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The versatile soil moisture budget — version three



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The versatile soil moisture budget — version three

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TABLE OF CONTENTS

	PAGE
Preface	2
Introduction	3
Evapotranspiration	4
- Root Extraction	7
- Crop Coefficients Adjustment	8
- Soil Water Retention	8
- Alternate Drying Curves	11
Infiltration and Drainage	11
- Drainage Rate Parameters	13
Snow Budget	14
- Snowpack Losses	16
- Snowmelt Infiltration	16
Field Performance Appraisal	17
- Results	19
Summary	22
References	23
Appendix A: VBIII Program	
Appendix B: Zonal Parameters Adjustment Program	
Appendix C: Run Control Data	
Appendix D: Output Data	
Appendix E: Evapotranspiration Coefficients (k, z)	

PREFACE

Soil water is an important topic in agriculture, forestry and hydrology. It plays a significant role in plant growth, in determining crop yields and in the hydrological state of a region. It affects farm operations, cultural practices, harvesting conditions, irrigation requirements and water supplies. To monitor the dynamic changes in the water content of soils, non-destructive methods of sampling are required. They must provide repetitive, timely and reliable information under a wide range of climatic, vegetative and physiographic conditions, as well as cultural practices. Weather based computer simulation models have proved to be an effective soil water monitoring technique.

Various soil moisture models have been proposed taking into account a number of biophysical factors. Many of these models follow the daily water budgeting approach. Budgets are a compromise between statistical and biophysical models. They are semi-empirical and incorporate many statistically derived coefficients to parameterize crop growth and soil water retention properties. They assess the soil water content for commonly grown crops, for normal soil conditions and for readily available climatic or weather data. One such budget is described in technical detail here.

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INTRODUCTION

Soil moisture budgets, such as the Versatile Soil Moisture Budget (Baier and Robertson, 1966), integrate present and past weather events to simulate daily soil water contents. The advantage of making such weather based estimates, over taking field measurements, is that such estimates are repeatable and non-destructive. Although field measurements are essential for development and verification of computer models, estimates are possible at times and locations where measurements are not feasible. Model estimates can therefore extrapolate information gained from periodic validation measurements. A detailed discussion of the range of soil water models that have been developed was prepared by De Jong (1981).

Soil moisture budgets have found a wide range of applications. Soil moisture reserve estimates are used in many crop growth and yield simulation models. One such model was developed for forages (Selirio and Brown, 1978). Soil moisture reserves, based on current and recent weather conditions, have been estimated in the prairie provinces and distributed weekly throughout the growing season (Edey, 1980). Moisture budgets have also been the basis of many field workday analyses (Dyer et al., 1978; Dyer, 1980), which play an important role in planning farm field operations.

The earliest budgets consisted of simple water balance equations, such as developed by Thornthwaite and Mather (1955). With the improvements in electronic data processing came the concept of multi-layer soil moisture budgets. A multi-layer budget developed by Holmes and Robertson (1959), known as the Modulated Budget, became one of the earliest and best known examples.

The Versatile Soil Moisture Budget (VB) developed by Baier and Robertson (1966) was an improvement on the Modulated Budget and achieved wide use and popularity. The VB has been described in detail in two previous technical publications (Baier et al., 1972; Baier et al., 1979). Each of these included refinements and the addition of submodels to the previous versions. The budget described here is the third version of the Versatile Soil Moisture Budget to be described in technical detail and is referred to as Versatile Budget - Version Three (VBIII).

This Budget (VBIII) includes features designed to make it more flexible and applicable to a wider range of uses. These new features include:

Drying curve index which can generate a wide range of different types of drying patterns. The index eliminates the so-called "z-tables" being read in.

Flexible soil zones. This budget can be run with two to six zones (or soil layers). As an auxiliary program, a routine is included which allows root coefficients to be modified to fit different zone patterns. This program (listed in Appendix B) can also be applied to the water holding properties of the zones.

Improved infiltration submodel. An experimental function for budgeting excess soil water is made available.

Reduced amount of data required as input controls (see Appendix C).

Revised output format. Zonal soil moisture contents can be expressed on a volumetric percent basis and displayed graphically by a line printer plotting function.

A variety of restart procedures are now available, recognizing a wide range of different possible applications to historical weather data.

The basic structure of the budget can still be described by the flow chart presented by Baier et al. (1979) shown in Figure 1. Model components can be split into evaporation functions, including all crop and soil water extraction characteristics, and recharge functions including infiltration, drainage, runoff and snowpack submodels. The computational steps in both soil water extraction and recharge are the same as the previous VB (Baier et al., 1979). However, many of the submodel components have had significant alterations. The input, computation and output of the new budget are shown in a flowchart in Appendix C.

EVAPOTRANSPIRATION

The basic drying relationship used by Baier and Robertson (1966) is still used here. This expresses the actual daily evapotranspiration (AE) as a function of the potential daily evapotranspiration rate (PE) as follows:

$$AE = \sum_{j=1}^n k_{ij} \frac{S_j Z_j PE}{C_j} \quad (1)$$

where AE = actual evapotranspiration for any day.

$\sum_{j=1}^n$ = summation carried out from zone j = 1 to zone j = n.

k_{ij} = coefficient accounting for soil and plant characteristics in the jth zone during growth stage i.

S_j = available soil water in the jth zone at the morning observation of each day.

C_j = capacity for available water in the jth zone.

Z_j = adjustment factor for different types of soil dryness curves.

PE = potential evapotranspiration on each day.

By this equation water is withdrawn simultaneously from all depths and the daily decrease in soil moisture in each zone due to drying is computed. The feature which most distinguishes this series of budget models from other types of soil water models is the k and Z coefficients developed empirically for different root extraction and soil water retention patterns respectively. This relationship is used here, but some modifications were made so that the selection and input of k and Z are easier.

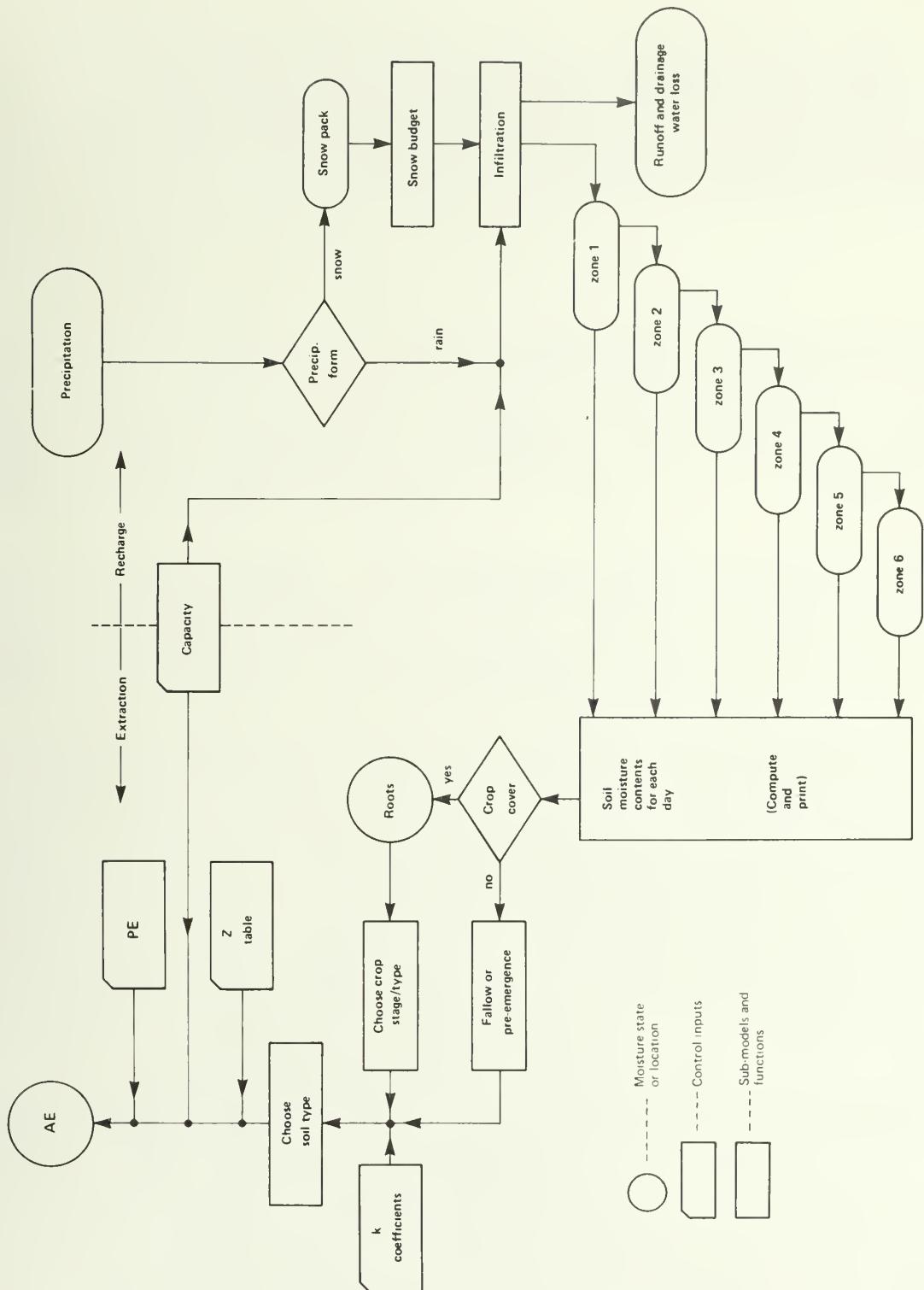


Figure 1. Soil-root-atmosphere pathways for water in the Versatile Budget.



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Reliable estimates of daily PE are required input to this model. For most sites in Canada with historical weather records these estimates have been made from standard meteorological data and are available for use in this model. General equations, based on regression techniques, have been devised for estimating PE from various combinations of available meteorological data (Baier and Robertson, 1965); however, any valid technique for estimating PE can be used as input to VB.

Root Extraction

Each k-coefficient in eq. 1 reflects the root activity at different depths (zones) during different times of the growing season. The transition dates between crop stages must be read into the program for each year. The k-coefficients in use at present have been determined by iterative comparisons between computed and measured soil moisture, or were estimated so that extraction rates resemble the most probable crop rooting pattern under the prevailing environmental conditions.

The k-coefficients are selected from a table which must be supplied as part of the control inputs. The k-coefficient table is based on 5 stages of growth and up to 6 soil zones (or layers). In previous versions these coefficients could be used only for a specific zoning pattern. That pattern required that 5, 7.5, 12.5, 25, 25, and 25% of the total plant available water capacity be attributed to zones one to six respectively.

Recently it has been found that k-coefficients can be adapted to soil zoning patterns other than the standard set used in the original budget (Dyer and Baier, 1980). In the same study it was found that changes in the number and distribution of soil zones has little effect on the performance of the budget. Therefore, the VBIII program allows between 2 and 6 zones to be used. Appendix E gives sets of k which were developed in previous studies for different crop stages for the specific zone pattern given above. To adapt these tables of k-coefficients to other zoning patterns the user should consult Dyer and Baier (1980) or Appendix B which gives the computer program for making these conversions. The program can also convert zonal distributions of other control parameters, such as water holding properties.

Dyer and Baier (1980) suggested that observed root patterns could be a basis for development of new sets of k-coefficients for different crops. A comparison of the VBIII with corn (maize) in a growth chamber was made by Dyer and Dwyer (1982). This study demonstrated the use of observed root distributions for deriving sets of k-coefficients which are applicable to a specific crop. Each k_j was related to the fraction of total root mass in each zone (j). Observed root distributions were also used to determine plant water uptake from each soil zone by De Jong and Shaykewich (1981). The growth chamber experiment (Dyer and Dwyer, 1980) also showed that coefficients representing root distributions from well watered conditions could also be adapted to dry conditions by using the adjustment procedure described in the next section.

Crop Coefficients Adjustment

In comparisons between observed and estimated soil moisture under non-irrigated crops, Baier (1969) found that during drought, plant roots absorbed comparatively more water from the lower, relatively moist layers than they did when the soil profile was uniformly moist. The effect of the k-coefficients for the upper zones, where water is no longer or less readily available, is decreased by giving more influence to the lower zones where water is still available. Thus the k-coefficient in each of the lower zones is increased as a function of the moisture content in the respective upper zones as follows:

$$k'_j = k_j + k_j \sum_{m=1}^{j-1} k_m \left(1 - \frac{S_m}{C_m}\right) \quad (2)$$

where k'_j = adjusted k-coefficient for the jth zone ($j=2,n$)

S_m = available soil water in the mth zone

C_m = capacity for available water in the mth zone

The use of this adjustment and the date of its commencement are optional.

The sum of k-coefficients over depth (all zones) is greater than one for periods of the growing season with fully developed crop canopies. These sums change with crop stages. This reflects the changing consumptive use factor defined by Baier and Russelo (1968), as the ratio of water use by a well watered crop to a free water surface. Consumptive use factors account for increased response to PE as the crop canopy develops and leaf area index values increase. Under well watered conditions, in a fully developed canopy AE can exceed PE.

Soil Water Retention

The evaporative loss from each zone was related to water content and soil water retention characteristics of that zone. In the previous VB each soil type was characterized by a drying curve, incorporated into equation 1 by the Z coefficient. For the water balance of a single soil layer, Z can be expressed as the ratio of the relative daily evapotranspiration (AE/PE) to the relative available water content (S/C). At each specific relative available water content a new value of Z is required. The curves developed and used by Baier et al. (1979) to describe the relationships between AE/PE and S/C are shown in Figure 2.

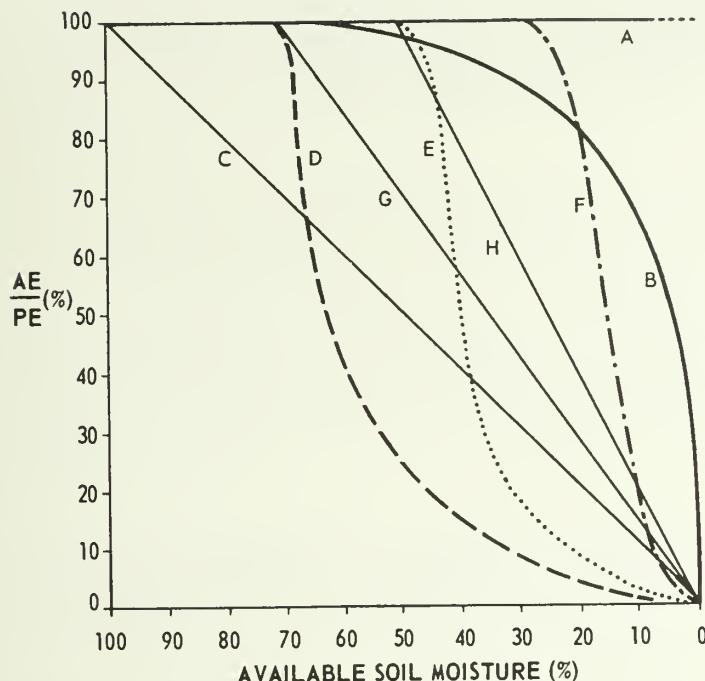


Figure 2. Proposals for the relationships between AE:PE ratio and available soil moisture (S/C).

Previously, sets of Z were read into the budget in tabular form, including one value for each of 100 possible S/C values. The so-called "z-tables" that correspond to curves in Figure 2, are listed in Appendix E. Each z-table is made up of Z values which correspond to 100 possible S/C values from 0 to 1. The z-tables had several disadvantages including a significant increase in the required control data and a restriction on the drying curves available. Therefore, an index for generalizing drying curves was developed. Derivation of this index has been shown elsewhere (Dyer and Baier, 1979a).

Typical drying curves, such as those in Figure 2, have the general characteristic of allowing evapotranspiration at the potential rate until some value of S/C, then having AE/PE decrease as a function of S/C. The decreasing portion of the curves can be described as concave upward, linear or convex downward. The general form of the index can generate all three classes of curves. The equation for the index is as follows:

$$Z = \left(\frac{X}{R}\right)^{hmn} \left[\left(\frac{X}{R}\right)^m + \left(\frac{R-X}{R}\right)^n \right] \quad (3)$$

where $X = S/C$
and $X \leq R \leq 1$

Table 1. COMBINATION OF CONTROL PARAMETERS USED IN EQUATION 3 TO GENERATE DIFFERENT DRYING CURVES

Curves' shape	m	n	h	Curve number from Fig. 3a, b
Concave	1	1	0	(1)
Convex	1	1	1	(3)
Deeply convexed	1	1	2,3 or 4	(4, 5 and 6)
Linear	1	0	0	(2)
Potential	0	1	0	

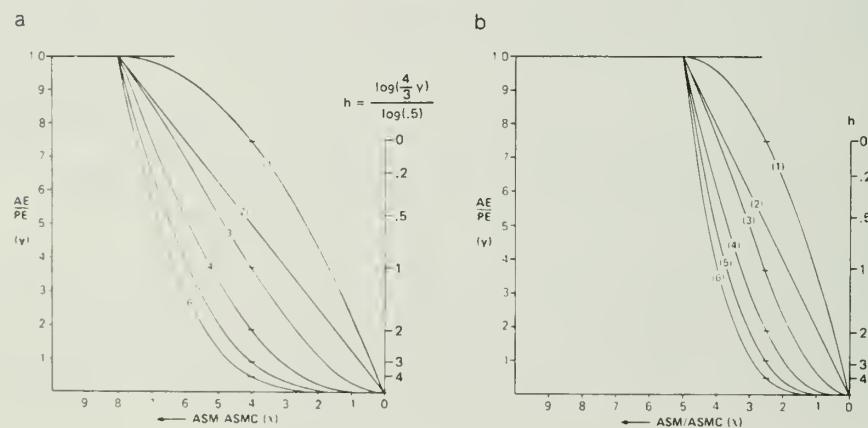


Figure 3: Drying curves derived from eq 5 for (a) $R = 0.8$ and (b) $R = 0.5$ and a function for h at $X = 0.5 R$.

To use the index the parameters m , n , h and R must be defined. The type of curve is controlled by m and n , each of which is either 0 or 1. The degree of downward curvature is controlled by h . The value of X where evapotranspiration changes from potential to a function of S/C , is equal to R . Examples of curves which can be generated are shown in Figure 3 for two values of R and five values of h (0 to 4). Table 1 gives the h , m and n which generate each type of curve.

The index can be more flexible by making the curvature parameter (h) non-integer. h can be defined as a logarithmic function of Y , X and R (where $Y = AE/PE$). The right hand axes of Figure 3 show the unique relationship between h and Y at $X = 0.5R$. From these axes, and selected "halfway" values of X in the range corresponding to decreasing Y , estimates of h can be made. Thus approximate "curve fitting" of the index to an appropriate curve for a particular type of soil can be done. Curves similar to those shown in Figure 2 can be generated. When the index is used new z-tables are actually generated internally.

Along with this new index VBIII can still accomodate the z-tables used in the previous versions. Generally curves which resemble D or G in Figure 2 are best applied to high clay content soils, whereas curves such as E and H would be applied to medium textured soils and F to very coarse textured soils.

Alternate Drying Curves

Two z-tables can be read and used by the program at one time. This feature can be used in two ways: (1) in heterogeneous soils having two distinct textural horizons, one z-table can be applied to the upper zones and another to the lower zones. If a homogeneous soil is assumed, one z-table is used throughout all six zones. (2) The relationships in Figure 2 depend on whether an active root system is present, or the soil is fallow. Therefore, to simulate the soil moisture distribution in a crop-fallow rotation, one drying curve (or z-table) can be used in cropped years and another drying curve (or z-table) can be used in fallow years. The procedure for using these two options is described in Appendix C.

INFILTRATION AND DRAINAGE

A new submodel for infiltration and drainage is included in VBIII to allow the budget to be applied more effectively to excess water problems. The submodel is based on a simple two zone budget developed for estimating fall field work conditions (Dyer and Baier, 1979). The basic concept is that drainage of excess, or gravity water is not immediate but takes place over one or more days. An essential assumption is that each zone can be filled to its saturation content, rather than just to field capacity. The excess or gravity water, that is the range of water content between field capacity and saturation, is free to drain out of each zone. However, only a certain fraction is allowed to drain from a near-surface zone on any one day.

To simulate the persistence of excess water near the surface from day to day the sequence of drainage into or out of each zone is critical. In the two-zone budget (Dyer and Baier, 1979b) drainage out of both zones was done before rainfall or surface water was added to the top zone, causing a one-day delay in drainage out of zone 1. When more than two zones are used this same sequence is followed but the computations become more complex. The one day delay principle is maintained, by splitting the total number of zones into two drainage layers. The first drainage layer defines or includes the maximum depth that surface water can infiltrate in one day.

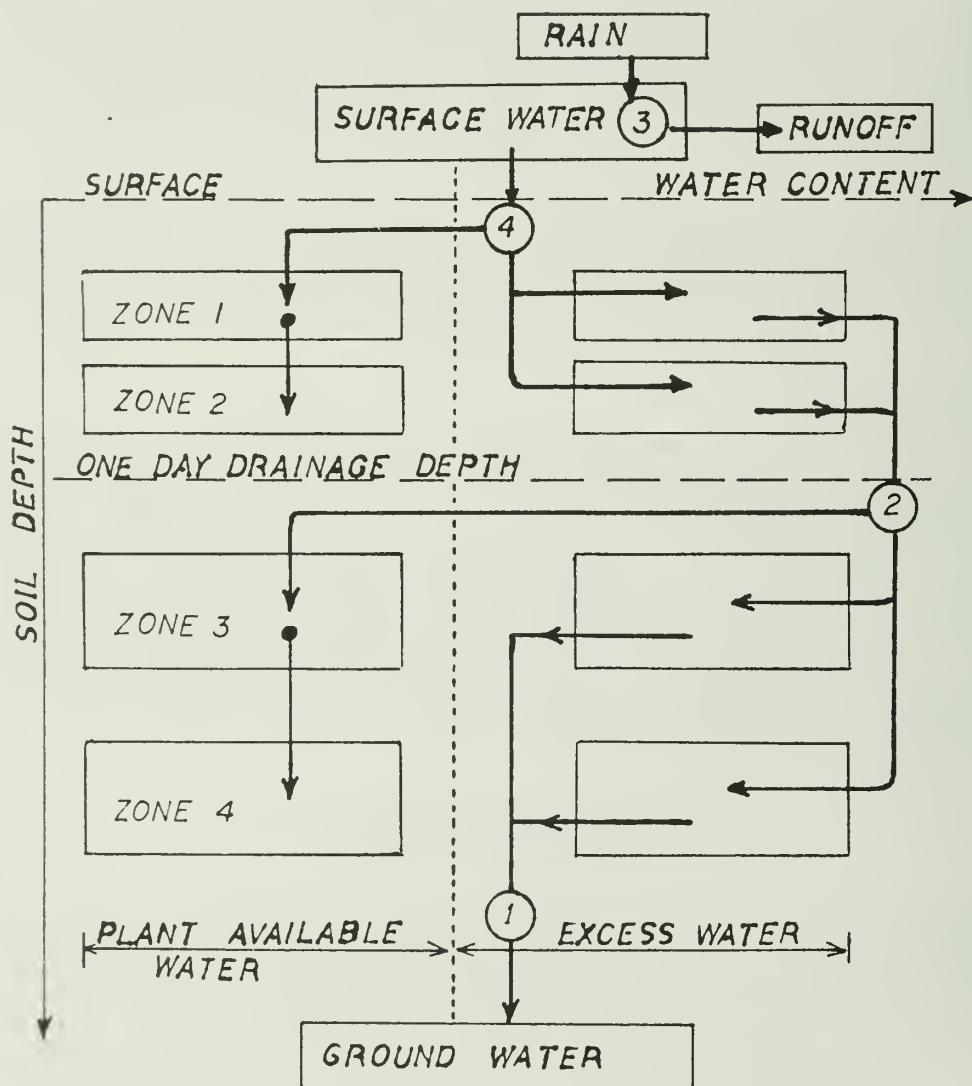


Figure 4. Assumed infiltration pathway for rain water through four layers of soil.

The computation steps in this submodel are illustrated in Figure 4 for a four-zone budget. These steps are: (1) drainage out of the bottom drainage layer, (2) drainage out of the upper drainage layer into the second drainage layer, (3) addition of precipitation to surface water and subtraction of surface runoff, and (4) drainage of surface water into the first drainage layer. This computational sequence ensures that surface water cannot enter or penetrate through the second drainage layer in one day.

Within each drainage layer the drainage water from above is added in three steps. First, excess water in any zone in the drainage layer is assumed capable of draining to the next drainage layer. Second, the plant available water deficits (below field capacity) are satisfied in sequence downward from the sum of excess water draining from above. Third, when there still remains excess water (more drainage water than required to satisfy the plant available water deficits in all zones in the layer) then this water is distributed evenly over the excess void spaces (field capacity to saturation) in all zones in the layer.

Drainage Rate Parameters

To operate the submodel and characterize drainage patterns of various types of soils several new control coefficients are required in VBIII. These include the saturation level water contents (or total void spaces per zone in mm), the number of zones in the upper drainage layer, a drainage rate coefficient and maximum amounts of drainage. The drainage rate defines the fraction of excess water in Drainage Layer 1 which can drain into Drainage Layer 2 during each day. This ensures that a small amount of excess water persists in Drainage Layer 1 until the next day.

Three coefficients control the maximum amount of water which can drain past three points in the profile (or levels) each day. These are the maximum water volumes which can infiltrate the surface (Drainage Layer 1), which can enter Drainage Layer 2 and which can drain out of the soil profile. These coefficients are in millimeters of water per day and can be considered as maximum daily water conductivities.

The depth of Drainage Layer 1 defines the maximum wetting front penetration from the surface in one day. Because the submodel is sensitive to the range between field capacity and saturation, the permanent wilting point of each zone is also required to distinguish field capacity from plant available water holding capacity. Soils can have similar plant available water holding capacities, but different field capacities, due to different permanent wilting points. This difference affects drainage patterns.

Although this submodel has not been tested against soil moisture observations, the two-zone version has proven successful in making estimates of days with surface soil conditions too wet to permit field work (Dyer and Baier, 1979b). The performance of the function was also assessed in a set of sensitivity tests not shown here, but which revealed that fine textured soils (higher clay and silt fractions), which are generally less permeable, are best simulated by shallow one-day drainage depths (20 cms) and low drainage coefficients (approximately 50%). For coarser textured soils one day drainage

depths of 40 to 60 cm are more realistic (assuming 120 cm total depth) and a drainage coefficient of 80 or 90%. The original two-zone application of this function (Dyer and Baier, 1979b) used 80%. The function is also sensitive to the range between field capacity and saturation, particularly for relatively high field capacity. Users should be aware that this new submodel is still experimental.

SNOW BUDGET

In some applications in temperate climates it is necessary to calculate a daily soil moisture content throughout the year, particularly when a reasonable estimate in spring is required as a starting point for the water budgeting during the growing season. In climates where snow occurs, the computation of soil moisture requires the amount of water penetrating the soil from snow. Therefore, a simple snow budget was developed in the previous version (Baier et al., 1979). The snow budget used here is little different from the previous version, but control parameters have been modified.

The inputs required for the snow budget are the daily maximum temperature and the precipitation total. Because the form of precipitation is not defined in the daily weather data used here, part of the snow submodel is dedicated to determining the precipitation form. Snow is not assumed unless the smoothed daily maximum temperature (A_{max}) is below a selected threshold value. The 5-day binomial smoothing function used in the previous budget was replaced by a 3-day function.

$$A_{max_i} = (3T_{max_i} + 2T_{max_{i-1}} + T_{max_{i-2}})/6 \quad (4)$$

where i = day and T_{max} = daily maximum temperature

This change means that temperatures for the two days following the date of calculations are not required input, as they were in the previous version.

In fall and early winter (July 1 to December 31), precipitation is assumed to be in the form of snow if $A_{max} < \text{threshold 1}$. Snow is then accumulated on the soil surface until $A_{max} \geq \text{threshold 1}$, when the melted snow is taken into the soil. In late winter and spring (January 1 to June 30) precipitation is assumed to occur as snow if $A_{max} < \text{threshold 2}$ and it is then accumulated on the surface. Temperature thresholds for Canada were determined by using various thresholds in repeated computer runs to compare estimated with observed snowfall. It was found that precipitation can be expected to occur as snow when the daily maximum temperature is below the thresholds in Table 2. It was also found in developing this submodel, that snow was more likely in colder, less humid climates in the same ambient temperature range. This is reflected by the higher thresholds for colder climates in Table 2.

TABLE 2: MAXIMUM TEMPERATURE THRESHOLDS FOR SNOW

Region	Threshold 1	Threshold 2
	July - Dec.	Jan. - June
COLD		
Central B.C.,	5° C	7° C
Prairies		
WARM		
Southern B.C.,	1° C	2° C
Ontario,		
Quebec,		
Atlantic Provinces		

The incidence of snowfall with the higher surface temperatures in spring reflects the seasonal difference in lapse rates. In spring, when the ratio of incoming solar to outgoing terrestrial radiation is usually higher than in fall, the lapse rates are steeper and conditions are less stable. Thus the chances of precipitation reaching the surface as snow rather than as rain are increased. This is reflected by using higher temperature thresholds for spring which designates precipitation to be snow more often. In Western Canada threshold values are higher because a larger proportion of precipitation occurs as snow, due to relatively more surface heating and less stable air masses.

Snowfall is also restricted to a period between specified dates in fall and spring. These two dates are required input control parameters.

Snowpack Losses

Only a fraction of the measured snowfall actually enters the soil after snowmelt, because a large proportion of the snow blows away, evaporates, or when melted, runs off as surface-water. The snowpack is also decreased daily by an amount equal to PE. To describe the snow remaining after blow-off, a snow coefficient was defined. The two most commonly used snow coefficients are 0.7 for stubble-covered fields and 0.5 for fallow fields. These values, which indicate the fraction of snow remaining after blow-off, were developed in repeated computer runs in which the snow coefficients were changed until the estimates were closest to the available soil moisture measurements in spring. In areas where blowing snow is not as serious a problem higher values can be used.

Provision is made for an alternate snow coefficient to be used if soil surface conditions change from one year to another. This situation occurs in a crop fallow system that has stubble during the first winter and is bare during the second winter. If the crop development stage on July 1 is past the preemergence-fallow stage, then a crop is assumed during that year and the first snow coefficient is used. Otherwise a fallow state is assumed and the second coefficient is used. July 1 was selected as the middle of the growing season for the northern hemisphere. In VBIII July 1 can be replaced with a date selected by the user. This feature is designed to allow a change in the snow accumulation rate in midwinter.

The choice of coefficients usually depends on the ground cover during winter and on the growth stage. When growth (or a ground cover) is assumed, the first coefficient is used. In some cases, such as a perennial crop, there may be no growth but a ground cover could still be present in winter; thus both coefficients would be 0.7. In cases where fall tillage is practiced there would be summer growth but no ground cover in winter, and both coefficients would be 0.5. Even though this system was first developed for wheat-fallow rotation it can be adapted to many cropping practices.

Snowmelt Infiltration

The factors considered for the contribution of snow to soil moisture are the rate of snowmelt, the retention of meltwater within the snowpack and the rate of penetration of meltwater into frozen or partially thawed soil. The rate at which snow melts is correlated with both the air temperature and the time of year. A set of four snowmelt curves was defined (McKay 1964) for four temperature intervals; 0-2.8, 2.8-5.6, 5.6-8.3, and above 8.3($^{\circ}$ C).

Previously, empirical constants for each month and for each of the four temperature intervals were required input control data to calculate daily snow melt. In VBIII, temperature dependent, monthly snowmelt values were calculated externally and stored as internal data. So the McKay equation (1964) used in the previous version does not appear in the VBIII program. Early and late in each month melt rates are averaged with the previous and the following months, respectively. This smoothing was required since daily snow melt values are no longer calculated or stored.

The melt term has the restriction that it cannot exceed the total moisture available in the snowpack. The snowpack is considered capable of retaining 15% of its volume as meltwater. The amount of melt must exceed this threshold before any moisture is presumed to reach the soil. Whenever the maximum daily temperature is less than 0°C, the portion of melt retained in the pack is considered once again to be part of the snowpack. All melt which reaches the soil is considered to enter it by the normal infiltration process. The first day after the designated date in fall that $A_{max} <$ the threshold is considered to be the beginning of the winter budget. If the maximum temperature is less than -6.7°C, the previous snowmelt is considered frozen in the upper layers of the soil, thus affecting penetration and runoff of future snowmelt. In VBIII the reduced rate of meltwater infiltration is related to the fraction of unfilled excess void space in the top (one-day) drainage depth. The drainage rate is assumed to be retarded by freezing. This is simulated in VBIII by reducing the drainage rate coefficient.

FIELD PERFORMANCE APPRAISAL

The performance of VBIII was assessed against soil moisture observations taken under alfalfa on a number of soils over three years (1966 to 1968) in South Western Ontario. These data were compiled by Selirio et al. (1978) at the University of Guelph. Three sites were selected, representing three different soil textures. The model was run with data from nearby weather sites. These sites were Delhi, Woodstock and Kather representing Fox Loamy Sand, Embro silt Loam and Haldimand Clay, respectively. The model was initialized on the day of the first observation with starting soil moisture contents equal to the first set of observations. The zones used in the budget were equal to the six observation layers. The root (k) coefficients given by Baier et al. (1979) for alfalfa (Appendix E) were adapted to the zones used here by the technique described by Dyer and Baier (1980).

The maximum possible water content (mm) or saturation level (Sat) in each zone was calculated from measured bulk density (bd) and grain density (gd) as follows:

$$Sat = \frac{gd - bd}{gd} \times (\text{zone thickness}) \quad (5)$$

Field capacity and the permanent wilting point for each zone were based on measurements taken at the sites. Field capacities, permanent wilting points and bulk densities, along with soil texture and daily moisture observations, were presented by Selirio et al. (1978). Permanent wilting points, field capacities and saturation levels used here are presented in Table 3. The parameters used in equation 3 to generate drying curves are also given in Table 3. Water holding properties and k-coefficients were converted to depth of observation basis by the program in Appendix B.

TABLE 3: Water holding properties used to compare VBIII estimates to observations of soil moisture contents from three sites

Zones	1	2	3	4	5	6
Depth ¹ (cm)	15.0	30.0	46.0	61.0	91.0	152.0
Permanent Wilting Point (mm)						
Fox Loamy Sand	5.1	6.6	4.4	6.8	13.9	19.7
Embro Silt Loam	11.0	12.0	13.0	14.0	40.0	60.0
Haldimand Clay	12.5	19.5	21.0	21.5	45.0	88.7
Field Capacity (mm)						
Fox Loamy Sand	12.7	16.4	9.7	12.7	26.1	50.4
Embro Silt Loam	42.0	35.9	42.2	44.3	97.4	175.8
Haldimand Clay	42.4	44.5	47.1	45.0	93.0	180.5
Saturation (mm)						
Fox Loamy Sand	41.8	54.1	37.2	90.3	194.3	348.1
Embro Silt Loam	59.4	65.0	63.4	65.2	100.6	343.4
Haldimand Clay	90.0	76.3	82.0	70.2	139.5	259.4

Drying Curve (z) Parameters

	<u>m</u>	<u>n</u>	<u>h</u>	<u>R</u>
Fox Loamy Sand	1	1	1.0	.5 ²
Embro Silt Loam	1	1	0.2	.7
Haldimand Clay	1	1	1.0	.6

¹To the bottom of each zone

²Changed to .6 in zone 6

RESULTS

The comparisons shown in Figures 5 to 7, give estimates of soil moisture content vs observations taken as close as possible to the end of each growth stage. Only the top three soil zones are shown, representing a depth of 45 cm since there was very little variation below the third zone. These comparisons are considered as only a demonstration because the accuracy of VBIII was hampered by a number of limitations in the observations used. Therefore, only a limited number of comparisons are shown and no statistical tests were made. They are presented here so that users can appreciate the performance to be expected of VBIII.

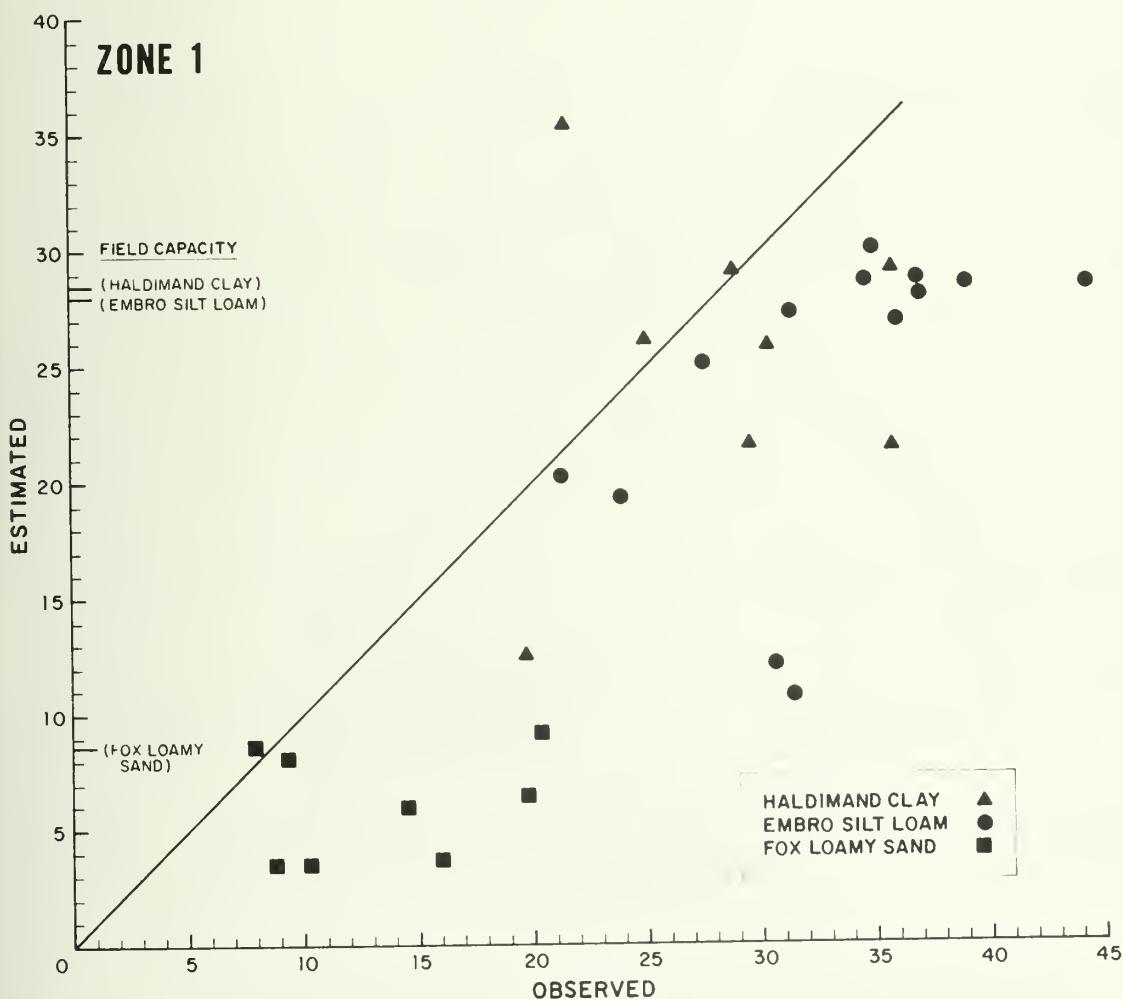


Figure 5. Comparison of estimated and observed soil moisture contents (%) volumetric) in the top 15 cm at three sites.

The primary limitation was the use of weather data from weather sites which were several km away from the soil moisture observation sites. Both the levels and the occurrence of rain were known to be quite different, since Selirio et al. (1978) did present some rainfall records at each site. These differences largely account for the scatter of comparisons in the top zones (Figure 5).

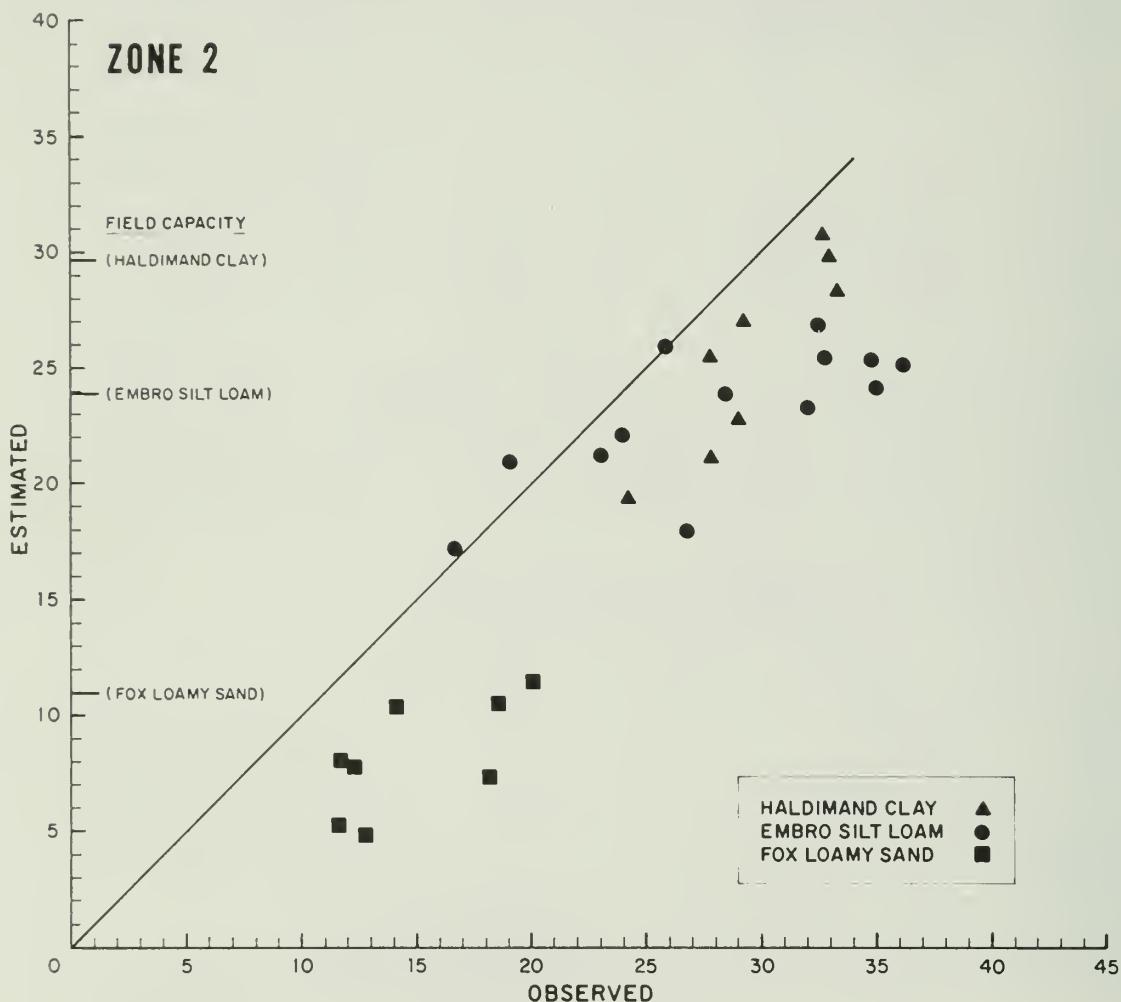


Figure 6. Comparison of estimated and observed soil moisture contents (% volumetric) in 16 to 30 cm layer of soil at three sites.

The VBIII estimates were also restricted by the use of measured soil water retention characteristics, listed in Table 3, which appear to be incompatible with the soil water content observations. For instance, the range of observed water contents is consistently higher than the observed range from permanent wilting point to field capacity even during periods without heavy rain. Most estimates fall well within the field capacity to permanent wilting point range. This caused the comparisons to be below the one to one line in all three zones (Figures 5 to 7).

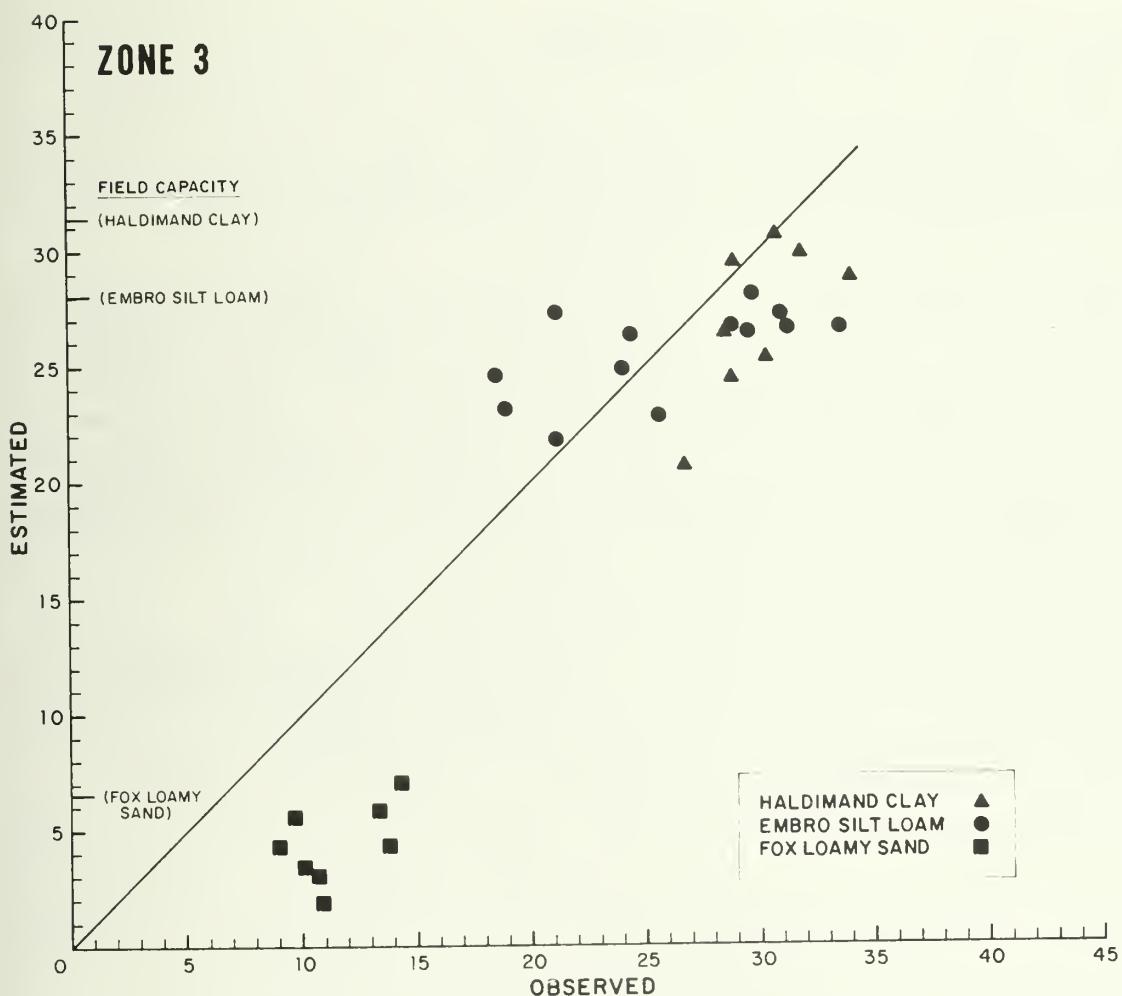


Figure 7: Comparison of estimated and observed soil moisture contents (% volumetric) in 31 to 46 cm layer of soil at three sites.

In spite of these shortcomings, there does appear to be reasonable correspondence between observations and estimates. The differences due to soil type are realistic. The rate of decrease in estimated water contents with time is also similar to observed decreases. The best fit appears to be in zone 3 in the two finer textured soils.

In the previous version of the VB (Baier et al., 1979) the results of a number of field validation trials showed that the VB performs acceptably well under semi-arid climates in water deficit conditions. It was not felt to be necessary to present these results again here.

SUMMARY

The soil moisture budgeting concept has been an important part of modelling and predicting soil water use by plants. The popularity of this concept is increasing. Soil water and crop yield predicting schemes, based on budgets are becoming more widely accepted and used. As the number of applications increase, the need for improvements in flexibility and applicability will also increase. A good example is the application to excess water problems. Restricting drainage rates in the lower zones to simulate water table effects, such as done by De Jong and Shaykewich (1981), could be a valuable expansion of the excess near-surface water submodel described here. There is a broader range of crops that require estimates of soil water use than when the original VB was designed. A soil surface evaporation term which is separate from root extraction, such as was suggested by Dyer and Dwyer (1982), could enhance the derivation of new root coefficients. There is also a need for budgets which are simpler. Often fewer soil zones are required and one or more sub-models, such as the snow-budget, can be ignored.

It is felt that the version of the Versatile Budget described here will provide much of the flexibility needed in some of the new applications. These applications can provide additional opportunities for comparison with field observations. In making the technical detail of VBIII available, the use and appraisal by other researchers is hoped for.

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APPENDIX A
VB III Program

The following is a listing of the computer program for VBIII. This program is a revision of the previous Versatile Budget program and is not a new program. As a result its design, structure and many of its variable names are unchanged. Also unchanged is the way in which the program is set up to read and write metric units. A flowchart (Figure A-1) is provided to assist the user in interpreting the computational sequence and restart options of this version.

Variable names used in the main text to discuss the principle algorithms are not the same as those used in the Fortran program. For discussion purposes simple, one-character variable names are generally more convenient and easy to follow than Fortran code names, which often use four or more characters. Whenever possible, variable names in the text were chosen to be consistent with the most relevant references to previous work. The following table provides a conversion of variable names from the main text to the program code names.

The authors are aware that this program itself is in need of streamlining. The intent of providing this version is to make available an experimental version of VB, so that other researchers would be able to use and assess the most recent additions. Input and output still require considerable effort by the user. But I/O formats, remain as much as possible, similar to the I/O format of the previous version (Baier et al., 1979). More details on input and output format are given in Appendices C and D, respectively.

TABLE A-1. The program variable names which correspond to symbols and terms used in the main text

<u>SYMBOLS AND TERMS</u>	<u>VARIABLE NAMES</u>
AE	SUMDEL
PE	PE OPE
K	COF, COEFS
Z	WORK, TABLE 1, 2
S	CONTNT
C _j	CAPAC
j	I
m	M9
n	N9
h	H9
R	R9
X	X9, DEL
Amax	MAXSM
Tmax	MAX, PAX
SNOWMELT	DD, AQ
RAIN	PRECIP, PCP
RUNOFF	RUNOFF
SURFACE WATER	PDL
GROUND WATER	AYE, EXTD
Deficit	X

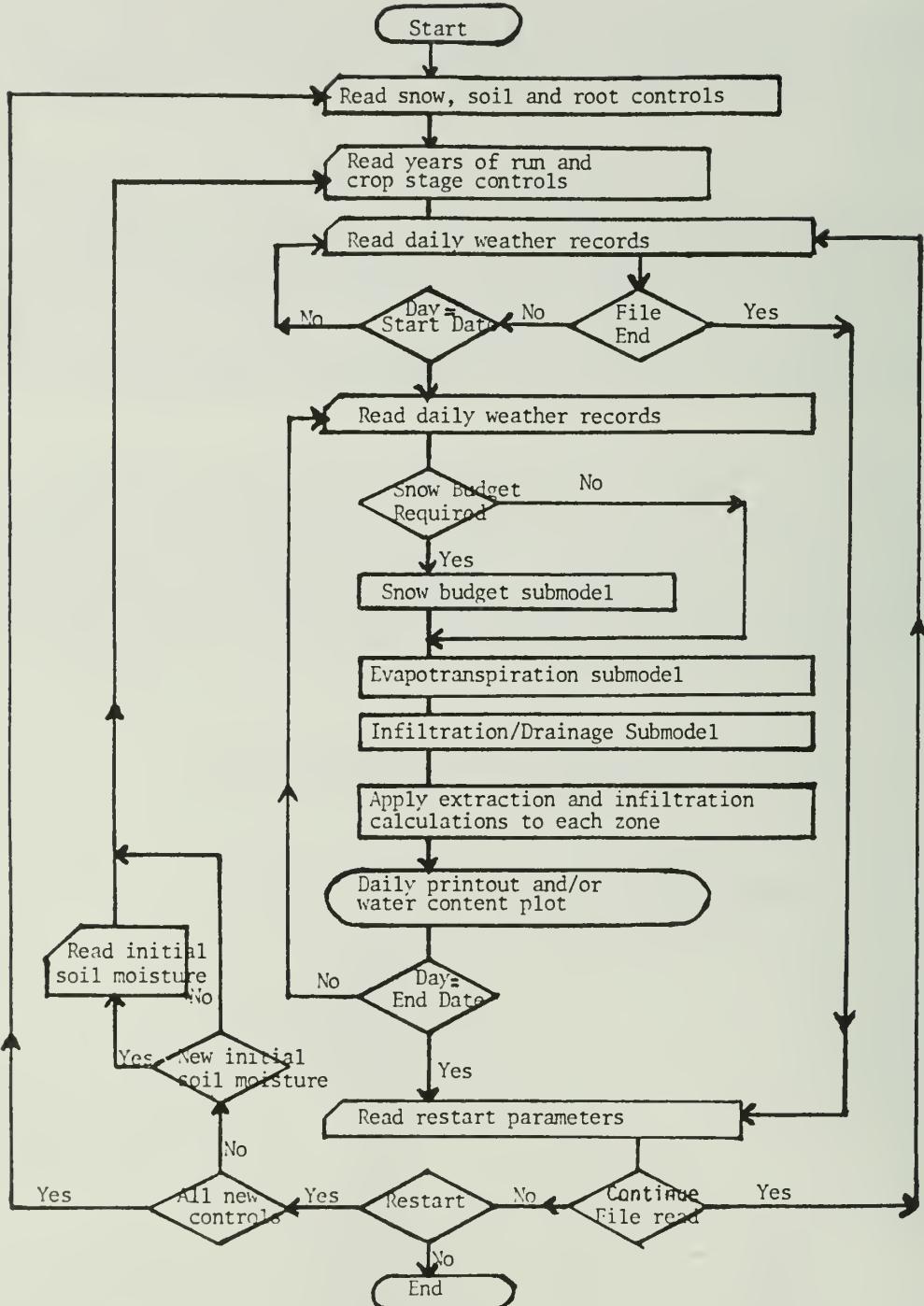


FIGURE A-1. VBIII PROGRAM FLOWCHART.

CPW63 - REVISED 1206 - Dyer
AS607.CPD.PENURAH.CPWB

REFINED CERAMIC CUFFLINGS

RESTART PARAMETERS-BLANK ON 1ST CARD
 1/2 UNITS-DAILY PRE-INTERCAFFEE IN S.M. PLOT
 BEGINNING DATE OF WINTER(SNOW) BUDGET
 ENDING DATE OF WINTER(SNOW) BUDGET
 RAIN/SNOW THRESHOLD TEMPERATURE-FALL
 RAIN/SNOW THRESHOLD TEMPERATURE-SPRING
 DRYING CURVE DATE
 & SNOWMELT BLOWING(CSNOW COEFFICIENT)
 SNOWMELT RATE TABLE
 DAYS PER MONTH
 DAILY SNOWMELT
 DRYING CURVE INDEX-PARAMETERS
 ZONES USING 1DIZ-TABLE
 1ST Z-TABLE (DRYING CURVE)
 2ND Z-TABLE
 2-TABLE READ/WRITE CONTROL
 AVAILABLE WATER CAPACITY OF EACH ZONE
 AVAILABLE WATER IN EACH ZONE AT START
 MOISTURE RESERVATION FOR EACH ZONE
 TOTAL VOID SPACE OF EACH ZONE
 SURFACE WATER AFTER FIRST DAY
 SLOPE/RUNOFF COEFFICIENT
 DRAINAGE RATE AND LIMITS
 NUMBER OF ZONES WEPT/DAY AFTER RAIN
 PERMANENT WILTING POINT
 BOLTZSCALING FACTOR
 AGRICULTURAL FACTORS
 TOTAL NUMBER OF ZONES
 K-COEFFICIENT(SNOW)


```

EXCAP(I)=EXCAP(1)-(C4*FAC(1)+(C4*FAC(1)+PRBLN(I)(1))
IF(CXCAP(1).LT.0.0) EXCAP(1)=0.0
2389 EXFRNT=EXCAP(1)
EXFRNT=EXCAP(1)
IF(I=2386.IE.1248 EXFRNT=EXFRNT+EXCAP(1)
EXFRNT=EXFRNT+EXCAP(1)
2386 CONTINUE
IF(I=1245 GO TO 2378
I=2377 I=1245
D=2377 EXCAP(I)=EXCAP(1)*2.0
2378 C1=C1+D
IF(CFRK(I)=0.0) DFK(I)=EXFRNT
IF(CDEW(I)=0.0) DFW(I)=DFK(I)
IF(CDK(I)=0.0) DRW(I)=DFK(I)
ORB=DR*(4)*U1
IF(DRS*(G1+U2) DRSS=1.0
IF(DRS*(H1+U2) DRSS=0.2
DR*(2)=DFR(I)/DRS
DFFCIT=0.
BYE=0.
I=2380 I=1245
IF(CSC(I)=0.0
IF(CCUM(I)*G1*CAPAC(I)) EXCSW(I)=COUNT(I)-CAPAC(I)
IF(CXCSV(I)*G1*EXCAP(I)) EXCSW(I)=EXCAP(I)
2385 COUNT=0
D=2385 I=1245
CAPAC(I)=EXCAP(1)/25.4
PRBLN(I)=PRBLN(I)/25.4
CFR(I)=UANP(I)/25.4
EXCAP(I)=EXCAP(I)/25.4
EXCSW(I)=COUNT(I)/25.4
001 COUNT(I)=COUNT(I)+1
FTP=1FTP
FTP=32.0+(1P*9.0/5.0)+.5
STP=1STP
ISIP=32.0+(1P*9.0/5.0)+.5
001 ISIP=1
CIR(I)=0.0
DR(I)=DR(I)/25.4
X(I)=0.0
SAONCF=SNOWCF(I)
SECCPF=SNOWCF(I)

C READING AND WRITING OF ZONAL COEFS. FOR THE RUN
C
READ(1,2)(COEFS(I,J),J=1,6),I=1,5
WRITE(3,2)(COEFS(I,J),(COEFS(I,J),J=1,6),I=1,5)
2 FORMAT(6S,2)
0139
0140
0141

```

MEASURING AND ASSESSING THE RISK CHARACTERISTICS

```

FORMAT(214,8,314)
LPC(SIGEST+15Y+EDK+NSY),LT,1) GO TO 252

```

READING AND WRITING THE CONTROL DATES FOR THE RUN
READ(1,3) (DUMARS(I),I=1,NUPDATE)
WRITE(3,0)(DUMARS(I),I=1,NUPDATE)
FORMAT(1,1,216)
FORMAT(14,9)
3

卷之三

R1=1.
 T1=0.
 I1=0.
 A1=0.
 S2=0.
 RES12=0.
 RFACT1=1.
 C1=1234
 D1=1234

P₁₂₃₀ = P₁₂₃₀(T₁₂₃₀) = 14.6
 S₂ = S₂+CAF₂(T₁₂₃₀)
 R₁₂₃₀ = R₁₂₃₀(T₁₂₃₀) = 0.001
 T₁₂₃₀ = T₁₂₃₀(P₁₂₃₀, S₂) = 1.601

```

IF P=1RTA-4
LIS=0
IF(C)DATE(1)=DATE(1300) GO TO 3169
GO 3159 DATE(1)=DATE(1)+1
DATES(1)=DATES(1)+SYR*10000

```

3150 CONSTNITUT
3150 CONSTNITUT
1F(CIDATES(CIDATEB)-(1R111*10000)).LT.1DATES(1)) IRT^q=1RT^q-1

REBUNDING UP DALLY DATA
ACCESSION # 25-4

YEAR	MILITARY TEMPERATURE	CIVILIAN TEMPERATURE
1941	DATE	DATE
	MAX (MAX)	MIN (MIN)
	27°C (21°C)	14°C (11°C)

234
444
111
000

PRECIPITATION
PREDICTIVE EVAPOTASSIMILATION

FESTLICHES GEBURTSTAG

7

```

22 COUNTS
DO 240 I=1,2
100 T(I)=DELT(I+1)
105 DATE(I)=DATE(J+1)
110 PGP(I)=PGP(I+1)
115 P(T)=PE(I+1)
120 FAN(T)=FAN(I+1)
125 MAX(I)=MAX(I+1)
240 CONTINUE

```

```

    PAX(3)=EAX
    PAX(3)=PIN
    PAX(3)=(PAX+P110)/2.0+.5
    ADI=ADI+1
    ADT=DATE(3)/100
    DAY=DATE(3)-ADT*100

```

LOADS	STAGE	DATES	CALL YEARS
SIGHT	STAGE	DATES	COUNTER
101	YEAR / MONTH / DAY	OF DAILY CALCULATIONS	
151	YEAR / MONTH / DAY	OF DAILY STAGE	
151	YEAR / MONTH / DAY	OF DAILY STAGE	

TABLE I. SUGGESTED TEMPERATURES FOR THE ESTIMATION OF SPACES.

$$\text{MAX}_m = (\text{MAX}(1) + \text{MAX}(2) * 2 + \text{MAX}(3) * 3) / 6.$$

APPLIED ECOLOGY

SUGAR AND CANCER

CALCULATION OF EQUIVALENT OF SAME PACK AND HOLDING CAPACITY

$\text{P}(\text{E} \mid \text{S}) = \frac{\text{P}(\text{S} \mid \text{E}) \cdot \text{P}(\text{E})}{\text{P}(\text{S} \mid \text{E}) \cdot \text{P}(\text{E}) + \text{P}(\text{S} \mid \text{E}^c) \cdot \text{P}(\text{E}^c)}$

CALCULATED, APPLICABLE CURVE AND POTENTIAL DAILY MELT
IN SNOWPACK FOR SNOW BUDGET IN EFFECT
DURING SNOWPACK AFTER BLOW-BUFF
TYPICAL DEFICIENCY (ALL ZONES)
TOTAL CAPACITY
MELTWATER RETAINED IN THE SNOWPACK
DAILY SNOWMELT
ACCOUNTED SNOWMELT IN THE SNOWPACK

LFC(MAX(3)) = 5.74750 FDI = 310
 LFC(MAX(3)) = 5.74250 TDI = 330
 LFC(MAX(3)) = 5.73750 GDI = 350

22345678
22222222
22222222
00000000

6229

023323 022223
000000 000000

0236

12345678
9876543210

0247

```

JF=1
G1 TU JFJ
310 JF=4 JFJ
330 JF=3 JFJ
350 JF=2 JFJ
360 GJ TINIE

C CARRY SNOWPACK FUGITIVE
      L=JF
      J=ENDTH
      JD=AG(I,J,J+1)
      IF (1DAY.GT.22) LD=(AG(I,J+2)+AG(I,J+1))/5
      IF (1DAY.LT.5) LD=(AG(I,J+1)+AG(I,J))/5
      P2=0.0
      IF (MAX(3)*LD*32) P2=0.0
      F2=LD
      R2=LD

C CALCULATE RETENTION AND ACTUAL LOSS TO SNOW PACK
      A1
      R1
      R2
      F1
      S1
      R1=H1
      R2=H1
      +35 IF(E1*LE*0.2) E1=E0.2
      IF(E1*GT*F2) E1=E0.2

C CALCULATE INfiltration, runoff and soil moisture deficit
      A1=E1
      F1=1.
      T1=0.
      EXFRIT=0.
      D0 1250 I=1 1000
      I1=T1+EXFSW(I)
      EXFRIT=EXFRIT+EXCAP(I)
      1260 CONTINUE
      I1=I1/EXFRT
      IF (DATE(3).LT.JSET) AND (DATE(3).GT.700) T1=0.
      D2=D1-A1
      D2=D2

0254 0255 0256 0257
0258 0259 0260 0261 0262 0263 0264 0265 0266
0267 0268 0269 0270 0271 0272 0273 0274 0275
0276 0277 0278 0280 0281 0282 0283 0284 0285 0286
0287 0288 0289 0290 0291 0292 0293 0294 0295 0296
0297 0298 0299 0300 0301 0302 0303 0304 0305 0306
0307 0308 0309 0310 0311 0312 0313 0314 0315 0316
0317 0318 0319 0320 0321 0322 0323 0324 0325 0326
0327 0328 0329 0330 0331 0332 0333 0334 0335 0336
0337 0338 0339 0340 0341 0342 0343 0344 0345 0346
0347 0348 0349 0350 0351 0352 0353 0354 0355 0356
0357 0358 0359 0360 0361 0362 0363 0364 0365 0366
0367 0368 0369 0370 0371 0372 0373 0374 0375 0376
0377 0378 0379 0380 0381 0382 0383 0384 0385 0386
0387 0388 0389 0390 0391 0392 0393 0394 0395 0396
0397 0398 0399 0400 0401 0402 0403 0404 0405 0406
0407 0408 0409 0410 0411 0412 0413 0414 0415 0416
0417 0418 0419 0420 0421 0422 0423 0424 0425 0426
0427 0428 0429 0430 0431 0432 0433 0434 0435 0436

```

0267 0281 0289 0290 0291 0292 0293 0294 0295 0296 0297 0298 0299 0300 0301 0302 0303 0304
 ACCSN=1 R2=E1=41
 A1=WL-B1 IFC(W1*B1+0.2)*W1=0.1 IF((MAX(3)*L1+32)*T2=0. T2=0.437
 IF((MAX(3)*L1+20)*T2=0.437

CALCULATION RATE ADJUSTMENT DUE TO FREEZING OF SOIL

F1=1.0-T1
 +37 EXECUTE=A1
 SUBRTE=R2
 GO TO 141

SUGAR PLUGGER COEFFS

CALCULATING EFFECT OF FE DEMAND RATE

101 CNT=101*(s)/100
 ACCSN=0.
 AVE=0.
 IS=0

F1=1.0-CoeffF=1.0
 SGNDEI=0.

141 SGNDEI=0.

COMPUTATION OF THE PLUGGER DEPLETION FROM EACH ZONE
 TOTAL PLUGGER DEPLETION
 SURFACE PLUGGER
 RELATIVE PLUGGER COEFFICIENT OF EACH ZONE
 ADJUSTED K-COEFFICIENTS

IF(CACCS>0.1) P1=(3)=0.
 UN1=101*I1,L1,S
 DEL=COMPUT(I1)/CAFAC(1)
 CAF(1)=CUP(S(I1),1)
 SIF(ST*H1,SE*G1)*P1
 IF(1.0*1.0)>TU 98
 OR 96 J=2,I
 K=U=1

ADJUSTING SURFACE PLUGGER COEFFICIENT FOR STRESS

0313
 0314
 0315
 0316
 0317
 0318
 0319
 0320

99 COF(I1)=CUP(I1)+CAF(1)*COF(s)*(1.0-CUN*P(K))/CAFAC(K)
 98 U=DEL*I1,G1
 11F(I1*GT,0.0)GU 10 102
 AND K=100
 102 CHECK(KRUL*0.1*0) GO TO 103
 11F(I1*GT,KRUL) GO TO 104
 10K=TABLE1(KT)

10. $\text{PDL} = \text{PDL} * \text{PDL}(3) * \text{CUT}(1)$
 $\text{IF}(\text{PDL} * \text{G1} * \text{CUT}(1)) \text{DEL} = \text{CUT}(1)$
 $\text{DELT}(1) \text{DEL}$
 11. $\text{SPLIT} = \text{SPLIT} + \text{DELT}(1)$

```

2320      EX10=EXT10+EXCSW(1)
           CSAT=DR(4)
           IF(CSAT.GT.CSAT) EXIT11=EXIT11+(EXT10-CSAT)
           IF(CSAT.LT.CSAT) EXIT10=CSAT
           CONTINUE
2330      DC 2330 1=1 Y 12
           XCAP=CAPAC(1)-CAPAC(1)
           IF(XCAP.LT.0.0) XCAP=0.0
           XCAP=XCAP+DELTA(C1)
           IF(XCAP.GE.1.0) XCAP=1.0

```

```

X(1)=X0
IF(X(1)=X0) EXTR=0.0
CONTINUE
2330
EXF=EXF/2.0*4
IF(EXF>0.0) EXP=EXP/10./EXP
IF(1.0>EXP) EXP=1.0
IF(1.0>EXF) EXF=1.0
IF(XD*G1*EXTR)>=X0
EXTR=EXTR-XD
IF(CS(1)=GT.0) RUL=RUL+EXTR
IF(CS(1)=LT.0) RUL=RUL-EXTR
IF(YE1)
YE1=TEPV
YR=POU+AYR
AC=PCSN(1)/ECAF(1)
AC=(2.*0.*YC)/3.0
CSLP=SHP*SC
PBNDFP=SPD*CSLP
IF(PBNDFP>0.0) PBNDFP=0.0
PBNDFP=POU
EXTR=EXTR-PBNDFP
CSATE=RE(1)*R1
IF(CSAT>CSAT) CSAT=CSAT
POU=POU-EXTR
EXTR=EXTR-EXTR
AYE=EXTR
EXF=EXF-RT
GO TO 2330
2340
CONTINUE
2350
CONTINUE
C 210 RUL=0.
C
C APPLYING PRECIPITATION AND EVAPORATION TO EACH ZONE
C
2360
DO 2361 LZ=1,LZS
CONT(1)=CONT(1)-POU*(1)+X(1)
IF(CONT(1).LT.0.0) CONT(1)=0.
2361
CONT(1)=
E1=EL*25.4
PCP(3)=2*CP(3)*25.4
POU=POU*25.4
SHP=SHP*25.4
TOPD=0.0
I1=0
DO 505 LZ=1,LZS
CONT(1)=CONT(1)+EXCSN(1)
0363 00005440
0364 00005450
0365 00005460
0366 00005470
0367 00005480
0368 00005490
0369 00005500
0370 00005510
0371 00005520
0372 00005530
0373 00005540
0374 00005550
0375 00005560
0376 00005570
0377 00005580
0378 00005590
0379 00005600
0380 00005610
0381 00005620
0382 00005630
0383 00005640
0384 00005650
0385 00005660
0386 00005670
0387 00005680
0388 00005690
0389 00005700
0390 00005710
0391 00005720
0392 00005730
0393 00005740
0394 00005750
0395 00005760
0396 00005770
0397 00005780
0398 00005790
0399 00005800
0400 00005810
0401 00005820
0402 00005830
0403 00005840
0404 00005850
0405 00005860
0406 00005870
0407 00005880
0408 00005890
0409 00005900
0410 00005910
0411 00005920
0412 00005930
0413 00005940
0414 00005950

```


13.3 SMOOTHING TECHNIQUE

```

456 COUNT(I)=COUNT(J)=XCSD(I)
457 COUNT(I)=0
458 FORMAT(3,4)000+1,1N+(3)
459 I=I+1
460 IF(I>UNIT+1) RUNIT=X0)UNIT+1
461 P=235,I=I,IZS
462 X(I)=0
463 INITIALIZING DATA FILE NEXT DATE AND SMOOTHING TECHNIQUE
464 K1=0,K2=0.
465 A(YE)=0
466 G1=0,0
467 G2=0,0
468 F1=0,0
469 F2=0,0
470 C 471 JF RUE CACER
471 IF(CURR(3,0).LT.YR) GO TO 241
472 GO TO 22
473 C 474 ORIGIN OF SMOOTHING
474 AND SMOOTHING PERIOD
475 C 476 CHARTING
476 C 477 DAY REQUEST NUMBER
477 IF(CURR(3,0).LT.DYS) GO TO 3110
478 IF(NYR.LT.DYS) GO TO 3110
479 D=3120,I=1,ICALE
480 DATES(I)=DATES(I)+(19000*IREW)
481 KOUNT=1
482 KEST=2
483 IFC(RST(1,LT,1)) GO TO 3132
484 RLT(3,2125)
485 FORKAT(2,1,RESTAR)
486 WAIT(2,3095) {0,0=1,10}
487 ARIT(2,3095) {0,0=1,10}
488 NFAC=1
489 ACCSN=SUSIR#*1
490 I=ACCSN/25*4
491 I=3130,I=1,1ZNS
492 COUNT(I)=CONFST(I)
493 COUNT(I)=UPDATE(I),I=((NYR+1)*190000)) GO TO 20
494 COUNT(I)
495 C 496 WRITE(18,3095) (J,J=1,10)
497 FORMAT(9A,10I10)
498 I=3080,I=1,1ZNS
499 BDFEEDBDFEED(I)=TOPG

```

```

0435 PCN1=PRW(1)/LB15
0436 PCN2=(CAPAC(1)/LB15)+PCN1
0437 PCN3=(EXCAF(1)/LB15)+PCN2
0438 TOEOF6=01&PWH(1)
0439 WRITE(3985,1) PCN1,PCN2,PCN3
0440 3985 FORMAT(15,3F10.5)

C   FILE CONTROL DATA FILE
C
C   0502  G7 TU 2527,END=259)NR,LB,1SEN,JP,LIT,IP,HEAD
C   0503  READ(1,254
C   0504  G7 TU 254
C   0505  COUNTING
C   0506  READ(1,987,END=253)FILE,1SEN,JP,LIT,IP,HEAD
C   0507  WRITE(3,987)FILE,1SEN,JP,LIT,IP,HEAD
C   0508  IF(1SEN.EQ.1) GO TO 3192

C   READ CHARACTER FILE FILE
C
C   0509  LF(1SE,OUT,2.0E,1SEN,61.5) GO TO 3196

C   FILE STARTING SOIL MOISTURE
C
C   0510  RFAND1,'SO2')C1NR$1
C   0511  ARITE(3,292)C1NR$1
C   0512  DO 3194 I=1,12NS
C   0513  C1NR$1(I)=C1NR$1(I)-PRK,WLF(I)
C   0514  C1NR$1(I)=C1NR$1(I)/25.4
C   0515  IF(C1NR$1(I).GT.CAPAC(I)) C1NR$1(I)=CAPAC(I)
C   0516  3193 C1NR$1(I)=C1NR$1(I)
C   0517  CONTINUE
C   0518  ACCSNES$1,I
C   0519  41=ACCSN$1/25.4
C   0520  3194 I=1,12NS
C   0521  C1NR$1(I)=C1NR$1(I)
C   0522  IF(C1NR$1(I).GT.99) GO TO 29
C   0523  IF(C1NR$1(I).LT.1) GO TO 3190
C   0524  CONTINUE
C
C   3192 C1NR$1(I)=C1NR$1(I)
C
C   FILE CONTROLS AND WEATHER FILE
C
C   0525  LF(NELT+1,0) GO TO 9997
C   0526  259 WRITE(3,5)
C   0527  259 FORMAT(1IH END OF RUN)
C   0528  251 CALL EXIT
C   0529  END

```

ZONE/DEPTH CONVERSIONS

CP242D - BASED ON R242 FROM AGMET
 IT CONVERTS ANY DEPTH RELATED VARIABLE TO THE DESIRED
 ZONE BASIS FOR VARIOUS SOILS. THESE INCLUDE DEPTH TO THE
 BOTTOM OF ZONES, WATER HOLDING PROPERTIES
 AND K-COEFFICIENTS.

INPUT: IZNS = NUMBER OF ZONES AS PER CENT OF TOTAL DEPTH.
 STNDRD = NO. OF SETS OF OBSERVATIONS
 NODAT = NO. OF DEPTHS OBSERVED IN PROFILE, NOT TO EXCEED 6.
 DEPTH = DEPTH OF SOIL IN EACH DEPTH
 CAPT = CAPACITY OF EACH OF THE DEPTHS
 CARS = OBSERVED VALUE OF EACH OF THE DEPTHS
 DIMENSION DEPTH(6),CAPD(6),DZONF(6),OPS(6),DHZ(6)
 DIMENSION X(6),Y(6),Z(6),STNDRD(6)

```

 120 READ(1,1) STNDRD,IZNS
 11 FORMAT(16F5.3,5X,15)
 1 IF(IZNS.LT.1) GO TO 110
 1 IF(IZNS.LT.2) IZNS=2
 DO 130 I=1,6
 DZONE(I)=0.0
 130 READ(1,1) NODDE,DEPTH,CAPD
 1 FORWAT(2I4,12F6.2)
 1 TCAPC=CAPD(1)+CAPD(2)+CAPD(3)+CAPD(4)+CAPD(5)+CAPD(6)
 DO 142 I=1,IZNS
 1 CAPZ(I)=TCAPC*STNDRD(I)
 12 CONTINUE
 12 WRITE(3,7) CAPZ
 7 FORMAT(16F5.1)
 1 J=1
 DO 9 I=1,IZNS
 9 X(I)=CAPZ(I)
 Y(I)=CAPD(I)
 Z(I)=DEPTH(I)
 9 DO 15 I=1,IZNS
 5 IF(Y(J).GT.X(I)) GO TO 10
 DZONE(I)=DZONE(I)+Z(J)
 X(I)=X(I)-Y(J)
 J=J+1
 10 GO TO 5
 10 XYZ=X(I)/Y(J)*Z(J)
 DZONF(I)=DZONE(I)+XYZ
 Z(J)=Y(J)-XYZ
 Y(J)=X(I)
 15 CONTINUE
 DO 20 I=2,IZNS
 20 DZONE(I)=DZONE(I)+DZONE(I-1)

```

CCCCCCCCCCCCCCCCCCCC

00001
 00002
 00003
 00004
 00005
 00006
 00007
 00008
 00009
 00010
 00011
 00012
 00013
 00014
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 00035

```

0036 DEPTH(I)=2*DEPTH(I)+DEPTH(I-1)
0037 WRITE(3,2) DZONE(NON,DEPTH,NDTF
2   FORMAT(2(6F6.2))
0040 K=1,NDTF
0041 READ(1,6)(ORS(I),I=1,6)
0042 FORMAT(6F6.2)
0043 FORMAT(8X,6F6.2)
0044 DO 35 I=1,6
0045 IF(OBS(I).LE.0.) OBS(I)=0.
0046
0047 OBZ(I)=0
0048 WRITE(3,3) OBS
0049 TON=0.
0050
0051 C      DEP=0. I=1 IZNS
0052      CALCULATE CONTROL VALUES IN ZONE AND WRITES AS CPVB3 INPUT
0053      IF(DZONE(I).GT.DPTH(J)) GO TO 50
0054      PDBZ=(DZONE(I)-DEP)/(DEPTH(J)-DEP)*OFS(I)
0055      OBZ(I)=OBZ(I)+PDBZ
0056      OBS(J)=OBS(J)-PDBZ
0057      GO TO 60
0058      OBZ(I)=OBZ(I)+OBS(J)
0059
0060      J=J+1
0061      DEP=DEPTH(J-1)
0062      GO TO 40
0063      TON=TON+OBZ(I)
0064      WRITE(3,4) OBZ(TON
0065      4 FORMAT(6X,7F6.2)
100      CONTINUE
0066      GO TO 120
110      CONTINUE
CALL EXIT
END
0067
0068

```

Table B-1. CP242D Program Sample Output

12.7	12.7	13.4	12.7	2.6	1.50	4	6.23.00	53.00114.00193.00300.00452.00	3	
8.14	16.22	35.0	7.8	8.0	1.58	4	6.23.00	53.00114.00193.00300.00452.00	3	
12.66	9.0	1.950	1.8	2.0	1.2	52.00	6.23.00	53.00114.00193.00300.00452.00	3	
12.66	1.6	39.76	1.9	5.6	2.6	6.27.0	6.23.00	53.00114.00193.00300.00452.00	3	
11.18	4.0	34.40	1.56	1.01	3.2	7.01.44	6.23.00	53.00114.00193.00300.00452.00	3	
4.17	6.54	0.63	3.7	2.3	9.0	3.21.94	6.23.00	53.00114.00193.00300.00452.00	3	
1.14	5.0	3.8	8.0	1.02	2.0	1.091.03	6.23.00	53.00114.00193.00300.00452.00	3	
5.1	1.38	6.7	6.2	5	4.5	1.145.1	6.23.00	53.00114.00193.00300.00452.00	3	
36.5	36.5	36.5	36.5	5.9	7.3	7.01.49	6.23.00	53.00114.00193.00300.00452.00	3	
10.42	20.0	8.4	4.5	5.6	5.6	0.62	6.01.30	6.23.00	53.00114.00193.00300.00452.00	3
36.46	36.46	39.46	35.8	3.24	3.6	4.67.5	6.23.00	53.00114.00193.00300.00452.00	3	
13.1	20.1	1.8	5.0	5.8	3.01	7.8	9.01.85	6.23.00	53.00114.00193.00300.00452.00	3
59.4	43.65	0.2	6.3	4.4	3.65	6.21.00	6.23.00	53.00114.00193.00300.00452.00	3	
24.2	20.26	8.0	3.9	7.2	0.5	7.04.7	7.60	6.23.00	53.00114.00193.00300.00452.00	3
10.96	1.1	6.9	1.4	0.7	1.5	5.84.4	6.361.	2.7158.50	5	
67.0	67.0	71.0	6.7	1.03	8.0	2.66.5	6.18.00	51.00104.00178.00300.00452.00	3	
17.75	5.6	67.9	0.93	6.6	2.0	8.02.8	6.452.00	6.18.00	51.00104.00178.00300.00452.00	3
66.95	6.95	6.6	9.5	7.1	0.1	6.69.5	1.379.7266	6.4676.30		
11.05	3.05	3.0	7.5	1.01	0.3	0.06.98	0.021.8701	3.110		
10.3	8.3	7.6	2.5	8.1	6.7	0.70.99	2.013.94.8259	3.35731.10		
4.0	3.9	0.4	7	7.0	6.3	2.0.71.801.63	2.01.70.1	2.70		
40.3	33.48	0.1	3.5	0.32	2.4	8.01.03.42197.	4.0488.50			
9.9	9.9	10.5	1.9	9.2	0.4	3.94				
20.01	4.3	7.9	8.0	7.1	1.0	0.81.18.	9.44.06.	6.07.60		
0.63	0.63	0.50	0.50	0.120	0.015	0.08.	0.050	0.050		
0.66	0.66	0.50	0.50	0.225	0.023	0.08.	0.040	0.050		
0.64	0.64	0.50	0.50	0.22	0.014	0.015.	0.0220	0.0150		
0.66	0.66	0.50	0.50	0.23	0.015	0.015.	0.03150	0.0150		
0.64	0.64	0.50	0.50	0.22	0.011	0.018.	0.07150	0.01150		
0.66	0.66	0.50	0.50	0.23	0.015	0.025.	0.02200	0.01180		
0.64	0.64	0.50	0.50	0.23	0.015	0.020.	0.01040	0.01140		
0.61	0.61	0.20	0.20	0.25	0.025	0.020.	0.01200	0.01200		
0.61	0.61	0.20	0.20	0.13	0.013	0.010.	0.0150	0.0150		

APPENDIX C
RUN CONTROL DATA

The following section describes and lists (Table C-1) the input controls to VBIII. The definition of the input variable names are given in comment statements within the program. Table A-1 allows the user to relate the controls back to the main text. They are listed here according to the particular input record that each appears on and the position in that record. Each record is a punch card, or a card image, and is 72 characters in length. Table C-1 lists the input parameters according to a numbered set of controls, each of which consists of one or more records. Each input record is also specified. Detailed instructions for each input variable are listed in Table C-2. Sample input control files are provided in Table C-3 for two different soil textures. The following description is intended for users who have some familiarity with computer programming in Fortran, but the user does not necessarily need to be proficient.

Numbers in brackets following some variables define the dimensions of the non-scalar variables. Single numbers give the length, or total possible number of entries for vectors. For example CAPAC(6) stores field capacity for zones 1 to 6. The variables followed by two numbers within brackets, separated by a comma, are matrices. For example in COEFS(5,6) there are 5 rows (one for each possible growth stage) and 6 columns (up to 6 zones). Each row is a new card (or card image).

The control parameters fall into two categories depending on whether they are integer or non-integer (real) numbers. Following the standard conventions, variable names starting with any letter I through N are integers. All other variables are real numbers, except for HEAD, which is a title. For real number inputs the location of the decimal points is specified.

The formats for all input control records are also shown in Table C-1. The letters in format statements, I,F and A designate input variables as integer, real and alphanumeric (title card) respectively. The number to the left of each letter indicates the number of variables read by each format, the number to the right indicates the length of record required by each variable (or element in the variable) and for real numbers, the number following the decimal indicates the number of places after the decimal. Blank spaces are indicated by Xs.

Soil Description

To describe a particular soil, the drying, drainage and water holding characteristics must be defined. The depth of soil and the zoning patterns must also be specified. The index for drying rates is enacted by defining two sets of parameters in Controls 3 and 5. These are M9, N9, H9, and R9 , based on parameters m,n, h and R in Table 1 of the main text. Records 4 and 6, which allow the z-tables to be read in, as in the previous version, are optional and can be omitted. These z-tables are given in Table E-2. Writing of z-tables is controlled by K in record 3 (not to be confused with k-coefficients described in the main text).

For K equal to any integer other than zero, z-tables are printed. A blank card for sets 3 and 5 causes the z-tables to be read-in requiring 10 cards each for controls and 4 and 6. Controls 3 and 5 cause z-tables to be generated internally. KNTROL defines the number of zones using the first z-table. For the option of using the second z-table to differentiate active root conditions from fallow conditions (see Alternate Drying Curves: Main text) KNTROL = 7.

Soil Water Holding Properties

Water holding properties include the saturation level (EXCAP), the field capacity (CAPAC) and the permanent wilting point (PRMWLT) of each zone. The number of zones (or soil layers) is defined by the number of elements in CAPAC (control 7). To describe a four-zone budget for example, supply values for the first four elements of this vector and leave the last two blank. If more than four values are provided in any parameters on controls 8 to 10 they will be ignored. If fewer than four values are provided zeroes will be substituted for the missing values. The actual depth (cm) to the bottom of each zone from the surface is defined in OBDPTH (control 10). These values are required to printout soil moisture contents on a percent volumetric basis or to plot them. The dimensions of the plot are controlled by SCL and IHOR which are described in Appendix D.

The infiltration/drainage function is controlled by the three maximum daily drainage amounts (DRN(1-3)), the fractional coefficient for drainage out of drainage layer 1 (DRN(4)) and by the number of zones in the top drainage layer (IFRNT). Other important factors are the actual depth of drainage Layer 1 and the differences between saturation and field capacity (EXCAP and CAPAC respectively). Default values for DRN and IFRNT are built into the program, so these can be left blank. TRP and SSLP are experimental parameters used to describe surface water and runoff rates and should be used with caution. TRP is the average depth of surface water trapped in depressions and not available for surface runoff. SSLP determines the rate of runoff. All infiltration/drainage parameters are supplied on Control number 9.

Crop Growth and Root Characteristics

The table of root coefficients is entered by zone and crop growth stage in COEFS (Control 11). When less than six zones are used, say four, then only four k-coefficients for each growth stage are required. The number of k-coefficients per stage should not affect the consumptive use factor assumed for each stage. A control card is required for each of the five growth stages, but these can be blank. Five are needed because Control 11 is always read in by five read steps or lines.

The crop stage dates are entered by reading the array IDATES in Control 13. Not all crop growth stage dates in the run are required as input unless they are all unique. If the dates are repeating from one year or group of years to the next then the dates specified in IDATES can be re-used. This feature can be used to reduce the required input for two-year (or more)

rotations. For example, when the number of stages read-in (ISTGES) is 10 and the number per year (NSY) is 5 (control 12), a repeating two-year rotation is given when the total number of years is greater than 2. The span of years analysed is set by ISYR and NDYR (Control 12). When the starting (ISYR) and ending (NDYR) years are given, only the month/day is required for each stage date, rather than the year/month/day. A typical stage date of June 15, 1963 would be read-in as "630615" or simply as "0615", if ISYR is specified. When stage dates are non-repeating throughout the run, then all dates can be entered in a string (12 dates per record), provided that the total number does not exceed 65 and is one more than the specified number of stages to be read (ISTGES).

Snow Budget

To enact this submodel, spring and fall termination and initiation dates and threshold temperatures are required. Two coefficients giving the fraction of daily snowfall added to the snowpack after blow-off are entered as SMCOF. The date for converting from the first to the second coefficient (KSNO) can be specified. A bypass (NOSNO) for the snow submodel is also available. All controls for this submodel are on control 2.

Restart Options

A feature of VBIII, which was developed to satisfy a variety of multi-weather file applications, is the flexibility in the restart procedures. The options include the ability to analyse (1) a complete weather file with only one set of controls being specified in the budget; (2) more than one segment of a weather file, skipping periods within a file, with only the crop stage dates and run dates (ISYR and NDYR) being re-specified; (3) multiple weather files with a new set of controls for each file; (4) multiple weather files with the original set of controls; (5) multiple weather files with the original controls, but the initial moisture contents being re-defined for each file; (6) multiple weather files with only the crop stage and start/end dates re-defined for each file; and (7) multiple weather files with both initial soil moisture and control dates being re-defined without changing other controls. These options are illustrated in the program flowchart in Figure A-1.

The restart options are controlled by the variables NFLE and ISEN (controls 1 and 14). The soil moisture contents are re-initialized after the last specified stage date (i.e. end of rotation) by reading CONRST on control 15. An integer value must be specified for MRST1 (on Control 8), otherwise soil moisture is re-initialized at the end of each rotation without re-defining other controls or skipping any weather records. NFLE and ISEN can be left blank on the first control record, but are re-entered at the end of the program.

The re-start control parameters are specified as follows: NFLE can be 0 or 1, ISEN can be 0, 1, 2 or 99 and MRSTI can be 0 or 1. For NFLE = 0 and ISEN = 99 the program reads, but doesn't compute, to the weather file end, and then reads a new NFLE and ISEN. For NFLE = 0 and ISEN = 1 the program re-initializes with the original starting moisture contents, whereas when ISEN = 2 a new set of starting moisture contents is read-in. When NFLE > 0 the program reads a complete new set of controls and ISEN is over-ridden.

Another option is to enter the control coefficients in two files. When record number 14 is not provided, the program looks for another record 14 if an end of file is encountered. The new record must be supplied in a new file. This feature is useful when the budget is applied to a number of sites or weather data files with one set of controls which may be altered or replaced.

TABLE C-1. Control data required to run VBIII, specified by the sequence of records, variable names and the format of each record

<u>CONTROL NUMBER</u>	<u>VARIABLE NAMES AND DIMENSIONS</u>	<u>INPUT FORMAT</u>	<u>RECORD FORMATS REPEATED</u>
1	NFLE, ISEN, NP, INT, IP, HEAD(57 characters)	(5I3,14A4, A1)	
2	ISFL, IESG, IFTP, ISTP, SMCOF(2), NOSNO, KSNO	(4I6, 6X, 2F10.5, 2I5)	
3	M9, N9, H9, R9, K, KNTROL	(2I5, 2F10.5, 2I5)	
4	TABLE 1(100)	(10F5.2)	x10
5	M9, N9, H9, R9, K	(2I5, 2F10.5, I5)	
6	TABLE 2(100)	(10F5.2)	x10
7	CAPAC(6)	(6F5.1)	
8	CONTNT(6), SNSTR, PESTR, MRST1, IDRN, NDRN	(6F5.1, 5X, 2F5.1, I5, 10X,2I5)	
9	EXCAP(6), TRP, SSLP, DRN(6), IFRNT*	(14F-5.1, I2)	
10	PRMWLT(6), OBDPTH(6), SCL, IHOR	{ 6F 5 1,5X, 6F5.1, F5.2, I2}	x5
11	COEFS(5,6)	{6F5.2}	
12	ISTGES, NEW, ISYR, NDYR, NSY	(2I4, 8X, 3I4)	
13	IOATES(65)	(13I6)	x(1 to 5)
14	NFLE, ISEN, NP, INT, IP, HEAD(57 characters)	(5I3, 14A4, A1)	
15	CONRST(6)	(6F5.1)	
16	ISTGES, NEW, ISYR, NDYR, NSY	(2I4, 8X, 3I4)	
17	IDATES(65)	(12I6)	x(1 to 5)
18	***blank card to end job***	---	

Note: that controls 4, 6, 14, 15, 16 and 17 are all optional and can be omitted.

*Leave DRN(5) and DRN(6) blank

TABLE C-2. CONTROL INPUT INSTRUCTIONS

CONTROL NUMBER	FORMAT	VARIABLE DESCRIPTION
-------------------	--------	----------------------

1	COL 1 TO 6 7 TO 9	IF E, LEN: RESTART PARAMETERS, LEN=0 ON FIRST CARD NF : OUTPUT UNIT OF THE DAILY PPOINT
		ALL THE INPUT RECORDS OF THE CONTROL FILE ARE PRINTED ON UNIT 3
10 TO 12	INT	INPUT UNIT FOR THE WEATHER DATA FILE FORMAT: (7,12,14,2F4.1,2F4.1,1I3,F4.1) INTENT, LOCATE, PAX, FIN, PPF, PE
		IDENT: YEAR
		DATE: MONTH, DAY
		PAT : DAILY MAXIMUM TEMPERATURE (C)
		FIN : DAILY MINIMUM TEMPERATURE (C)
		SIF : DAILY PRECIPITATION (MM)
		PE : DAILY POTENTIAL EVAPOTRANSPIRATION (MM)
12 TO 15	IF	OUTPUT UNIT FOR THE SOIL-MOISTURE PLOT
12 TO 60	HEAT	TITLE CONSISTING WITH 56 CHARACTERS
2	COL 1 TO 2 7 TO 12	IEFL : BEGINNING DATE OF WINTER (SHOULD) BUDGET. SEE TABLE 2. IESG : ENDING DATE OF WINTER BUDGET. SEE TABLE 2
	12 TO 12	ISTP : RAIN SNOW THRESHOLD TEMPERATURE FOR FALL
	15 TO 24	ISTP : RAIN/SNOW THRESHOLD TEMPERATURE FOR SPRING. SEE TABLE 2 IN TEXT
	21 TO 50	SMOF : % OF SNOW REMAINING AFTER BLOW-OFF (2 VALUES) WHEN THE SOIL SURFACE CONDITIONS ARE NOT CHANGING BETWEEN 2 WINTERS, SMOF(1) SHOULD HAVE THE SAME VALUE AS SMOF(2).
		SMOF(1) IS FOR SNOW BLOW-OFF IN THE FIRST WINTER WHILE SMOF(2) IS FOR THE SECOND WINTER. SMOF(1 OR 2) HAS A HIGH VALUE (.0.7) FOR A GROUND COVER (SOIL OR STUBBLE) AND A LOW VALUE (.2.5) FOR EARLY SOIL.
COL 51 TO 55	NOSH	: THE SNOW SUPPLY/EVAPAGE =0 : CALCULATION OF THE SNOW BUDGET =1 : BYPASS THE SNOW BUDGET
56 TO 60	FEND	: SNOW BLOW DATE CHANGE. FINES THE DATE AFTER WHICH SMOF(2) WILL BE USED INSTEAD OF SMOF(1). SUGGEST KEND=070! FOR NORMAL CROP GROWTH.

7 COL : TO 32 MC, NO, HF, P7 DRYING CURVES IN GEM PARAMETERS. SEE TABLE 1
 IF NO=N7=Q, THE ORIGINAL Z-TABLES WILL BE USED (APPENDIX E-2)
 NO AND NO ARE 0 OR 1

31 TO 36 K : Z-TABLE WRITE CONTROL
 I=Q NO PRINTING
 I=1 PRINTING ON UNIT 7 OF THE DRYING CURVES AS CALCULATED OR READ

37 TO 41 KNTROL : NUMBER OF ZONES USING THIS FIRST DRYING CURVE
 KNTROL=7 THE SECOND TABLE RECORDS 4 AND 5 WILL BE USED ONLY FOR FALLOW CONDITIONS
 KNTROL=5 DEFAULT VALUE

GPT 4 COL 1 TO 50 TABLE1 : OPTIONAL Z-TABLES
 THESE RECORDS AREN'T REQUIRED IF Z-TABLES HAVE TO BE CALCULATED FOLLOWING EQUATION 2

5 SAME MEANING AS FILE CONTROL NUMBER 3. KNTROL DOESN'T HAVE TO BE DEFINED.

GPT 5 SAME MEANING AS CONTROL NUMBER 4

7 COL 1 TO 30 CAPAC : FIELD CAPACITY (MM) FOR EACH ZONE,
 E.G. FOR 4 ZONES, CAPAC(5) AND CAPAC(6) CAN BE BLANK

8 COL 1 TO 30 CONHT : INITIAL SOIL-MOISTURE CONTENT IN EACH ZONE (MM)
 35 TO 46 SNSTR : INITIAL ACCUMULATION OF SNOW ON GROUND
 41 TO 45 PESTR : VALUE OF POTENTIAL EVAPOTRANSPIRATION
 . . .
 =Q POTENTIAL EVAPOTRANSPIRATION IS READ ON THE WEATHER DATA FILE
 >0 A FIXED VALUE OF THE POTENTIAL EVAPOTRANSPIRATION. E.G. FOR CONTROLLED ENVIRONMENT
 46 TO 50 MESTR : MOISTURE RE-INITIALIZE PARAMETER. MUST =1 TO RE-INITIALIZE SNSTF AND CONHT.
 OTHERWISE =0

56 TO 55 ICFTL NEED: DATES FOR NO RAIN ASSUMED

C COL 1 TO 30 ERCAF : TOTAL VOLUME SPACE OF EACH ZONE (MM) OR SATURATION LEVEL
 31 TO 35 TSP : SURFACE WATER TRAPPED IN DEPRESSIONS
 AND NOT AVAILABLE FOR SURFACE RUNOFF

36 TO 45 SCLP : SLOPE/RUNOFF COEFFICIENT. DETERMINES THE RATE OF RUNOFF
 46 TO 50 DFL : DRAINAGE RATE AND LIMITS. MAXIMUM WATER VOLUME DRAINING
 FROM THE SURFACE TO DRAINAGE LAYER 1 (DRN(1))
 FROM DRAINAGE LAYER 1 TO DRAINAGE LAYER 2 (DRN(2))
 OUT OF THE BOTTOM OF DRAINAGE LAYER (DRN(3))
 DRN(4) IS THE RATE OF DRAINAGE OUT OF DRAINAGE LAYER 1
 DEFAULT VALUE DRN(1)= EXCESS WATER CAPACITY IN THE DRAINAGE LAYER 1
 DRN(2)= DRN(1); DRN(3)= DRN(2); DRN(4)=20%;
 DRN(5)=0;

51 TO 79 IFFNT : NUMBER OF ZONES IN DRAINAGE LAYER 1

10 COL 1 TO 30 PENWLT : PERMANENT WILTING POINT (MM) OF EACH ZONE
 COL 31 TO 60 GEDPTH : BOTTOM DEPTH OF EACH ZONE (MM), OPTIONAL
 COL 61 TO 70 SOL : THE PLOT SCALING FACTOR FOR SOIL-MOISTURE AXES
 =@ FOR ONE CHARACTER PER ONE PERCENT VOLUMETRIC
 =! FOR TWO CHARACTERS PER ONE PERCENT
 71 TO 72 HPER : HORIZONTAL FACTOR. NUMBER OF LINES BETWEEN DAYS. HPER=0 NO LINES SKIPPED

11 COL 1 TO 30 COEF5 : CROP COEFFICIENTS FOR EACH ZONE AND 5 STAGES.
 IF LESS THAN 5 STAGES ARE CONSIDERED, BLANK CARDS MUST BE INSERTED TO
 COMPLETE FIVE STAGES.

12 COL 1 TO 4 STGES : TOTAL NUMBER OF CROP DEVELOPMENT STAGES
 5 TO 8 NEW : CROP STAGE FOR A-ADJUSTMENT START. SEE EQUATION 2
 17 TO 20 ISYE : STARTING YEAR
 21 TO 24 NDYE : LAST YEAR OF RUN
 25 TO 29 NSY : CROP STAGES PER YEAR OF ROTATION.

13 COL 1 TO 72 IATES : OPT DEVELOPMENT STAGE DATES ENTERD YEAR, MONTH, DAY (OF STARTING DATE OF EACH STAGE PLUS THE DATE OF THE END (YEAR IS OPTIONAL) NUMBER (IF DATE= IATES+1)

OPT 14 COL 1 TO 2 NFLI,ISEN: RESTART PARAMETERS
 NFLI = 1 ISEN IS OVER-FIFTEEN AND THE PROGRAM READS A COMPLETE NEW SET OF CONTROLS. CONTROL NUMBER 2 TO 13 MUST BE PROVIDED.
 NFLI=0, ISEN=0 ENDS JFE
 NFLI=0, ISEN=1 PROGRAM RE-INITIALIZE WITH THE ORIGINAL STARTING MOISTURE CONTENT AS READ ON CONTROL NUMBER 8. CONTROL NUMBER 16 AND 17 MUST BE PROVIDED.
 NFLI=0, ISEN=2 PROGRAM READS A NEW SET OF MOISTURE CONTENT CONTROL NUMBER 15, 16, 17 MUST BE PROVIDED.
 NFLI=0, ISEN=99 WEATHER DATA FILE READ TO THE END WITHOUT COMILATION AND A NEW CONTROL NUMBER 14 WILL BE READ. THIS ALLOWS MULTIPLE FILE PROCESSING.

COL 7 TO 86 NF,INI,IF,HEAD : SAME MEANING AS IN CONTROL NUMBER 1

OPT 15 COL 1 TO 30 CONSET : NEW SET OF INITIAL SOIL MOISTURE CONTENTS WHICH MUST BE PROVIDED IF NFLI=0, ISEN= 0
 SAME AS ON CONTROL NUMBER 12 . MUST BE PROVIDED IF NFLI =0, ISEN >0 BUT < 99
 *** LAST CARD TO END JOB ***

15

TABLE C - 3. SAMPLE INPUT CONTROL DATA

APPENDIX DOutput Data

The output from VBIII has been altered from the previous program. An extra line of output per day has been added, giving water contents of each zone on a percent volumetric basis, k-coefficients and surface water. A table is provided to assist the user in interpreting the output. Table D-1 considers the daily printout as a 20 column table with one or two lines per day. The second line is optional, depending on whether soil moisture contents are expressed on a percent volumetric basis. If soil depths, which are also optional, are not defined volumetric based moisture contents are not calculated. Table D-2 gives a sample of the printout.

VBIII provides a second type of daily output, which is graphical. A simple line-printer plot of soil moisture on a volumetric basis is given for each zone. The symbols representing each zone are integers 1 to 6 for zones 1 to 6, respectively. The dates (left hand columns) and daily precipitation (right hand column) are included in the plot. Table D-3 illustrates the plot for four zones. Hand drawn lines joining the zone number symbols illustrate the plotted water contents.

The plot option is controlled by parameters on Input Control 10. The scale of the soil moisture axis is controlled by SCL. The default, when SCL is zero, is one character per one percent volumetric. The number of characters which represent each percent volumetric water content is expanded by a factor of 1.+SCL. The time scale is controlled by IHOR, which indicates the number of extra lines per day, or lines skipped between days. When IHOR = 0, no lines are skipped. To effectively use the plot option, the output unit for the plot (IP) must be different from the output unit for daily printouts (NP) (see Input Control 1). When no zone depths (OBDPTH) are specified, no plotting is done.

TABLE D-1

Guide to reading output

COLUMN	VARIABLE TYPE	VARIABLE DEFINITION
<hr/>		
Line 1		
1	integer	year
2,3	integer	month, day
4	integer	crop stage number
5	real	precipitation (rain or snow)
6,7	real	PE, AE (mm)
8, 13	real	available moisture; zones 1 to 6 (mm)
14, 15	real	runoff, drainage (mm)
16	integer	minimum daily temperature (°C)
17	integer	maximum daily temperature (°C)
18	real	snow pack, can include melt water (mm)
19	real	melt water (mm)
20	real	water collected on the surface (mm)
<hr/>		
Line 2		
8, 13	real	soil moisture; zones 1 to 6, expressed on a percent volumetric basis (mm)
15, 20	real	k-coefficients used each day in zones 1 to 6, takes into account k-adjustments

TABLE D-2. Sample daily output

60	502	1	6.0	3.6	3.0	0	15.6	15.4	15.4	15.6	3.0	6.0	60	502	1
60	503	1	6.0	4.0	4.0	0	12.2	12.2	12.2	12.2	4.0	6.0	60	503	1
60	504	1	6.0	4.0	4.0	0	14.5	14.5	14.5	14.5	4.0	6.0	60	504	1
60	505	1	6.0	5.0	5.0	0	12.1	12.1	12.1	12.1	5.0	6.0	60	505	1
60	506	1	6.0	4.6	3.9	0	13.0	13.0	13.0	13.0	4.6	6.0	60	506	1
60	507	1	6.0	4.0	3.0	0	12.8	12.8	12.8	12.8	4.0	6.0	60	507	1
60	508	1	6.0	3.0	2.0	0	12.5	12.5	12.5	12.5	3.0	6.0	60	508	1
60	509	1	6.0	3.0	1.5	0	12.4	12.4	12.4	12.4	3.0	6.0	60	509	1
60	510	1	6.0	3.0	1.0	0	12.3	12.3	12.3	12.3	3.0	6.0	60	510	1
60	511	1	6.0	3.0	0.5	0	12.2	12.2	12.2	12.2	3.0	6.0	60	511	1
60	512	1	6.0	2.0	1.5	0	12.1	12.1	12.1	12.1	2.0	6.0	60	512	1
60	513	1	6.0	1.7	1.3	0	12.0	12.0	12.0	12.0	1.7	6.0	60	513	1
60	514	1	6.0	1.0	0.7	0	11.9	11.9	11.9	11.9	0.7	6.0	60	514	1
60	515	1	6.0	0.5	0.3	0	11.8	11.8	11.8	11.8	0.3	6.0	60	515	1
60	516	1	6.0	0.0	0.0	0	11.7	11.7	11.7	11.7	0.0	6.0	60	516	1
60	517	1	6.0	-0.3	-0.3	0	11.6	11.6	11.6	11.6	-0.3	6.0	60	517	1
60	518	1	6.0	-0.6	-0.6	0	11.5	11.5	11.5	11.5	-0.6	6.0	60	518	1
60	519	1	6.0	-0.9	-0.9	0	11.4	11.4	11.4	11.4	-0.9	6.0	60	519	1
60	520	1	6.0	-0.3	-0.3	0	11.3	11.3	11.3	11.3	-0.3	6.0	60	520	1
60	521	1	6.0	-0.6	-0.6	0	11.2	11.2	11.2	11.2	-0.6	6.0	60	521	1

TABLE D-3. Sample line-printer plot using simulated weather data

x	Open Circles (Y)	Solid Squares (Y)
0.0	0.0	0.0
0.1	0.0	0.0
0.2	0.0	0.0
0.3	0.0	0.0
0.4	0.0	0.0
0.5	0.0	0.0
0.6	13.5	13.5
0.7	1.0	1.0
0.8	0.0	0.0
0.9	0.0	0.0
1.0	0.0	0.0

APPENDIX E. EVAPOTRANSPIRATION COEFFICIENTS (k_z)

Table E-1. k-coefficients available for several crops and cropping practices

Zone	1	2	3	4	5	6
Stages						
Dormant season	.50	.20	.10	.04	.02	.01
Growing season	.55	.19	.17	.08	.03	.01
Brome grass						
SS-FC ^a	.50	.20	.15	.12	.08	.05
FC-1st	.50	.25	.23	.22	.15	.10
1st-FC	.50	.22	.18	.15	.15	.10
FC-2nd	.50	.25	.25	.20	.18	.12
2nd-FC	.45	.25	.20	.20	.20	.15
Alfalfa						
P-E ^d	.20	.15	.15	.10		
E-F	.20	.20	.15	.10	.05	.05
F-Pf	.15	.15	.10	.10	.10	.05
Pf-Fe	.15	.15	.20	.20	.15	.10
Fe-M	.10	.15	.20	.15	.10	.10
Soybean^b						
P-E or R-P ^d	.40	.15	.12	.10	.02	.01
E-J	.40	.20	.13	.12	.03	.02
J-H	.40	.25	.15	.12	.10	.03
H-S	.40	.30	.20	.15	.10	.05
S-R	.40	.30	.20	.15	.07	.03
Small grain^c						
P-E ^d	.40	.15	.12	.10	.02	.01
E-T	.40	.20	.13	.12	.03	.02
T-Si	.40	.25	.15	.12	.10	.03
Si-Ee	.40	.30	.20	.15	.10	.05
Ee-H	.40	.30	.20	.15	.07	.03
Corn						
P-E ^d	.40	.15	.12	.10	.02	.01
E-T	.40	.20	.13	.12	.03	.02
T-Si	.40	.25	.15	.12	.10	.03
Si-Ee	.40	.30	.20	.15	.10	.05
Ee-H	.40	.30	.20	.15	.07	.03

^aSymbols used to define stages: SS, start of growing season; FC, full cover; 1st, first cut; 2nd, second cut; P, planting; E, emergence; F, flowering; Pf, pod filling; Fe, end of flowering; M, maturity; R, ripening; J, jointing; H, heading; S, soft dough; T, tasseling; Si, silking; Ee, ear emergence.

^bSoybean statistics from Ravelo (1978).

^cSmall grain includes wheat, barley, and millet.

^dIncludes fallow or bare soil.

Table E-2.z-tables used in the VB accounting for different moisture release characteristics

A										
99.99	50.00	33.00	25.00	20.00	16.66	14.28	12.50	11.11	10.00	
9.09	8.33	7.69	7.14	6.67	6.25	5.88	5.56	5.26	5.00	
4.76	4.55	4.35	4.17	4.00	3.85	3.70	3.57	3.45	3.33	
3.23	3.13	3.30	2.94	2.86	2.78	2.70	2.63	2.56	2.50	
2.44	2.38	2.33	2.27	2.22	2.17	2.13	2.08	2.04	2.00	
1.96	1.92	1.89	1.85	1.82	1.79	1.75	1.72	1.69	1.67	
1.64	1.61	1.59	1.56	1.54	1.52	1.49	1.47	1.45	1.43	
1.41	1.39	1.37	1.35	1.33	1.32	1.30	1.28	1.27	1.25	
1.23	1.22	1.20	1.19	1.18	1.16	1.15	1.14	1.12	1.11	
1.10	1.09	1.08	1.06	1.05	1.04	1.03	1.02	1.01	1.00	
B										
10.00	10.00	8.33	7.50	7.40	7.16	7.00	6.87	6.44	6.00	
5.81	5.58	5.38	5.21	5.00	4.75	4.52	4.33	4.16	4.00	
3.86	3.73	3.60	3.50	3.40	3.31	3.22	3.14	3.07	2.97	
2.90	2.81	2.76	2.68	2.63	2.55	2.49	2.44	2.38	2.33	
2.26	2.24	2.18	2.13	2.11	2.06	2.02	1.97	1.94	1.92	
1.88	1.85	1.81	1.78	1.76	1.73	1.70	1.67	1.66	1.63	
1.60	1.58	1.56	1.53	1.52	1.50	1.47	1.46	1.43	1.41	
1.40	1.38	1.36	1.35	1.33	1.31	1.29	1.28	1.26	1.25	
1.23	1.21	1.20	1.19	1.17	1.16	1.14	1.13	1.12	1.11	
1.09	1.08	1.07	1.06	1.05	1.04	1.03	1.02	1.01	1.00	
C										
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
D										
.00	.00	.00	.00	.20	.16	.14	.13	.11	.10	
.09	.16	.15	.14	.13	.13	.12	.17	.16	.15	
.14	.18	.17	.21	.20	.19	.22	.21	.24	.23	
.26	.25	.27	.29	.29	.30	.32	.34	.36	.35	
.36	.37	.37	.39	.40	.41	.43	.46	.47	.48	
.49	.50	.54	.56	.56	.59	.61	.64	.66	.68	
.70	.76	.79	.83	.85	.91	1.00	1.03	1.16	1.41	
1.40	1.38	1.35	1.34	1.33	1.31	1.29	1.28	1.26	1.25	
1.23	1.21	1.19	1.18	1.17	1.15	1.14	1.13	1.12	1.11	
1.10	1.08	1.07	1.06	1.05	1.04	1.03	1.02	1.01	1.00	

continued next page

Table E-2 (continued)

E									
.02	.04	.06	.08	.10	.12	.14	.16	.18	.20
.21	.23	.25	.27	.29	.31	.32	.34	.36	.38
.40	.42	.44	.46	.48	.50	.52	.54	.56	.60
.65	.65	.70	.71	.74	.78	.81	.91	1.05	1.25
1.34	1.43	1.63	1.82	2.00	2.00	2.00	2.00	2.00	2.00
1.96	1.92	1.89	1.85	1.82	1.79	1.75	1.72	1.69	1.67
1.64	1.61	1.59	1.56	1.54	1.52	1.49	1.47	1.45	1.43
1.41	1.39	1.37	1.35	1.33	1.32	1.30	1.28	1.27	1.25
1.23	1.22	1.20	1.19	1.18	1.16	1.15	1.14	1.12	1.11
1.10	1.09	1.08	1.06	1.05	1.04	1.03	1.02	1.01	1.00
F									
1.00	.75	.66	.50	.60	.66	.85	1.12	1.44	1.66
1.82	2.33	2.69	3.00	3.33	3.43	3.70	3.89	4.00	4.00
4.00	4.00	4.00	3.91	3.80	3.69	3.59	3.50	3.41	3.33
3.20	3.10	3.00	3.92	2.85	2.77	2.69	2.60	2.55	2.50
2.45	2.37	2.30	2.26	2.22	2.16	2.10	2.07	2.04	2.00
1.95	1.90	1.86	1.83	1.80	1.77	1.75	1.72	1.69	1.66
1.63	1.60	1.58	1.56	1.53	1.51	1.49	1.47	1.45	1.42
1.40	1.38	1.36	1.34	1.32	1.30	1.28	1.27	1.26	1.25
1.23	1.21	1.19	1.18	1.17	1.15	1.14	1.13	1.12	1.11
1.10	1.09	1.08	1.06	1.05	1.04	1.03	1.02	1.01	1.00
G									
1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
1.40	1.38	1.35	1.34	1.33	1.31	1.29	1.28	1.26	1.25
1.23	1.21	1.19	1.18	1.17	1.15	1.14	1.13	1.12	1.11
1.10	1.08	1.07	1.06	1.05	1.04	1.03	1.02	1.01	1.00
H									
2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
1.96	1.92	1.88	1.85	1.81	1.78	1.75	1.72	1.69	1.67
1.64	1.61	1.59	1.56	1.53	1.52	1.49	1.47	1.45	1.43
1.40	1.38	1.35	1.34	1.33	1.31	1.29	1.28	1.26	1.25
1.23	1.21	1.19	1.18	1.17	1.15	1.14	1.13	1.12	1.11
1.10	1.08	1.07	1.06	1.05	1.04	1.03	1.02	1.01	1.00

