WATER TABLE DEPTH SIMULATION FOR FLAT AGRICULTURAL LAND UNDER
SUBSURFACE DRAINAGE AND SUBIRRIGATION PRACTICES

by

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We accept this thesis as conforming
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ABSTRACT

Drainable porosity as a function of water table was investigated to replace the common practice of treating it as a constant. A continuous function in the form of a negative exponential equation relating drainable porosity to water table depth was developed by three methods: (1) laboratory core-sample analysis; (2) rainfall rate and water table depth analysis; (3) drainage rate and water table depth analysis. Furthermore, this function was derived for four different water table regimes: (1) subsurface drainage; (2) low subirrigation and subsurface drainage; (3) high subirrigation and subsurface drainage; (4) no drainage and no subirrigation.

The drainable porosity function was incorporated into a water balance model which simulated the soil moisture profile and the water table depth on a daily basis. Major modification of the previous model was the elimination of separate falling and rising water table equations since discrete porosity values were no longer assigned to particular soil depth intervals. A subroutine program which computed the total maximum transient storage and the transient storages to each of the four successive soil zones was also incorporated.

The 'maximum drainable porosity' and the 'rate constant' parameters in the negative exponential equation were found to be different among the three methods of analysis and among the four water table regimes. Good agreement between simulated and actual water table depths of each regime for 1984 and 1985 was found. The modified water balance model could be used to generate different water table depths by changing the input parameter of design drainage rate. From these outputs, an appropriate drainage rate which gives the desired water table depth could be selected for the purpose of horizontal subsurface drainage system design.
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LIST OF SYMBOLS AND ABBREVIATIONS

A  area
AE  actual evapotranspiration
b₀, b₁, b₂, ..., b₆  constants to curve fitting equations
C  governing fact, 4K/L²
C.V.  coefficient of variance
C₁  AE/PE ratio for first soil zone
C₂  AE/PE ratio for second soil zone
C₃  AE/PE ratio for third soil zone
C₄  AE/PE ratio for fourth soil zone
D  vertical distance from drain center to the impermeable soil layer
D₁ or D₁  depth from the soil surface of the first zone
Dₑ  Hooghrout's equivalent depth of soil, below the drain center, through which flow to drains occurs
df  degree of freedom
DP  drainable porosity
Drain.  drainage rate
DW  depth of zone from soil surface that RMAX occurs
EX  excess water
F or f  drainable porosity
f*  f_drain or f_lab
f_drain  f determined by drainage rate method
\( f_{\text{lab}} \)  \( f \) determined by laboratory method

\( f_{\text{rain}} \)  \( f \) determined by rainfall rate method

\( f_i \)  drainable porosity of the \( i \)th zone

\( f_1 \)  drainable porosity of the first zone

\( f_2 \)  drainable porosity of the second zone

\( H \) or \( H_{\text{MAX}} \)  total drain depth

\( \Gamma \)  index of correlation

\( h \)  height of water table at midspacing, above subdrain center

\( (I) \)  counter for the current day

\( K \)  hydraulic conductivity

\( (K) \)  counter for the previous day

\( m \)  number of independent variables

\( n \)  number of samples

\( L \)  horizontal spacing distance between subdrain centers

LAB.  laboratory

PE  potential evapotranspiration

PPT or PRE  precipitation

\( R \)  drainage rate (drainage coefficient), volume of outflow per unit area of land drained per unit time

\( R^2 \)  coefficient of determination

REG  regime

RMAX  maximum drainage rate or design drainage rate

RO  surface runoff

S.D.  standard deviation
SEW$_{30}$  
sum of total daily water table height recorded above the depth of 30cm at midpoint between drains

SMCF  
total available soil moisture content

SMC1  
available soil moisture content for first soil zone

SMC2  
available soil moisture content for second soil zone

SMC3  
available soil moisture content for third soil zone

SMC4  
available soil moisture content for fourth soil zone

SSreg  
sum of squares of regression

SSres  
sum of squares of residuals

SSy  
total sum of squares

Syx  
standard error

TR  
transient storage

TR1  
transient storage for first soil zone

TR2  
transient storage for second soil zone

TR3  
transient storage for third soil zone

TR4  
transient storage for fourth soil zone

TRMAX  
maximum total transient storage

YR  
year

Z or z  
water table depth from soil surface

$\Delta H$  
change in water table height

$\Delta t$  
change in time

$\Delta (TR)$ or $\Delta TR$  
change in transient storage

$\Delta Z$  
change in water table depth
ACKNOWLEDGEMENT

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1. INTRODUCTION

1.1. STATEMENT AND NATURE OF PROBLEM

The control of moisture level in a soil that is otherwise water-saturated during excess precipitation periods or water depleted during drought periods is agriculturally beneficial. The implementation of a dual water management system, which serves to drain or irrigate, can bring previously uncultivable waterlogged land into production or enhance the production of existing arable lands.

In the Lower Fraser Valley of British Columbia, Canada, where land is relatively flat and the climate is such that alternate seasons of water surplus and deficit occur, a combined subsurface drainage and subirrigation system is well suited to controlling the water table (Goldstein, 1978). The predominant hydraulic condition exhibited by the local soils is moderately poor to poor drainage. It is estimated that an area of 40,000 to 50,000 ha requires some form of water management scheme (Driehuyzen, 1983).

In arriving at a practical water management system, the design drainage rate or drainage coefficient (R) must be determined first. The general design criterion is to have minimal water control system costs with maximal crop yield and positive soil conditioning. The drainage coefficient is a function of the soil's drainable porosity as well as the soil's water holding capacity, regional climate, water table depth requirements of particular crops and field machine operations. In order to attain a realistic drainage coefficient, the drainable porosity itself must be properly described. The common definition of drainable porosity as the volume of water that can be drained from a unit of soil by a certain water table drawdown implies it is a constant, independent of pressure head. Such constants are commonly assigned to
particular soil types or soil depths. This, however, is not correct. Childs (1960) and Taylor (1960) have reported the dependence of drainable porosity upon water table depth and the rate of change of water table depth. The pressure gradient created by a falling water table and the time interval over which this event occurs affect the volume of water released from the soil profile. Thus a continuous relationship between drainable porosity and water table position is needed. This replaces the inadequate approach of using a constant value to represent drainable porosity. A function that expresses drainable porosity in terms of water table position can then be applied in a water balance model to derive an appropriate drainage coefficient.

1.2. OBJECTIVES

The main objectives of this research project are:

1. to derive a functional relationship between drainable porosity \( f \) and water table depth \( z \) for the local region by:
   a. laboratory analysis on disturbed and undisturbed soil samples;
   b. analysis of in situ rainfall rate and water table depth data;
   c. analysis of in situ drainage rate and water table depth data;

2. to incorporate the derived \( f-z \) relationship into an existing water balance model that simulates soil moisture profile and water table movements for flat agricultural lands;

3. to verify the modified water balance model by using recorded field data;

4. to use the verified model to generate water table depths for a given set of conditions.
1.3. SCOPE

The scope of this thesis is restricted to flat agricultural land whose water regime can be managed by a horizontal subsurface drainage system. This requires relatively uniform soil properties over an area of a few hectares and seasonal drainage characteristics of alternating high and low water table levels during the year. The refined water balance model will take the local conditions into account when the local weather data are used.
2. LITERATURE REVIEW

2.1. SUBSURFACE DRAINAGE

Proper drainage of agricultural land is of major importance to increasing the efficiency and reliability of crop production. Subsurface drainage is a means of implementing this needed water management. It is a system of artificial channels existing beneath the soil surface at a specific depth which collects and conveys excess water away from the root zone. The system consists of buried perforated plastic tubings or clay tiles commonly arranged in three possible layouts: random, herringbone, or gridiron as shown in Figure 1 (Donnan and Schwab, 1974). The general topographic and soil features govern the appropriate system to be installed (Chieng, 1986):

1. Parallel pattern: A series of drains placed parallel to each other and usually spaced at regular intervals.
2. Herringbone pattern: This arrangement consists of one main line and a series of laterals which enter the main line at an angle. This system is most suited to drainage of relatively narrow and sloping depressions or valleys where the main line is placed in the lowest areas.
3. Random pattern: This system is generally used where the topography is undulating or soils vary and the field contains isolated wet areas. Drains are laid out in a manner to connect relatively small, isolated, poorly drained depressions in the most economic and effective way.

Subsurface drainage serves primarily two functions: (a) to improve the trafficability of the land for field operations such as seed bed preparation, planting, and harvesting, (b) to provide a growth-maintaining environment within the root zone during high rainfall events. Subsurface drainage therefore modifies certain properties of
FIGURE 1: Subsurface Drainage System Layouts (Chieng, 1986)

PARALLEL PATTERN  HERRINGBONE PATTERN  RANDOM PATTERN
the soil matrix and processes within the soil–water–atmosphere regime. Three areas of particular significance are: physical properties of the soil; trafficability and timeliness; and plant crop production.

2.1.1. Physical Properties of the Soil

Hundel et al. (1976) reported a number of measurable soil properties that are affected by drainage: drainable porosity and pore size distribution, hydraulic conductivity, crust density and penetration, and compressible strength. The combined analyses of these properties indicate the soil’s behaviour or vulnerability to external forces -- structural and aggregate stability.

The porosity is an index of the relative pore volume in a soil profile. Both total porosity and pore size distribution characterize the process of aggregation. Soils with a high volume of air-filled pores are indicative of good soil structure. Hundel et al. (1976) found subsurface drainage to improve soil structure by increasing the density of large and medium sized pores. The effectiveness of both air and water pathways is enhanced due to the increased cohesiveness of soil aggregates resulting from a drying soil structure (Hillel, 1980).

Closely related to the porosity is the soil’s hydraulic conductivity. By definition, the hydraulic conductivity is the ratio of the specific discharge to the hydraulic gradient. This soil property is characteristically constant for saturated soil of stable structure or for rigid porous medium; the hydraulic conductivity is $10^{-2}$ to $10^{-1}$cm/sec for sandy soils and $10^{-4}$ to $10^{-3}$cm/sec for clayey soils (Hillel, 1980). In addition to texture, soil structure and in particular, the number and geometry of the pores affect the hydraulic conductivity (Doering, 1965). It then follows that since subsurface drainage alters the pore distribution favourably, the hydraulic conductivity is correspondingly
enhanced. Leyton and Yadar (1960), and Hundel et al. (1960) have demonstrated this observation between subsurface drained and undrained fields.

Soil properties which are important to the root development of seedlings are penetration resistance and compressive strength. Because individual root branches encounter mechanical obstructions within the soil matrix, it is beneficial to minimize these two factors. Fausey and Schwab (1969) found them to be less in subsurface drainage treatments than those with surface or no drainage treatments. The problem of crusting also arises in the latter two cases. Upon drying, these fields exhibit high crust density, wide crack spacings, and large, thick crust units (Hundel et al., 1976). The crust creates poor tillage for seed bed preparation. In addition to causing obstructive and distorted pathways to root penetration, crusting also damages seedling roots by tearing them apart. Subsurface drainage reduces surface crust strength which is a function of the drying rate (Hillel, 1980).

Two thermal properties that are affected by soil moisture variations are specific heat capacity and thermal conductivity. The specific heat capacity (C) is defined as the change in heat content of a unit mass per unit change in temperature. It is a function of the soil’s composition; according to De Vries (1975), C is given by the arithmetic sum of the heat capacities of its various constituents. Therefore an increase in the soil moisture capacity causes an increase in the soil’s heat capacity. Also with wet soils, more radiant energy is absorbed than radiated back to the atmosphere, and a longer warming time is required when compared with dry soils (Unesco/FAO, 1973). Much of the incident energy is utilized by the increased rate of evaporation.

Similarly, soil with a high water content exhibits high thermal conductivity. It is the amount of heat transferred through a unit area in a unit time under a unit temperature gradient. Thermal conductivity is dependent upon the soil’s solid, water and
air fractions. Hillel (1980) states that the thermal conductivity of water is one order of magnitude greater than that of air. When soil pores become constricted or saturated with water, air is displaced thus increasing the soil’s thermal conductivity.

2.1.2. Trafficability and Timeliness

Farm operations are time dependent and cannot usually be postponed for any length of time without incurring further risks of reduced yield and increased cost of the production system. Timeliness of farm operations involves the consideration of the soil’s condition and response to any external forces subjected to it. The soil structure is affected directly by the shrinking and swelling due to varying water table level and indirectly by the weather and biotic elements. Introducing a subsurface drainage system further influences the soil structure to the farmer’s advantage. By reducing the soil moisture content and correspondingly increasing the matric suction, the soil strength is improved. By their field experiments, Paul and De Vries (1979) showed a linear relationship between soil strength and water table depth.

Trafficability is the soil’s capacity to provide traction and to allow unobstructed overland passage of vehicles without receiving serious structural damage (Hillel, 1980). Amount of soil moisture removal and, hence, degree of trafficability are a function of the antecedent moisture content, type of soil, and farm activities. Bornstein and Hedstrom (1981) reported moisture level in the top 15cm of silty clay soils to have the greatest effect on trafficability. Subsurface drainage shortens the soil drying time which is dependent upon evapotranspiration. Land preparation for seeding may therefore start earlier in the growing season. Fausey and Schwab (1969) reported that subsurface drainage allowed spring cultivation to commence one month ahead than was possible with surface drainage. Paul and De Vries (1983) reported earlier trafficability of two to
four weeks in silty clay loam fields and by up to five weeks in a muck field when comparing subsurface drainage with no drainage. Chieng et al. (1987) further demonstrated this measure of time available for field work or opportunity days. The benefits of a well designed subsurface drainage system was found to be an increase in the number of opportunity days by 18 to 78 days from March 1st to May 31st during an average year. Table 1 shows the actual gain in opportunity days during the spring from 1983 to 1985 in the Boundary Bay area.

Prasher et al. (1985) made theoretical applications of this dependence of soil trafficability on the water table depth. They investigated a method of deriving the probability of obtaining a satisfactory workable period. The probability was assumed to follow a Markov chain process and was constrained to the criterion of at least 12 consecutive days in the month of March when the water table is 60cm or more below the soil surface. The 12 consecutive days represented the minimum number of necessary opportunity days. It was proposed that this probabilistic method be used as an alternative tool for assessing the performance of a proposed drainage system. Costly computer runs of drainage simulation models could thus be avoided.

When soil structure is poor due to high moisture content, long term losses in crop production may result. Excessive traffic on plastic-behaving soil causes puddling and eventual compaction upon drying. This is particularly important to soils high in clay content (Reeve and Fausey, 1974). Subsurface drainage reduces this risk and also lengthens considerably the time available for tilling. Steinhardt and Trafford (1974) observed effective reduction in wheel submergence and lateral compaction when a subsurface drainage was installed. The absence of a compacted layer allows for easier root penetration and water infiltration. Also, traction pull is reduced during tillage operation. Thus, the interplay between timely drainage of the field and subsequent
Table I: Opportunity Days Gained From Drainage Improvement (Chieng et al., 1987)

<table>
<thead>
<tr>
<th>REGIME</th>
<th>1983</th>
<th>1984</th>
<th>1985</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>83</td>
<td>90</td>
<td>89</td>
</tr>
<tr>
<td>B</td>
<td>75</td>
<td>59</td>
<td>80</td>
</tr>
<tr>
<td>C</td>
<td>80</td>
<td>54</td>
<td>74</td>
</tr>
<tr>
<td>D</td>
<td>19</td>
<td>4</td>
<td>29</td>
</tr>
</tbody>
</table>

Ave. opportunity days gained (A–D) 64 86 60

...production operations is vital.

2.1.3. Plant Growth and Crop Production

Proper management of the water table improves the growth condition of the root zone. High water table results in insufficient soil aeration. The infiltrating water not only displaces the air, but also hinders gaseous diffusivity by decreasing air phase and increasing discontinuities between air-filled pores. (Harris and van Barel, 1967). Clark and Kemper (1967) observed oxygen to diffuse through air-filled pores 10000 times faster than through water-filled pores. One immediate growth-limiting effect of deficient aeration is reduced root respiration (Wesseling, 1974). This is crucial since energy produced from respiration is required in all the metabolic processes. A properly functioning cell is able to control solute absorption. As a cell dies, its membrane permeability increases, allowing the leakage of ions and other small molecules (Salisbury and Ross, 1978). Consequently, a poorly aerated root zone would lower crop production.

A number of field experiments has been conducted to evaluate the effectiveness
of subsurface drainage system in improving the soil for crop production. Carter and coworkers (1973, 1983) have reported an increase in annual sugar cane yield of 24 to 32% and in the number of single crop grown per year from three to five. Sugar cane is very susceptible to prolonged high water table conditions. During winter, cane seed stubbles decay. In the spring, early root development is inhibited by low soil temperature and anaerobic soil conditions (Carter and Camp, 1981). Increased crop yields from lowered water table were attributed to: 1) increased depth of root development, 2) improved soil aeration, 3) warmer soil temperature earlier in the growth season, and 4) improved trafficability and timeliness of farm operations. This is supported by the studies of Yang et al. (1977) which demonstrated that higher root density and deeper root growth enabled the root system to explore a larger volume for nutrients and, during drought, for water in the capillary fringe.

In terms of efficient water, land, and energy usages, subsurface drainage may be an option to other systems such as conventional water furrows. Campbell et al. (1978) found that potatoe plants grown under this type of water management produced 10% more with 12% less water. The overall yield increase averaged 40% in a year. In this case, up to 12.5% of productive land area was made available for cultivation. Where land is scarce, areas occupied by open drains need to be minimized. This also lessens the difficulty in maneuvering farm equipments. Other crops benefitting from subsurface drainage are corn, soybeans and oats (Erickson, 1965; Schwab et al., 1966, 1974; Carter and Camp, 1978).
2.2. SUBIRRIGATION

Given the proper physical conditions, an existing subsurface drainage system can be operated as a "controlled and reversible" drainage system. Termed as subirrigation, this is the process of upward water movement from the water table and capillary fringe as a result of an artificially generated hydraulic gradient. Incorporating subirrigation replenishes the soil profile with needed water during periods of drought due to lack of irrigation, rainfall or overdrainage.

The feasibility of subirrigation is determined by several existing natural conditions. Early experiments by Fox et al. (1956) indicated the importance of a high natural water table or a shallow impermeable layer to prevent excessive seepage losses. The dual drainage/subirrigation system also requires a gently sloping topography of 0.5% or less (Massey et al., 1983). It is crucial that the water table rise to the proper height at an adequate rate. Thus the soil should provide high hydraulic conductivity similar to those exhibited by fine sandy soils and coarse silty soils. In the case of heavier or finer soil structure, in which water rises slowly, two alternatives have been studied. Working with silty clay and silty loam soils, Carter et al. (1983) used concrete and plastic borders to confine the field plot and restrict lateral water movement. Doty and Parsons (1979) experimented with a water mound developed above the drain tiles. The latter method enhanced the precision of subirrigation by reducing the large water table fluctuation found within the sandy clay loam profile.

The use of subirrigation is well suited to crops whose yield response is maximum at a certain minimum water table depth. Doty et al. concluded from regression analysis that the number of days the water table was less than 106.7cm from the soil surface influenced production yield. Their second-order regression function shows that for each additional day between 25 and 55 days that the water table was
106.7 cm or less from the surface, silage yield could be increased 110 to 220 kg/ha. Other advantages to this type of water management system include: 1) reduced initial cost as compared to separate drainage and irrigation set ups, 2) low labour and maintenance requirements, 3) simultaneous operation of subirrigation with other farm activities, and 4) reduced nutrient leaching due to reduced downward water flow. Massey et al. (1983) made a comparative study between subirrigation and sprinkler irrigation while focussing on the energy and water requirements of the systems. They showed that a gravity-operated subirrigation system was more energy efficient than a sprinkler nozzle operation.

2.3. CAPILLARY FLOW

Capillary flow is an important factor affecting subsurface drainage and subirrigation. It occurs in the capillary fringe where the moisture is continuous. The capillary fringe is commonly defined as the soil zone in which the pores are saturated, but the water pressure is less than that of atmospheric. It is also the region of uniform moisture above the water table where the hydraulic conductivity is essentially the same as the saturated hydraulic conductivity (Childs, 1957). Thus the capillary fringe provides an additional water pathway.

The phenomenon of soil water capillarity has been extensively modelled by the behaviour of water rise and retention in a capillary tube. The migration of capillary water occurs in response to equilibrating water pressure differences. When expressed as a stress term of capillary potential, capillary flow is similar to electric or heat current in that the direction of flow is always from high to low potential levels. Physical factors determining the extent of capillary flow include: soil pore size and conformation, degree of saturation, surface tension and pressures in the water relative
The distribution of capillary potential fluctuates simultaneously with changes in soil moisture content. Capillary potential itself is dependent on the radii of menisci between soil grains, which is determined by the moisture level. A reduction in overall soil moisture content causes water to recede farther into the interstices between grains, and therefore decreases the radii and the capillary potential. This results in an increased attraction for water in order to re-establish a state of equilibrium.

The nonequilibrium that causes capillary flow can occur under several conditions. Water is drawn upward in response to water loss from the capillary zone by transpiration of crops and by evaporation at the soil surface. Stuff and Dale (1978) have found capillary water to supply an average of 27% of the evapotranspiration during periods of little or no precipitation. Thomas et al. (1977) demonstrated the differing capillary potential distribution below and above subirrigation laterals for barley and corn crops grown in two differently textured soils. They accounted the distribution patterns to varying degrees of root activity and the nonlinearity of the hydraulic conductivity. The actual height of capillary rise from the water table can vary widely depending on the textural and humus content differences in soil profile and on the depth of the water table (Bloemen, 1980). This is illustrated in Figures 2, 3 and Table II. The direction of flow is reversed when rain or irrigation water falls on the ground surface, inducing downward seepage. This reversed capillary potential gradient is enhanced by the presence of subsurface drainage tiles which act as a sink.
FIGURE 2: Relationship between capillary rise and water table depth for sandy subsoils of various geo-genetical group (Bloemen, 1980)
FIGURE 3: Height of capillary rise in relation to soil moisture suction in marine clays at increasing clay contents (Bloemen, 1980)
Table II: Characteristic grain size distribution of sandy subsoils of various geo-genetical groups, in percentages of the mineral part of the soil (Bloemen, 1980)

<table>
<thead>
<tr>
<th>GROUP</th>
<th>0-2 (µm)</th>
<th>2-16 (µm)</th>
<th>16-50 (µm)</th>
<th>50-75 (µm)</th>
<th>75-105 (µm)</th>
<th>105-150 (µm)</th>
<th>150-210 (µm)</th>
<th>210-300 (µm)</th>
<th>300-420 (µm)</th>
<th>420-600 (µm)</th>
<th>600-850 (µm)</th>
<th>850+ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young marine</td>
<td>2.1</td>
<td>1.0</td>
<td>2.3</td>
<td>-</td>
<td>9.4</td>
<td>29.4</td>
<td>27.6</td>
<td>24.0</td>
<td>3.8</td>
<td>0.3</td>
<td>0.1</td>
<td>-</td>
</tr>
<tr>
<td>Old marine</td>
<td>6.2</td>
<td>2.6</td>
<td>13.83</td>
<td>27.5</td>
<td>33.8</td>
<td>14.7</td>
<td>1.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fluvial</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
<td>2.5</td>
<td>2.0</td>
<td>5.0</td>
<td>18.0</td>
<td>24.0</td>
<td>16.0</td>
<td>17.5</td>
<td>9.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Pleistocene aeolian</td>
<td>-</td>
<td>2.5</td>
<td>4.0</td>
<td>6.0</td>
<td>14.0</td>
<td>36.0</td>
<td>21.5</td>
<td>10.5</td>
<td>4.0</td>
<td>1.0</td>
<td>0.5</td>
<td>-</td>
</tr>
</tbody>
</table>
2.4. DRAINABLE POROSITY

Drainable porosity (f), or specific yield, is one of the important parameters used in subsurface drainage design. Drainable porosity is the volume of water that can be drained from a unit of soil by a unit depth of water table drawdown in the absence of a natural source or sink. Conversely, f is the volume of water per unit area taken up by the unsaturated soil above the water table for a unit rise in the water table (Prasher, 1978). Drainable porosity has not always been included in the analysis of agricultural drainage, especially when steady state flow into drainage tiles is assumed (Bouwer and van Schilfgaarde, 1963; Toksoz and Kirkham, 1971). In the area of analytical and water balance modelling of non-steady subsurface drainage, f is commonly assigned a constant value particular to the soil under study. The analytical model of Young and Lignon (1972) uses a logarithmic relationship between drainable porosity (f) and hydraulic conductivity (K) developed originally by the U.S. Bureau of Reclamation. Skagg (1976,1981) has further replaced this basic parameter by a ratio expression of K/f in the water management model, DRAINMOD. The weakness of these analyses arises from the erroneous assumption of f being a constant for the entire soil profile considered. Early investigation by Childs (1960) and Taylor (1960) have shown f to be affected by both the water table depth and the rate of depth change. A functional relationship between f and water table depth was proposed; Taylor (1960) suggested an exponential relationship. Dos Santos and Young (1969) derived the functional relationship as "the sum of the air content at the soil surface and the ratio of the rate of change of the volume of water held in the moisture profile above the water table to the rate of rise or fall of the water table". Inherent in their calculation is the effects of rainfall and evaporation upon the soil profile. Another approach taken by Duke (1972) considers the hydraulic properties of capillary
To account for this characteristic of variability, researchers at MacDonald College of McGill University (Montreal, Canada) developed a water balance model which assigned different values of \( f \) in relation to varying depth zones in the soil profile (Foroud, 1974; Chieng, 1975; Bhattacharya et al., 1977; Chieng et al., 1978). In their case, the soil profile was divided into four successive zones of interest. Each zone was assumed to have its available soil moisture storage depleted by evapotranspiration after its transient storage was depleted. Bhattacharya and Broughton (1979) subsequently derived a curvilinear relationship between drainable porosity (\( f \)) and water table depth (\( h \)). A nonlinear least-square curve fitting computer program was applied to their extensive laboratory data. The resulting nonlinear regression equations shown in Table 3 were generated for the sand and the clay soils. These \( f-h \) relations are applicable within the constraints of a maximum suction of 2m of water and a maximum drain depth of 1.5m, which are conditions generally found in the arable regions of the Ottawa–St. Lawrence Lowland in Canada.

2.5. WATER BALANCE MODEL

In the present study, a water balance approach is used to analyze water movement within a defined soil volume. Simply stated, the concept of water balance defines the water content of a given soil volume at any time as the balance between water inflow and outflow and the change of the soil water storage. Mathematically, a water balance model can be expressed as:

\[
\text{Inflow} = \text{Outflow} \pm \text{Change in Storage} \quad (2.1)
\]

Such water balance models have been developed to simulate soil moisture changes due
Table III: Nonlinear Regression Equations (Bhattacharya and Broughton, 1979)

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>TYPE OF EQUATION</th>
<th>VALUES OF FITTED PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland sand</td>
<td>[ f = \left( \frac{1}{1 + 2^{-B_1 (h - 0.5)}} \right) - \left( \frac{1}{1 + 2^{0.5B_1}} \right) \beta_2 ] [ \beta_1 = -11.6466 ] [ \beta_2 = 3.2993 ]</td>
<td></td>
</tr>
<tr>
<td>Ste. Rosalie clay</td>
<td>[ f = h(e^{-B_3 h} - e^{-B_4 h}) + \beta_5(1 - e^{-B_6 h}) ]</td>
<td>[ \beta_3 = 0.4154 ] [ \beta_4 = 0.3484 ] [ \beta_5 = 0.3305 ] [ \beta_6 = 0.6480 ]</td>
</tr>
</tbody>
</table>

The water balance model applied in this study was originally developed by Foroud (1974) and further modified by Chieng (1975) to optimize the subsurface drainage design. The model computed the daily available soil moisture content at the midspacing between adjacent parallel drains along a profile of four successive soil zones extending from the soil surface to the drain depth. In addition, the model computed the water table depth to be expected in a certain soil for certain drainage system capacities with varying drain depths. An appropriate drainage coefficient could then be selected to determine the spacing between laterals from the Hooghoudt's relationship (Equation (4.7)). This water balance model has been described and applied by Chieng et al. (1978).

The simulation model was designed to determine the daily change in water
table depth:

\[ \Delta z = \Delta (TR)/f_i = R \Delta t/f_i \]  

(2.2)

where: \( \Delta z \) = change in water table depth  
\( \Delta (TR) \) = change in transient storage  
\( f_i \) = drainable porosity of the \( i \)th zone  
\( R \) = drainage rate  
\( \Delta t \) = time interval

The result was then used to obtain the revised water table depth \( z_t \):

\[ z_t = z_{t-1} \pm \Delta z \]  

(2.3)

Since each successive soil zone was assigned a fixed drainable porosity value, separate falling and rising water table equations were needed to describe the movement across the boundaries of any two zones. These are shown below:

1) the falling water table equation:

\[ z_t = D_1 - [(D_1 - z_{t-1})f_1 + \Delta TR]/f_2 \]  

(2.4)

2) the rising water table equation:

\[ z_t = D_1 + [(z_{t-1} - D_1)f_2 + \Delta TR]/f_1 \]  

(2.5)

where: \( D_1 \) = depth of the 1st soil zone  
\( f_1 \) = drainable porosity of the 1st soil zone  
\( f_2 \) = drainable porosity of the 2nd soil zone

In this model, the drainable porosities for the third and fourth zones were assumed to be the same as that of the second zone.

The modifications made in the present model re-expresses the drainable porosity as an explicit function of water table depth. This replaces the unrealistic representation of an average porosity value for a particular depth interval. The derived function is
based on Taylor's (1960) observation as possibly being an exponential one with parameters specific to the local conditions. More recent work by Bhattacharya and Broughton (1979) has supported this assumption. For this study, effort was made to keep the function simple and parameters few.
3. MATERIALS AND METHODS

3.1. EXPERIMENTAL FIELD AND MEASUREMENTS

The experimental site of 3.4 ha was located at the northwest corner of the Boundary Bay Airport in the Lower Fraser Valley of British Columbia, Canada. Common to this part of the province is the low-lying, flat alluvial landform. The soil was classified as Humic Luvic Gleysol developed on moderately fine to fine textured deposits with moderately poor to poor drainage (Driehuyzen, 1983). The soil was also found to belong to the Ladner Series.

Four different types of crops were planted on individual treatment plots. These included corns, grass forage, strawberry, and potatoes. The crop layout in the experimental field was randomly designed with the corns planted on the west side to reduce shading effects on adjacent crops.

Each water-controlled treatment plot size was 42m wide by 100m long, giving an area of 4200m². The drainage set up for each plot consisted of three parallel drainage pipes installed at an average depth of 1.1m from the soil surface. These 100mm-diameter laterals spaced at 14m apart were perforated and corrugated polyethylene tubings. They ran a length of 100m in the east-west direction before emptying into a nonlined earth ditch at the east end as shown in Figure 4. An open ditch was excavated and used as a collector. For the purpose of the study, the ditch was subdivided into three sections and interconnected by plastic pipes at the ditch bottom. A pump was installed to empty the collector ditch into the main ditch. The highway ditch along 72nd Street then carried all the water from the main ditch and away from the drained area. For the purpose of subirrigation, overflow stand pipes of proper height controlled the different water levels in the experimental plots. Water
FIGURE 4: Experimental Field Layout
from the domestic supply line was introduced into the collector ditch from which it flowed above the drain lines and into the soil. The water control system is diagrammatically illustrated in Figure 5.

In operating the water control system, certain criteria were considered. One criterion for subsurface drainage was to keep the water table low enough such that the SEW_{30} value did not exceed 200cm during the 1st of November to the 31st of March. SEW_{30} is the sum of daily water table recorded above the 30cm depth at midspacing between laterals. Defined originally by Seiben (1965), the SEW value is an index to crop yield in relation to the water regime in the upper soil layer. Above a certain minimum value, crop yield is negatively affected by the presence of excessive water. A second criterion was to obtain trafficability of the land during early spring from the 31st of March to the 1st of May. Different subirrigation operations were to be maintained throughout the summer and early fall months when periods of water deficit were prevalent.

Four water table regimes were tested at the experimental set up:

1. REGIME A: free subsurface drainage at all times; water table controlled at or below subdrains
2. REGIME B: subsurface drainage during high precipitation periods; subirrigation by maintaining water table depth at 60cm from soil surface during periods of water deficit

3. REGIME C: subsurface drainage during high precipitation periods; subirrigation by maintaining water table depth at 30cm from soil surface during periods of water deficit

4. REGIME D: no drainage or subirrigation at any time

The subirrigation levels of 60cm and 30cm water table depth were based on published sources. In Holland, the water table is to be kept at a minimum of 50cm below soil surface for arable land and 40cm for grassland (Luthin, 1978). In the B.C. Agricultural Drainage Manual, the required water table depth is at 50cm or more below soil surface 48 hours after a storm rainfall event ceases so that crop and soil structure damage is minimized. The height of capillary rise in the local field have been observed to be approximately 20cm (Chieng, 1987). It was concluded that the two proposed subirrigation levels represented the lower and upper limits from the reported optimum of approximately 50cm depth.

Subsurface drainage began during the winter of 1981 when the subdrains and sub-ditches were installed at the experimental site. The pump was installed in early 1983 and put into operation for subirrigation in the summer of 1983. The water table height at the midpoint between laterals were recorded using automatic water table chart recorders. Three were installed in the drained area (Regimes A, B and C) and one in the adjacent undrained area (Regime D). In situ rainfall readings were not collected until 1984 when a rain gauge was placed next to the pump station. For this reason, rainfall measurements recorded at the Delta Ladner South weather station, which was about 5km away from the site, were used for analyses prior to this date. The
locations of the recording instruments are indicated in Figure 4. The daily values of potential evapotranspiration were computed from Equation 1 of the technique proposed in 1965 by Baier and Robertson (Russelo et al., 1974). This method took into account the local maximum temperature, temperature range, and incident solar energy on a daily basis.

3.2. PHYSICAL CHARACTERIZATION OF SOIL

Laboratory analyses of the soil in each treatment plot were conducted to determine the physical and hydraulic properties of: satiated hydraulic conductivity, drainable porosity curve, bulk density, particle size distribution, and moisture retention curve.

Three undisturbed core samples were randomly collected from each of the four treatment plots. Their approximate locations are indicated in Figure 4. The core dimensions were 7.3 cm in diameter and 7.5 cm in height. These were removed from a depth halfway between maintained water table level and soil surface with a cylindrical metal sampler. The sampling depth for Regimes A, B, C and D were 50, 30, 15, and 50 cm, respectively. At the same time, loose soil samples were obtained at successive depth intervals from each core sampling site for the analyses of soil moisture content, particle size distribution, and moisture retention curve.

The satiated hydraulic conductivity was determined for each core sample. Since the cores were extracted above the water table level where the soil pores were essentially saturated but with the water held at less than atmospheric pressure, the satiated and not the saturated hydraulic conductivity was representative of the field condition. The falling head method described by Klute (1965) was applied with a few modifications. The core bottom was wrapped with cheesecloth and placed on top of a
steel grid, thus exposing it to the atmosphere. An accompanying steel cylinder taped to its top end acted to contain the draining water. In place of the standard stand pipe, a screw dial gauge was set up to measure the hydraulic head drop. At least four runs were performed on each core sample. The statistics of mean, standard deviations, and coefficient of variance were computed for analysis.

The drainable porosity curve consisted of discrete porosity values for the tension range of 0 to 80cm at 10cm intervals. The unconsolidated porous plate was constructed of saturated, sieved sand high in ferrous and aluminum oxide content. The plate was large enough to hold all twelve core samples. The sand was initially passed through a 0.246mm sieve. To ensure complete saturation, the plate was vibrated temporarily using a pneumatic vibrator set at 70kPa. This step caused close-packing configuration to take place, thus removing any trapped air. Preparation of the core samples involved initial drainage at 60cm tension for 24 hours, followed by saturation from below for 24 hours. Tension measurements were taken from the midpoint of the core height. Each sample was weighed at saturation and again at each successive tension level when drainage ceased to continue. The plate was moistened prior to replacement of the core to prevent discontinuity of water at the interface. The apparatus was observed to fail due to air entry at 90cm tension.

Bulk density determination was the final analysis performed on these core samples. The standard core method (Blake, 1965) was applied.

For speed and convenience, the hydrometer method for particle size analysis was chosen. Pretreatment of the loose soil samples consisted of screening through a 2mm sieve followed by removal of organic matter using a 6% hydrogen peroxide solution. Soil dispersion was aided by the addition of a Calgon solution. The entire experiment was carried out in a temperature-controlled room. The step-by-step procedure is
The soil moisture retention curve for each sample was obtained with a standard pressure-plate and pressure-membrane apparatus (Richards, 1965). Tensions of 3, 9, 30, and 150 m of water were applied on all samples. Due to the low holding capacity of the pressure chambers, samples were tested only in duplicates.

3.3. FORMULATION OF DRAINABLE POROSITY EQUATION

3.3.1. In Situ Drainable Porosity

The in situ drainable porosity values were derived in two ways using the equation given by Broughton and Foroud (1978):

\[ f = R \Delta t/\Delta z \] (3.1)

One method was to define \( R \) as the daily rainfall intensity measured in the field. From the water table charts, the total change in water table level from start to end of the related rainfall event was measured to give \( \Delta z \). This dealt with the rising limb of the water table curve and hence represented the subirrigation aspect of the water table control. The time lag between start of a rainfall event and response of the water table was observed to be approximately 12 hours. Only distinct rainfall events and water table peaks were chosen to calculate drainable porosity values.

The other method was to define \( R \) as the in situ drainage rate or specific discharge. From measurements of total discharge in the field and the known area of discharge, the drainage rate was calculated. These field data were made available by Kerr-Wilson (1985). Since the instantaneous drainage rate was recorded, the change in both time and water table position were re-expressed as the slope on the water table charts at the time of measurement. It should be noted that the drainable porosity
derived this way concerned with the falling limb of the water table curve and hence the drainage behaviour of the water table movement. Again, only drainage rate which indicated a clear drop in water table level were used.

3.3.2. Curve Fitting

Two possible types of regression functions were considered in the curve fitting process:

1. the polynomial equation

\[ f = b_0 + b_1z + b_2z^2 + b_3z^3 + \ldots + b_nz^n \]  \hspace{1cm} (3.2)

2. the negative exponential equation

\[ f = b_0(1 - e^{-b_1z}) \]  \hspace{1cm} (3.3)

Both functions consisted of the independent variable, tension \((z)\) and the dependent variable, drainable porosity \((f)\). The initial regression analyses were performed on the laboratory-derived \(f\) data to determine the more suitable function. These data were used since they provided an orderly range of drainable porosity and tension values. Also the drainable porosity values determined in the laboratory were considered to be correct over those determined from rainfall intensities and drainage rates. In this study, it was assumed the conditions in the laboratory setting were more controlled than those found in the field. The appropriate function was then fitted to the in situ data for each of the four water regimes.

3.3.3. Corrected \(f\)-\(z\) Function

The drainable porosity curve derived from laboratory procedures on core samples was considered to be an accurate representation of what happens in the field, especially when given an adequate sample size. However, due to the time and labour
consumptiveness of this method, it is oftentimes impractical. In this research, one of the objectives was to use in situ data of rainfall intensity, drainage rate, and water table depth, to generate the drainable porosity curve. Such data could be conveniently collected using meteorological instruments that are easy to install and operate on site. Also, these data inherently take into account the actual effects of evapotranspiration, rainfall, and hysteresis on water table movement.

Although use of meteorological data is emphasized, the measurement of a drainage event was found to be difficult compared to that of a rainfall event. Thus, the conclusion was to focus on the rainfall data to generate the drainable porosity curve. However, since a rainfall event represented only the rising limb on a water table curve, the derived $f$-z function needed to be corrected in order to account for water table drawdown.

3.4. WATER BALANCE MODEL

The main and subroutine programmes of the water balance model was written in the FORTRAN IV G language for an IBM 360/370 computer. For practicality, the incorporation of the $f$-z function was best facilitated by a subroutine programme. Its usage was then easily invoked by a CALL command within the main programme. The parameters passed were the water table depth and the constants of the $f$-z equation which were specific to each water regime.

Another subroutine programme added dealt with the transient storage of the soil moisture. The original water balance model described soil moisture storage by two components: (1) soil moisture storage which was the difference between the field capacity and the wilting point; and (2) transient storage which occurred in the drainable pore space. The soil moisture storage was assumed to drain as quickly as
the specified drainage coefficient would allow. When soil moisture of the whole soil profile reached its field capacity, excess moisture was assumed to enter transient storage causing the water table to rise. Since the drainable porosity across the soil profile was defined by a continuous function of depth, the maximum total and zonal transient storages must be calculated instead of assigning constant values as previously.

3.5. STATISTICAL ANALYSES

A nonparametric sign test was used to test the degree of accuracy by which the water balance model and hence the incorporated f-z function could simulate the behaviour of the water table over a period of one year. The Wilcoxon’s matched-pairs signed-rank test, or simply, the Wilcoxon paired-sample test, was chosen to test the null hypothesis that there is no difference between actual and simulated water table levels. This test utilized both direction and magnitude of the difference between paired observations (Siegel, 1956). The assumptions made were (1) a random sample of pairs of observations have been taken, and (2) the absolute difference in the paired observations could be ranked. As with any nonparametric method, no assumptions were made about the form of the population probability distribution. Since the direction of the difference was not predicted in advance, a two-tailed region of rejection was required.
4. RESULTS AND DISCUSSION

4.1. SOIL PHYSICAL ANALYSES

The results of the physical analyses of the four experimental plots (Regimes A, B, C and D) are tabulated in Table IV to Table VI. Each analysis was performed on a sample size of three (n=3). All plots were found to have a textural classification of silt loam under the standards of the United States Department of Agriculture (USDA). In the analysis of particle size distribution, Regime B exhibited the highest silt content while Regime C exhibited the lowest. The reverse trend was observed in their sand contents. The clay contents were similar among the plots with their sand contents varying the greatest.

The dry bulk density values of 1.46, 1.32, 1.29 g/cm$^3$ for Regimes A, B, C, respectively, must be explained with respect to their sampling depths -- 50, 30, 15cm from the soil surface. Thus, although the drainage practice in Regime A with no subirrigation should lead to a less dense soil matrix, its associated core analysis at a much greater depth revealed a naturally increasing dry bulk density with soil depth. The overall range of 1.29g/cm$^3$ to 1.46g/cm$^3$ was realistically agreeable with the value of 1.40g/cm$^3$ reported by Driehuyzen (1983) given the small sample size and the inherent variability in evaluating this soil property. In addition, a concurrent study by Kodsi (1987) using 12 composite soil samples per plot resulted in a characteristic dry bulk density of 1.47g/cm$^3$. 
Table IV: Soil Particle Size Distribution (USDA)

<table>
<thead>
<tr>
<th>REGIME</th>
<th>%CLAY</th>
<th>%SILT</th>
<th>%SAND</th>
<th>n</th>
<th>DEPTH (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>21</td>
<td>69</td>
<td>10</td>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>23</td>
<td>73</td>
<td>4</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>C</td>
<td>26</td>
<td>58</td>
<td>16</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>22</td>
<td>64</td>
<td>14</td>
<td>3</td>
<td>50</td>
</tr>
</tbody>
</table>

Table V: Textural Classification (USDA)

<table>
<thead>
<tr>
<th>REGIME</th>
<th>CLASSIFICATION</th>
<th>n</th>
<th>DEPTH (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>silt loam</td>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>silt loam</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>C</td>
<td>silt loam</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>silt loam</td>
<td>3</td>
<td>50</td>
</tr>
</tbody>
</table>

4.2. SOIL HYDRAULIC ANALYSES

Hundel et al. (1976) reported a number of soil properties affected by drainage. Particularly important to the hydraulic behaviour of the soil profile are the hydraulic conductivity, pore size distribution and drainable porosity. The freely drained plot of Regime A displayed the highest satiated hydraulic conductivity among the treatment plots as shown in Table VII. Conversely, the satiated hydraulic conductivity decreased progressively with increased subirrigation practices. This was illustrated by the near 50% reduction between Regimes B and A and by the reduction of one order of magnitude between Regimes C and A. From Figure 6, Regime A also correspondingly exhibited
Table VI: Dry Bulk Density

<table>
<thead>
<tr>
<th>REGIME</th>
<th>MEAN (g/cm³)</th>
<th>S.D. (g/cm³)</th>
<th>C.V.</th>
<th>RANGE (g/cm³)</th>
<th>n</th>
<th>DEPTH (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.46</td>
<td>0.04</td>
<td>0.03</td>
<td>1.43 - 1.51</td>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>1.33</td>
<td>0.14</td>
<td>0.11</td>
<td>1.03 - 1.50</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>C</td>
<td>1.29</td>
<td>0.06</td>
<td>0.05</td>
<td>1.23 - 1.35</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>1.30</td>
<td>0.31</td>
<td>0.24</td>
<td>0.94 - 1.49</td>
<td>3</td>
<td>50</td>
</tr>
</tbody>
</table>

Table VII: Satiated Hydraulic Conductivity

<table>
<thead>
<tr>
<th>REG</th>
<th>MEAN (m/s)</th>
<th>S.D. (m/s)</th>
<th>C.V.</th>
<th>RANGE (m/s)</th>
<th>n</th>
<th>DEPTH (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.6(10⁻⁶)</td>
<td>0.3(10⁻⁶)</td>
<td>0.13</td>
<td>1.6(10⁻⁶) - 3.8(10⁻⁶)</td>
<td>12</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>1.5(10⁻⁶)</td>
<td>0.5(10⁻⁶)</td>
<td>0.35</td>
<td>2.4(10⁻⁶) - 4.2(10⁻⁶)</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>C</td>
<td>3.9(10⁻⁷)</td>
<td>0.4(10⁻⁷)</td>
<td>0.19</td>
<td>9.8(10⁻⁷) - 9.5(10⁻⁷)</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>1.7(10⁻⁷)</td>
<td>0.2(10⁻⁷)</td>
<td>0.13</td>
<td>4.0(10⁻⁷) - 3.2(10⁻⁷)</td>
<td>15</td>
<td>50</td>
</tr>
</tbody>
</table>

the lowest moisture retention behaviour at all water tension levels. Similar works by McWhorten and Duke (1976), Skagg (1981) and Shih (1983) support this observation. In the presence of a shallower water table resulting from poor drainage or subirrigation, more moisture is brought into the surface zone by the interactive forces of evapotranspiration and capillary rise. Between Regimes B and C, however, Regime B consistently showed greater moisture content over the entire tension range of 0m to 158m. Due to the inadequate sample size of 6 per regime per tension levels of 0, 3,
FIGURE 6: Soil Moisture Retention Curves

FIGURE 7: Drainable Porosity Curves From Laboratory Analysis
9, 29 and 158m, no statistical analysis was performed to determine if this difference is significant. From simple observation, DeVries (1984) concluded that the effects of the two subirrigation practices would not be apparent after only one summer of actual operation.

4.3. LABORATORY DETERMINED IN SITU DRAINABLE POROSITY

The drainable porosity curves for Regimes A, B, C and D in Figure 7 show clearly the effect of subirrigation on drainable porosity. The approximate drainable porosity at 120cm tension were 9, 7, 5 and 9% by volume for Regimes A, B, C and D, respectively. These differences were due to the change in soil structure resulting from reversed drainage flow. It was speculated that possibly the transport and deposition of soil particles within soil pores reduced the soil's capacity to release or absorb water in response to water table movement. However, some researchers have argued that this convective process would be minimal for a stable soil where the extent and frequency of water table fluctuations were not excessive. Further field work would be needed to confirm this.

Referring again to Figure 7, the drainable porosity of Regime A was consistently greater than that of Regime D between the tension range of 0cm to 100cm. According to Hundel et al. (1976), subsurface drainage increases the density of large and medium sized pores. The improved hydraulic behaviour of Regime A over Regime D was also made evident in the hydraulic conductivity and moisture retention analyses.
4.4. IN SITU DRAINABLE POROSITY

4.4.1. Rainfall Rate Method

Drainable porosity computed from water table charts and rainfall readings for the years 1983 and 1984 are shown graphically in Figures 8 to 11. A typical hydrograph followed the pattern of sharp rise and then slow recession with the receding limb extending much with respect to time before reaching a plateau. Symmetry was preserved only when a subsequent rainfall event occurred prior to completion of recession of the present hydrograph event. Another point of importance was the time interval the meteorological data represented. Since the rainfall data was collected on a daily basis, the accumulated value was considered to occur over the entire 24-hour period. This limited the accuracy with which the porosity could be computed although the scale on the water table charts was more refined at 8 hours per axis division.

A general comparison between these porosities and those determined in the laboratory indicated a trend of lower values by this approach. This was especially true for porosity values falling within the laboratory tension range. The best agreement was found with the higher subirrigation of Regime C. Regime D showed the poorest agreement although there was a lack of valid data. With the undrained treatment, it was observed that during initially high water table conditions, a rainfall event did not induce a large rise in water table level. From Equation (2.2), this condition resulted in large porosity values. Physically, this implied large pore sizes and well distributed pore spaces within the upper 10cm depth in the undrained plot.
FIGURE 8: Drainable Porosity Based on Rainfall Rate Method For Regime A

FIGURE 9: Drainable Porosity Based on Rainfall Rate Method For Regime B
FIGURE 10: Drainable Porosity Based on Rainfall Rate Method For Regime C

FIGURE 11: Drainable Porosity Based on Rainfall Rate Method For Regime D
4.4.2. Drainage Rate Method

The drainage rates computed from the division of collected total discharge by area drained were representative mainly of the summer months in 1984 (Kerr-Wilson, 1985). Since the total discharge was collected from the middle lateral of a treatment plot, the drainage area was 1400m$^2$. Data collection was performed only on the treatment plots of Regimes A and B. These data were limited due to the absence of drain flow resulting from either lack of rainfall events or random sampling schedules. Porosities derived from this method are shown in Figures 12 and 13. By general inspection, these porosities tended to be higher than those derived by either the laboratory or rainfall rate method.

4.5. THE DRAINABLE POROSITY EQUATION

4.5.1. Curve Fitting

A MIDAS (Fox and Guire, 1976) program and a SAS (Ray, 1982) program were used to determine the suitable curve fitting equation between the polynomial and the negative exponential regressions. The sample coefficients of determination, $R^2$, for all regimes under each regression are shown in Tables VIII and IX. The $R^2$ value was found to be quite high in either cases when considered separately. To compare the two regressions, the correlation index, $F^*$, was necessary. This statistic was computed for the negative exponential regression, and, from Table X, again a high correlation value was found with each regime. The negative exponential equation was the logical choice for the following reasons:

1. simplicity in expression, fewer number of parameters;
2. inherent asymptotic characteristic.
FIGURE 12: Drainable Porosity Based on Drainage Rate Method For Regime A

FIGURE 13: Drainable Porosity Based on Drainage Rate Method For Regime B
Table VIII: Regression Statistics to the Negative Exponential Curve Fitting

<table>
<thead>
<tr>
<th>REG</th>
<th>n</th>
<th>m</th>
<th>df</th>
<th>SSreg</th>
<th>SSres</th>
<th>SSy</th>
<th>R^2</th>
<th>Syx</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>39</td>
<td>1</td>
<td>37</td>
<td>2107.594</td>
<td>28.130</td>
<td>2135.724</td>
<td>0.987</td>
<td>0.872</td>
</tr>
<tr>
<td>B</td>
<td>39</td>
<td>1</td>
<td>37</td>
<td>1329.257</td>
<td>15.242</td>
<td>1344.499</td>
<td>0.989</td>
<td>0.642</td>
</tr>
<tr>
<td>C</td>
<td>39</td>
<td>1</td>
<td>37</td>
<td>710.533</td>
<td>11.127</td>
<td>721.660</td>
<td>0.985</td>
<td>0.548</td>
</tr>
<tr>
<td>D</td>
<td>39</td>
<td>1</td>
<td>37</td>
<td>1941.974</td>
<td>10.423</td>
<td>1952.397</td>
<td>0.994</td>
<td>0.531</td>
</tr>
</tbody>
</table>

Table IX: Regression Statistics to the Polynomial Curve Fitting

<table>
<thead>
<tr>
<th>REG</th>
<th>n</th>
<th>m</th>
<th>df</th>
<th>SSreg</th>
<th>SSres</th>
<th>SSy</th>
<th>R^2</th>
<th>Syx</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>39</td>
<td>6</td>
<td>32</td>
<td>233.660</td>
<td>25.351</td>
<td>259.011</td>
<td>0.902</td>
<td>0.890</td>
</tr>
<tr>
<td>B</td>
<td>39</td>
<td>6</td>
<td>32</td>
<td>146.160</td>
<td>14.842</td>
<td>161.002</td>
<td>0.901</td>
<td>0.681</td>
</tr>
<tr>
<td>C</td>
<td>39</td>
<td>6</td>
<td>32</td>
<td>80.899</td>
<td>10.828</td>
<td>91.727</td>
<td>0.882</td>
<td>0.582</td>
</tr>
<tr>
<td>D</td>
<td>39</td>
<td>6</td>
<td>32</td>
<td>252.120</td>
<td>7.631</td>
<td>259.750</td>
<td>0.971</td>
<td>0.488</td>
</tr>
</tbody>
</table>

Table X: Correlation Index Statistics to the Negative Exponential Curve Fitting

<table>
<thead>
<tr>
<th>REG</th>
<th>n</th>
<th>m</th>
<th>df</th>
<th>SSreg</th>
<th>SSres</th>
<th>SSy</th>
<th>I^1</th>
<th>Syx</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>39</td>
<td>1</td>
<td>37</td>
<td>2107.571</td>
<td>28.153</td>
<td>2135.724</td>
<td>0.993</td>
<td>0.872</td>
</tr>
<tr>
<td>B</td>
<td>39</td>
<td>1</td>
<td>37</td>
<td>1329.117</td>
<td>15.382</td>
<td>1344.499</td>
<td>0.994</td>
<td>0.645</td>
</tr>
<tr>
<td>C</td>
<td>39</td>
<td>1</td>
<td>37</td>
<td>712.560</td>
<td>9.100</td>
<td>721.660</td>
<td>0.994</td>
<td>0.496</td>
</tr>
<tr>
<td>D</td>
<td>39</td>
<td>1</td>
<td>37</td>
<td>1941.818</td>
<td>10.578</td>
<td>1952.396</td>
<td>0.997</td>
<td>0.535</td>
</tr>
</tbody>
</table>
With the polynomial regression, a higher $R^2$ value was always possible given enough parameters. However, the expression would become unnecessarily cumbersome. In this case, a polynomial of the sixth power was needed. Also the resulting polynomial fit would have to be constrained within the 0cm to 120cm tension range since it was not asymptotic.

In Table XI, the parameters $b_0$ and $b_1$ to the chosen equation

$$f = b_0(1 - e^{-b_1z})$$

are given with the $R^2$ statistic. Focussing on the drainable porosity derived by laboratory analysis, the maximum porosity, $b_0$, confirmed the apparent effect of subirrigation by its successively reduced value when comparing the regimes in the order of D, A, B and C. The rate at which the maximum porosity was reached with respect to increased tension was slowest for Regime B. In the drainage rate analysis of $f$, the available data was limited to the summer period of April 1st to September 30th. By this method of analysis, the resulting $b_0$ values were highest, 13.8% for Regime A and 11.7% for Regime B. This observation was caused by the nature of the soil to form cracks and channels, and also by the channeling effects of plant root and earthworm activities. In the rainfall rate analysis, the noticeable difference was the consistently lower $f$ values in the tension range up to 80cm when compared to the corresponding $f$ values derived from the previous two methods. The low sample coefficient of determination for Regimes B, C and D were due to the lack of data for tensions greater than 80cm, 50cm and the entire tension range, respectively.

The drainable porosity derived by all three methods represented a cumulative value with respect to the direction in which the water table travels. With the rainfall rate analysis, the water table was rising; the wetting front was moving through a soil profile of small pores to larger pores. The incremental change in drainable porosity
Table XI: Parameters to the Negative Exponential Drainable Porosity Equation

<table>
<thead>
<tr>
<th>POROSITY</th>
<th>REGIME</th>
<th>n</th>
<th>b₀(%)</th>
<th>b₁(1/cm)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_lab</td>
<td>A</td>
<td>39</td>
<td>8.6023</td>
<td>0.04978</td>
<td>0.987</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>39</td>
<td>6.7775</td>
<td>0.05248</td>
<td>0.989</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>39</td>
<td>5.0225</td>
<td>0.04808</td>
<td>0.985</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>39</td>
<td>8.7246</td>
<td>0.03706</td>
<td>0.995</td>
</tr>
<tr>
<td>f_rain</td>
<td>A</td>
<td>30</td>
<td>12.8716</td>
<td>0.01460</td>
<td>0.915</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>24</td>
<td>10.9392</td>
<td>0.01245</td>
<td>0.887</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>20</td>
<td>7.2742</td>
<td>0.01755</td>
<td>0.872</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>8</td>
<td>7.5398</td>
<td>0.03495</td>
<td>0.859</td>
</tr>
<tr>
<td>f_drain</td>
<td>A</td>
<td>13</td>
<td>13.7657</td>
<td>0.01925</td>
<td>0.910</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>6</td>
<td>11.7094</td>
<td>0.01956</td>
<td>0.971</td>
</tr>
</tbody>
</table>

increased with height. Drainable porosity itself increased sharply upon nearing the soil surface. The water table was receding in the drainage rate analysis. Conversely, the direction of flow was from larger pores to smaller pores. The incremental change in drainable porosity near the soil surface was always greatest and decreased with each successive depth interval. Thus the incremental increase in drainable porosity decreased as the water table dropped farther.

Test for variability was performed on the two parameters b₀ and b₁ for the laboratory analysis. There was insufficient evidence to indicate a significant difference in b₁ among the four regimes. By the Duncan's Multiple Range Test, a significant difference was found to exist in b₀ between Regimes C (subirrigation at 30cm) and D.
(undrained). The effects between drained and subirrigated treatments, and between the two levels of subirrigation were found not to be statistically significant in the research in view of the regression parameters. However, the trend in the differing treatment effects were present.

4.5.2. Corrected f-z function

An underlying objective of the present research was to utilize readily obtainable meteorological data collected on site and at weather stations, in particular water table charts and rainfall data. The application of these data to derive the drainable porosity curve was considered more convinient than that by direct laboratory measurement method and drainage rate method. The latter two methods entailed a greater amount of physical expenditure.

Before the drainable porosity function based on rainfall analysis alone could be incorporated into the water balance model, it was corrected by the two regression equations derived from laboratory and drainage rate analyses. This took into account the reverse direction with which drainable porosity was determined, a rising water table event corrected by a falling water table event in order to reduce the hysteresis effect. Firstly, ratio values of \( \frac{f_{\text{rain}}}{f_{\text{lab}}} \) and \( \frac{f_{\text{rain}}}{f_{\text{drain}}} \) were computed at various tension levels. For all regimes, a constant value, denoted by \( b_4 \), existed for tensions less than 0.1cm. Above this level, the curves all followed the general negative exponential form. It was above this point on each curve that a regression equation was fitted and the constant \( b_4 \) appended afterwards. The correction term was of the general mathematical form:

\[
\frac{f}{f^*} = b_4( 1 - e^{-b_4z} ) + b_4 \tag{4.2}
\]

Thus the final corrected f-z equation was of the form:
Table XII: Parameters to the Corrected Drainable Porosity Equation

<table>
<thead>
<tr>
<th>POROSITY RATIO</th>
<th>REGIME</th>
<th>b₁</th>
<th>b₂</th>
<th>b₄</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>1.08616</td>
<td>0.009976</td>
<td>0.438</td>
<td>0.998</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1.26521</td>
<td>0.009192</td>
<td>0.383</td>
<td>0.995</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0.93948</td>
<td>0.001214</td>
<td>0.529</td>
<td>0.995</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>0.04984</td>
<td>0.001942</td>
<td>0.815</td>
<td>0.998</td>
</tr>
<tr>
<td>f_rain</td>
<td>A</td>
<td>0.23289</td>
<td>0.008327</td>
<td>0.709</td>
<td>0.998</td>
</tr>
<tr>
<td>f_rain</td>
<td>B</td>
<td>0.35408</td>
<td>0.007193</td>
<td>0.595</td>
<td>0.999</td>
</tr>
</tbody>
</table>

\[
f_{\text{corrected}} = b_0(1 - e^{-b_1 z}) / [b_2(1 - e^{-b_1 z}) + b_4] \quad (4.3)
\]

The parameters \( b_2, b_3 \), and \( b_4 \) were obtained for all regimes under the laboratory-based correction. However, with the drainage-rate-based correction, only those for Regimes A and B were obtainable. Those for Regimes C and D were not obtainable due to lack of available data. These parameters are tabulated in Table XII. With these parameters, Equation (4.3) was used in the water balance model to compute the drainable porosity for a given water table depth. This was facilitated by a subroutine program.

4.6. THE MODIFIED WATER BALANCE MODEL
4.6.1. Assumptions to the Model

The following assumptions were made for:

4.6.1.1. The Water Balance Model

1. The basic principle of water balance in the form of:
   \[ \text{Inflow} = \text{Outflow} \pm \text{Change in Storage} \quad (4.4) \]
   is applied with inflow of precipitation and outflows of surface runoff, subsurface runoff and actual evapotranspiration. No inflow of irrigation is considered since artificial water replenishment was through subirrigation.

2. Two distinct storages are considered:
   a. soil moisture storage which is the difference between field capacity and wilting point;
   b. transient storage which is the drainable pore space.

3. The soil profile is divided into four zones. Depths of first, second, third and fourth zones are 30cm, 30cm, 40cm and the remaining distance to drain depth, respectively.

4. The water balance equation to each zone is given by:
   \[ \text{SMC}(I) = \text{SMC}(K) + \text{PPT}(I) - \text{AE}(I) - \text{EX}(I) \quad (4.5) \]
   The variable counters I and K represent the current day and previous day, respectively.

5. Excess Water: EX(I)
   a. When the soil profile is at field capacity before a rainfall, EX(I) is equivalent to the net precipitation for that day. It is the difference between precipitation, PPT(I) and actual evapotranspiration, AE(I). EX(I) goes into transient storage causing a rise in water table.
b. When the soil moisture content is less than field capacity before a rainfall, the net precipitation replenishes the soil moisture of the first, second, third and fourth zone, respectively, up to field capacity. The remaining amount of water becomes EX(I) and goes into transient storage.

6. Actual Evapotranspiration: AE(I)

When an insufficient rainfall occurs such that soil moisture is not brought up to field capacity, EX(I) is zero and actual evapotranspiration, AE(I), takes place. The total evapotranspiration from surface retention, bare soil and plant transpiration is assumed as AE(I). Water extracted as AE(I) occurs from the uppermost zone firstly and then progresses down to the next lower zone. Therefore, AE(I) is the product of the potential evapotranspiration and the AE/PE value of the zone from which water is withdrawn.

a. AE(I) occurs directly from transient storage at the maximum rate of PE(I) x (AE/PE) if the water table is at the surface or in the top 25cm of the profile.

b. On days with precipitation, AE(I) takes place from that rainfall event at a maximum rate of PE(I) x (AE/PE).

c. On days when precipitation exceeds AE(I), the remainder replenishes the moisture storage of the first, second, third and fourth zones, respectively, followed by transient storage, subsurface runoff and surface runoff.

7. All subsurface runoff occurs through the subsurface drainage system.

8. Surface runoff occurs only when the soil profile is saturated to the surface. This is not true when the rainfall rate exceeds the infiltration rate so that surface runoff occurs before the water table reaches the surface. However, this is a conservative assumption since the event of an earlier surface runoff results in
less transient storage and a faster lowering of the water table than predicted by the model.

9. Water held in the drainable pore space between saturation and field capacity percolates to the drains at the design drainage rate with the drain tube center located at the bottom of the fourth zone.

10. Deep seepage is considered as part of the subsurface drain outflow.

4.6.1.2. The Water Table Model

1. Assumption of a nearly flat water table allows for the expression of daily change in water table at midspacing between drains as:

\[
\Delta z = \frac{\Delta (TR)}{f_1} = \frac{R \Delta t}{f_1} \tag{4.6}
\]

This implies that the subsurface drainage flow is restricted by drain tube capacity.

2. When the water table is in the top 40cm of the soil profile, drainage rate is restricted by the drain tube capacity and is at the maximum design rate, RMAX. Below this depth, drainage rate, R, follows Hooghoudt's relationship:

\[
R = 4K \left( 2d_eH + H^2 \right) / S^2 \tag{4.7}
\]

where

- \( R \) = drainage rate
- \( K \) = hydraulic conductivity
- \( d_e \) = equivalent depth
- \( H \) = water table height above drain
- \( S \) = lateral spacing
4.6.1.3. The Computer Model

1. The water table is at the soil surface at the start of each water balance year (January 1st to December 31st). Thus the initial water table depth is assigned zero and the initial soil moisture for each zone is assigned their respective maximum values. Although in reality, this is not always the case, by middle of January the water table is usually at or very near the soil surface at least once in this region and hence, the accuracy of the model is restored there afterward.

2. In determining the drainable porosity from the f-z function, the associated water table depth is necessary. This poses a problem since the current water table depth, \( Z(I) \), to be predicted is itself needed to compute \( f(I) \). To overcome this problem, a procedure of a first crude prediction followed by refinement is used. This involves the computation of an initial crude \( Z'(I) \) based on previous day’s \( Z(K) \) and \( f(K) \). Then a second drainable porosity \( f'(I) \) is obtained from this \( Z'(I) \). The final predicted water table depth is derived by the use of \( f(I) \) which is an average of \( f(K) \) and \( f'(I) \). Due to the shape of the f-z equation given by the negative exponential form, the iterative procedure is convergent.

3. Given the condition that the water table is at the drain level and change in transient storage is positive due to positive \( EX(I) \), drainable porosity based on previous day’s water table depth, \( Z(K) \), is revised to allow for the depletion of transient storage before the water table reaches the drain level. It is assumed no current rainfall event will result in a change in transient storage greater than the maximum transient storage for the fourth zone.

4. Given the conditions that the water table is low and a sudden large rainfall event occurs, only \( f'(I) \), the second drainable porosity resulting from \( Z'(I) \), is used. This ensures the selection of a larger and more realistic drainable porosity.
value and the result is a more subdued rise in water table.

The basic daily algorithm to the water balance model is illustrated in Figure 14 as a generalized flowchart. The FORTRAN program itself is listed in the appendix.

4.7. WATER TABLE SIMULATION

Weather conditions for the two consecutive years of 1984 and 1985 were quite different. The low precipitation and thus dry conditions of 1985 were apparent in the lower water table levels and fewer sharp peaks compared to those of 1984. The actual water tables for each regime of these two years are shown in Figures 15 and 16.

In the simulation, the maximum drainage rate, RMAX, was the varying parameter used to arrive at a visually acceptable agreement between the model and actual water table depths. Figures 17 to 24 give the simulation results to Regimes A, B, C and D for the two years. These were based on the laboratory-corrected drainable porosities. The results based on drainage-rate-corrected drainable porosities are given in Figures 25 to 28.

The model set the initial position of the water table at the soil surface. There was no minimum depth to which the daily water table could be computed. The water table height was determined by the Hooghoudt's relationship, Equation (4.7). This equation was valid only for the prediction of water table height at or above the drain level. In the simulation, whenever the water table was at or below the drain level, the water table height was set to zero. This assumption would not affect the continuity principle since the mass balance was performed for the soil profile above the drain lines only. From all the simulations, the water table tended to reach and stay at the drain level during the period of June 11th to November 10th in 1984 and May 10th to November 3rd in 1985. These results corresponded well with the
FIGURE 14: Generalized Flowchart of the Water Balance Model
FIGURE 15: Actual Water Table Curves For Regimes A, B, C, D of 1984

FIGURE 16: Actual Water Table Curves For Regimes A, B, C, D of 1985
FIGURE 17: Laboratory-Based Water Table Simulation For Regime A of 1984

FIGURE 18: Laboratory-Based Water Table Simulation For Regime B of 1984
FIGURE 19: Laboratory-Based Water Table Simulation For Regime C of 1984

FIGURE 20: Laboratory-Based Water Table Simulation For Regime D of 1984
FIGURE 21: Laboratory-Based Water Table Simulation
For Regime A of 1985

FIGURE 22: Laboratory-Based Water Table Simulation
For Regime B of 1985
FIGURE 23: Laboratory-Based Water Table Simulation For Regime C of 1985

FIGURE 24: Laboratory-Based Water Table Simulation For Regime D of 1985
FIGURE 25: Drainage-Rate-Based Water Table Simulation
For Regime A of 1984

FIGURE 26: Drainage-Rate-Based Water Table Simulation
For Regime B of 1984
FIGURE 27: Drainage-Rate-Based Water Table Simulation For Regime A of 1985

FIGURE 28: Drainage-Rate-Based Water Table Simulation For Regime B of 1985
observed water table levels as shown in Figures 15 and 16.

In general, the model simulated the trend of the actual water table in that peaks and valleys did coincide. This was especially true with Regimes B and C for both years, and with Regime D for the earlier part of both years. In the latter part of the year with Regime D, the trend was present but at a consistently lower depth. With Regime A, the model tended to overshoot with peaks and undershoot with valleys before June but simulated well for the last three months of the year. The water table was observed to fluctuate most pronouncedly with Regime A.

Referring to Table 13, the model confirmed the apparent effects of the different water control regimes. The RMAX values decreased in the order of Regimes A, B, C and D. This followed correctly the respective water regimes of "drainage", "low subirrigation and drainage", "high subirrigation and drainage", "no drainage and no subirrigation". The different drainable porosity characterizing each regime was also made evident in Figures 29 and 30. In both years, the water table heights of Regime A were consistently lower than those of Regimes B and C. Due to the high subirrigation operation, Regime C exhibited the highest levels. These trends were agreeable with those of Figures 15 and 16 which showed the actual field water table heights. Another observation made was the similarity of RMAX between laboratory-corrected simulations and drainage-rate-corrected simulations. Thus, it is possible to work with field data of rainfall and drainage rates in place of laboratory core samples to derive the drainable porosity equation.

Application of the Wilcoxon's paired-sample test was attempted. However due to the nature of the test, what was visually a good simulation needed not to be a statistically significant agreement. Since both direction and magnitude of the difference between the paired observations were considered, the test was not able to optimize the
Table XIII: Maximum Design Drainage Rate RMAX

<table>
<thead>
<tr>
<th>METHOD</th>
<th>REGIME</th>
<th>1984</th>
<th>1985</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>4.5</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Lab.</td>
<td>C</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Based</td>
<td>D</td>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Drain.</td>
<td>A</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Rate</td>
<td>B</td>
<td>3.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

absolute minimum differences summed over the analysis period. Thus a large overshoot could be compensated by a large undershoot occurring anywhere within the one year period. At the end, the model simulations were tested visually.

In being able to reasonably simulate the water table, the usefulness of the model is in its relationship to the SEW_{30} criterion. For this research field and the Lower Fraser Valley, the sum of daily water table height recorded above the depth of 30cm at the midpoint between drains is not to exceed 200cm (SEW_{30} < 200cm) during November 1st to March 31st. A simple accompanying computer program could conveniently compute the SEW_{30} value after each simulation. Furthermore, the graphical plots of the simulation could provide the information of approximately when the water table is at or above the 30cm depth during the year.
FIGURE 29: Water Table Simulation For Regimes A, B and C of 1984 (Based on Laboratory Method)

FIGURE 30: Water Table Simulation For Regimes A, B and C of 1985 (Based on Laboratory Method)
5. SUMMARY AND CONCLUSIONS

1. The experimental field at Boundary Bay, Delta, was placed under four types of water control regimes: drainage, low subirrigation with drainage, high subirrigation with drainage, and no subirrigation with no drainage (Regimes A, B, C, D, respectively). Physical and hydraulic soil properties of each treatment plots were analyzed using undisturbed core samples and loose soil samples. All the regimes were classified as silt loam with high percentage content of silt. The bulk density ranged from 1.29 g/cm$^3$ to 1.46 g/cm$^3$ which agreed well with the results of other independent studies on the same field. The satiated hydraulic conductivity of Regime A was the highest followed by those of Regimes B, C and D. Regime A also exhibited the lowest water retention curve among the four treatments.

2. Drainable porosities derived from laboratory analysis showed clearly the negative effect of subirrigation on this property. The approximate drainable porosity at 120cm tension for Regimes A, B, C and D were 9, 7, 5 and 9% by volume, respectively. The decrease in drainable porosity was probably attributed to the transport and deposition of fine soil particles brought about by subirrigation. The reduced pore spaces led to the reduction in drainable porosity.

3. Drainable porosities determined from the recorded water table charts and measured drainage rates were generally higher than those determined in the laboratory. This conclusion, however, was not substantiated by an adequate sample size.

4. Drainable porosities determined from water table charts and rainfall data were generally lower than those determined by either laboratory or drainage rate method. This was especially true for the tension range of 0cm to 120cm. Since the drainable porosity is a cumulative value affected by the direction of flow, these observations are reasonable. In the rainfall rate analysis, the water table was rising,
moving through a profile of smaller to larger pores. The incremental change in drainable porosity increased with the height of the water table and was greatest near the soil surface. Conversely with the drainage rate analysis, the water table was receding from the surface, moving through larger to smaller pores. The incremental change in drainable porosity decreased progressively with water table depth. However, the initial drainable porosities near the surface depth was always greater than those derived by a rising water table reaching the soil surface.

5. Drainable porosities derived in the laboratory were used for the curve fitting procedure. The negative exponential form was chosen over the polynomial form since it was simple in expression and was inherently asymptotic. The polynomial fit was equally acceptable but only when fitted to the sixth power.

6. Test for variability was performed on the two parameters, \( b_0 \) and \( b_1 \), to the negative exponential drainable porosity equation:

\[
f = b_0(1 - e^{-b_1z})
\]  

\( b_0 \) represented the maximum drainable porosity while \( b_1 \) represented the rate constant. No significant difference was found for \( b_1 \) among treatments. For \( b_0 \), a significant difference existed between Regimes C and D. At this point in the research, only the apparent trends indicating the effects of different water treatments were reportable.

7. Since an underlying objective of the study was to utilize readily available meteorological data in defining drainable porosity, the drainable porosity function based on rainfall analysis was corrected by those based on laboratory analysis and drainage rate analysis. The corrected \( f-z \) expression was of the general mathematical form of:

\[
f_{\text{corrected}} = \frac{b_0(1 - e^{-b_1z})}{[b_2(1 - e^{-b_3z}) + b_4]}
\]  

8. Equation (5.2) was incorporated into the computer water balance model by a subroutine program, DPORE(....). In the simulation process, \( Z(I) \) itself is needed in
advance for use in the f-z equation. This problem was solved by using \( Z(K) \), the previous day's water table depth, to obtain \( f(K) \) which in turn gave a first approximated \( Z'(I) \) value. A second \( f'(I) \) was obtained from \( Z'(I) \). The final \( f(I) \) was derived from the average of \( f(K) \) and \( f'(I) \). This \( f(I) \) value was used to compute the present day's water table depth, \( Z(I) \).

9. The results generated by the modified water balance model were visually tested for good agreement with actual water table depths. Although weather conditions for 1984 and 1985 were quite different, the model did follow the trend of actual water table patterns. Better simulation was found for Regimes B, C and D over Regime A. Water table fluctuation was most pronounced for Regime A such that the model tended to correspondingly overshoot or undershoot.

10. The Wilcoxon's paired-sample test was found to be inappropriate for this study in comparing simulated and actual water table levels. It did not optimize the absolute minimum differences summed over the analysis period.

11. One of the additional usefulness of this water balance model lies with the SEW information that it is able to provide. Furthermore, the graphical representation of its simulation results easily shows when the water table is likely to be at or above this critical depth of 30cm given a wet or a dry year.
6. RECOMMENDATIONS

As a result of this study, the following recommendations are suggested for further investigation:

1. To determine the variability of drainable porosity within a regime, drainable porosity curves obtained from laboratory analysis on core samples extracted from varying depths are required.

2. Further observation of the effects the four types of water regimes have on drainable porosity is needed along with obtaining information of possible statistical significance on the negative exponential parameters.

3. Determination of the applicability of the negative exponential function to other soil types, and, if so, the determination of the parameters for these soil types.

4. Continued drainage rate data collection is needed to supplement this part of the drainable porosity analysis.

5. A more suitable statistical analysis is necessary to test the accuracy with which the water balance model is able to simulate water table depth.

6. The implementation of field trials of the drainage coefficient determined from model simulation should be performed to confirm the validity of RMAX and thus the practicality of the model itself.
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The water table model is accessible on the MTS System at the University of British Columbia from the Department of Bio-Resource Engineering.

APPENDIX

The water table model is accessible on the MTS System at the University of British Columbia from the Department of Bio-Resource Engineering.
C TRMAX = MAXIMUM TRANSIENT STORAGE FOR WHOLE PROFILE.
C TR1,TRISUM = MAXIMUM TRANSIENT STORAGE FOR 1ST ZONE.
C TR2,TR2SUM = MAXIMUM TRANSIENT STORAGE FOR 2ND ZONE.
C TR3,TR3SUM = MAXIMUM TRANSIENT STORAGE FOR 3RD ZONE.
C TR4,TR4SUM = MAXIMUM TRANSIENT STORAGE FOR 4TH ZONE.
C WTH = MAX. HEIGHT FROM DRAIN CENTER THAT HOOGHOUT'S EQUATION APPLIES.
C Z = WATER TABLE DEPTH FROM SOIL SURFACE.

TABLES:
1. DISTRIBUTION OF DAILY WATER TABLE DEPTH.
2. MONTHLY SUMMARY WATER TABLE DEPTH DISTRIBUTION FOR EACH WATER BALANCE YEAR.
3. MONTHLY SUMMARY WATER TABLE DEPTH DISTRIBUTION FOR N YEARS.
4. MONTHLY FREQUENCY DISTRIBUTION OF WATER TABLE DEPTH FOR N YEARS.
5. SEASONAL FREQUENCY DISTRIBUTION TABLE.
6. SUMMARY OF FREQUENCY DISTRIBUTION FOR N YEARS.

NOTE: N IS THE TOTAL NUMBER OF YEARS FOR THAT RUN.

MISSING = WHEN "MISSING" APPEARS, THIS MEANS THE DAILY DATA FOR PRECIPITATION OR/AND PE WAS/WERE NOT AVAILABLE FOR THESE DAYS. CALCULATIONS WILL NOT BE DONE FOR THESE DAYS BUT CONTINUE RIGHT AFTER MISSING DAYS WHEN DAILY DATA IS AVAILABLE BY USING THE INFORMATION FROM THE DAY BEFORE THE MISSING DAYS.

ICOND = COUNTER FOR DAILY WATER TABLE DISTRIBUTION.
ICONT = COUNTER FOR MONTHLY SUMMARY OF WATER TABLE DEPTH.
IFDOWT = COUNTER FOR FREQUENCY DISTRIBUTION OF WATER TABLE DEPTH.
ICONF1 = COUNTER FOR TOTAL FREQUENCY OF WATER TABLE DEPTH.
ICONF2 = COUNTER FOR SEASONAL FREQUENCY DISTRIBUTION OF WATER TABLE DEPTH (APRIL-MAY).
ICONF3 = COUNTER FOR SEASONAL FREQUENCY DISTRIBUTION OF WATER TABLE DEPTH (JUNE-SEPTEMBER).
ICONF4 = COUNTER FOR SEASONAL FREQUENCY DISTRIBUTION OF WATER TABLE DEPTH (OCTOBER-NOVEMBER).
ICONF5 = COUNTER FOR MONTHLY FREQUENCY DISTRIBUTION OF WATER TABLE DEPTH FOR N YEARS.

NOTE: WHEN THE COUNTER IS ASSIGNED TO 0, NO OUTPUT OF THE APPROPRIATE TABLES ARE WANTED. IF THE COUNTER IS ASSIGNED TO 1, THEN THE APPROPRIATE TABLES WILL BE PRINTED.

DIMENSION MONTH(380),PRE(380),PE(380),AE(380),REM(380),DP(380),
* RO(380),TR(380),SMC1(380),SMC2(380),SMC3(380),DELT(380),Z(380),
* DELZ(380),SD(380),IDAY(380),KMDNT(12,5),DEP(10),IYEAR(380),
* MAT(150.10),MJA(62,10),MANF(62,10),M5F(31,10),
* M(12,14),I(12,14),I(12,14),I(380),H(380),MMFJ(62,10),
* MGF(31,10),M7F(31,10),MBF(31,10),M9F(31,10),M10F(31,10),
* M11F(31,10),PERIOD(5,18),STA(10),SOIL(10),MNDF(62,10),MSDF(62,10),
* M1F(31,10),M2F(31,10),M3F(31,10),M12F(31,10),
REAL KCORR,KLAB,KFIELD

INTEGER STAT

READ(5,10) IRD,ISTART,IEND,MSTART,MEND
10 FORMAT(5I2)

READ(5,11) RMAX,HMAX,D,DW,D1,SMCF,SZMCF1,SZMCF2,SZMCF3,SZMCF4
11 FORMAT(F5.1,2F5.0,7F5.1)

READ(5,12) ALAB,KLAB,AFIELD,KFIELD,ACORR,KCORR,CONST,C1,C2,C3,C4
FORMAT(3(F8.4,F8.5),F6.3,4F5.2)
READ(5,13)((KMONT(I,J),J=1,5),I=1,12)
FORMAT(8(5A2))
READ(5,14)((PERIOD(I,J),J=1,18),I=1,5)
FORMAT(3(18A1,2X))
READ(5,15) (DEP(I),I=1,10)
FORMAT(1012)
WH=HMAX-DW
C=RMAX/(2*D*WTH+WTH**2)
CALL TRANST(D1,KFIELD,KCORR,AFIELD,ACORR,CONST,HMAX,
*TR1SUM,TR2SUM,TR3SUM,TR4SUM,TRMAX)
TR1=TR1SUM
TR2=TR2SUM
TR3=TR3SUM
TR4=TR4SUM
CALL FACTOR(RMAX,DW,D,HMAX,C,SMCF,SMCF1,SMCF2,SMCF3,SMCF4,
*TRMAX,TR1,TR2,TR3,TR4,C1,C2,C3,AFIELD,KFIELD,ALAB,KLAB,ACORR,
*KCORR,CONST)
TEMP1=0.99
TEMP2=98.99
DO 25 N=1,366
DO 25 M=1,14
ITOTF(N,M)=0
DO 30 N=1,12
DO 30 M=1,14
MATT(N,M)=0
DO 50 I=1,31
DO 50 J=1,10
M1F(I,J)=0
M2F(I,J)=0
M3F(I,J)=0
M4F(I,J)=0
M12F(I,J)=0
IF(I.EQ.31) GO TO 35
M5F(I,J)=0
M6F(I,J)=0
M7F(I,J)=0
M8F(I,J)=0
IF(I.EQ.31) GO TO 40
M9F(I,J)=0
M10F(I,J)=0
IF(I.EQ.31) GO TO 50
M11F(I,J)=0
CONTINUE
DO 55 KJM=1,124
DO 55 MLK=1,10
MANF(KJM,MLK)=0
DO 60 IUN=1,10
DO 60 NJI=1,10
MJAF(IUN,NJI)=0
DO 70 I=1,10
DO 70 J=1,10
MNDF(I,J)=0
175 MSOF(I,J)=0
176 MMJF(I,J)=0
177 MAX1=0
178 MAX2=0
179 MAX3=0
180 MAX4=0
181 MAX5=0
182 MAX6=0
183 IJK=0
184 C
185 I=2
186 READ(5,120) ( STA(IJ),I,J=1,10)
187 90 READ(IRD,100,END=130) STAT,JYEAR,IMONT,JDAY,PPT,PET
188 100 FORMAT(17,312,16X,F4.1,11X,F4.1)
189 110 IF(STAT.EQ.9999999.0 OR STAT.EQ.1111) GO TO 1470
190 120 FORMAT(IOA2)
191 IF(JYEAR.LT.ISTART) GO TO 90
192 IF(JYEAR.GT.IEND) GO TO 1470
193 IF(IMONT.LT.ISTART) GO TO 90
194 IF(IMONT.GT.IEND) GO TO 130
195 IF(IMONT.EQ.12) GO TO 131
196 GO TO 132
197 131 IJK=IJK+1
198 MONTH(I)=IMONT
199 IDAY(I)=JDAY
200 PRE(I)=PPT
201 PE(I)=PET
202 I=I+1
203 IF(IJK.EQ.31) GO TO 130
204 GO TO 90
205 132 CONTINUE
206 MONTH(I)=IMONT
207 IDAY(I)=JDAY
208 PRE(I)=PPT
209 PE(I)=PET
210 I=I+1
211 GO TO 90
212 130 CONTINUE
213 II=I-1
214 IJK=II
215 C
216 140 IF(ICOND.EQ.0) GO TO 150
217 CALL TITLE1(STA,JYEAR,RMAX,SMCF,HMAX)
218 150 K=1
219 ZKEEP=0
220 Z(K)=0.0
221 CALL DPORE(Z(K),HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP(K))
222 DELTR(K)=0.0
223 DELZ(K)=0.0
224 SMC1(K)=SZMCF1
225 SMC2(K)=SZMCF2
226 SMC3(K)=SZMCF3
227 TR(K)=TRMAX
228 H(K)=HMAX-Z(K)
229 SD(K)=RMAX
230 ICHECK=0
231 IDAYC=1
232 ICOM=0
IF (ICONO.EQ.0) GO TO 170
WRITE(6,160) SD(K),TR(K),SMC1(K),SMC2(K),SMC3(K),DELTR(K),
1 DELZ(K),Z(K),H(K)
FORMAT(58X,5F6.2,4F8.2)
DO 1020 I=2,II
IF (PE(I).EQ.TEMP1.OR.PRE(I).EQ.TEMP2) GO TO 980
ICOM=0
IF (ICHECK.EQ.0) GO TO 180
K=JSTAY+1
ICHECK=0
GO TO 190
K=I-1
IF (PRE(I)-C1*PE(I)) 650,640,200
REM(I)=SMC1(K)+SMC2(K)+SMC3(K)-SMCF+PRE(I)-C1*PE(I)
NA=0
IF (REM(I)) 640,210,210
IF (TR(K)+REM(I)-TR2-TR3-TR4) 560,550,220
CALL DPOR(Z(K),HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP(K))
DPK=DP(K)
SD(I)RMAX
IF (TR(K)+REM(I)-RMAX-TRMAX) 540,530,230
DO(I)=TR(K)+REM(I)-RMAX-TRMAX
TR(I)=TRMAX
IF (NA.EQ.1) GO TO 690
SMC1(I)S2MCF1
SMC2(I)S2MCF2
SMC3(I)S2MCF3
AE(I)=C1*PE(I)
DELTR(I)=TR(I)-TR(K)
IF (DELTR(I).GT.0.0.AND.Z(K).GE.HMAX) GOTO 301
GOTO 302
CALL DP4(DELTR(I),D1,HMAX,TR4,Z(K),KFIELD,KCORR,AFIELD,ACORR,CONST,DP(K))
DPK=DP(K)
IF (DP(K).GT.0.0) GOTO 304
DP(K)=0.0
DELZ(I)=0.0
GOTO 306
DELZ(I)=DELTR(I)/DP(K)
Z(I)=Z(K)-DELZ(I)
IF (Z(I).GE.HMAX) Z(I)=HMAX
REM(I)=SMC1(K)+SMC2(K)+SMC3(K)-SMCF+PRE(I)-C1*PE(I)
CALL DPOR(Z(I),HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP(I))
DPI=DP(I)
DP(I)=(DPK+DPI)/2.0
IF (DP(I).GT.0.0) GOTO 326
DP(I)=0.0
DELZ(I)=0.0
GOTO 328
DELZ(I)=DELTR(I)/DP(I)
Z(I)=Z(K)-DELZ(I)
GIVEN THE CONDITION WHERE THE WATER TABLE IS AT DRAIN LEVEL AND
DELTR(I) IS POSITIVE DUE TO POSITIVE EXCESS, DP(K) IS ASSIGNED
A VALUE WITH THE ASSUMPTION THAT NO CURRENT PRECIPITATION EVENT
WILL RESULT IN DELTR(I) GREATER THAN TR4.
IF (DELTR(I).GT.0.0.AND.Z(K).GE.HMAX) GOTO 301
GOTO 302
CALL DP4(DELTR(I),D1,HMAX,TR4,Z(K),KFIELD,KCORR,AFIELD,ACORR,CONST,DP(K))
DPK=DP(K)
IF (DP(K).GT.0.0) GOTO 304
DP(K)=0.0
DELZ(I)=0.0
GOTO 306
DELZ(I)=DELTR(I)/DP(K)
Z(I)=Z(K)-DELZ(I)
IF (Z(I).GE.HMAX) Z(I)=HMAX
REM(I)=SMC1(K)+SMC2(K)+SMC3(K)-SMCF+PRE(I)-C1*PE(I)
CALL DPOR(Z(I),HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP(I))
DPI=DP(I)
DP(I)=(DPK+DPI)/2.0
IF (DP(I).GT.0.0) GOTO 326
DP(I)=0.0
DELZ(I)=0.0
GOTO 328
DELZ(I)=DELTR(I)/DP(I)
Z(I)=Z(K)-DELZ(I)
GIVEN THE CONDITION THAT THE WATER TABLE IS LOW AND A
SUDDEN LARGE RAINFALL EVENT OCCURS, DRAINABLE POROSITY
IS CORRECTED (INCREASED) BY USING THE MOST CURRENTLY
PREDICTED WATER TABLE DEPTH OF TODAY.
IF (H(K).LT.200.0.AND.PRE(I).GT.15.0) GOTO 329
GOTO 435
CALL DPORE(Z(I),HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP(I))
IF (DP(I).GT.0.0) GOTO 432
DP(I)=0.0
DELZ(I)=0.0
GOTO 433
DELZ(I)=DELT(I)/DP(I)
Z(I)=Z(K)-DELZ(I)
H(I)=HMAX-Z(I)
IF(Z(I).GE.(HMAX-0.01)) Z(I)=HMAX
IF(H(I).LE.0.01) H(I)=0.0
IF(H(I).GT.HMAX) H(I)=HMAX
IF(ICOND.EQ.0) GO TO 470
IF(MONTH(I).GE.2.AND.MONTH(I).LE.12) GO TO 440
GO TO 450
IF(IDAY(I).NE.1) GO TO 450
CALL TITLE 1(STA,JYEAR,RMAX,SMCF,HMAX)
WRITE(6,460) IDAY(I),MONTH(I),JYEAR,PE(I),AE(I),PRE(I),RO(I),DP(I)
WRITE(7,455) IDAY(I),MONTH(I),JYEAR,H(I)
IF(Z(I).GE.999.99) GO TO 1020
DO 500  IM=1,10
IMM=10-IM+1
IK=100*IM
IF(Z(I).LT.IK.AND.Z(I).GE.(IK-100)) GO TO 510
CONTINUE
GO TO 1020
RO(I)=0.
GO TO 570
CALL DPORE(Z(K),HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP(K))
DPK=DP(K)
RO(I)=0.0
GO TO 570
CALL DPORE(Z(K),HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP(K))
DPK=DP(K)
RO(I)=0.0
IF(TR(K)+REM(I)-TR3-TR4) 610,570,570
IF(H(K).GE.(HMAX-DW)) GO TO 580
IF (TR(K).GT.0.0.AND.H(K).LE.0.0) GOTO 582
SD(I)=C*(2*D*(H(K)+(H(K))**2)
GOTO 600
SD(I)=C*(2*D*0.005*HMAX*(0.005*HMAX)**2)
GOTO 600
590 SD(I)=RMAX
600 TR(I)=TR(K)+REM(I)-SD(I)
601 RO(I)=0.0
602 GO TO 250
610 IF(TR(K)+REM(I)-TR4) 620,580,580
620 IF (TR(K).GT.0.0.AND.H(K).LE.0.0) GOTO 625
625 SD(I)=C*(2*D*H(K)+(H(K))*2)
626 GOTO 626
627 IF(SD(I).GE.(TR(K)+REM(I))) GO TO 630
628 GO TO 600
630 TR(I)=0.0
631 RO(I)=0.0
632 GO TO 250
640 REM(I)=0.
641 NA=1
642 GO TO 210
650 IF(TR(K)-TR3-TR2-RMAX) 651,660,660
651 IF (TR(K)-TR2-TR3-TR4) 652,660,660
652 IF (TR(K)-TR3-TR4) 653,660,660
653 IF (TR(K)-TR4) 654,660,660
654 IF (TR(K)+PRE(I)-C1*PE(I)) 655,656,656
655 REM(I)=PRE(I)-C1*PE(I)
656 TR(I)=0.0
657 SD(I)=C*(2*D*H(K)+(H(K))*2)
658 RO(I)=0.0
659 CALL DPORE(Z(K),HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP(K))
660 DPK=DP(K)
665 GOTO 840
666 IF(H(K).GT.0.0) GOTO 670
667 IF (H(K).GE.(HMAX-DW)) GO TO 670
668 IF (H(K).GT.0.0.AND.H(K).LE.0.0) GOTO 672
669 SD(I)=C*(2*D*H(K)+(H(K))*2)
670 GOTO 680
671 SD(I)=RMAX
672 IF(PRE(I)-C1*PE(I)) 700,710,710
673 IF(SMC2(K)+SMC3(K)-SZMCF2-SZMCF3) 720,710,710
674 IF(SMC1(K)+PRE(I)-C1*PE(I))=SMC1(K)+PRE(I)-C1*PE(I)
675 DPK=DP(K)
676 GO TO 840
677 IF(PRE(I)-C1*PE(I)) 870,840,700
678 IF(SMC2(K)+SMC3(K)+SMC3(K)-SZMCF2-SZMCF3) 720,710,710
679 IF(SMC1(K)+PRE(I)-C1*PE(I)-SZMCF1) 740,770,780
680 IF(SMC2(K)+PRE(I)-C1*PE(I)-SZMCF1) 740,770,780
681 SM0M0=SMC1(K)+PRE(I)-C1*PE(I)
682 GO TO 270
683 DPK=DP(K)
684 GO TO 840
685 IF(SMC2(K)-SMC3(K)-SZMCF3) 790,730,730
686 IF(SMC1(K)+PRE(I)-C1*PE(I)-SZMCF1) 740,770,780
687 SM0M0=SMC1(K)+PRE(I)-C1*PE(I)
688 IF(SMC2(K)+PRE(I)-C1*PE(I)-SZMCF1) 740,770,780
689 SM0M0=SMC2(K)
690 GO TO 290
SMC1(I)=SZMCF1
GO TO 850
SMC1(I)=SZMCF1
SMC2(I)=SZMCF1
SMC3(I)=SZMCF1
GO TO 280
SMC3(I)=SMC3(K)
GO TO 810
IF (TR(I).GT.0.0) GOTO 842
SMC1(I)=SMC1(K)+TR(I)
TR(I)=0.0
GOTO 850
SMC1(I)=SMC1(K)
SMC2(I)=SMC2(K)
SMC3(I)=SMC3(K)
GO TO 290
SMC1(I)«SMC1(K)+TR(K)
GO TO 850
SMC1(I)«SMC1(K)
SMC2(I)«SMC2(K)
SMC3(I)«SMC3(K)
GO TO 300
SMC2(I)=SMC2(K)+PRE(I)-C1*PE(I)
SMC1(I)«SMC1(K)
SMC2(I)«SMC2(K)
GO TO 850
SMC1(I)«SMC1(K)
SMC2(I)«SMC2(K)+C2*(SMC1(K)+PRE(I)-C1*PE(I))
AE(I)=SMC1(K)-C2*(SMC1(K)+PRE(I)-C1*PE(I))
SMC3(I)=SMC3(K)
GO TO 300
SMC2(I)=SMC2(K)+PRE(I)-C1*PE(I)
SMC1(I)=SMC1(K)+PRE(I)-C1*PE(I)
SMC1(I)«SMC1(K)
IF(SMC2(I).EQ.0.0) GO TO 950
SMC1(I)=SMC1(K)+PRE(I)-C1*PE(I)
SMC3(I)=SMC3(K)
GO TO 300
SMC2(I)«SMC2(K)+C2*(SMC1(K)+PRE(I)-C1*PE(I))
SMC3(I)=SMC3(K)
GO TO 300
SMC2(I)«SMC2(K)+PRE(I)-C1*PE(I)
SMC1(I)=SMC1(K)+PRE(I)-C1*PE(I)
SMC1(I)=SMC1(K)+PRE(I)-C1*PE(I)
IF(SMC1(I).LT.0.0) GO TO 960
SMC1(I)=SMC1(K)+SMC2(K)+SMC3(K)
SMC3(I)=SMC3(K)
GO TO 300
SMC3(I)=SMC3(K)
GO TO 300
IF(SMC1(K)+SMC2(K)+SMC3(K)<SZMCF2) 970,900.900
SMC1(I)=SMC1(K)+PRE(I)-C1*PE(I)
SMC2(I)=SMC2(K)+C2*(SMC1(K)+PRE(I)-C1*PE(I))
AE(I)=SMC1(K)-C2*(SMC1(K)+PRE(I)-C1*PE(I))
SMC3(I)=SMC3(K)
GO TO 300
SMC2(I)=SMC2(K)+PRE(I)-C1*PE(I)
SMC1(I)=SMC1(K)+PRE(I)-C1*PE(I)
SMC1(I)=SMC1(K)+PRE(I)-C1*PE(I)
IF(SMC1(I).LT.0.0) GO TO 960
SMC1(I)=SMC1(K)+SMC2(K)+SMC3(K)
GO TO 300
SMC3(I)=SMC3(K)
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SMC3(I)=SMC3(K)
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SMC3(I)=SMC3(K)
GO TO 300
SMC2(I)=SMC2(K)+PRE(I)-C1*PE(I)
SMC1(I)=SMC1(K)+PRE(I)-C1*PE(I)
SMC1(I)=SMC1(K)+PRE(I)-C1*PE(I)
IF(SMC1(I).LT.0.0) GO TO 960
SMC1(I)=SMC1(K)+SMC2(K)+SMC3(K)
GO TO 300
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SMC3(I)=SMC3(K)
GO TO 300
SMC3(I)=SMC3(K)
GO TO 300
SMC3(I)
IF(IDAY(I).EQ.1.AND.MONTH(I).NE.1) CALL TITLE1(STA,JYEAR,
1 RMAX,SMCF,HMAX)
466 IF(P(E(I).EQ.TEMP1.AND.PRE(I).EQ.TEMP2) WRITE(6,990) IDAY(I),MONTH(
467 1),JYEAR)
469 N90 FORMAT( ' ',19X,3(I2,1X),'MISSING',5X,'MISSING')
470 IF(P(E(I).EQ.TEMP1.AND.PRE(I).EQ.TEMP2) WRITE(6,9900)IDAY(I),MONTH(
471 1),JYEAR)
472 T000 FORMAT( ' ',19X,3(I2,1X),'MISSING',4X,F6.2)
473 IF(P(E(I).EQ.TEMP1.AND.PRE(I).EQ.TEMP1) WRITE(6,1010)IDAY(I),MONTH(
474 1),JYEAR,P(E(I)
475 1010 FORMAT( ' ',19X,3(I2,1X),F5.2,7X,'MISSING')
476 CONTINUE
477 END LOOP FOR YEAR
478 C OUTPUT TABLE 2
479 IF(ICONT.EQ.0) GO TO 1090
480 WRITE(6,1030)(STA(I),I=1,10),JYEAR
481 1030 FORMAT( ' ',5(/),27X,'TABLE : MONTHLY SUMMARY OF THE NUMBER OF
482 1DAYS THAT THE PREDICTED WATER',/,,42X,
483 2'TABLE DEPTH IS LESS THAN THE INDICATED WATER TABLE DEPTH',/,,45X,
484 3'STATION : ',10A2.9X,'YEAR : 19',12)
485 WRITE(6,1040) (DEP(I),I=1,10)
486 1040 FORMAT(/,21X,87('**'),/,.21X,'** WATER TABLE **',70X,'**',/,.121X,'** DEPTH **',1X,F5.0,9(F7.0),1X, '**',/,.21X,
487 2** (MM) **',70X,'**',/,.21X,87('**'))
488 DO 1050 J1=1,12
489 1050 WRITE(6,1060) (KMONT(J1,J2),J2=1,5), (MATT(J1,J2),J2=1,10)
490 1060 FORMAT(21X,'* ',5A2,' * ',14,3X,8(I4,3X),14,2X,
491 1',* ',21X,'* ',14,2X,14,3X,8(I4,3X),14,2X,
492 1',* ',70X,'**',/,.21X,87('**'))
493 WRITE(6,1070) RMAX,SMCF,HMAX
494 1070 FORMAT(/,22X,'RMAX = ',F4.0,'MM/DAY',/,,22X,'AVAILABLE SOIL MOISTURE',,
495 2' FOR TOP THREE ZONES = ',F5.0,'MM',/,,22X,'SUBSURFACE DRAIN',,
496 3'DEPTH = ',F6.0,'MM')
498 DD 1085 JI=1,14
499 1085 WRITE(6,1090) (ITOTAL(IJ,J1),J1=1,5), (MATT(IJ,J1),J1=1,10)
500 1090 IF(IFDOWT.EQ.0) GO TO 1450
503 C C CHECKING FOR LEAP YEAR
504 C C Z1=DEP(II)
505 IF(Z1-1000.0) 1100,1100,3000
506 1100 IC=1
507 UC=1
508 INMJ=1
509 INJA=1
510 INAN=1
511 MZ=1900+JYEAR
512 MM=MZ/4
513 MM=4*MM
514 IF(MM.EQ.MZ)IIK=367
515 IIK=366
516 DD 1440 II=1,10
517 Z1=DEP(II)
518 IR=II
519 IF(Z1-1000.0) 1100,1100,3000
520 IC=1
521 UC=1
522 INMJ=1
523 INJA=1
524 INAN=1
DO 1430 I*2,IIK
IF(P(E(I)).EQ.TEMP1.OR.PRE(I).EQ.TEMP2) GO TO 1430
IF(Z(I).LE.Z1) GO TO 1120
IC=1
JC=1
INMJ=1
INJA=1
INAN=1
INGS=1
INNS=1
GO TO 1430
IF(CONF1.EQ.0) GO TO 1140
DO 1130 IN-1.IC
INF=INF+I
1130 IT0TF(IN,IR)=IT0TF(IN,IR)+1
IF(MAX1.LE.INF) MAX1=INF
IC=IC+1
IF(IC.EQ.367) GO TO 4000
IF(CONF2.EQ.0) GO TO 1160
MZ=1900+JYEAR
MM=MZ/4
MM=4*MM
IF(MM.EQ.MZ) GO TO 1
MN=60
KKL=MN
GO TO 2
1 MN=61
KKL=MN
CONTINUE
IF(I.LT.2.OR.I.GT.MN) GO TO 1170
DO 1150 IMJ=1,INMJ
IMF2=IMJ
1150 MMJF(IMJ,IR)=MMJF(IMJ,IR)+1
IF(MAX2.LE.IMF2) MAX2=IMF2
INMJ=INMJ+1
IF(INMJ.EQ.63) GO TO 5000
IF(CONF3.EQ.0) GO TO 1190
N1=KKL+61
N2=KKL+1
CONTINUE
IF(I.LT.N2.OR.I.GT.N1) GO TO 1200
DO 1180 IMA=1,INJA
IMF3=IMA
1180 MJAF(IMA,IR)=MJAF(IMA,IR)+1
IF(MAX3.LE.IMF3) MAX3=IMF3
INJA=INJA+1
IF(INJA.EQ.63) GO TO 6000
CONTINUE
IF(Constructor4.EQ.0) GO TO 1220
N3=N1+123
N4=N1+1
IF(I.LT.N4.OR.I.GT.N3) GO TO 1201
CONTINUE
581 1210 MANF(IAN,IR)=MANF(IAN,IR)+1
582 IF(MAX4.LE.IMF4) MAX4=IMF4
583 INAN=INAN+1
584 IF(INAN.EQ.125) GO TO 1200
585 1220 IF(ICONF5.EQ.0) GO TO 1204
586 1201 CONTINUE
587 N5=N3+61
588 N6=N3+1
589 IF(I.LT.N6.OR.I.GT.N5) GO TO 1202
590 DO 1203 ING=1,INGS
591 IMF5=ING
592 1203 MSOF(ING,IR)=MSOF(ING,IR)+1
593 IF(MAX5.LE.IMF5) MAX5=IMF5
594 INGS=INGS+1
595 IF(INGS.EQ.63) GO TO 1201
596 1204 IF(ICONF6.EQ.0) GO TO 1206
597 1202 N7=N5+61
598 N8=N5+1
599 IF(I.LT.N8.OR.I.GT.N7) GO TO 1230
600 DO 1205 INN=1,INNS
601 IMF6=INN
602 1205 MNDF(INN,IR)=MNDF(INN,IR)+1
603 IF(MAX6.LE.IMF6) MAX6=IMF6
604 INNS=INNS+1
605 IF(INNS.EQ.63) GO TO 1203
606 1206 IF(ICONF7.EQ.0) GO TO 1230
607 1230 IF(IDAY(I).GT.1) GO TO 1240
608 JC=1
609 1240 DO 1250 NM=1,12
610 IF(MONTH(I).GT.NM) GO TO 1250
611 NN=NM-3
612 GO TO (3,4,5,1260,1280,1300,1320,1340,1360,1380,1400,6),NM
613 1250 CONTINUE
614 3 DO 44 M1=1,JC
615 44 M1F(M1,IR)=M1F(M1,IR)+1
616 GO TO 1420
617 4 DO 56 M2=1,JC
618 56 M2F(M2,IR)=M2F(M2,IR)+1
619 GO TO 1420
620 5 DO 57 M3=1,JC
621 57 M3F(M3,IR)=M3F(M3,IR)+1
622 GO TO 1420
623 1260 DO 1270 M4=1,JC
624 1270 M4F(M4,IR)=M4F(M4,IR)+1
625 GO TO 1420
626 1280 DO 1290 M5=1,JC
627 1290 M5F(M5,IR)=M5F(M5,IR)+1
628 GO TO 1420
629 1300 DO 1310 M6=1,JC
630 1310 M6F(M6,IR)=M6F(M6,IR)+1
631 GO TO 1420
632 1320 DO 1330 M7=1,JC
633 1330 M7F(M7,IR)=M7F(M7,IR)+1
634 GO TO 1420
635 1340 DO 1350 M8=1,JC
636 1350 M8F(M8,IR)=M8F(M8,IR)+1
637 GO TO 1420
638 1360 DO 1370 M9=1,JC
M9F(M9,IR)=M9F(M9,IR)+1
GOTO 1420

DO 1390 M10=1,JC
M10F(M10,IR)=M10F(M10,IR)+1
GOTO 1420

DO 1410 M11=1,JC
M11F(M11,IR)=M11F(M11,IR)+1
GOTO 1420

DO 1420 M12=1,JC
M12F(M12,IR)=M12F(M12,IR)+1
GOTO 1420

JC=JC+1
CONTINUE

READ(IRD,1460).END=1470)STAT,JYEAR,IMONT,JDAY,PPT,PET
FORMAT(1,7,312,1GX,F4.1,1IX.F4.1)
IJK=0
GO TO 110

IF(ICONT.EQ.0) GO TO 1500
WRITE(6,1480) (STA(I),I=1,10),ISTART,IEND
FORMAT('1',5(/),27X,'TABLE : MONTHLY SUMMARY OF THE NUMBER OF
1DAYS THAT THE PREDICTED WATER',/.42X,
2TABLE DEPTH IS LESS THAN THE INDICATED WATER TABLE DEPTH',/.45X,
3'STATION : ',10A2,4X,'YEAR : 19',12,'-19',12)
WRITE(6,1040) (DEP(IJ),IJ=1,10)
ITIT=1,12
WRITE(6,1060)(KMONT(ITIT,JJJ),JJJ=1,5),(ITOTAL(ITIT,JK),JK=1,10)
WRITE(6,1070) RMAX,SMCF,HMAX
WRITE(6,1600) (KMONT(1,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(2,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(3,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(4,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1690) I,(M1F(I,J),J=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX
WRITE(6,1600) (KMONT(2,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(3,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(4,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1690) I,(M2F(I,J),J=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX
WRITE(6,1600) (KMONT(3,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(4,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1690) I,(M3F(I,J),J=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX
WRITE(6,1600) (KMONT(4,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1480) (STA(I),I=1,10),ISTART,IEND
CONTINUE

FORMAT(1,5(/),32X,'TABLE : FREQUENCY DISTRIBUTION OF PREDICT
1ED WATER TABLE DEPTHS',/.46X, 'FOR THE MONTH OF', 5X, 5A2, 3X,
2'YEAR : 19',12,'-19',12,'/50X,'STATION : ',10A2)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(1,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(2,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(3,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(4,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1480) (STA(I),I=1,10),ISTART,IEND
CONTINUE

FORMAT(1,7,312,1GX,F4.1,1IX.F4.1)
I=2
IJK=0
GOTO 110

IF(ICONF4.EQ.0) GO TO 1760
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(1,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(2,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(3,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1600) (KMONT(4,K1),K1=1,5),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
WRITE(6,1480) (STA(I),I=1,10),ISTART,IEND
CONTINUE

FORMAT(1,5(/),32X,'TABLE : FREQUENCY DISTRIBUTION OF PREDICT
1ED WATER TABLE DEPTHS',/.46X, 'FOR THE MONTH OF', 5X, 5A2, 3X,
2'YEAR : 19',12,'-19',12,'/50X,'STATION : ',10A2)
WRITE(6,1680) RMAX,SMCF,HMAX

1680 FORMAT(31X,'W.T.D. IS WATER TABLE DEPTH IN MM',//,34X,'4E PRESCRIBED'.,41X,'DEPTH FOR THE NUMBER OF SUCCESSIVE DAYS INDIC
2RI0D.'.,34X,'WATER TABLE DEPTH IS EQUAL TO OR LESS THAN TH
4E MOISTURE FOR THE TOP THREE ZONES = ',F5.0.,/,'SUBSURFACE'.

WRITE(6,1600) (KMONT(5,K1),K1=1,5), ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
DO 1690 1=1,31
1690 WRITE(6,1670) I,(M5F(I,d),d=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX

WRITE(6,1600) (KMONT(6,K1),K1=1,5), ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
DO 1700 1=1,30
1700 WRITE(6,1670) I,(M6F(I,d),d=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX

WRITE(6,1600) (KMONT(7,K1),K1=1,5), ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
DO 1710 1=1,31
1710 WRITE(6,1670) I,(M7F(I,d),d=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX

WRITE(6,1600) (KMONT(8,K1),K1=1,5), ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
DO 1720 1=1,30
1720 WRITE(6,1670) I,(M8F(I,d),d=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX

WRITE(6,1600) (KMONT(9,K1),K1=1,5), ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
DO 1730 1=1,31
1730 WRITE(6,1670) I,(M9F(I,d),d=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX

WRITE(6,1600) (KMONT(10,K1),K1=1,5), ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
DO 1740 1=1,31
1740 WRITE(6,1670) I,(M10F(I,d),d=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX

WRITE(6,1600) (KMONT(11,K1),K1=1,5), ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
DO 1750 1=1,30
1750 WRITE(6,1670) I,(M11F(I,d),d=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX

WRITE(6,1600) (KMONT(12,K1),K1=1,5), ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
DO 1694 1=1,31
1694 WRITE(6,1670) I,(M12F(I,d),d=1,10)
WRITE(6,1680) RMAX,SMCF,HMAX

IF(ICONF2.EQ.0) GO TO 1800
WRITE(6,1780)(PERIOD(1,I),I=1,18),ISTART,IEND,(STA(I),I=1,10)

WRITE(6,1780) PERIOD(1,I),ISTART,IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA2=MAX2+1
DO 1790 1=1,IMA2
1790 WRITE(6,1670)d,(MMdF(d,d1).d1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
1800 IF(ICONF3.EQ.0) GO TO 1820
WRITE(6,1780)(PERIOD(2,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA3 = MAX3 + 1
DO 1810 L = 1,IMA3
WRITE(6,1670) L,(MJAF(L,L1),L1 = 1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
1820 IF(ICONF5.EQ.0) GO TO 1840
WRITE(6,1780)(PERIOD(3,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA5 = MAX5 + 1
DO 1830 K = 1,IMA5
WRITE(6,1670) K,(MANF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(4,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA6 = MAX6 + 1
DO 1832 K = 1,IMA6
WRITE(6,1670) K,(MSOF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(5,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA7 = MAX7 + 1
DO 1834 K = 1,IMA7
WRITE(6,1670) K,(MNDF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(6,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA8 = MAX8 + 1
DO 1836 K = 1,IMA8
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(7,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA9 = MAX9 + 1
DO 1840 K = 1,IMA9
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(8,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA10 = MAX10 + 1
DO 1842 K = 1,IMA10
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(9,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA11 = MAX11 + 1
DO 1844 K = 1,IMA11
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(10,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA12 = MAX12 + 1
DO 1846 K = 1,IMA12
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(11,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA13 = MAX13 + 1
DO 1848 K = 1,IMA13
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(12,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA14 = MAX14 + 1
DO 1850 K = 1,IMA14
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(13,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA15 = MAX15 + 1
DO 1854 K = 1,IMA15
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(14,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA16 = MAX16 + 1
DO 1858 K = 1,IMA16
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(15,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA17 = MAX17 + 1
DO 1860 K = 1,IMA17
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(16,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA18 = MAX18 + 1
DO 1862 K = 1,IMA18
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(17,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA19 = MAX19 + 1
DO 1866 K = 1,IMA19
WRITE(6,1670) K,(MGNF(K,K1),K1=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
WRITE(6,1780)(PERIOD(18,I),I=1,18),ISTART, IEND,(STA(I),I=1,10)
WRITE(6,1650) (DEP(I),I=1,10)
IMA20 = MAX20 + 1
DO 1870 N = 1,IMA20
WRITE(6,1670) N,(ITOTF(N,M),M=1,10)
WRITE(6,1680) RMAX, SMCF, HMAX
1880 WRITE(6,1890)...
1890 FORMAT(' ',10X,' PROGRAM HAS FUNCTIONED VERY WELL  BYE BYE ') GO TO 9000
2000 WRITE(6,2100)...
2100 FORMAT(' ',10X,'FREQUENCY DISTRIBUTION IS NOT  WANTED') GO TO 9000
3000 WRITE(6,3100)...
3100 FORMAT(' ',10X,'YOU HAVE EXCEEDED  THE SIZE  OF THE ITOTF MATRIX') GO TO 9000
4000 WRITE(6,4100)...
4100 FORMAT(' ',5X,'YOU HAVE EXCEEDED THE SIZE OF THE ITOTF MATRIX') GO TO 9000
5000 WRITE(6,5100)...
5100 FORMAT(' ',5X,'YOU HAVE EXCEEDED THE SIZE OF THE MMJF MATRIX') GO TO 9000
6000 WRITE(6,6100)...
6100 FORMAT(' ',5X,'YOU HAVE EXCEEDED THE SIZE OF THE MJAF MATRIX') GO TO 9000
7000 WRITE(6,7100)...
7100 FORMAT(' ',5X,'YOU HAVE EXCEEDED THE SIZE OF MANF MATRIX')
GO TO 9000
7001 WRITE(6,7002)
7002 FORMAT('0',10X,'YOU HAVE EXCEEDED THE SIZE OF MSOF MATRIX')
GO TO 9000
7003 WRITE(6,7004)
7004 FORMAT('0',10X,'YOU HAVE EXCEEDED THE SIZE OF MNDF MATRIX')
STOP
END

C*****************************************************************************
SUBROUTINE TRANST(D1,KFIELD,KCORR,AFIELD,ACORR,CONST,
HMAX,TR1SUM,TR2SUM,TR3SUM,TR4SUM,TRMAX)
REAL KFIELD,KCORR
C MAXIMUM TRANSIENT STORAGE CALCULATED BY DECREMENTS OF DELTZ FROM SOIL
C SURFACE TO DRAIN DEPTH (HMAX).
DELTZ=10.0
C CALCULATE MAXIMUM DRAINABLE POROSITY AT SOIL SURFACE (DPMAX)
Z=0.0
CALL DP0RE(Z,HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DPMAX)
C MAXIMUM TRANSIENT STORAGE FOR ZONE 1
D11=0.0
TR1SUM=0.0
CALL DP0RE(D11,HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP)
DP1=DP
D11=D11+DELTZ
10 IF (D11.GT.D1) GOTO 20
CALL DP0RE(D11,HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP)
DP2=DP
WATER1=DELTZ*(DP2+DP1)/2.0
TR1SUM=TR1SUM+WATER1
DP1=DP2
D11=D11+DELTZ
GOTO 10
20 D2=D11+DELTZ
TR2SUM=0.0
30 IF (D2.GT.(D1+300.)) GOTO 40
CALL DP0RE(D2,HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP)
DP2=DP
WATER2=DELTZ*(DP2+DP1)/2.0
TR2SUM=TR2SUM+WATER2
DP1=DP2
D2=D2+DELTZ
GOTO 30
40 D3=D2+DELTZ
TR3SUM=0.0
50 IF (D3.GT.(D1+300.+400.)) GOTO 60
CALL DP0RE(D3,HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP)
DP3=DP
WATER3=DELTZ*(DP2+DP1)/2.0
TR3SUM=TR3SUM+WATER3
DP1=DP2
D3=D3+DELTZ
GOTO 50
60 D4=D3+DELTZ
TR4SUM=0.0
70 IF (D4.GT.HMAX) GOTO 80
CALL DPORE(D4,HMAX,KFIELD,AFIELD, KCORR,ACORR,CONST,DP)
DP2=DP
WATER4=DELTZ*((DP2+DP1)/2.0)
TR4SUM=TR4SUM+WATER4
DP1=DP2
D4=D4+DELTZ
GOTO 70
C TOTAL MAXIMUM TRANSIENT STORAGE
TRMAX=TR1SUM+TR2SUM+TR3SUM+TR4SUM
C MAX. REMAINING TRANSIENT WATER STORAGE FOR ZONE 1
TR1=TRMAX-TR1SUM
C MAX. REMAINING TRANSIENT WATER STORAGE FOR ZONE 2
TR2=TR1-TR2SUM
C MAX. REMAINING TRANSIENT WATER STORAGE FOR ZONE 3
TR3=TR2-TR3SUM
C MAX. REMAINING TRANSIENT WATER STORAGE FOR ZONE 4
TR4=TR3-TR4SUM
IF (TR4.LE.0.0) TR4=0.0
RETURN
END

SUBROUTINE DP4(DELTR,D1,HMAX,TR4,ZK,KFIELD,KCORR,AFIELD,ACORR,CONST,DPK)
REAL KFIELD,KCORR
C ASSIGNED DRAINABLE POROSITY GIVEN THE CONDITION THAT THE WATER
C TABLE IS AT THE DRAIN LEVEL AND POSITIVE TRANSIENT STORAGE
D4 =HMAX-(D1+300.0+400.0)
IF (DELTR.LT.TR4*2.0/3.0) GOTO 10
IF (DELTR.LT.TR4/3.0) GOTO 20
Z=ZK-D4*5.0/6.0
GOTO 30
10 Z=ZK-D4/6.0
GOTO 30
20 Z=ZK-D4/2.0
30 CALL DPORE(Z,HMAX,KFIELD,AFIELD, KCORR,ACORR,CONST,DPK)
RETURN
END

SUBROUTINE DPORE(Z,HMAX,KFIELD,AFIELD,KCORR,ACORR,CONST,DP)
REAL KFIELD,KCORR
C DRAINABLE POROSITY CALCULATED BY AN EXPONENTIAL RELATIONSHIP
HT=HMAX-Z
C CONVERT WATER TABLE DEPTH TO WATER TABLE HEIGHT
ZCM=HT/10.0
PRAIN=AFIELD*(1-EXP(-KFIELD*ZCM))
PCORR=PRAIN/(ACORR*(1-EXP(-KCORR*ZCM))+CONST)
DP=PCORR/100.0
RETURN
END

SUBROUTINE FACTOR(RMAX,DW,D,HMAX,C,SMCF,SZMCF1,SZMCF2,SZMCF3,
SZMCF4,TR4,TR1,TR2,TR3,TR4,C1,C2,C3,AFIELD,KFIELD,ALAB,KLAB,ACORR,
*KCORR,CONST)
REAL KFIELD,KLAB,KCORR
WRITE(6,10)
10 FORMAT(1",15(1.),30X,68('*'),/.,30X,  
11" INPUT DRAINAGE PARAMETERS FOR PROGRAMMING :',21X,'*')  
12 WRITE(6,20) RMAX,DW,D,HMAX,C  
13 20 FORMAT(30X,\'','/.,30X,  
14' MAXIMUM DRAINAGE RATE (RMAX)',23('-'),F5.1,'MM/DAY *',/.,30X,  
15' DEPTH OF ZONE FROM SOIL SURFACE THAT RMAX OCCURS (DW)--',  
16' MAXIMUM DRAIN DEPTH FROM IMPERMEABLE LAYER DRAIN (D)','10('-'),F5.0,  
17' DEPTH MAXIMUM DRAINAGE RATE (HMAX)',29('-'),  
18" POROSITY OF LAB MODEL (ALAB)',16('-'),F5.0,'%',/.,30X,  
19' MAXIMUM RATIO OF CORRECTION (ACORR)'\',8('-'  
20' CORRECTION CONSTANT (CONST)'\',30('-'),F5.3,'  *')  
21 WRITE(6.50) TRMAX,TR1,TR2,TR3,TR4  
22 50 FORMAT(30X,\'','/.,30X,  
23' AVAILABLE SOIL MOISTURE FOR 3RD ZONE (SZMCF3)',11('-'),F5.1,'MM',/.,30X,  
24' AVAILABLE SOIL MOISTURE FOR 4TH ZONE (SZMCF4)',11('-'),F5.1,'MM *')  
25 WRITE(6.60) C1,C2,C3  
26 60 FORMAT(30X,\'','/.,30X,  
27' COEFFICIENT OF AE/PE FOR THE 1ST ZONE (C1)',11('-'),F4.2,'MM *',/.,30X,  
28' COEFFICIENT OF AE/PE FOR THE 2ND ZONE (C2)'\',11('-'),F4.2,'MM *',/.,30X,  
29' COEFFICIENT OF AE/PE FOR THE 3RD ZONE (C3)',11('-'),F4.2,'MM *',/.,30X,  
30' COEFFICIENT OF AE/PE FOR THE 4TH ZONE (C4)=0.',11X,'*')  
31 RETURN  
32 END  
33 SUBROUTINE TITLE (STA, JYEAR,RMAX,SMCF,HMAX)
DIMENSION STA(10)
WRITE(6,10) STA, JYEAR, RMAX, SMCF, HMAX
10 FORMAT('1',30X,'TABLE : PREDICTED DAILY WATER TABLE DEPTHS A
ND WATER BALANCE PARAMETERS',/,48X,
2'STATION : ',10A2,12X,'YEAR : 19',I2,/,48X,'RMAX = ',F4.1,
3'MM/DAY',4X,'R=4K(2DH+H**2)/L**2 FOR 400<Z<HMAX',/,48X,
5'AVAILABLE WATER IN TOP THREE ZONES = ',F4.0, 'MM',/,48X,
6'SUBSURFACE DRAIN DEPTH = ',F5.0, 'MM',/,20X,100(' - '))
WRITE(6,20)
20 FORMAT('+',/,21X,
1'D M Y',/.,21X,'A O E
2 ',/.,21X,' Y N A PE AE PRE RO DP SD
3 TR SMC1 SMC2 SMC3 DELTR DELZ Z H',/.,24X,'T
4 R MM MM MM MM MM MM MM MM
5MM MM MM MM ',/.,24X,' H',/.,20X,100(' - '))
RETURN
END