RNDLX	TNDLX	RFDLX	PRCH	TCHAN	QPKD	DSMT LPTC
SDMNCT	SDMNSA	TCVR	CODE LPTC				
MM	INCHES	TONS/A	INCHES	INCHES	CENT	IN/HR	LB/D LUNT
PCI/G	PCI	FRAC LUNT					
							RECORD 1
1.0	5.0	9.0	13.	17.	29.	25.	45.
37.	57.	61.	315.	1.0			
VTRND	VLAT	AICE	VRFL	CFSPD	DSMT	VAQF	VLOSS
WIX	HTX	PRCH	CODE				
CFD	CFD	MM	CFD	CFS	LB/D	CF	CFD
FEET	FEET	MM					
							RECORD 2
							BIOPLT
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
							EXIT

TABLE 3. Scenarios 2 & 3 Input Description

100.++	6.0	8.0	0.0	0.0	0.0	1.0	
Y2	ANZ	APX	ZDDX	AN1X	HUMX	BPX	
4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0 APL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AIRX
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0 WATX
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 FRMNX
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AQUAX
++ VALUE FOR SC3;Y2=10. FOR SC2							MAIN
							CLIMAT
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 CLM

270.	723.	90.	33.9	68.4	120.		
T1	T2	L1	T3	T4	L2		
2.0	.2	7200.	.005	136.	0.0	0.0	
TMXV	PRCV	RELV	ALPSR	RANDN	DMOD	YMOD	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
TRE(1,1)	TRE(2,1)	TRE(3,1)	TRE(4,1)	TRE(5,1)	TRE(6,1)	TRE(7,1)	TRE(8,1)
4.0	4.0	3.0	4.0				
TRE(9,1)	TRE(10,1)	TRE(11,1)	TRE(12,1)				
.046	.038	.062	.046	.064	.059	.178	.216
X(1,1)	X(2,1)	X(3,1)	X(4,1)	X(5,1)	X(6,1)	X(7,1)	X(8,1)
.094	.085	.053	.058				
X(9,1)	X(10,1)	X(11,1)	X(12,1)				
18.	7000.	0.0	138.	37.			REGION 1
R	G1	L3	FFP	ALATD			

270.	723.	90.	33.9	68.4	120.		
2.0	.2	7150.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
18.	7000.	0.0	138.	37.			REGION 2

270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.794	.085	.053	.058				
18.	7000.	0.0	143.	37.			REGION 3

270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
17.	7000.	0.0	143.	37.			REGION 4

270.	723.	90.	33.9	68.4	120.		
2.0	.2	6850.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
16.	7000.	0.0	150.	37.			REGION 5

270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
17.	7000.	0.0	143.	37.			REGION 6

270.	723.	90.	33.9	68.4	120.		
2.0	.2	6850.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				

TABLE 3. (cont)

16.	7000.	0.0	150.	37.	REGION 7		
*****	*****	*****	*****	*****	*****	*****	*****
270.	723.	90.	33.9	68.4	120.		
2.0	.2	6850.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
16.	7000.	0.0	150.	37.	REGION 8		
*****	*****	*****	*****	*****	*****	*****	*****
CLIMAT							
1.0	100.++	1.0	0.0	0.0	4.0	93.+++	WATFLX
DMDD	YMDD	PHEFF	CLAYEF	CALEFF	CHNNU	SEDGAT	1.0
1.0	1.0	1.0	1.0	1.0	1.0	1.0	AQUGAT
0.1	0.1	0.1	0.1	0.1	0.0	0.1	1.0 WTF
O.0 BDRK							
++ VALUE FOR SC3;YMDD=10. FOR SC2							
+++ VALUE FOR SC3;SEDGAT=3. FOR SC2							
GEOFLX							
0.0	0.0	0.0	0.0	AKOND (CHANNELS)			
0.0	0.0	0.0	0.0	C1HR			
0.0	0.0	0.0	0.0	C2HR			
0.0	0.0	0.0	0.0	C5HR			
*****	*****	*****	*****	*****	*****	*****	*****
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
DSZ(1,1)	DSZ(2,1)	DSZ(3,1)	DSZ(4,1)	DSZ(5,1)	DSZ(6,1)	DSZ(7,1)	DSZ(8,1)
.015	.005	.05	.12	.39	.37	.05	
DSF(1,1)	DSF(2,1)	DSF(3,1)	DSF(4,1)	DSF(5,1)	DSF(6,1)	DSF(7,1)	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 1
DZAS(1,1)	DZAS(2,1)	DZAS(3,1)	DZAS(4,1)	DZAS(5,1)	DZAS(6,1)	DZAS(7,1)	
*****	*****	*****	*****	*****	*****	*****	*****
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
.015	.005	.05	.12	.39	.37	.05	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 2
*****	*****	*****	*****	*****	*****	*****	*****
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
.015	.005	.05	.12	.39	.37	.05	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 3
*****	*****	*****	*****	*****	*****	*****	*****
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
.015	.005	.05	.12	.39	.37	.05	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 4
*****	*****	*****	*****	*****	*****	*****	*****
0.0	0.0	2.0	1.0	ENTCHN			
1.0	1.0	1.0	1.0	RNCHN			
9.0	10.0	CHNE					
11.0	CHNE						
1.0	CHLAT						
2.0	CHLAT						
6.0	CHLAT						
8.0	CHLAT						
0.0	0.0	6.0	8.0	CHNAQ			
3.0	3.0	24.	43.	TCH (AQUIFER)			
1.5	1.5	14.	21.	BCH			
2.0	2.0	6.0	15.	HTP			
6.0	6.0	15.	35.	HBT			
24.	24.	43.	191.	TBCH			
14.	14.	21.	46.	BBCH			
0.0	0.0	0.0	0.0	VAQF			
0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0
3.0	4.0	REGX					
5.0	7.0	REGX					
246.	72.	56.4	56.4	28.	3.2	28.	6.9
*****	*****	*****	*****	*****	*****	*****	*****
0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
DSZ(1,1)	DSZ(2,1)	DSZ(3,1)	DSZ(4,1)	DSZ(5,1)	DSZ(6,1)	DSZ(7,1)	DSZ(8,1)
.42	.09	.10	.12	.16	.10	.01	
DSF(1,1)	DSF(2,1)	DSF(3,1)	DSF(4,1)	DSF(5,1)	DSF(6,1)	DSF(7,1)	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 1
DZAS(1,1)	DZAS(2,1)	DZAS(3,1)	DZAS(4,1)	DZAS(5,1)	DZAS(6,1)	DZAS(7,1)	
*****	*****	*****	*****	*****	*****	*****	*****

TABLE 3. (cont)

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 2

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 3
16.	7000.	0.0	150.	37.			REGION 7

270.	723.	90.	33.9	68.4	120.		
2.0	.2	6850.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
16.	7000.	0.0	150.	37.			REGION 8

CLIMAT							

1.0	100.++	1.0	0.0	0.0	4.0	93.+++	WATFLX
DMOD	YMOD	PHEFF	CLAYEF	CALEFF	CHNNU	SEDGAT	1.0
1.0	1.0	1.0	1.0	1.0	1.0	1.0	AQUGAT
0.1	0.1	0.1	0.1	0.1	0.0	0.1	1.0 WTF
++ VALUE FOR SC3;YMOD=10. FOR SC2							
+++ VALUE FOR SC3;SEDGAT=3. FOR SC2							

GEOFLX							
0.0	0.0	0.0	0.0 AKOND (CHANNELS)				
0.0	0.0	0.0	0.0 C1HR				
0.0	0.0	0.0	0.0 C2HR				
0.0	0.0	0.0	0.0 C5HR				

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
DSZ(1,1)	DSZ(2,1)	DSZ(3,1)	DSZ(4,1)	DSZ(5,1)	DSZ(6,1)	DSZ(7,1)	DSZ(8,1)
.015	.005	.05	.12	.39	.37	.05	
DSF(1,1)	DSF(2,1)	DSF(3,1)	DSF(4,1)	DSF(5,1)	DSF(6,1)	DSF(7,1)	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 1
DZAS(1,1)	DZAS(2,1)	DZAS(3,1)	DZAS(4,1)	DZAS(5,1)	DZAS(6,1)	DZAS(7,1)	

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
.015	.005	.05	.12	.39	.37	.05	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 2

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
.015	.005	.05	.12	.39	.37	.05	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 3

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.9
.015	.005	.05	.12	.39	.37	.05	
4.60	2.22	1.0	0.83	0.1	0.01	.001	CHANNEL 4

0.0	0.0	2.0	1.0 ENTCHN				
1.0	1.0	1.0	1.0 RNCHN				
9.0	10.0 CHNE						
11.0 CHNE							
1.0 CHLAT							
2.0 CHLAT							
6.0 CHLAT							
8.0 CHLAT							
0.0	0.0	6.0	8.0 CHNAQ				
3.0	3.0	24.	43. TCH (AQUIFER)				
1.5	1.5	14.	21. BCH				
2.0	2.0	6.0	15. HTP				
6.0	6.0	15.	36. HBT				
24.	24.	43.	191.TBCH				
14.	14.	21.	46. BBCH				
0.0	0.0	0.0	0.0 VAQF				
0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0 REGENT
3.0	4.0 REGX						
5.0	7.0 REGX						
246.	72.	56.4	56.4	28.	3.2	28.	6.9 RAREA

TABLE 3. (cont)

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
DSZ(1,1)	DSZ(2,1)	DSZ(3,1)	DSZ(4,1)	DSZ(5,1)	DSZ(6,1)	DSZ(7,1)	DSZ(8,1)
.42	.09	.10	.12	.16	.10	.01	
DSF(1,1)	DSF(2,1)	DSF(3,1)	DSF(4,1)	DSF(5,1)	DSF(6,1)	DSF(7,1)	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 1
DZAS(1,1)	DZAS(2,1)	DZAS(3,1)	DZAS(4,1)	DZAS(5,1)	DZAS(6,1)	DZAS(7,1)	

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 2

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 3
100.++	6.0	8.0	0.0	0.0	0.0	1.0	
Y2	ANZ	APX	Z00X	ANIX	HUMX	BPX	
4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0 APL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AIRX
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0 WATX
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 FRMNX
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AQUAX
++ VALUE FOR SC3;Y2=10. FOR SC2							MAIN

0.0	0.0	0.0	0.0	0.0	0.0	0.0	CLIMAT
*****							0.0 CLM
270.	723.	90.	33.9	68.4	120.		
T1	T2	L1	T3	T4	L2		
2.0	.2	7200.	.005	136.	0.0	0.0	
TMXV	PRCV	RELX	ALPSR	RANDN	DMOD	YMOD	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
TRE(1,1)	TRE(2,1)	TRE(3,1)	TRE(4,1)	TRE(5,1)	TRE(6,1)	TRE(7,1)	TRE(8,1)
4.0	4.0	3.0	4.0				
TRE(9,1)	TRE(10,1)	TRE(11,1)	TRE(12,1)				
.046	.038	.062	.046	.064	.059	.178	.216
X(1,1)	X(2,1)	X(3,1)	X(4,1)	X(5,1)	X(6,1)	X(7,1)	X(8,1)
.094	.085	.053	.058				
X(9,1)	X(10,1)	X(11,1)	X(12,1)				
18.	7000.	0.0	138.	37.			REGION 1
R	G1	L3	FFP	ALATD			

270.	723.	90.	33.9	68.4	120.		
2.0	.2	7150.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
18.	7000.	0.0	138.	37.			REGION 2

270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.794	.085	.053	.058				
18.	7000.	0.0	143.	37.			REGION 3

270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
17.	7000.	0.0	143.	37.			REGION 4

270.	723.	90.	33.9	68.4	120.		
2.0	.2	6850.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
16.	7000.	0.0	150.	37.			REGION 5

TABLE 3. (cont)

270.	723.	90.	33.9	68.4	120.		
2.0	.2	7000.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				
17.	7000.	0.0	143.	37.			REGION 6

270.	723.	90.	33.9	68.4	120.		
2.0	.2	6850.	.005	136.	0.0	0.0	
4.0	4.0	4.0	4.0	4.0	3.0	8.0	9.0
4.0	4.0	3.0	4.0				
.046	.038	.062	.046	.064	.059	.178	.216
.094	.085	.053	.058				

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 4

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 5

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 6

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 7

0.062	0.125	0.250	0.500	1.000	2.000	4.000	0.13
.42	.09	.10	.12	.16	.10	.01	
4.60	2.22	1.0	0.83	0.1	0.01	0.001	REGION 8

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 C1HR
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 C2HR
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 C5HR
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AKSOIL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 CSOIL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 PSOIL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 ALSOIL
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 AKOND
.07	.10	.10	.10	.10	.048	.10	.039 SCHAN
1.0 SCHXI							
.03	.03	.03	.03	.03	.03	.03	.03 RCHAN
1.0 RCHXI							
1.152	.461	.788	.788	.485	.788	.485	.485 XCHAN
1.152	.461	.788	.485	XCHAN (CHANNELS)			
3.0	3.0	3.0	3.0	1.0 WCHAN,WCHI			
.046	.082	.048	.039	1.0 SCHAN,SCHI			
.03	.03	.03	.03	1.0 RCHAN,RCHI			
5929.	4524.	0.0	0.0 VTRNDP				GEOFLX

92.	7.0	7.0	15.	15.	19.	ATNO (NUCLIDES)	
238.	14.	14.	30.98	30.98	39.1	AWT	
0.0	0.0	0.0	0.0	0.0	0.0	HFLIF	

0.0	0.0	0.0	0.0	YZF (PLANTS)			
1.0	0.0	0.0	0.0	0.0	0.0	0.0 YAZ (NUCLIDES)	
1.0	0.0	0.0	0.0	0.0	0.0	0.0 YSRT	
1.0	0.0	0.0	0.0	0.0	0.0	0.0 DSRT	
0.0	0.0	0.0	0.0	0.0	0.0	0.0 WATCHN	
0.0	0.0	0.0	0.0	0.0	0.0	0.0 YUP	
3.0	-1.	-1.	-1.	RCODE (PLANT)			
420.0	420.0	420.0	420.0	SDPTH (PLANTS)			
20.	150.	250.	SLICE (SOIL LAYERS)				
.10	.10	.10	ROCK				
.39	.39	.43	SAND				
.36	.36	.30	SILT				
.15	.15	.17	CLAY				

TABLE 3. (cont)

13.	13.	13.	W1		
38.	38.	32.	H		
33.	33.	28.	F1		
6.1	6.6	6.1	PH		
2.000E+01	1.000E+01	0.500E+00	Z1 (NUCLIDE CONC.,ACTIVITY)		
2.000E+01	1.000E+01	0.500E+00	Z1		
2.000E+01	1.000E+01	0.500E+00	Z1		
2.000E+01	1.000E+01	0.500E+00	Z1		
				REGION 1	
0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
420.0	420.0	420.0	420.0		
20.	150.	250.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
				REGION 2	
0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
420.0	420.0	420.0	420.0		
20.	150.	250.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
				REGION 3	
0.0	0.0	0.0	0.0		
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.		
420.0	420.0	420.0	420.0		
20.	150.	250.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
				REGION 4	

TABLE 3. (cont)

0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.	0.0	0.0
420.0	420.0	420.0	420.0	0.0	0.0
20.	150.	250.		0.0	0.0
.10	.10	.10		0.0	0.0
.39	.39	.43		0.0	0.0
.36	.36	.30		0.0	0.0
.15	.15	.17		0.0	0.0
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
REGION 5					
0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.	0.0	0.0
820.0	820.0	820.0	820.0	0.0	0.0
20.	300.	500.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
REGION 6					
0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.0	-1.	-1.	-1.	0.0	0.0
420.0	420.0	420.0	420.0	0.0	0.0
20.	150.	250.			
.10	.10	.10			
.39	.39	.43			
.36	.36	.30			
.15	.15	.17			
13.	13.	13.			
38.	38.	32.			
33.	33.	28.			
6.1	6.6	6.1			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
2.000E+01	1.000E+01	0.500E+00			
REGION 7					
0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

TABLE 3. (cont)

3.0	-1.	-1.	-1.
820.0	820.0	820.0	820.0
20.	300.	500.	
.10	.10	.10	
.39	.39	.43	
.36	.36	.30	
.15	.15	.17	
13.	13.	13.	
38.	38.	32.	
33.	33.	28.	
6.1	6.6	6.1	
2.000E+01	1.000E+01	0.500E+00	
2.000E+01	1.000E+01	0.500E+00	
2.000E+01	1.000E+01	0.500E+00	
2.000E+01	1.000E+01	0.500E+00	

REGION 8

WATFLX

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	PLTGRO
0.0	0.0								0.0 PGR
DMOD	YMOD								
1.0	0.0	1.0							
RSCDE	AICHE	ADSUC							
15.	16.	18.	19.	PLTID					
0.0	0.0	0.0	0.0	ARIG					
0.0	0.0	0.0	0.0	AHRV					
1.	1.	1.	1.	RGCPLT	PONDEROSA-OAK-GRASS				
2.0	1.0	1.0	1.0	RGC					
0.0	0.0	0.0	0.0	RIRRC					
0.0	0.0	0.0	0.0	RSS					
246.	246.	246.	246.	ACRES					
REGION 1									
1.0	0.0								
15.	16.	18.	19.						
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
1.	1.	1.	1.		PONDEROSA-OAK-GRASS				
2.0	1.0	1.0	1.0						
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
72.	72.	72.	72.						
REGION 2									
1.0	0.0								
15.	16.	18.	19.						
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
1.	1.	1.	1.		PONDEROSA-OAK-GRASS				
2.0	1.0	1.0	1.0						
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
56.4	56.4	56.4	56.4						
REGION 3									
1.0	0.0								
15.	16.	18.	19.						
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
1.	1.	1.	1.		PONDEROSA-OAK-GRASS				
2.0	1.0	1.0	1.0						
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
56.4	56.4	56.4	56.4						
REGION 4									
1.0	1.0								
5.0	8.0	15.	18.						
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
1.	1.	1.	1.						
2.0	1.0	2.0	1.0		PINYON-PONDEROSA ECOTONE				
0.0	0.0	0.0	0.0						
1.0	2.0	1.0	2.0						
28.	28.	28.	28.						
REGION 5									

TABLE 3. (cont)

1.0	0.0						
16.	18.	19.	21.				
0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0				
1.	1.	1.	1.				
1.0	1.0	1.0	2.0				
0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0				
3.2	3.2	3.2	3.2				REGION 6
1.0	1.0						
5.0	8.0	15.	18.				
0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0				
1.	1.	1.	1.				
2.0	1.0	2.0	1.0				
0.0	0.0	0.0	0.0				
1.0	2.0	1.0	2.0				
28.	28.	28.	28.				REGION 7
1.0	1.0						
8.0	15.	16.	18.				
0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0				
1.	1.	1.	1.				
1.0	2.0	1.0	1.0				
0.0	0.0	0.0	0.0				
1.0	0.0	0.0	1.0				
6.9	6.9	6.9	6.9				REGION 8
							PLTGRO
0.0	0.0						
DMDD	YMOD						
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 UPK UPTAKE
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 FRM
0.0	0.0						
DMDD	YMOD						
0.0	2.0	.31	.43	1.0	0.0	PONDEROSA	
TBRM	XJ1	V8	C9	C6	TNTR		
0.0	2.0	.31	.43	1.0	0.0	PONDEROSA	
0.0	2.0	.31	.43	1.0	0.0	PONDEROSA	
0.0	2.0	.31	.43	1.0	0.0	PONDEROSA	
0.0	2.0	.20	.46	1.5	0.0	PINYON	
0.0	2.0	.31	.43	1.0	0.0	PONDEROSA	
0.0	2.0	.23	.40	1.5	0.0	DECIDUOUS TREE	
0.0	2.0	.20	.46	1.5	0.0	PINYON	
0.0	2.0	.31	.43	1.0	0.0	PONDEROSA	
0.0	2.0	.31	.43	1.0	0.0	PONDEROSA	
							FORMAN
0.0	0.0	2.0					
GMT (1)	GMT (2)	REC					
29.	19.	20.	21.	22.	23.	24.	25. XPTC
26.	27.	28.	302.	1.0 XPTC			
PREC	RNDLX	INDLX	RFDLX	PRCH	TCHAN	QPKD	DSMT LPTC
SDMNCT	SDMNSA	TCVR	CODE LPTC				
MM	INCHES	TONS/A	INCHES	INCHES	CENT	IN/HR	LB/D LUNT
PCI/G	PCI	FRAC LUNT					
							RECORD 1
1.0	5.0	9.0	13.	17.	29.	25.	45.
37.	57.	61.	315.	1.0			
VTRND	VLAT	AICE	VRFL	CFSPD	DSMT	VAQF	VLOSS
WTX	HTX	PRCH	CODE				
CFD	CFD	MM	CFD	CFS	LB/D	CF	CFD
FEET	FEET	MM					
							RECORD 2

TABLE 3. (cont)

.....							
							BIOPLT
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
							EXIT
.....							

2. **SC2 and SC3:** Input to subroutine CLIMAT for sc1, sc2, and sc3 are identical with three exceptions. The first difference is in the assignment of site elevation (relv = 7200, 7150, 7000, 7000, 6850, 7000, 6850, and 6850 for regions 1, 2,...,8) of each region in sc3. The annual precipitation amounts for all regions included in sc1 are set at 18 in., whereas sc2 and sc3 are not all equal (18, 18, 18, 17, 16, 17, 16, and 16 in. for regions 1 to 8, respectively). The third difference is the frost-free period (ffp = 138, 138, 144, 143, 150, 143, 150, and 150 for regions 1, 2,...,8) assignments for each region. These last values are estimated for these regions.

C. Input to WATFLX

1. **SC1:** The first line of input concerns the day (dmod = 1) and year (ymod = 4) moduli, the effects of pH (pheff = 1) and clay (clayef = 0) on the uptake of uranium by plants (0 = no effect simulated), the number of channels (chnnu = 4), erosion initiation year (sedgat = 3), and a gate for aquifer operation (aqugat = 1) (a zero does not allow operation). The second line of input is a selection gate for output from a given region (wtx = 1 for all; a zero disallows), whereas the third line specifies the fraction of each regional surface overlain by moisture impervious material (bdrk = 0.1 for regions 1, 2, 3, 4, 5, and 7; bdrk = 0 for regions 6 and 8). If the watershed model is being used (chnnu > 0), then subroutine GEOFLX is accessed for input (to be described under that heading) before returning to line 4 of WATFLX input. Shot line enters the atomic numbers (atno) for uranium, nitrate-nitrogen, ammonia-nitrogen, labile phosphorus, soluble phosphorus, and potassium in that order, followed by the respective atomic weights (awt) and half-lives (hflif) of these nuclides in lines 5 to 6; the latter is set to zero for stable elements.

Beginning with line 7, and continuing until the end of WATFLX input, eight sets of WATFLX input corresponding to the regions simulated (apx) are entered in sequence until completed. Line input (yzt = 0) is a gate for selectively entering root fractions in each soil layer for each vegetation type (a value of 0 causes default values to be calculated internally). Line 8 input (yaz = 1 for uranium; yaz = 0 for all other nuclides) determines whether nuclide concentrations in soil layers are entered (yaz > 0, yaz < 3), or calculated internally (yaz = 0, or yaz = 3). Furthermore, when yaz = 3, soil nuclide concentrations for all soil layers are set equal to the concentration in the top layer. If the half-life (hflif) of specific nuclide is greater than zero, then the specific activity of pCi/g dry weight of soil is calculated. If yaz = 1, then the soil concentrations entered as µg/g soil are converted internally to specific activity units (hflif > 0). Finally, values of yaz = 2,3 will allow soil concentrations to retain the same concentration units either from input or internally calculated estimates of a given element or radionuclide. Ultimately, all element (non-radioactive nuclide) concentrations entered as µg/g are converted to g/g internally.

Lines 8 and 9 determine what year (ysrt = 1 for uranium; ysrt = 0 for all other radionuclides) and what day (dsrt = 1 for uranium; dsrt = 0 for all other nuclides) soil concentrations of specific nuclides will enter the simulation (a value of 0 defaults to all years and days in the simulation). Line 10 enters the concentration (watch = 0) of irrigation water for cultivated plant types; it is not used in sc1. Line 11 is a gate (yup = 0) for entering plant/soil concentration factors for a given nuclide (a value of 0 defaults to internal calculation).

The remaining input in WATFLX specifies soil characteristics relating to plant growth and nuclide uptake by plants. Line 12 enters the number of soil layers (rcode = 3) for all plant types in a given region. When -1 is entered as input, it designates that a specific plant has the same soil characteristics as the first plant designated. All plant types in all regions are set to have identical soil characteristics with the exception of soil depth. Line 13 enters specific soil depths (sdpth = 420 mm for regions 1, 2, 3, 4, 5, and 7; and sdpth = 820 mm for regions 6 and 7) for all plants of a given region. The soil layer thicknesses (slcoe = 20, 150, 250 mm for regions 1, 2, 3, 4, 5, and 7; slcoe = 20, 300, 500 for regions 6 and 8) for all plants of a given region are presented in line 14. Lines 15 to 18 enter stone (rock = 0.1), sand (sand = 0.39, 0.43), silt (silt = 0.36, 0.30), and clay (clay = 0.15, 0.17) fractions in each soil layer described for a given region; the second value in each set of parentheses represents the fractions in the innermost soil layer. Lines 19 to 22 enter wilting points (w1 = 0.15, 0.17), holding capacity (h = 38%, 32%), field capacity (f1 = 33%, 28%), and pH (ph = 6.1 for layers 1, 3; ph = 6.6 for layer 2) of each soil layer; the second value in each set of parentheses for w1, h, and f1 represents values for the innermost soil layer. Finally, lines 23 to 26 enter the soil concentration for uranium (z1 = 2, 1, 0.5 pCi/g for layers 1, 2, and 3) for each plant type of each region; all are identical.

2. SC2 and SC3: Input to subroutine WATFLX for sc3 differs from that of sc1 in modules assignment (ymod = 100) and initial access to the hydrological portion of the model (sedgat = 93).

D. Input to GEOFLX

1. SC1: Input from subroutine GEOFLX is accessed from subroutine WATFLX when chnnu > 0, as mentioned previously. However, all input requirements required for operation of EROSON and AQUIFER are included in this subroutine. Line 1 enters the hydraulic conductivity (akond = 0) of the channel beds. A default value of 0 sets the conductivity internally to 3 in. h. Lines 2 to 4 enter the constants required for estimating runoff flow duration (c1hr = 0, c2hr = 0), and peak flow (c5hr = 0). Default values used when the input is zero are c1hr = 2.53, c2hr = 0.2, and c5hr = 4.82).

Lines 5 to 7 enter the channel bed alluvium diameter distributions (dsz = 0.062, 0.125, 0.500, 1.000, 2.000, 4.000, and 0.9 mm), the mass fractions for each particle diameter category (dsf = 0.015, 0.005, 0.05, 0.12, 0.39, 0.37, and 0.05 mm), and particle uranium specific activity (4.6, 2.22, 1.0, 0.83, 0.1, 0.01, and 0.001 pCi/g) for the first channel. Input for all other channels (lines 8 to 16) are identical to channel 1 in sc1. The eighth value of dsz (0.9) is the mass median diameter of the alluvial particles. Line 18 enters the number of tributary channels (entchn = 0, 0, 2, 1 for channels 1, 2, 3, and 4) to a specific channel. Line 19 enters the number of laterals (rnchn = 1 for all channels) or regions draining directly into each channel. Lines 20 and 21 enter specific tributaries (chne = 1.2 into channel 3; chne = 3 into channel 4). The tributary can also include a portion or segment of the same channel (channels 3 and 4 are segments of the same channel). Also, the channel numbers are identified (9, 10, 11, and 12) with values commensurate to the regions in the scenario (1, 2, 3, ..., apx) because regions and channels share some common arrays or variables in the model and are processed similarly. Lines 22 to 25 enter the direct laterals or regions (chlat = 1, 2, 6, 8 into channels 1, 2, 3, and 4) draining into a specific channel.

Line 26 enters the region overlying an aquifer (chnaq = 0, 0, 6, 8 for channels 1, 2, 3, and 4) and its associated channel. A value equal to 0 indicates that a channel does not have an alluvial plain or region through which the channel flows. In sc1 channels 3 and 4 have alluvial plains (regions 6 and 8), whereas they are not modeled in channels 1 and 2.

Lines 27 to 32 enter the aquifer dimensions beneath each aquifer upstream and downstream. Sections are modeled as trapezoids connected to form the aquifer volume. Line 27 enters the top dimensions (tch = 3, 3, 24, 43 ft for channels 1, 2, 3, and 4) for the upstream portion of each aquifer. Line 28 enters the bottom dimensions of the trapezoids for the upstream portion (bch = 1.5, 1.5, 14, 21 ft for channels 1, 2, 3, and 4). Line 29 enters the depth of the aquifer of the upstream portion (htp = 2, 2, 6, 15 ft for channels 1, 2, 3, and 4); line 30 enters the downstream or distal depth of the aquifer (hbt = 6, 6, 15, 36 ft for channels 1, 2, 3, and 4). Line 31 enters the top dimensions (bbch = 24, 24, 43, 191 ft for channels 1, 2, 3, and 4) at the distal or downstream end of each aquifer; line 32 enters the bottom dimensions (bbch = 14, 14, 21, 46 ft for channels 1, 2, 3, and 4) at the downstream end of each aquifer. Finally, line 33 enters the initial aquifer volume (vaqf = 0, 0, 0, 0 for channels 1, 2, 3, and 4).

Line 34 enters the number of regions which transport surface runoff, subsurface return flow, and sediment into another region (regent = 0 for regions 1, 2, 3, 4, 5, and 7; regent = 2 for regions 6 and 8). A value of 0 indicates that a given region does not receive such transport. Lines 35 and 36 enter the specific regions which contribute runoff, return flow, and sediment to a specific region (regx = 3, 4 regions to region 6; regx = 5, 7 regions to region 8). Regions 6 and 8 are thus modeled as alluvial plains receiving these materials from adjacent regions normal to the channel segment. The surface areas of all regions (rarea = 246, 72, 56.4, 56.4, 28, 3.2, 28, 6.9 acres for regions 1, 2, ..., 8) are entered in line 37.

As described earlier for channels, the top 20 mm of soil of each region is sized and qualified, starting with region 1. Lines 38 to 61 enter these characteristics; however, they are identical for each region modeled in sc1. Hence, lines 38 to 40 will describe all regions. Line 38 enters the particle soil diameter (dsz = 0.062, 0.125, 0.250, 0.500, 1, 2, 4, 0.13 mm), line 39 enters the mass fraction of each particle size (dsf = 0.42, 0.09, 0.10, 0.12, 0.16, 0.10, 0.01), and line 40 enters the uranium specific activity (dzas = 4.6, 2.22, 1, 0.83, 0.1, 0.01, 0.001) for each particle size. The eighth value of dsz (0.13) is the mass median diameter for the soil particles described.

Lines 62 to 64 enter the runoff duration and peak flow coefficients (c1hr = 0, c2hr = 0, c5hr = 0, for all regions). The default values (0) for those coefficients are c1hr = 3.3, c2hr = 0.25, and c5hr = 4.84. Lines 65 to 69 enter the MUSLE soil erosion coefficients (aksoil = 0, csoil = 0, psoil = 0, and alsol = 0 for all regions). The default values (0) for these parameters are aksoil = 0.2, scoll = 0.1, psoil = 1.0, and alsol = 1.0. Line 70 enters the slope of each region (schan = 0.07, 0.1, 0.1, 0.1, 0.1, 0.048, 0.1, and 0.039 for regions 1, 2, ..., apx, schxl = 1). Line 71 enters the Manning roughness coefficient for each region (rchan = 0.03 for all regions, rchxl = 1). Line 72 enters the length of each region parallel to its associated channel (xchan = 1.152, 0.461, 0.788, 0.485, and 0.485 mi for regions 1, 2, ..., apx). Line 73 enters the channel length (1.152, 0.461, 0.788, 0.485 mi for channels 1, 2, 3, and 4). Line 74 enters the width of each channel (wchan = 3 ft for all channels, wchl = 1). Line 75 enters the slope of each channel (schan = 0.046, 0.082,

0.048, 0.039 for channels 1, 2, 3, and 4, $schl = 1$), and line 76 enters the Manning coefficients of the channels ($rchl = 0.03$ for all channels, $rchl = 1$). When the parameters $schl$, $rchl$, $wchl$, $schl$, and $rchl$, are equal to 1, they preserve the input value for the respective parameters during the entire simulation. A value of 0 for these parameters activates internal calculation of them whenever surface runoff and/or stream flow occur in the simulation. Finally, line 77 enters the perennial addition of water to a given channel ($vlrndp = 5929, 4524, 0, 0$ ft³/day for channels 1, 2, 3, and 4).

2. SC2 and SC3: Input requirements for GEOFLX are identical to those of $sc1$.

E. Input to PLTGRO

1. SC1: Line 1 of input for this subroutine enters the output selector for each region ($pgr = 0$ for all regions). A value of 0 does not allow output from this subroutine through BIOPLT. Line 2 defaults the advanced succession mode ($adsuc = 0$), and the day and year moduli ($dmod = 0$, $ymod = 0$). A value of 0 for $adsuc$ does not allow the advanced-succession strategy to operate.

Lines 3 to 75 enter plant growth parameters for all eight regions simulated in $sc1$; however, the input, with one exception, is identical for all regions. Hence, input for region 1 (lines 3 to 12) will be representative of input for all regions in PLTGRO. Line 3 enters the succession mode option ($rsdce = 1$), and the niche competition mode option ($aiche = 1$) for the simulation. A value of 0 for these options does not allow their operation in the simulation. Line 4 enters the plant types simulated in the given region ($pltid = 7, 8, 19, 18$). These values correspond to warm-season annuals (7) and perennial grasses (8) and cool-season annual (19) and perennial grasses (18). Line 5 enters the irrigation input specification for a given plant ($arig = 0$ for all plants). An input value of 0 specifies that irrigation is not simulated. Line 6 enters the number of harvests for a specific plant of a given region ($ahrv = 0$ for all regions). The latter variable applies primarily to cultivated plants. Line 7 enters the printing option for a given plant in a region ($rgcplt = 1$ for all regions). A value of 0 does not allow input from BIOPLT for a given plant type. Line 8 enters the forest management mode for a given plant in a region ($rgc = 1$ for all plants). A value of 1 does not allow operation of the mode, a value of 2 allows operation of the mode on a yearly basis, and a value of 3 allows operation on a daily basis. Ordinarily, tree growth accesses the forest management model FORMAN on a yearly basis ($rgc = 2$). The use of daily access to FORMAN is sometimes desirable to structure the growth of irrigated crops such as corn. Daily access to FORMAN for tree growth is not recommended because it is wasteful of computer execution time.

Line 9 enters the irrigation mode option for each plant ($rirrc = 0$ for all plants). A value of 0 does not allow irrigation and harvesting input for a given plant of a given region. Line 10 enters the niche competition mode ($rss = 1$ for plants 1 and 3, $rss = 2$ for plants 2 and 4). Plant types with matching rss numbers are placed into niche competition. Finally, line 11 specifies the surface area for each crop type ($acres = 246$ acres for all plants in region 1). Acreage for other regions ($acres = 72, 56.4, 56.4, 28, 3.2, 28, 6.9$ acres for region 2, 3, ..., apx) is the only exception to identical input from PLRGRO for each site.

2. SC2 and SC3: The input requirements for sc2 and sc3 differ with respect to several parameters of sc1 input: access to the niche competition model (alche = 0 for regions 1, 2, 3, 4, and 6; alche = 1 for regions 5, 7, and 8) and in plant type assignments described below. Plant types (pltid = 15, 16, 18, 19 for regions 1, 2, 3, and 4; pltid = 5, 8, 15, 18 for regions 5 and 7; pltid = 16, 18, 19, 21 for region 6; pltid = 8, 15, 16, 18 for region 8) are entered to specify a ponderosa-oak forest, pinyon-ponderosa ecotone, a riparian community, and a ponderosa-meadow, respectively, for the regions simulated. Pinyon and ponderosa are set into niche competition in regions 5 and 7, as are cool- and warm-season perennial grasses. In region 8, only warm- and cool-season grasses are set into niche competition. The advanced-succession strategy (adsuc = 1) is entered for all regions. Plant identifications for the regions are pinyon (5), warm-season perennial grasses (8), ponderosa pine (15), cool-season deciduous shrubs (16), warm-season perennial grasses (18), cool-season annual grasses and herbs (19), and cool-season deciduous trees (21).

F. Input to UPTAKE

1. SC1: There are only two lines of input in this subroutine. Line 1 enters the day (dmod = 0), and year (ymod = 0) moduli for subroutine output selection (a value of 0 omits output). Line 2 contains a regional output option (upk = 0 for all regions); a value of 0 negates output for a given region. There is no output from this subroutine in sc1.

2. SC2 and SC3: Input requirements for UPTAKE are identical to those of sc1.

G. Input to BIOPLT

1. SC1: Input to this subroutine determines the specific output variables selected for output from any or all subroutines involved in the simulation. Input to line 1 determines whether specific information [(gmt(1) = 0)] from each subroutine accessed by BIOPLT will be specified as output; general information [(gmt(2) = 0)] is not used. When a value of 0 is entered in each case, it disallows formatted output in the output file. Generally, formatted output is not selected because output from BIOPLT is utilized for computer graphics analysis.

Lines 2 to 13 enter output specifications for two records of output (as many as 10 records may be specified for output). Lines 2 to 7 enter input for one record: lines 2 and 3 enter the specific variables (xptc = 29, 19, 20, 21, 30, 23, 24, 25, 26, 27, 28; k = 302, 1). The first 11 parameters identify specific variables selected for output (prec, rndix, indlx, rdlx, b1t, tchan, qpkd, dsmt, sdmnct, sdmnsa, and tcvr); the last two parameters identify the subroutine (302 = WATFLX) from which output originates (all 300 series values identify WATFLX output) and whether time units will be in years (1) or days (0). Lines 4 and 5 identify the variables entered in lines 2 and 3, and lines 6 and 7 enter the units for these variables. The second output specifications from WATFLX (315) are entered in lines 8 to 13. The variables selected as output are vtrnd, vlat, aice, vrfl, cfspd, dsmt, vaqf, vloss, wtx, htz, and prch. All of the variables specified have been discussed previously except for b1t in the first record. This variable represents the total live standing biomass due to all plant types in a given region on a given day. This and all other variables in these records will be discussed further in the next section of this document. Finally, the last line in the

input file terminates execution (0) of BIOTRAN. A value other than zero, will cause BIOTRAN to initiate another simulation for a different scenario.

2. SC2 and SC3: Input requirements for BIOPLT are identical to those of sc1.

IV. RESULTS

This section of the report will focus on a description of selected output for purposes of documenting model operation. Output for channels and regions of the watershed are presented in Figs. 2a-c through 18a-c, where the subscripts a,b,c, refer to scenarios sc1, sc2, and sc3, respectively. A schematic of the watershed area together with its channel network is presented in Fig. 1, as described previously. Finally, input data described previously will be summarized as needed for clarity.

A. Regions, Precipitation

Precipitation events for the 10th simulation year (sc1 and sc2), and the 100th simulation year (sc3) are presented in Figs. 2a-c for all eight regions of the watershed. Precipitation patterns (4,4,4,4,4,3,8,9,4,4,3, and 4 rain events per month from January-December, respectively) are the same for all scenarios. The variations observed on the graphs (rain-event day number and amount of precipitation) are due in part to differences in annual precipitation input. A significant difference is due to the uniform and standard distribution generators in subroutine CLIMAT, which select event day number and precipitation variance for each event, respectively. Most of the precipitation amounts simulated in all scenarios are generally below 0.6 in., however, a small number of events exceeded 1.5 in. with a maximum value of about 2.0 in. simulated on the 100th year of sc3. It should be noted that the simulated annual precipitation amount may be greater or less than that entered as input because of the stochastic nature of the simulation.

B. Regions, Mean Daily Temperature

Annual variation of regional mean daily temperature are presented in Figs. 3a-c for sc1, sc2, and sc3, respectively. Only one pattern is observed for all regions in a given scenario, but each scenario has a unique pattern. The significant fluctuations observed are due to modeled temperature variations on a monthly basis using the normal distribution generator. The minimum (33.9°C) and maximum (68.4°C) mean daily temperatures as well as the monthly coefficient of variation (0.2) are entered for all regions of a given scenario. Regional differences in elevation are modeled to affect daily temperatures through the use of the lapse rate (0.005°F/ft for all regions) in sc2 and sc3; however, the range in mean elevation (6850-7200 ft above sea level) compared with the reference elevation (7000 ft) was not large enough to produce any significant differences in the pattern. Of particular interest for each scenario are the effects of temperature on snowfall and snowmelt and on the formation of ice on channel surfaces. The effect on snowmelt can be observed in the surface runoff plots together with the effect on channel ice formation to be described later in this report.

Fig. 2a. Precipitation events for the 10th simulation year for scenario 1, sc1.

Fig. 2b. Precipitation events for the 10th simulation year for scenario 2, sc2.

Fig. 2c. Precipitation events for the 100th simulation year for scenario 3, sc3.

Fig. 3a. Mean daily temperature for the 10th simulation year for scenario 1, sc1.

Fig 3b. Mean daily temperature for the 10th simulation year for scenario 2, sc2.

Fig. 3c. Mean daily temperature for the 100th simulation year for scenario 3, sc3.

Fig. 4a. Total above ground live biomass for scenario 1, sc1, for annual and perennial grasses and herbs on the 10th simulation year.

Fig. 4b. Total above ground live biomass for scenario 2, sc2, for grasses, shrubs, and trees in niche competition and succession on the 10th simulation year.

Fig. 4c. Total above ground live biomass for scenario 3, sc3, for grasses, shrubs, and trees in niche competition and succession on the 100th simulation year.

Fig. 5a. Regional surface runoff events for the 10th simulation year in scenario 1, sc1. Compare with Fig. 2a.

Fig. 5b. Regional surface runoff events for the 10th simulation year in scenario 2, sc2. Compare with Fig. 2b.

Fig. 5c. Regional surface runoff events for the 100th simulation year in scenario 3, sc3. Compare with Fig. 2c.

Fig. 6a. Subsurface return flow for the 10th simulation year for scenario 1, sc1.

Fig. 6b. Subsurface return flow for the 10th simulation year for scenario 2, sc2.

Fig. 6c. Subsurface return flow for the 100th simulation year for scenario 3, sc3.

Fig. 7a. Regional soil erosion for the 10th simulation year in scenario 1, sc1.

Fig. 7b. Regional soil erosion for the 10th simulation year in scenario 2, sc2.

Fig. 7c. Regional soil erosion for the 100th simulation year in scenario 3, sc3.

Fig. 8a. Mass of soil removed by erosion from regions in 10th simulation year for scenario 1, sc1.

Fig. 8b. Mass of soil removed by erosion from regions in 10th simulation year for scenario 2, sc2.

Fig. 8c. Mass of soil removed by erosion from regions in 100th simulation year for scenario 3, sc3.

Fig. 9a. Regional soil uranium specific radioactivity for 10th simulation year in scenario 1, sc1.

Fig. 9b. Regional soil uranium specific radioactivity for 10th simulation year in scenario 2, sc2.

Fig. 9c. Regional soil uranium specific radioactivity for the 100th simulation year in scenario 3, sc3.

Fig. 10a. Regional total soil uranium radioactivity for 10th simulation year for scenario 1, sc1.

Fig. 10b. Regional total soil radioactivity for 10th simulation year for scenario 2, sc2.

Fig. 10c. Regional total soil uranium radioactivity for 100th simulation year for scenario 3, sc3.

Fig. 11a. Lateral runoff into channels from adjacent regions for 10th simulation year for scenario 1, sc1.

Fig. 11b. Lateral runoff into channels from adjacent regions for 10th simulation year for scenario 2, sc2.

Fig. 11c. Lateral runoff into channels from adjacent regions for 100th simulation year for scenario 3, sc3.

Fig. 12a. Water transmission at end of channel on 10th simulation year for scenario 1, sc1.

Fig. 12b. Water transmission at end of channel on 10th simulation year for scenario 2, sc2.

Fig. 12c. Water transmission at end of channel on 100th simulation year for scenario 3, sc3.

Fig. 13a. Peak channel discharge rates for runoff events in 10th simulation year in scenario 1, sc1.

Fig. 13b. Peak channel discharge rates for runoff events in 10th simulation year in scenario 2, sc2.

Fig. 13c. Peak channel discharge rates for runoff events in 100th simulation year in scenario 3, sc3.

Fig. 14a. Return flow volume entering a channel from adjacent regions on 10th simulation year for scenario 1, sc1.

Fig. 14b. Return flow volume entering a channel from adjacent regions on 10th simulation year for scenario 2, sc2.

Fig. 14c. Return flow volume entering a channel from adjacent regions on 100th simulation year for scenario 3, sc3.

Fig. 15a. Aquifer transport losses at distal face below channels for 10th simulation year for scenario 1, sc1.

Fig. 15c. Aquifer transport losses at distal face below channels for 100th simulation year for scenario 3, sc3.

Fig. 15c. Aquifer transport losses at distal face below channels for 100th simulation year for scenario 3, sc3.

Fig. 16a. Aquifer height below channel for 10th simulation year for scenario 1, sc1.

Fig. 16b. Aquifer height below channel for 10th simulation year for scenario 2, sc2.

Fig. 16c. Aquifer height below channel for 100th simulation year for scenario 3, sc3.

Fig. 17a. Alluvial aquifer volume for 10th simulation year for scenario 1, sc1.

Fig. 17b. Alluvial aquifer volume for 10th simulation year for scenario 2, sc2.

Fig. 17c. Alluvial aquifer volume for 100th simulation year for scenario 3, sc3.

Fig. 18a. Sediment discharge from channels in 10th simulation year for scenario 1, sc1.

Fig. 18b. Sediment discharge from channels in 10th simulation year for scenario 2, sc2.

Fig. 18c. Sediment discharge from channels in 100th simulation year for scenario 3, sc3.

C. Regions, Total Above Ground Biomass

Annual variations of regional above-ground biomass for a given year are presented in Figs. 4a-c for sc1, sc2, and sc3, respectively. Only annual and perennial grasses and herbs are simulated in sc1, and the biomass variation is more pronounced than in sc2 or sc3, where trees and shrubs predominate. The rapid drop in biomass at the end of the growing season due to the death of annuals is clearly visible (Fig. 4a). With the exception of regions 6 and 8, all regions show a similar growth pattern and magnitude with a maximum above-ground biomass of about 100 g/m² during midseason. The inclusion of a riparian community in the scenario receiving both runoff from adjacent land surfaces into an alluvial plain and the addition of simulated outfall water from TA-50 and TA-48 increases the available soil moisture for the growth of plants. This is reflected by a maximum biomass of almost 300 g/m² during midseason for region 6. A smaller but significant effect is noted for an alluvial plain with larger surface area in region 8, where a maximum biomass of about 200 g/m² is observed in the 10-yr simulation. The latter simulations were performed with the advanced secondary succession strategy in BIOTRAN, which assigns primary resource advantage to perennial grasses. The same strategy applied to grasses, shrubs, and trees in sc2; sc3 assigns primary resource advantage to climatic climax trees in the simulation. The simulation of sc2 (Fig. 4b) shows only a very small effect of annual grasses on the overall biomass density because most vegetation is associated with woody tissue which persists from year to year. The significantly larger biomass density of about 8000 g/m² for the riparian community (region 6) clearly illustrates this point of analysis despite the relatively short simulation time (10 yr) for the growth of woody plants. Other regions simulated in sc2 show biomass densities between 1500 and 2000 g/m², which are above those observed in sc1, but do not show complete dominance of trees over shrubs and grasses including annuals. It should be noted that the more rapid approach to the climax stage in region 6 is due to the enhanced moisture availability and to the presence of deciduous trees and shrubs in the simulation for that region.

The advanced succession strategy applied to sc3 (Fig. 4c), which for biomass density simulation is identical to all aspects of sc2 with the exception of the simulation time (100 yr), serves to illustrate the final climax stage for each region. Region 6 simulates the riparian community along channel 3 of the watershed at an equilibrium biomass density of about 17000 g/m², whereas other regions show biomass densities between 3500 and 5500 g/m² over the same time period. The degree to which vegetation reached equilibrium biomass density during this simulation period can be approximated by a similar simulation in which a plant type (ponderosa pine) has no competitors for resources. A simulation of this type yielded a biomass density of about 5900 g/m² for this vegetation type alone after a 100-yr simulation period. Hence, the advanced succession strategy is 80%-90% efficient with regard to the production of a pure stand of this vegetation type without any competition from other kinds of plants. Also, a 100-yr simulation of a pure stand of ponderosa without the limiting effects of nutrients, nitrate and phosphate, yielded about 7000 g/m² biomass density. This is important to the analysis because national mean concentrations of these nutrients were used to limit growth in all other scenarios.

With the exception of region 6, equilibrium biomass was not attained in a 100-yr simulation for ponderosa pine forests, and it appears that 120 to 150 yr would be required for this

to occur. Hence, runoff and associated erosion events were simulated in an early-climatic serial stage (sc2) and two late-climatic subclimax stages (sc1 and sc3). The grassland scenario (sc1) could also be considered a disclimax stage where shrub and tree growth were prevented by man or the chemical-physical effects of the environment (edaphic). This discussion also applies to pinyon forests at LANL. Finally, the enhanced biomass accumulation in regions 6 and 8 is also due to the availability of ground water once the root depth has penetrated the simulated surface of the shallow aquifers below the soil horizons in these regions.

D. Regions, Surface Runoff

Regional surface runoff events for the 10th year (sc1 and sc2), and the 100th year (sc3) are presented in Figs. 5a-c. The grassland scenario (sc1) shows 11 runoff events in excess of 0.1 in. for all regions. Ten runoff events are observed in sc2, including one event in region 6. Thirty-five runoff events are observed for all regions in sc3 with 4 events involving region 8 and 5 events involving region 4. The grassland scenario also shows 29 runoff events between 0.095 and 0.1 in. The sc1 and the sc2 scenarios show 31 events yielding runoff in this range, whereas scenario sc3 shows 29 events of this magnitude. An appreciable number of events below 0.05 in. are observed in all scenarios. The largest runoff event recorded for all regions is about 1 in. occurring in region 8 with relatively few events above 0.4 in. in all scenarios. Events in regions 6 and 8 reflect cumulative runoff from adjacent regions (3 and 4; 5 and 7), which would tend to magnify runoff depth in some instances due to the large difference in surface area (region 6 = 3.2 acres; regions 3 and 4 = 56.4 acres each) between region 6 and regions 3 and 4, which articulate with the former. A similar situation exists between region 8 (6.9 acres) and regions 5 and 7, which occupy 28 acres each. However, this effect is observed only in response to large simulated rain events. In summary, between 29 and 31 runoff events less than 0.1 in. occurred in the scenarios over all regions, and in most cases less than 2 in. of runoff occurred over the entire year in any one region. An average number of runoff events per region of a given magnitude can be obtained by dividing the observed events by the number of regions (8) or by inspecting the graphs. Also, the runoff events include the spring runoff caused by snowmelt in all regions and icemelt in regions 6 and 8.

E. Regions, Return Flow

Subsurface return flow for the 10th simulation year (sc1 and sc2), and the 100th simulation year (sc3) are presented in Figs. 6a-c, respectively. Excluding regions 6 and 8, which are alluvial plains, daily return flows for all regions were less than 0.1 in. with most of it occurring during spring snowmelt; a cumulative total return flow of less than 0.2 in. is observed in the simulations for these regions. Region 6 shows numerous return flow events in all scenarios primarily during early spring. A late fall series is observed in sc1, and middle summer events are observed in sc3. A smaller number of events of this type are recorded for region 8, most of which are observed in sc1 during late spring and early summer; it is observed to occur in both sc2 and sc3 primarily at the end of the growing season. A main source of soil moisture for region 6 is derived from its underlying aquifer below channel 3. The middle-summer paucity of events is caused by evapotranspiration of deciduous trees and shrubs and annual and perennial grasses in

sc2 and sc3; annual and perennial grasses evapotranspire water in sc1. A trend of return flow cessation during the growing season is observed for all scenarios, which corresponds with increasing live standing biomass in the regions. Region 8 has an underlying aquifer below channel 4, but it is unsaturated for the most part and does not contribute significant moisture to the overlying soil in the simulation. More details on this specific analysis will be presented when aquifers are considered.

F. Regions, Erosion

Simulated soil erosion from each region for the 10th simulation year (sc1 and sc2), and the 100th simulation year (sc3) are presented in Figs. 7a-c. Thirty erosion events above 0.03 ton/acre are observed for sc1 with one event involving region 8. Thirty erosion events above 0.03 ton/acre are recorded for sc2, two of which involve regions 6 and 8. Forty erosion events above 0.03 ton/acre are recorded for sc3 with five of these events involving region 1 and four events involving region 6. A total of 2733 erosion events between 0.003 and 0.03 ton/acre are observed for sc1 with five of these events associated with region 5. Twenty-four erosion events between 0.003 and 0.03 ton/acre are observed for sc2 with six of these events associated with region 1. Twenty-one erosion events between 0.003 and 0.03 ton/acre are observed for sc3 with two events associated with region 8 and four such events associated with region 6. Only 4 to 13 erosion events above 0.2 ton/acre are observed in each scenario with the maximum value between 1 and 2 ton/acre over all scenarios. In both sc1 and sc2, erosion events are more uniformly distributed throughout the year, whereas larger events in sc3 are clustered primarily within the growing season. However, events below 0.003 ton/acre, which are the most numerous type for all scenarios, are more uniformly distributed throughout the year with only a small tendency to cluster within the growing season in sc3.

The major erosion events correspond very closely to major runoff events in each region as shown in Figs. 5a-c. The stochastic nature of the precipitation pattern and precipitation amounts may obscure any trends associated with vegetation types simulated and approach the climax stage. However, it does not appear that a decrease in significant erosion events associated with region 6 are observed from grassland (sc1) to early forest stage (sc2) to advanced forest stage (sc3) described previously. Also, it appears that enhanced surface runoff from regions 6 and 8 is the result of higher antecedent soil moisture due to aquifer moisture transport to be described later in this report.

Using an assumed bulk density for soil of 1.5 g/cm^3 , the removal of 1 ton/acre of soil in an erosion event amounts to the removal of approximately 0.15-mm mean thickness from that surface or about 225 g/m^2 (0.046 lbs/ft^2). For example, the total weight of soil removed from all regions for scenarios sc1, sc2, and sc3 are presented in Figs. 8a-c, expressed in lbs/day. The comparatively large differences in soil erosion rates are primarily due to the large range in areas of the regions (246, 72, 56, 4, 56, 4, 28, 3.2, 28, and 6.9 acres for regions 1 to 8, respectively). The highest discharge rate was observed to be about 500 000 lbs/day in region 1 of sc3. This discharge amounts to the removal of about 0.1-mm thickness from the entire regional surface.

The latter was observed in response to a simulated 2.0-in. rainfall event during midsummer of the 100th year. This rain event was the largest observed in all the scenarios.

G. Regions, Soil Specific Activity

The specific activity in all regions for sc1, sc2, and sc3 are presented in Figs. 9a-c. The initial specific activity for all regions was set at about 2.35 pCi/g when averaged over all particle sizes and associated mass fractions. Specific activities in excess of this initial estimate for any region show net sedimentation, whereas those regions with specific activities below the initial value represent net scouring of soil toward channels or alluvial plains. Regions 6 and 8 in all scenarios show net sedimentation based on specific activities between 2.6 and 3.6 pCi/g; all other regions in the scenarios represent variably scoured areas (2.1 to 2.34 pCi/g) on this basis. An increase of specific activity above 2.35 pCi/g also indicates a deposition of 0.063-mm diameter particles (suspended load) in a region (specific activity of 0.063-mm particles = 4.60 pCi/g). The specific activity in all regions is observed to change abruptly, corresponding to major surface runoff events.

H. Regions, Total Activity Inventory

The total activity inventory for all regions assuming a 20-mm erosion layer are presented in Figs. 10a-c, for sc1, sc2, and sc3. The initial activity for each region was set at 70.2, 20.5, 16.1, 16.1, 7.99, 0.913, 7.99, and 1.97 mCi for regions 1 to 8, respectively; the activity was uniformly distributed over the surface. Region 1 in all scenarios showed the greatest loss of activity. Regions 2, 3, 4, 5, and 7 in all scenarios had significantly lower losses, whereas regions 6 and 8 both registered activity gains with region 6 exhibiting the highest gains in all scenarios of about 270%. Region 8 showed gains of about 150% in all scenarios; the losses from those regions exhibiting net erosion were generally less than 3% over 7 yr of cumulative events. Losses of soil involved the suspended particles or "fines," which initially had the largest mass fraction (0.42) and the highest specific activity (4.6 pCi/g), and accounts for most of the losses of activity from all regions in all scenarios.

The loss or gain patterns for each region showed abrupt changes associated with significant rain events presumably over the 7 simulation years of runoff history for all scenarios. The stochastic nature of precipitation events, patterns, and amounts, however, precludes our giving any cause for the observed losses, although similar reductions were observed in all scenarios. Major erosion events from region 1 are observed more frequently as shown in Figs. 8a-c.

I. Channels, Lateral Runoff

Lateral runoff into all channels from adjacent regions for sc1, sc2, and sc3 are presented in Figs. 11a-c. The majority of lateral runoff events for all scenarios range between 100 and 100000 ft³/day with only a few events exceeding 100 000 ft³/day, corresponding to major precipitation events. Channel 1, which receives lateral flow from region 1, had the largest event of this type (sc3) for all scenarios (about 1 000 000 ft³/day for a 2.0-in. rain event). In general, the

number of lateral events decreased from sc1 to sc3, and a clustering of events within the growing season also followed the same trend. Most of the reduction of events was due to decreased lateral events from channel 1 exclusive of events during summer. Lateral runoff input events to channels 3 and 4 in sc2 and sc3 show significant decreases when compared with sc1, particularly sc3. As both channel 3 and channel 4 are situated in alluvial plains, it appears that a riparian community which includes trees and shrubs is more efficient in reducing lateral flow events under these conditions. In contrast, the number of lateral runoff events in channels 1 and 2 were not significantly different for sc1 and sc2 but decreased in sc3.

J. Channels, Water Transmission

The transmission of water past the distal end of each channel for sc1, sc2, and sc3 are presented in Figs. 12a-c. Channel 1 is modeled to accept 5929 ft³/day from TA-48, and channel 2 receives 4524 ft³/day from TA-50. The former channel transmits about 5000 ft³/day and the latter about 4000 ft³/day; the volume difference enters the underlying aquifers. These quantities remain almost constant for all scenarios unless a precipitation event or snow- and ice-melt create additional runoff moisture. The greater transmission fraction for channel 2 over channel 1 in all cases for perennial flow from the technical areas is attributed to the larger aquifer volume of channel 1. The transmission of water from the distal end (about 5000 ft³/day) of channel 3 is also perennial but considerably less than at its anterior end (about 9000 ft³/day); these quantities are also increased by watershed runoff events. The distal end of channel 4 in all scenarios is observed to transmit about 3000 ft³/day and also to respond to major runoff events in the entire watershed. The largest single channel runoff events are observed to be in channels 3 and 4 for all scenarios (1 000 000 to 2 000 000 ft³/day followed by channel 1, then by channel 2. Most events of significance are between 2000 and 40 000 ft³/day with the majority in the lower portion of the range for all scenarios. The total number of events are also reduced (with the exception of those associated with snow- or icemelt) from sc1 to sc3. The major cause of the latter reduction is the reduction of precipitation generated events in channels 3 and 4; this is consistent with the reduction of lateral runoff events described earlier. Events associated with snow- and/or icemelt are observed to be quite variable and may be either lacking (sc2) or delayed (sc3).

K. Channels, Peak Discharge Rate

Peak discharge rates for given runoff events for sc1, sc2, and sc3 are presented in Figs. 13a-c. The modeling of a peak discharge rate assumes that water passing past a point in a channel will reach a maximum volume discharge rate depending on the total volume involved and on the duration of the event (Lane 1985), which will result in the production of a hydrograph. Discharges from TA-50 into channel 2 meet this criterion, but the duration of the event used in the model would be that which is characteristic of region 2 (1.63 hr). Hence, the observed peak runoff of about 3.5 ft³/s in all scenarios is probably a low estimate of this daily event. The waste discharge from TA-48 into channel 1 is also estimated with a duration period characteristic of region 1 (2.1 hr) that results in a high estimate (3.2 ft³/s) assuming continuous flow of 0.043 ft³/s (4000 ft³/day) as described previously. The peak flow estimate for TA-50- and TA-48-derived outflow channel 3 using 2.34-hr duration of flow yields 2.1 ft³/s; a continuous flow estimate for this channel yields 0.057 ft³/s. Increased discharge volumes resulting from surface runoff events

including snow- and icemelt are superimposed on technical area discharges, and peak discharges incorporate these volumes in making such estimates. The major peak discharges observed (60 to 250 ft³/s) were in response to simulated rainfall events between 1 and 2.0 in. in all scenarios. The majority of peak discharge rates in sc1 and sc2 were between 1 and 10 ft³/s, while most observed events in sc3 were between 1 and 60 ft³/day; about 8 of the events in sc3 were between 20 and 60 ft³/s. Only 3 to 11 events in each scenario exceeded 100 ft³/s with most of them occurring during the same rain event. Finally, the smaller number of peak discharge events, less than 1 ft³/s, were simulated in all three scenarios. Whereas all peak discharge estimates are affected by the daily water discharges from TA-50 and TA-48, the observed events below 3 ft³/s are most affected because these effluent volumes are included in making peak discharge determinations.

L. Channels, Return Flow

The volume of water entering a channel and/or alluvium through return flow from adjacent regions for sc1, sc2, and sc3 is presented in Figs. 14a-c. With the exception of channel 3, return flow for all other channels is observed to occur only during middle to late spring in all scenarios; return flow is not observed in channel 4 for sc2 and only three times in sc3. Additionally, there is a general reduction of return flow events for channels 1 and 2 from sc1 to sc3 and the presence of return flow events only in channel 3 after the beginning of the frost-free period. The volume of such flow for channels 1 and 2 ranges between 9 and 800 ft³/day when it occurs in sc2 and sc3. Return flow volumes for channel 4 in sc1 range between 4 and 8 ft³/day, and a maximum of about 2000 ft³/day was observed in channels 2 and 3 during spring.

Return flow events in channel 3 are more numerous and variable in all scenarios because it lies in an alluvial plain which overlies a mostly saturated aquifer to be described later in this report. BIOTRAN models the transport of moisture to the soil above the aquifer if the potential volume exceeds the volume of the "tipped" aquifer. Thus, the soil contains an additional source of moisture for plant evapotranspiration and for "back" return flow when the amount exceeds soil field capacity in any or all layers modeled. Hence, return flow in channel 3 for all scenarios varies from a maximum of about 2400 ft³/day (sc3) during minimal plant moisture use to negligible values during the middle of the growing season and other times. There is also an overall reduction in return flow rates to this channel from sc1 to sc3. Soil moisture enhancement from the aquifer is part of the modeling process.

M. Channels, Aquifer Transport Losses and Aquifer Heights

Losses of moisture from the distal aquifer cross sections of channels 1 and 4 are presented in Figs. 15a-c. Corresponding aquifer heights from the bottom of each channel segment are presented in Figs. 16a-c. The flow through distal faces of channels 1 and 2 are observed in a given scenario. Aquifer losses from channels 3 and 4 show a similar response to ice formation and also remain fairly constant thereafter. The outflow from the aquifer below channel 3 stabilizes at about 300 ft³/day, and the one below channel 4 stabilizes at loss rates

about 2100 to 2400 ft³/day depending on the magnitude of runoff events. The latter aquifer is observed to be more sensitive to runoff than is the aquifer below channel 3.

The height of the aquifers below channels 3 and 4 follow a similar pattern to aquifer volume losses in being responsive to ice formation and rainfall events but to a lesser degree. The height of the aquifers below channels 1 and 2 stabilize at 6 ft, which is the height of the aquifer at the distal ends of these channels. The height of the aquifer below channel 3 stabilizes at about 14 to 15 ft, while the one below channel 4 stabilizes at about 35 ft above the bottom of the aquifer at its distal end. Hence, the aquifers below channels 1 and 3 are saturated for the most part throughout the year, while the aquifer below channel 4 is always observed to be near saturation because of the 10 453 ft³/day water input described previously. The movement of moisture through the total aquifer appears to be underestimated in the model and may require tuning to give more representative aquifer heights at the designated locations.

N. Channels, Aquifer Volumes

The dynamic volumes of aquifers below channels 1 to 4 for sc1, sc2, and sc3 are presented in Figs. 17a-c. With the exception of the aquifer below channel 4, all other aquifers are near or at saturation during most of the year (100 000, 40 000, 400 000, and 21 000 000 ft³ for aquifers below channels 1 to 4, respectively). Short aquifer depletion periods are observed during snow and ice accumulation periods when they occur. Transient increases in volume are observed in response to large simulated rain events but are generally balanced with technical area discharges noted earlier, with a discharge of about 90% of the daily input into the upper channels (10 453 ft³/day). Evapotranspiration losses appear to account for about 10% of this input. This estimate can be further verified by specified output of evapotranspiration losses in subroutine BIOPLT. Aquifer volumes appear to be overestimated, and the model may require tuning to give more representative volume estimates. Note that aquifer discharge to the underlying tuff is currently unknown for Mortandad Canyon and is not modeled.

O. Channels, Sediment Discharges

The loss of sediments from adjoining regions through the channel network and out of the study area are presented for sc1, sc2, and sc3 in Figs. 18a-c. The losses are coincident with snow- and icemelt processes and major runoff events. The largest single-daily loss rate is observed in sc2 in channel 4 (1 000 000 lbs/day); most of the loss events for all scenarios are observed between 100 and 20 000 lbs/day with the majority in the lower range. An exponential decrease of varying slope is observed for sediment removal following a major rain event or during snow and icemelt for all scenarios. The perennial flow through the channels selectively removes sediment particles in a continuous process until another major runoff event provides the channel(s) with additional sediment from the drainage area. This effect is more pronounced for

channel 1, which has a higher scouring rate and where this rate may vary from 0.1 to 300 000 lbs/day within a very short time period. The sediment discharge from channel 4 is of particular interest because this material is lost from the system together with its associated radionuclide content from the entire watershed area (496.9 acres).

V. DISCUSSION

The primary dependence of hydrological processes and erosion on the modeling of precipitation events makes it important to specify statistical information on such events as accurately as possible, particularly the number of these events in a given month. The fewer the number of events per month coupled with a significant rainfall fraction and large stochastic increment, the larger the individual precipitation amount. Combinations of this type occurred in the scenarios to produce events of this type (such as the 2.0-in. rain in sc3). The assumption of a normal distribution (c.v. = 0.2) may result in a higher frequency of large precipitation events if the actual distribution is log-normal and skewed to the lower end of the probability curve. A data set developed by Wenzel (1986) called METDAT includes a 35-yr history of precipitation events in the LANL area and possibly could be used to determine precipitation patterns and distributions more accurately. The inclusion of these events directly in a BIOTRAN scenario would also be of value in testing model assumptions. However, the report of Baldwin (1973) on climates of the US is an excellent reference in the absence of more site-specific data for the development of climatic input for BIOTRAN, and it was used extensively to develop the scenarios under discussion.

Onishi et al. (1982) utilized BIOTRAN together with hydrological models ARM, DKWAV, and TODAM to model surface and channel runoff and sediment transport in Mortandad Canyon. BIOTRAN was used to simulate the vegetative cover of the site for 100 yr before hydrological application. The model was calibrated by use of actual precipitation and temperature data for stations in proximity to the upper reaches of the canyon (OHL, SM-43, and LAMPF). The precipitation events recorded at these three sites are presented in Table 4 as reported by Onishi et al. (1982). A comparison of these observations with simulated runoff events are presented in Table 5 where available.

Although it was not possible in those scenarios to duplicate areal averages of precipitation for the observed rain events, there is general overlap between simulated and observed surface and channel runoff at GS-1; however, the model yields runoff events which are generally higher than those observed. If the LANL effluent contribution (10 453 ft³/day, which is equivalent to about 0.1 in. of surface runoff and 7.4 ft³/s at the intersection of channels 1 and 2 with channel 3 called GS-1) is added to the runoff total, then better agreement is observed. It is not known how corrections were made for effluent discharges for a specific observed rain event, but it is conceivable that some events could be confounded by this component depending on the time and duration of the event. A similar argument can be extended to the estimates of peak discharge and channel runoff by the model. Further study of the conditions under which the observed data were recorded should help in determining whether the model needs tuning of the runoff equations used or whether the input parameters should be adjusted to obtain the desired degree of agreement. Finally, the simulation results involving sc3 should be in closer agreement with observed values because the near-climax vegetation simulated compares more closely to

TABLE 4. Observed Precipitation Near Mortandad Canyon at Three LANL Sites

<u>Date</u>	<u>Precipitation, Inches</u>			<u>Area Mean</u>
	<u>LAMF</u>	<u>SM-43</u>	<u>OHL</u>	
7/12/76				0.39
7/14/76	1.19		0.72	0.72
7/16/76				0.72
7/17/76	0.22		1.19	0.72
7/20/76				0.35
7/21/76	0.15	0.43	0.45	0.55
7/22/76				0.14
7/26/76				0.25
7/27/76	0.01	0.62	0.59	0.42
8/1/76	0.71	0.64	0.45	0.53
8/11/76	0.70		0.81	0.81

the actual environment of the study area. The annual moisture runoff from both surface and return flow events predicted by the model is shown in Table 6.

These simulations compare with the data of Dortignac (1956) for different vegetation zones of the Rio Grande Basin in New Mexico. The data indicate a runoff between 5% and 10% of the mean annual precipitation between 14 and 19 in. Considering that the model used mean annual precipitation estimates between 16 and 18 in., the simulations are in good agreement, particularly scenario sc1. However, the model also predicts higher total runoff for climax vegetation (sc3) when compared with annual and perennial grasslands and immature forest. The increase in runoff of the mature forest when compared with grassland is probably due to a decrease in ground cover of the latter at climax and an increase of leaf litter; the effect of leaf litter on runoff rates was not modeled as it was assumed to be included in crown cover effects. Also, the contribution of the stochastic effects of the model on these predictions requires further study.

The simulated discharge of sediment from GS-1, GS-2, and from the distal end of the last channel segment (GS-E) modeled (channel length of 0.5 mi from GS-2) along with other related output variables are presented below in Table 7.

A comparison between model output and observed values of instantaneous discharge vs suspended sediment loading (Hakonson et al. 1976) at the GS-2 weir shows reasonable agreement, although only one event was examined by these observers. In this event a range of instantaneous discharge values between 0.06 and 0.4 m³/s were observed, corresponding to a range in suspended sediment values between about 10 and 800 kg/min; the amount of precipitation which caused this runoff was not measured. Model output for mean rain events causing outflow of sediment at GS-2 for sc3 taken from Table 7 is shown in Table 8.

Model output of these parameters for sc1 and sc2 are comparable although there appears to be a general increase of sc3 values at higher levels of precipitation. The variability of model output indicates that sediment loading is dependent not only on instantaneous discharge

TABLE 5. Observed and Simulated Precipitation and Runoff Events
in Mortandad Canyon Above Upper Weir (GS-1)*

ID	Freq.**	Precip. Interval Inches***	Chan. Flow Interval CFD	Lat. Flow Interval CFD	Peak Flow Interval CFS	Runoff Interval Inches
obs	1****	-0.35	-230			-0.0002
obs	1	-0.39	-70			-0.00006
obs	1	-0.43	-16161			-0.014
obs	1	-0.53	-8298			-0.006
obs	1	-0.55	-17315			-0.015
obs	1	-0.72	-18470			-0.016
obs	1	-0.72	-21933		-5.5	-0.019
obs	1	-0.80	-19624		-4.4	-0.017
sc1	47	.004-.009	0-22630	-0	0-15.9	-0
sc1	31	.111-.495	10370-30010	0-14620	7.44-24.5	0-0.12
sc1	12	.504-.7745	10510-263400	153-264300	7.53-206.6	.001-.229
sc1	1	-1.04	-539700	-557700	-2346.6	-.483
sc2	31	.003-.089	0-19640	-0	0-13.85	-0
sc2	26	.118-.489	10370-49200	0-40070	7.44-32.32	0-0.035
sc2	15	.515-.882	13700-97760	3514-91980	9.58-65.26	.003-.080
sc2	1	-1.35	-1486000	-1552000	-1016	-1.34
sc3	75	.002-.097	0-21670	0-1.66	0-15.26	0-0.000001
sc3	23	.1540-.438	10370-29140	0-7986	7.43-21.40	0-0.007
sc3	7	.561-.901	35910-515400	26710-531500	26.4-344.1	.02-.460
sc3	2	.101-1.30	297200-1280000	301900-1335000	197-855	.261-1.16

* Watershed area (318 acres) above GS-1 corresponds to the area of Regions 1 and 2 combined for all scenario simulated (sc1, sc2, sc3).

** The effects of surface and channel flow increment resulting from snowmelt and icemelt, respectively, are included.

*** Precipitation intervals are estimated as the areal average of region 1 and region 2 for all scenarios. Simulated data were not corrected for daily volume increments (10453 cfd), and its associated (apparent) peak volume flow (about 7.4 cfs) from LANL effluent discharges. Also, the precipitation which were in actuality produced by snowmelt are also included as part of the analysis.

**** Observed values (obs) taken from Onishi et al. (1982).

TABLE 6. Simulated Moisture Runoff from Surface and Return Flow Events

<u>Scenario</u>	<u>Area Used, Acres</u>	<u>Runoff, Inches</u>	<u>Percent</u>
sc1	318 (17.81)	1.12	6.3
sc1	434 (17.91)	1.22	6.8
sc1	497 (17.84)	1.31	7.3
<hr/>			
sc2	318 (19.84)	1.85	9.3
sc2	434 (19.58)	1.88	9.6
sc2	497 (18.87)	1.77	9.4
<hr/>			
sc3	318 (16.26)	2.45	15.1
sc3	434 (17.22)	2.98	17.3
sc3	497 (16.85)	2.89	17.2

*Value in parenthesis is the weighted average precipitation for a watershed above the respective weir.

but also on the available amount of suspended sediment available. The modeled sediment discharge rates shown in Figs. 18a-c show an almost continuous discharge, which is expected because of effluent contributions. However, almost six orders of magnitude in discharge are predicted by the model with abrupt increases followed by exponential declines in discharge rates. The abrupt increases are associated with significant runoff events resulting from rainfall, snowmelt, and icemelt.

The mean annual erosion rates for the total watershed area modeled (497 acres) are 1.28, 1.72, and 2.74 tons/acre for sc1, sc2, and sc3, respectively. These values are between 25% and 55% of the values predicted for "tolerable" croplands (5 tons/acre, Branson 1981). The same source reports runoff values for forests of about 1 to 2 tons/acre/yr. If one assumes that row-crop vegetal cover has an average USA erosion rate of about 10 tons/acre/yr, then the erosion rates simulated are about 12% and 28% of these observations. These simulated erosion rates appear reasonable in that the less mesic climate of Mortandad Canyon might cause higher forest erosion rates when compared with wetter sites having more ground cover. Finally, it should be noted that the model predicts an erosion rate for a near-climax forest of ponderosa pine/pinyon-juniper which is about twice as high as that predicted for the watershed when annual and perennial grasses are the source of ground cover. This predictive outcome deserves further investigation as does sediment loading comparisons between scenarios.

An important goal of this investigation was to predict the movement of surficial deposits of radionuclides into the main channel of Mortandad Canyon and beyond the confines of the most distal outflow models (GS-E). A listing of annual water and sediment budgets leaving this outflow is presented in Table 9.

TABLE 7. Simulated Discharge Rates and Other Related Parameters for Mortandad Canyon

Location	ID	No	Precip Inches	Chan. Flow CFD**	Sed. Yield Peak Flow Intervals		Mean Vel. M3/sec***	Duration Hours
					Kg/min***	CFS**		
GS-1	SC1	47	.04-.09	0-22630	0-14.2	0-15.9	0-008	1.9
GS-2	SC1	55	.04-.09	0-18190	0-32.4	0-10.4	0-061	2.3
GS-E	SC1	56	.03-.10	0-15560	0-43.7	0-8.66	0-051	2.4
GS-1	SC2	31	.03-.09	0-19640	8-14.6	0-13.9	0-076	1.9
GS-2	SC2	34	.03-.09	0-14290	0-24.1	0-8.17	0-048	2.3
GS-E	SC2	35	.03-.10	0-12800	0-23.3	0-7.12	0-042	2.4
GS-1	SC3	75	.02-.10	0-21670	0-26.6	0-15.3	0-084	1.9
GS-2	SC3	74	.02-.10	0-17280	0-45.9	0-9.88	0-058	2.3
GS-E	SC3	74	.02-.09	0-14670	0-57.2	0-8.17	0-048	2.4
GS-1	SC1	31	.11-.50	10370-35010	.11-.41.2	7.43-24.5	.043-.136	1.9
GS-2	SC1	32	.11-.47	6536-50280	.25-147.3	3.74-28.8	.022-.169	2.3
GS-E	SC1	32	.11-.47	4233-46730	.29-168.1	2.36-26.0	.013-.153	2.4
GS-1	SC2	26	.12-.49	10370-49200	20-50.4	9.58-65.3	.043-.370	1.9
GS-2	SC2	30	.10-.48	6536-84150	.45-77.3	5.55-64.5	.022-.370	2.3
GS-E	SC2	30	.12-.48	4233-79630	0-99.1	4.07-72.6	.014-.427	2.4
GS-1	SC3	23	.15-.44	10370-29140	1.29-25.3	7.44-21.4	.043-.118	1.9
GS-2	SC3	24	.10-.49	6536-56980	4.31-56.6	3.74-32.6	.022-.192	2.3
GS-E	SC3	24	.10-.48	5324-65360	3.70-77.5	2.36-29.6	.017-.174	2.4
GS-1	SC1	12	.50-.77	10510-263400	14-594	7.53-207	.043-1.17	1.9
GS-2	SC1	11	.53-.81	6679-247100	.30-1285	3.82-141	.023-.830	2.3
GS-E	SC1	11	.52-.80	4372-303100	.39-1577	2.43-169	.014-.991	2.4

TABLE 7. (cont)

Location	ID	No	Precip Inches	Chan. Flow CFD**	Sed. Yield Peak Flow Intervals		Mean Vel. M3/sec***	Duration Hours
					Kg/min***	CFS**		
GS-1	sc2	15	52-38	13700-97760	52-86.1	9.58-65.3	.057-.370	1.9
GS-2	sc2	12	50-88	9706-112800	6.06-194.	5.55-64.5	.033-.379	2.3
GS-E	sc2	11	54-83	7312-130400	10.2-60.6	4.07-72.6	.024-.427	2.4
GS-1	sc3	7	56-91	35910-515400	3.60-756.	26.3-344	.148-1.95	1.9
GS-2	sc3	7	56-98	31290-613500	31.9-3278	17.9-351	.106-2.06	2.3
GS-E	sc3	7	53-95	28300-594200	51.1-3153	15.8-331	.092-1.94	2.4
GS-1	sc1	1	-1.04	-539700	-47.1	-347	-2.03	1.9
GS-2	sc1	1	-1.11	-947100	-156.	-542	-3.18	2.3
GS-E	sc1	1	-1.13	-1156000	-315.	-644	-3.78	2.4
GS-1	sc2	1	-1.34	-1486000	-1385	1016	-5.69	1.9
GS-2	sc2	1	-1.34	-1962000	-3375	-1122	-6.59	2.3
GS-E	sc2	1	-1.26	-1954000	-3614	-1088	-6.39	2.4
GS-1	sc3	2	1.00-1.30	297200- 1280000	326-1856	197-855	1.23-4.84	1.9
GS-2	sc3	2	1.03-1.40	490000- 19020000	1200-3369	280-1088	1.67-6.39	1.2
GS-E	sc3	2	1.03-1.37	597200- 2076000	1153-1493	332-1155	1.915-6.79	2.4

* Mean precipitation event is estimated as a weighted areal average of those regions serving as headwaters to the respective weirs and/or outflows from a given channel: GS-1 (regions 1,2); GS-2 (regions 1, 2, 3, 4, 6); GS-E (regions 1, 2, 3, 4, 5, 6, 7, 8).

** Transmission values (CFD), and peak discharges (CFS) were not corrected for moisture additions due to waste outfalls from TA-50 and TA-48 as described under Table 5.

*** Instantaneous discharge (M3/sec), and suspended sediment load (Kg/min) were estimated in correspondence to respective volume outflows described above: GS-1 (channels 1,2); GS-2 (channel 3); GS-E (channel 4). These values represent mean or integral values obtained taking the ratio of the modeled daily discharge (load) to the estimated flow duration shown in the last column of this Table.

TABLE 8. Simulated Sediment Outflow at Weir GS-2 for Scenario 3

<u>Mean Precipitation Inches</u>	<u>Sediment Load Range Kg/min</u>	<u>Instantaneous Discharge CMS</u>
.02-.01	0-45.9	0-058
.10-.49	4.31-56.8	.022-.192
.56-.98	31.9-2378	.106-2.06
1.03-1.40	1200-3369	1.67-6.39

TABLE 9. Annual Water and Sediment Outflows From GS-Z

<u>ID</u>	<u>Channel Loss CFY</u>	<u>Aquifer Loss CFY</u>	<u>Total Loss CFY</u>	<u>Adjusted Loss CFY*</u>	<u>Sediment Loss Lbs/Y</u>
sc1	2351700	766500	3118200	-696800	1272320
sc2	2951840	766500	3718340	-96660	1709680
sc3	4907200	766500	5673700	1858700	2723560

*Outflow volume adjusted for TA-50 and TA-48 annual effluent volume increment of 3815000 cubic feet.

The estimated annual precipitation average based on area for the portion of Mortandad modeled is about 17.84, 18.87, and 16.85 in. for sc1, sc2, and sc3 (the watershed area modeled equals 496.9 acres), which translates to about 32 200 000, 34 000 000, and 30 400 000 ft³/yr, respectively, for these scenarios. The ratios of the adjusted losses to the latter yield runoff percentages between -0.28% from sc2 to 6.1% from sc3. Hence, between 94% and 100% of precipitation is lost from the watershed as evapotranspiration. However, the model predicts that most if not all of the added effluent volume is lost by both channel and aquifer outflows. Also, the effects of effluent outflow on overall channel transmission of incoming runoff water from the watershed is probably of significance and is worthy of future study.

The mean annual concentration of sediment ranges between 0.54 and 0.58 lbs/ft³. Conservatively assuming that most of the sediment losses are due to the suspended fraction (less than or equal to 63µm), we can estimate the mean annual radionuclide losses (4.6 pCi/g U-238 for this diameter class) to range between 2.66 and 5.53 mCi/yr. The total assumed activity for the entire watershed is modeled to be 141.76 mCi; hence, between 1.9% and 3.9% of the total inventory of the watershed is predicted to be lost from the system annually. It should be noted that these losses also assume a homogeneous distribution of U-238 on the soil surface. For radioactive waste sites that concentrate contaminants over much smaller areas of a watershed and where waste is buried below the surface, one would expect much smaller loss rates. In fact, a great deal of activity dilution would be expected from uncontaminated sediments entering the channel at the same time. Again, the mature forest shows the largest simulated losses (sc3).

The fact that effluent from TA-50 contains radionuclides such as plutonium-239, uranium-238, americium-241, and cesium-137 (Hakonson 1973) that enter the drainage channels would warrant the development or inclusion into BIOTRAN of radionuclide partitioning between aqueous and sediment phases (partition coefficients). Onishi et al. (1982) used the data of Hakonson (1976) to estimate adsorption of Pu-239 on channel sediments, and this information could be incorporated into the model for this purpose. The present simulation assumed that the major fraction of U-238 was present in the sediments and soils of Mortandad Canyon with only a small fraction present in the aqueous phase during runoff events.

VI. ACKNOWLEDGMENTS

Development of the hydrogeological portions for the BIOTRAN model was inspired by the leadership of Wayne R. Hanson, Tom Buhl, and Ken Rea at LANL. Many others assisted in the early conception of a higher resolution model to simulate watersheds for risk assessment purposes. We are indebted to Bill Purtymun for assisting during set up of the Mortandad Canyon input and to Everett Springer for his excellent technical review and guidance. Special thanks go to Gloria Brito for her patient and thorough report preparation and word processing skills.

VII. REFERENCES

- Baldwin, J. L., 1973. *Climates of the United States*. U.S. Dept. of Commerce, NOAA, Washington, D.C.
- Baltz, E. H., J. H. Abrahams, and W. D. Purtymun, 1963. *Preliminary Report on the Geology and Hydrology of Mortandad Canyon Near Los Alamos, New Mexico, With Reference to Disposal of Low-Level Radioactive waste*. United States Department of the Interior Geological Survey in Cooperation with USAEC and LASL. Open-File Report, Los Alamos, NM.
- Branson, F. A., et al., 1981. "Rangeland Hydrology." 2nd ed., Society for Range Management, Denver, Colorado, Kendall/Hunt Publishing Co., Dubuque, Iowa.
- Cole, G. W., et al., 1976. "ELM: Version 2.0." Colorado State University Range Sciences Department. Science Series 20. Colorado State University, Fort Collins, Colorado.
- Dortignac, E. J., 1956. "Watershed Resources and Problems of the Upper Rio Grande Basin. U. S. Forest Service, Rocky Mountain Forest and Range Experimental Station, 107 p.
- Gallegos, A. F., B. J. Garcia, and C. M. Sutton, 1980. *Documentation of TRU Biological Transport Model (BIOTRAN)*. Los Alamos National Laboratory Report, LA-8213-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Gallegos, A. F., and W. J. Wenzel, 1984. *HUMTRN: Documentation and Verification For an ICRP-Based Age and Sex-Specific Human Simulation Model for Radionuclide Dose Assessment*. Los Alamos National Laboratory Report, LA-9994-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.

- Gallegos, A. F., W. J. Wenzel, and M. E. Ennis, 1990. BIOTRAN Users Manual. Los Alamos National Laboratory Report, in preparation.
- Gilbert, B. J., 1974. "Range IV Grassland Simulation Model, Regional Analysis of Grassland Environmental Systems." Colorado State University Report 17-18. Colorado State University, Fort Collins, Colorado.
- Hann, C. T., et al., Eds., 1982. "Hydrologic Modeling of Small Watersheds." American Society of Agricultural Engineers, St. Joseph, Michigan.
- Hakonson, T. E., et al., 1973. Ecology Investigation of Radioactive Materials in Waste Discharge Areas. Los Alamos National Laboratory Report, LA-5282-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Hakonson, T. E., et al., 1976. "Accumulation and Transport of Soil Plutonium in Liquid Waste Discharge Areas at Los Alamos." Transuranic Nuclides in the Environment, IAEA, Vienna.
- Hillel, D., and C. H. M. Von Bavel, 1976. "Simulation of Profile Water Storage as Related to Soil Hydraulic Properties." Soil Science Journal (40:6), pp 807-815.
- Knisel, W. G., Ed., 1980. "CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems," U.S. Dept. of Agric., Conservation Research Report 26.
- Lane, L. J., et al., 1985. New Estimating Procedures for Surface Runoff, Sediment Yield and Contaminant Transport in Los Alamos County, New Mexico. Los Alamos National Laboratory Report, LA-10335-MS. Los Alamos National Laboratory, Los Alamos, New Mexico.
- Nyhan, J. W., et al., 1980. Soil Plutonium and Cesium in Stream Channels and Banks of Los Alamos Liquid Effluent-Receiving Areas. Los Alamos National Laboratory Document, LA-UR-80-1184. Los Alamos National Laboratory, Los Alamos, New Mexico.
- Ohishi, Y., et al., 1982. Development of a Multimedia Radionuclide Exposure Assessment Methodology for Low-Level Waste Management. Pacific Northwest Laboratory Report, PNL-3370. Pacific Northwest Laboratory, Richland, Washington.
- Purtymun, W. D., 1974. Dispersion and Movement of Tritium in a Shallow Aquifer in Mortandad Canyon at the Los Alamos Scientific Laboratory. Los Alamos National Report, LA-5716-MS. Los Alamos National Laboratory, Los Alamos, New Mexico.
- Wenzel, W. J., and A. F. Gallegos, 1985. EFFECTS: Documentation and Verification for a BEIR III Cancer Risk Model for BIOTRAN. Los Alamos National Laboratory Report, LA-10371-MS. Los Alamos National Laboratory, Los Alamos, New Mexico.

Wenzel, W. J., et al., 1987. Cesium-137, Plutonium-239/240, Total Uranium and Scandium in Trees and Shrubs Growing in Transuranic Waste at Area B. Los Alamos National Laboratory Report, LA-11126-MS. Los Alamos National Laboratory, Los Alamos, New Mexico.

Wenzel, W. J., et al., 1986. METDAT. Los Alamos National Laboratory unpublished data, Los Alamos National Laboratory, Los Alamos, New Mexico.

Wight, J. R., et al., 1982. "SPUR- Simulation of Production and Utilization of Rangelands: A Rangeland Model for Management and Research." U.S. Dept. of Agric., Agricultural Research Service, Miscellaneous Pub. 1431.

END

DATE FILMED

11 / 07 / 90