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ANALYSIS OF CHILEAN METEOROLOGICAL DATA TO ESTIMATE EVAPOTRANSPIRATION AND IRRIGATION REQUIREMENTS

by

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of the requirements for the degree

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ABSTRACT

Analysis of Chilean Meteorological Data to Estimate Evapotranspiration and Irrigation Requirements

by

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Thesis Director: Professor Emeritus J. E. Christiansen
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A formula for estimating Class A pan evaporation was developed using data from six ENDESA meteorological stations and eight Meteorological Institute stations. The formula is of the form

$$E_v = K \text{ RMM } C_c$$

where

E_v = pan evaporation

K = a constant

RMM = extraterrestrial radiation

C_c = climatic coefficients.

An evapotranspiration equation was developed using Class A pan evaporation as a base. Using this equation, and the gamma distribution that calculated the dependable precipitation at five probability levels, the irrigation requirements for twelve stations were calculated.

An equation that estimates dependable precipitation at 75 percent probability level was developed using the gamma distribution as a base.

Equations to estimate crop coefficients were developed using measured evapotranspiration and climatic data.

(110 pages)

INTRODUCTION

Description of Chile

Location and Boundaries

Chile is a republic located in the very southwest of South America. It is a narrow and long strip of land. Its length is about 4,200 kilometers with a width that varies from 80 to 400 kilometers. Chile is situated between latitude 18° south and 55° south. The country borders on Peru on the north, the South Pole on the south, Bolivia and Argentina separated by the Los Andes range on the east, and the Pacific Ocean on the west.

Climate

According to climate it is possible to divide the country from north to south as follows (A map of Chile is shown in Figure 1.):

Norte Grande: From the Lluta River to the Copiapo River. Its climate is typical of deserts with extremely scarce water.

Norte Chico: From Copiapo River to Aconcagua River. It has the characteristics of a semi-arid stepe with scarce and variable precipitation from one year to another.

Zona Central: From Aconcagua River to Bio-Bio Province. It has a Mediterranean climate with well differentiated seasons.

Zona Sur: To the south of Bio-Bio Province. Here the climate is cooler and more humid and water is very abundant.

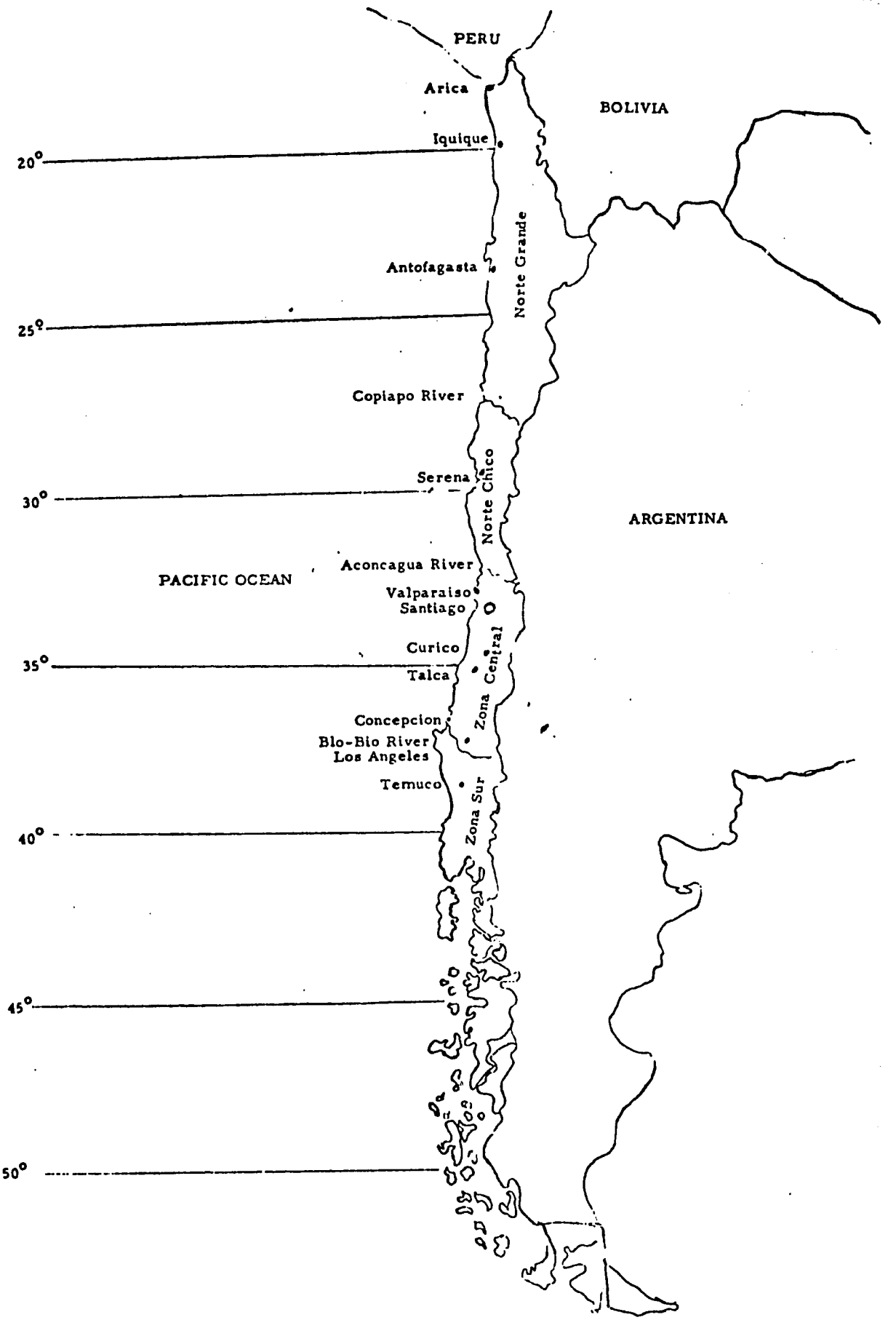

Figure 1. Map of Chile Showing the Climatic Zones

There is also a variation in climate from west to east. Along the coast the climate is moderated by the ocean. In the central valley the climate is warmer. Farther inland the climate cools with elevation to the top of the Andes.

The Coastal and Los Andes ranges influence the climate by acting as curtains intercepting the fronts that come from the Pacific Ocean.

In the Central Coast zone there is an increase of precipitation due to the effect of the Coastal Range. Going to the east of this range the precipitation decreases and then increases again as the Andes Range is approached.

Without considering the antarctic territory, Chile has an area of 75.7 million hectares from which 50.3 million are non-arable. Of the remaining 25.4 million hectares, 13.8 million constitute the agricultural area of the country, of which 5.5 million are plow land and 8.3 million are used only for pastures.

Almost 4 million hectares of the plow land are to the north of the Temuco Province. In most places this area could benefit from artificial irrigation. About 1.4 million hectares of this area would probably require sprinkler irrigation because of the topography and soil conditions. This area is not irrigated at the present time. The area that is economically irrigable is, therefore, about 2.4 million hectares which represents 3 percent of the national territory. This indicates that there is a necessity for a highly intensive and specialized agriculture under irrigation.

At this moment 1.17 million hectares that are irrigated have an adequate water supply. Another 0.8 million hectares are irrigated but with a deficient water supply.

Agricultural Development

According to the Office of Agricultural Planification (ODEPA) as cited by Politica Nacional de Riego (1970), it will be necessary to add another 600,000 hectares of new land to the irrigated area before 1983 in order to produce enough foodstuff to achieve a balanced diet for the population of the country.

Another important aspect in the process of agricultural development is the Agrarian Reform which has resulted in a modification of the water laws. According to this new set of laws, the water will be delivered to the farmers in relation to the water requirements (Tasa de use racional y beneficioso) of the farm.

All the considerations expressed above show the necessity of an accurate calculation of evapotranspiration and effective precipitation. Through these two basic parameters one can arrive at a good estimate of the actual water requirements. This information will provide a firm foundation for water supply planning and development and effective management for new projects.

The objective of this study then is to:

1. Analyze the available climatic data for Chile and determine the best formula for estimating potential evapotranspiration. Com-

plete climatic data are available from 13 stations for this study.

2. Process the available monthly rainfall data to estimate the dependable and effective precipitation.

3. Relate the dependable precipitation with estimated potential evapotranspiration to determine potential irrigation water requirements.

4. To show how the study can be used to determine actual water requirements for the crops grown.

DEFINITION OF TERMS

Evaporation

Evaporation from natural surfaces such as open water, bare soil or vegetative cover is a diffusive process by which water in the form of vapor is transferred from the underlying surface to the atmosphere.

Pan Evaporation

Pan evaporation is the amount of water that evaporates from a standard Class A U.S. Weather Bureau pan. These pans have been adopted by the World Meteorological Organization and are used in many countries including Chile. It is expressed as depth per unit of time, i.e., mm per month.

Evapotranspiration

Evapotranspiration is the amount of water used by the vegetative growth of a given area in transpiration and that evaporated from soil, snow, or intercepted precipitation on the area in any specified time. It is usually expressed as a depth for unit of time, i.e., mm per month.

Consumptive Use

According to Israelsen and Hansen (1965) consumptive use is for all practical purposes identical with evapotranspiration. It differs by the inclusion of water retained in plant tissues. For most agricultural plants the amount of water retained by plants is insignificant when compared with evapotranspiration.

Potential Evapotranspiration

Potential evapotranspiration is defined as the consumptive use or the evapotranspiration loss from a short, green, vigorously growing crop (usually grass) that completely shades the ground or provides full crop cover under conditions where moisture supply is not limiting on moisture use.

Actual Evapotranspiration

Actual evapotranspiration is the evapotranspiration, Et, for any specified crop which may or may not completely shade the ground, and which may be less than potential Et because of soil moisture limitations. It is usually calculated or estimated by multiplying a crop coefficient times a soil water coefficient times potential evapotranspiration, or by a pan evaporation.

Crop Coefficients

Crop coefficients are estimated values of the ratios of actual evapotranspiration to computed potential evapotranspiration for different stages of growth, or the ratios as compared to measured or computed pan evaporation. It is very important when using crop coefficients to specifically state whether they apply to potential evapotranspiration or to pan evaporation. Soil water status if important.

Irrigation Water Requirement

Irrigation water requirement is defined as the quantity of water

required to maintain the desired soil moisture and salinity level during a crop growing season, in addition to precipitation.

Potential Irrigation Requirement

This is defined as the difference between potential evapotranspiration and dependable precipitation.

Precipitation

Precipitation is the total amount of water that is received from the atmosphere in the form of rain, snow or hail. It is expressed as a depth per unit of time, i.e., mm per month. Precipitation intensities are most often expressed as mm (or inches) per hour for any specified period of time.

Dependable Precipitation

Dependable precipitation is the precipitation that can be anticipated at a specified probability level from an analysis of available precipitation records. Probability levels of from 60 to 80 percent may be used for irrigation projects because agricultural crops can withstand some moisture deficiency without serious injury.

Effective Precipitation

Effective precipitation is that part of the dependable precipitation that can be stored in the root zone of the crops grown and used by the crop. It excludes surface runoff and deep percolation, and will, there-

fore, depend on the rainfall intensity as related to the infiltration rate and the moisture holding capacity of the soil, and on the crops grown.

Moisture Availability Index (MAI)

Hargreaves (1971) defines this term as an index of the adequacy of precipitation in supplying moisture requirements. It is computed by dividing the dependable precipitation by the potential evapotranspiration.

Adequacy Percentage

Hargreaves (1971) defines this term as the percentage of years in the precipitation record during which precipitation for any given month equals or exceeds the potential evapotranspiration.

Moisture Deficit

Moisture deficit is the difference between potential evapotranspiration and dependable precipitation. A moisture excess is indicated by a negative number.

REVIEW OF LITERATURE

Evaporation

The concept of evaporation from water surfaces has been a very useful tool used by scientists and engineers in the development of irrigation.

Utilization of Evaporation Data

Evaporation has been measured by many kinds of evaporimeters including the Class A pan. These measurements are used to estimate actual evaporation from lakes and reservoirs, as well as evapotranspiration from crops, by applying a suitable coefficient.

One use of this concept is to estimate the evaporation from reservoirs and lakes by applying a coefficient to the observed or derived pan evaporation. The Special Committee of Irrigation Hydraulics of the American Society of Civil Engineers adopted the value .7 as the ratio of the annual evaporation from a reservoir to the evaporation of a USWB Class A pan. This ratio is called the pan coefficient. The monthly ratios have been found to vary considerably because of the greater heat storage capacity of reservoirs compared with a standard pan.

Because of its heat storage capacity, the water temperature lags behind the air temperature during the daily cycles. The temperature of a leaf from which transpiration occurs follows the air temperature more closely.

The evaporation from a pan is affected by advective energy more than a large body of water, and hence a coefficient of less than 1.0 must be applied to reduce the measured evaporation to lake or reservoir evaporation.

According to Kohler, Northenson and Fox (1955) this coefficient may lead to appreciable error without consideration of advective energy to either the pan or lake.

Allen and Crow (1966) showed that the ratio between evaporation from Hefner Lake to a 15-foot tank was 1.01. They also presented an equation which expresses lake evaporation as a function of the product of a 9-foot or 15-foot tank evaporation and the ratio of the vapor pressure deficits over the lake and the tank, respectively.

Probably the most important application of evaporation from a water surface in irrigated agricultural development is its relationship with evapotranspiration.

Tanner (1967) stated that there is a relatively high correlation of ETP (potential evapotranspiration) to Ep (pan evaporation). The correlation between actual evapotranspiration, ETa, and Ep may be low when soil moisture is limiting and when the crop cover percentage is low.

Pruitt and Lourence (1968) compared evapotranspiration for different crops in California with Class A pan evaporation. They related the values

By calculating evaporation from climatic data it is possible to get a good estimation of evapotranspiration for areas with similar climatic conditions by multiplying the calculated evaporation by this coefficient. The importance of this is that it would not be necessary to measure evapotranspiration in very many places in an area, because it is very difficult and costly to measure evapotranspiration accurately.

Weaver and Stephens (1963) concluded that the standard open pan as an integrator of climate appears to have a real value as an index of crop water requirements in the southern Florida area where management does not permit soil water to become limiting.

Pruitt (1960) stated from his results that the coefficient relating consumptive use to evaporation (he worked with grass) depends upon the type, size and environment of the pan. The coefficients obtained ranged from a low of .75 up to 1.25. He found a difference in the coefficients of from 30 to 35 percent for like pans located in different environments. He also showed that the relationship between consumptive use and evaporation from pans emained fairly constant through the season regardless of the type of pan, but that the USWB Class A pan was somewhat more consistant than smaller above-ground pans.

Pan Evaporation Measurements

There are several instruments that have been developed to measure evaporation. The most prominent ones are: atmometers, Piche

evaporimeter, Bellani plate atmometer, Fuess evaporimeter, and various other pan evaporimeters.

The Standard Weather Bureau Class A pan evaporation is the method most widely used, and it is being recommended by engineers even for scheduling irrigation on the farm.

Details of construction and operation of Class A pan are given by the U.S. Weather Bureau (1962).

Some advantages of Class A pan evaporation are:

1. More data are available from Class A pans than for any other type of evaporimeter.

2. It is comparatively inexpensive.

3. It is not appreciably affected by heat transfer to or from the soil through the bottom.

4. It is less liable to corrosion than a sunken pan of galvanized iron and leakage is more easily detected.

5. Being raised it collects less drifting weeks and soil than sunken pans.

6. It is less affected by splash in rain storms than sunken pans.

Some disadvantages of Class A pan are:

1. Its average rate of evaporation is high and must be multiplied by a low coefficient or reduce it to the less from a large surface of open water.

2. Errors result from birds and animals drinking from the pan and bathing in it. When screens are used to exclude birds and animals, the evaporation rate is reduced, but the relative amount is not well-known.

Nimmo (1964) describes the following type of pans for measuring evaporation:

1. Colorado sunken pan.
2. U.S. Bureau of Plant Industry pan.
3. Los Angeles County Flood Control District pan.
4. Twelve-foot diameter pans.
5. Two-foot screened pans.

Evapotranspiration

To attempt concurrently to measure evapotranspiration of the many species of irrigated crops grown in a large area is impractical because of financial and manpower requirements. It is also impractical to measure evapotranspiration for a single crop at more than a few locations. For this reason the most promising approach, according to the Department of Water Resources of California (1963), appears to be to determine the important annual measurable parameters affecting evapotranspiration rates, and to correlate actual measurements of evapotranspiration with those parameters.

Factors Affecting Evapotranspiration

The most important factors which appear independently to affect evapotranspiration are: climate, plant conditions, and soil moisture availability.

Climate, in the evapotranspiration process, can be thought of as a combination of parameters such as air temperature, wind, humidity, elevation, precipitation, solar radiation, and length of daylight. These parameters are not independent factors but are interrelated in a complex manner.

The energy sources for the evapotranspiration process are derived principally from direct solar radiation and advection or exchangeable heat from the air. The evaporative demand of the atmosphere is largely a function of those two elements, however. According to Penman et al. (1967) not all of the solar radiation that falls directly on the plant or ground surface is used in evapotranspiration. A portion is reflected back into the atmosphere, a portion is utilized in heating up the air, a portion is absorbed in heating the soil, and the balance is utilized in evapotranspiration and plant growth.

It is likewise probable that the energy available from advection is not all utilized, depending upon many factors such as vapor pressure deficits and extent of wind movement. Under certain conditions it has been demonstrated that advecting cooling, as well as advecting heating, can occur.

The difference between incoming total radiation and the amount lost by reflection and long wave raditation from a surface is commonly referred to as the net radiation at the surface, as described by Rose (1966). Of this energy, a relatively small amount would go into heating up the soil. At midday the net energy consumed in plant processes is also a small percentage of the net radiation available. Of the remaining energy, the greatest amount would normally be used up in evapotranspiration, with smaller amounts in warming the air. At night sensible heat losses from the soil and air would provide the main source of energy loss.

As the moisture content of the air increases through evaporation and transpiration, the moisture gradient (vapor pressure gradient) between an air mass and an evaporating surface decreases and retards further moisture transfer. Under field conditions the air mass near the ground is far from stable. Air movements act to mix moisture-saturated air near the evaporating surface with drier air from above.

Wind speed and surface roughness influence the relative turbulence of air, moving the moisture away from the evaporating surface and bringing in drier air to further the evaporation process. Thus it is apparent that the evaporative demand of the atmosphere is determined by the interaction of several climatic elements.

Progress is being made in determining the relationship between the aforementioned climatic factors to arrive at a quantitative approach to estimate evapotranspiration.

The estimation of evapotranspiration from a purely theoretical approach is not entirely practical because the d a required are not normally available. The two basic approaches to evapotranspiration are from the energy budget standpoint and from the vapor transfer standpoint.

Crop Factors

While evaporation from a shallow, free water surface is limited only to the evaporative demand at the earth's surface, evapotranspiration may be controlled also by the physiological and physical conditions of the transpiring vegetation.

According to Gates and Hanks (1967) a plant leaf loses water at a rate that depends on the concentration gradient of water vapor between the saturated cell walls of the mesophyll and that in the face air beyond the plant. The rate is regulated by the diffusion resistance in the substomatal, stomatal, and boundary layer regions of the diffusion path. The water vapor density at the saturated mesophyll cell walls depends on the temperature of the leaf which in turn depends on the energy budget of the leaf.

The greatest difference among crops occurs during the growth period when the crop cover is less than 50 percent complete. During this time evapotranspiration of most irrigated crops is less than where the cover is greater, because evaporation from bare soil decreases rapidly as the surface soil dries. There appears to be little difference

in evapotranspiration among many crops after the cover is greater than 50 percent until maturity. Pineapple, however, is a notable exception.

Penman (1956), cited by Gates and Hanks (1967) in relation with this difference of evapotranspiration for different plant species, states:

1. "For complete crop covers of different plants having about the same color, i.e., the same reflection coefficient, the potential transpiration rate is the same irrespective of plant or soil type."

2. This potential rate is determined by the prevailing weather.

Van Bavel, Fritschen and Reeves (1963) concluded that a full stand of sudan-grass under conditions of high temperature, high light intensity, very low humidity of air, and sufficient soil moisture (in short, in a highly evaporative environment) can transpire in proportion to the evaporative demand. This does not mean that a sudan-grass stand is physically identical to an open water surface nor that the conclusion would apply to another crop. Both the radiation balance and the convective sensible heat exchange of a crop differ materially from those of an open water surface.

Gates and Hanks (1967) discuss in some detail the specific properties of the plant community that influence evapotranspiration.

Soil Factors

The primary means by which the soil can influence the rate of evapotranspiration is through the affect of various soil properties

upon the storage capacity and availability of moisture at the soil surface or to the plant.

Evaporation from Soil Surfaces

Ekern, Robins, and Staple (1967) indicate that the rate at which the bare soil supplies water at the evaporative site is controlled by the water content and hydraulic conductivity of the soil.

According to the Department of Water Resources, California (1967) the rate of movement of moisture through the soil to the surface is related primarily to soil texture and structure. Surface evaporation, however, under usual irrigation practices, is not appreciably affected by the rate of moisture movement.

A soil with a very moist surface will lose about the same amount of moisture as a very shallow water body or an irrigated, improved pasture. Evaporation and/or evapotranspiration rates are nearly the same for all three. In each case, the evaporation rate is controlled almost entirely by the climate, that is, the evaporative demand. In cropped lands the plants act as a sort of wick connecting the subsurface soil moisture to the atmosphere. With bare soils, the connection is broken as soon as the soil surface becomes dry through evaporation.

Availability of Soil Moisture to Plants

The availability of soil moisture to plants depends upon the amount that either can be, or is stored, within the soil, and upon various

internal and external factors that limit the availability of such moisture. Some of the factors that affect moisture availability are: amount and intensity of precipitation as related to the soil infiltration rate, the effective rooting depth of crops, and available moisture holding capacity of the soil.

Various concepts have been advanced regarding the effect of moisture availability on evapotranspiration rates of plants. According to one concept, the evapotranspiration rate decreases as available moisture in the soil decreases from field capacity to the permanent wilting point. Another concept is that, as long as available moisture exists within the root zone, the evapotranspiration rate is not materially affected.

Field observations by the Department of Water Resources of California (1967) relating soil moisture depletion from deep permeable soils to evapotranspiration, support the position that evapotranspiration rates are not affected over a wide range of soil moisture availability. However, there are indications that crop yields are sometimes materially affected before evapotranspiration rates decrease.

Jensen (1968) indicates that as the soil water content decreases and is not replenished by rainfall or irrigation, the effective hydraulic resistance increases greatly. This increase in hydraulic resistance results in various degrees of plant water stress, depending on the evaporative demand and plant characteristics. As plant water stress

increases, diffusive resistance also increases, illustrating the interdependence of hydraulic and diffusive resistances.

Summary of Factors Affecting Evapotranspiration

While the numerous factors affecting evapotranspiration may at first appear to be so complex that realistic estimates of crop water use are beyond our present power to predict, this is not the case. Numerous factors do exist, but they are physical processes and subject to physical laws. Through an understanding of these physical processes the insight necessary to make reasonable estimates of water use by crops is gained.

Determination of Evapotranspiration

Tanner (1967) divides the determination of evapotranspiration into three classes:

1. Water balance or hydrologic methods.
2. Micrometeorological methods.
3. Empirical methods.

The methods of the first two classes have a rational basis: they are based on measurements of theoretical variables which affect evapotranspiration. Such measurements are not normally made and reported by meteorological services, hence, in most instances, these methods cannot be used without first performing the research necessary to obtain such data. Empirical methods, if reasonable confidence is to

be obtained, must be "calibrated" by relating the empirical evapotranspiration indices to actual evapotranspiration measurements.

Water Balance Method

This method includes natural catchment hydrology, soil water depletion sampling, and/or lysimeters.

The general equation for water balances as described by Tanner (1967) is as follows:

$$ET = P - (Dr + De + Di + \Delta Dw + \Delta Ds)/A \quad (1)$$

in which all variables are expressed in depth per unit time.

ET = evapotranspiration

P = precipitation or irrigation

Dr = surface or subsurface runoff

De = deep percolation

Di = intercepted precipitation

ΔDw = change in groundwater storage

ΔDs = change in water stored above the water table (soil moisture).

The three methods that will be discussed next are based upon this general equation.

Catchments. This method is usually applied to large areas. For such cases the value, De, is generally assumed to be zero. To obtain satisfactory results, the remaining variables must be measured with the required precision. Because of the problems involved in obtaining

exact measurements of these variables, independent meteorological methods should be used where possible to check the results obtained from the hydrological measurements.

Soil Water Depletion. The most common method of determining the average evapotranspiration rate is soil sampling as described by Pair (1969), Jensen (1967), Davidson and Nielsen (1966) and Christiansen (1972). This method consists of taking soil samples at two or more times between consecutive irrigations and drying these samples in an oven at a temperature of 105°C. The decreases in soil moisture between samplings is used to compute the rate of evapotranspiration. The precipitation occurring during the interval between irrigations must be taken into account.

To obtain satisfactory results the following precautions must be observed:

1. The water table must be well below the root zone so that it does not have an effect on the soil moisture in the sampling depth.

2. The soil should be sampled to a depth greater than the actual rooting depth.

3. A pre-irrigation to completely wet the root zone should be applied, when the soil has not been thoroughly wetted by precipitation, about ten days before planting. The amount of water added at each irrigation should then not exceed that which can be stored within the rooting depth in order to prevent deep percolation losses.

4. Extreme care should be exercised to prevent loss of moisture from samples before they are weighed and dried.

5. The depth of water applied in each irrigation should be measured when possible as a check on the results obtained.

6. The soil texture in the plots or fields to be sampled should be quite uniform without appreciable stratification.

7. Samples should be taken in nearby locations at exactly the same depth at each sampling.

8. In order to convert the soil moisture percentage losses to actual depths of water used, the bulk density of the soil must be accurately determined and used in the computation. An alternative procedure is to use a precision soil sampler that takes a sample of a precise length so that the actual depth of water in the sample can be determined directly. Such a sampler is described by Taylor et al. (1961).

9. The first sampling after an irrigation should be made within a period of two to four days after the irrigation when the soil moisture can be assumed to be at an approximate field moisture capacity, i.e., when most of the downward movement of soil moisture has taken place.

Errors in this method may result from any of the following causes:

1. Deep percolation or drainage from the root zone occurs during the sampling period and is neglected in the determination.

2. Heavy precipitation may occur during the period and may cause either deep percolation losses or runoff which cannot be accounted for.

3. Moisture losses from samples before weighing.

4. Variations in texture and moisture holding capacities of the soil in different samples. For example, if the first sample after an irrigation were of coarser texture than the later one before the next irrigation, the difference in soil moisture between these samples would be in error.

Taylor et al. (1961) indicate that a probable relative error of ten percent or more may be expected in measuring evapotranspiration by the soil sampling method. They also indicate that soil volume sampling will not give reliable values over periods much shorter than two or three weeks. They also discuss the use of the neutron meter to measure soil moisture. Tanner (1967) says the neutron meter has several advantages and that it is preferred over other methods for determining soil moisture.

Lysimeter. Lysimeters are tanks filled with soil in which crops are grown to measure the amount of water used. This is the only hydrological method in which the experimenter has complete knowledge of all the terms in equation (1). This lysimeter has great importance, not only for gathering evapotranspiration information, but also as an independent check on the suitability of micrometeorological methods and for calibrating empirical formulas used for estimating evapotranspiration.

Lysimeters have some advantages and some disadvantages as compared with soil sampling. Since lysimeters are of several kinds, including sensitive weighing lysimeters, the accuracy of the moisture loss determination varies with the kind of lysimeter used. Very sensitive and accurate weighing lysimeters of the type used by Pruitt (1960) in California are very expensive. He can measure Et values to $\pm$ .025 mm per day, whereas pan evaporation cannot be determined much closer than 0.25 mm per day, although they may be reported to the nearest 0.1 mm. Inexpensive lysimeters in which only the water added and the drainage are measured are not highly accurate and cannot be used for short period determinations.

The principal difficulty in obtaining accurate determinations of most crops with lysimeters is in being able to obtain the same density and height of growth inside and outside of the lysimeter. Often the growth inside the lysimeter is more vigorous than outside, and for small lysimeters the area actually receiving the radiation energy is appreciably greater than the actual area of the lysimeter. This is especially true for tall crops. Griffin (1971) using one meter diameter lysimeters with maise reported that "The corn (maise) in the lysimeters grew more vigorously than the corn in the surrounding area and was soon two feet (60 cm) higher..." although "no fertilizer was applied" to the lysimeters. In addition to the greater incoming radiation received, these taller plants received considerably more advective energy

than the remainder of the field. His results showed that the ratios of the water loss from the lysimeters for the medium and wetter treatments averaged from 105 to 117 percent of the evaporation from a Class A pan. The percentages are appreciably greater than are normally obtained from field moisture sampling.

Lysimeters are best suited for low growing crops such as grass for which reasonably good values of potential evapotranspiration can be obtained.

Micrometeorological Methods

The more common microclimatological methods are: aerodynamic methods, energy balance methods and combinations of both.

The aerodynamic method has not been successful in all instances. Under some conditions it has given reasonable results.

According to Hanks (1971) the basic assumptions are not always met.

The energy balance methods starts from the basic equation

$$LE = RN - G - H \tag{2}$$

in which

LE = evapotranspiration

RN = net radiation

G = heat flux density into ground

H = sensible (or non-latent) heat flux into the atmosphere.

RN and G are measured in the field with currently available instruments.

H is not easily measured so this value is obtained through the Bowen ratio, consequently the equation (2) is modified as follows:

$$LE = \frac{RN - G}{1 + B}.$$

where B is the Bowen ratio. The value of B, the most uncertain of the above, does not make much difference on LE if $B = \pm 0.1$, which will normally be the case in humid regions.

Combinations of aerodynamic and energy balance methods are discussed by Tanner (1967).

The major problem of these theoretical methods is the need for highly precise instrumentation to collect the data needed.

Empirical Methods

Many formulas have been developed relating measured climatic variables to measured evapotranspiration. All of them estimate potential evapotranspiration and then make corrections for different crops and soil status. These formulas are especially useful for prediction of future water needs for irrigation in areas where measurements of evapotranspiration have not been made. Some of the more prominent methods are reviewed in detail by Criddle (1952) and Pardo (1968).

In most instances simultaneous measurements of climatic variables and pan evaporation are also made so that the measured evapotranspiration can be compared directly with the pan evaporation. This makes it possible to develop formulas relating pan evaporation to the climatic variables. Then evapotranspiration can be estimated from relationships developed from highly accurate determinations of both pan evaporation and evapotranspiration, such as have been made by Pruitt (1960).

Blaney-Criddle Formula

A study of this method is given by Blaney and Criddle (1966). This formula was developed in the arid western United States and is one of the most popular formulas in use today. The formula, in metric units, can be written in the form:

$$Ep = k\,p\,(.457\,t_c + 8.13)$$

in which

Ep = monthly consumptive use in mm per month

t = mean monthly temperature, in ^{o}C

k = crop coefficient

p = monthly percent of annual daytime hours.

The main problem associated with this method is that some important variables such as wind, humidity and radiation are ignored, and to obtain good results the crop coefficient must have been determined for similar climatic conditions and crops. Often no reliable k values are available to the user.

Thornwaite Formula

Thornwaite (1948), cited by Pair (1969), correlated mean monthly air temperature with evapotranspiration as determined by water balance studies in valleys of the east-central USA with adequate soil moisture so as not to limit evapotranspiration. The following empirical equation was obtained:

$$Ep = 1.6\ Ld\ (10\ T/I)^a$$

in which

Ld = total daytime hours in month days in month times 12 hours

T = mean monthly temperature in ^oC

a and I are constants depending on location, such that

$$i = (T/5)^{1.514}$$

$$I = \sum_{i}^{12} i \text{ (summation of 12 monthly values of i)}$$

$$a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-4} I^2 + 1.792 \times 10^{-2} I + .4924$$

Ep = potential evapotranspiration in cm/month

The disadvantage of this method is that it relies on the correlation between radiation and temperature, which is not always good, and neglects some important factors that influence Ep such as wind and humidity.

Jensen and Haise

Jensen and Haise (1963) developed an equation for evapotranspiration that can occur in well watered, irrigated fields located in semi-arid and arid areas.

This equation can be written:

$$Etp = (0.014\ t - 0.37)\ Rs$$

in which

Etp = potential evapotranspiration in inches per day or mm/day

t = air temperature in ^{o}F

Rs = incoming solar radiation, expressed as equivalent evaporation in inches per day or in mm/day.

They state that solar radiation, Rs, when not measured, can be calculated using the following equation:

$$Rs = Rso\ (.35 + .61\ Sf)$$

in which

Rs = solar radiation under existing conditions

Rso = solar radiation on a cloudless day

Sf = fraction of possible sunshine for the time period.

Formulas Developed at Utah State University

Rujirakul (1970) reviewed the studies and the development of formulas for computing evaporation and evapotranspiration at Utah State University (USU). Since 1960, Professor Christiansen and several graduate students have developed some equations for evaporation or evapotranspiration which are easy to apply and which take into consideration most of the important climatic parameters that affect evaporation and evapotranspiration.

Christiansen Formulas

The approach was both rational and empirical. Christiansen (1968) presented a detailed explanation of this methodology. He states the following:

1. "Only data of the kind that are readily available to the user should be required for application of the procedure, and only such data should be used in the development of formulas.

2. The procedure or formulas should utilize all of the available climatic parameters that are found to significantly affect evaporation or evapotranspiration, but should permit use of more limited data.

3. The formulas developed should be dimensionally sound and should be applicable in either English or metric units.

5. The formulas should, insofar as possible, provide the practicing engineer with a working tool that would give reliable results when applied to climatic data from any part of the world."

Christiansen (1968), and graduate students at USU, first developed a formula for estimating Class A pan evaporation using, as a basis, extraterrestrial radiation, Rt and climatic data. He later developed formulas for estimating both pan evaporation and evapotranspiration using incoming radiation and climatic data (Christiansen and Hargreaves, 1969).

The basic formula for pan evaporation, based on data from many countries of the world and a wide range of climatic conditions is:

$$Ev = 0.459\ R_t\ C_t\ C_w C_h\ C_s\ C_e\ C_m$$

where

R_t = extraterrestrial radiation reaching the earth's atmosphere, computed from a solar constant of 2 calories per cm^2 per minute (these values are given in the tables)

The coefficients given in dimensionless form in metric units are: for mean temperature in ^oC, Tc, and for $T_0 = 20^o$

$$C_t = 0.393 + 0.559\ (Tc/T_0) + 0.048\ (Tc/T_0)^2.$$

For mean wind velocities, W, above the evaporation pan at a height above ground of 60 cm, W_0 = 96.7 kilometers per day

$$C_w = 0.708 = 0.328\ (W/W_0) - 0.036\ (W/W_0)^2$$

For mean relative humidity at noon, Hn, or average humidity for 11 and 17 hours, and for H_0 = 40 percent or 0.40:

$$C_h = 1.250 - 0.348\ (Hn/H_0) + 0.120\ (Hn/H_0)^2 - 0.022\ (Hn/H_0)^4$$

or, where mean humidity is available, and $Hm_0 = 0.55$, an approximate relation is

$$C_{nm} = 1.255 - 0.242\ (Hm/Hm_0) - 0.013\ (Hm/Hm_0)^6.$$

For mean sunshine percentage, S, and for S_0 = 80 percent, or 0.80

$$C_s = 0.542 + 0.640\ (S/S_0) - 0.499\ (S/S_0) + 0.317\ (S/S_0)^3.$$

For elevation, E, and for E_0 = 1.000 feet or 305 meters

$$C_e = 0.970 + 0.030\ (E/E_0).$$

The monthly coefficient, C_m, is the ratio of the reported pan evaporation to the computed value, which appears to vary somewhat from place to place and possibly depends on factors not taken into consideration in the formula, such as the pan exposure, days of precipitation, and shading from mountains. The mean value of C_m is 1.00, and the standard deviation for 3928 months of data from more than 80 stations in 8 countries was 0.116. Ordinarily the coefficient C_m is omitted.

Formulas for Potential Evapotranspiration, Etp. Christiansen gives three formulas developed for potential evapotranspiration using data from Pruitt for rye grass from 6.1 meter diameter weighing lysimeter (Christiansen and Hargreaves, 1969). The evapotranspiration data used were recorded to 0.001 inch per day (0.025 mm) and all climatic factors considered were carefully measured.

The first formula used pan evaporation, Ev, as a base, the second one used exterrestrial radiation, Rt, as the base, and the third used incoming measured radiation, Rs, as the base.

The formula relating potential evapotranspiration, Etp, to pan evaporation, Ev, can be expressed by the equation

$$Etp = 0.755\ Ev\ C_{t2}\ C_{w2}\ C_{h2}\ C_{s2}$$

where Ev is the measured Class A pan evaporation.

$$C_{t2} = .862 + 0.179\ (Tc/Tc_0) - 0.041\ (Tc/Tc_0)^2$$

where Tc is the mean temperature in ^{o}C, and $Tc_0 = 20^{o}C$.

$$C_{w2} = 1.189 - 0.240\ (W/W_0) + 0.051\ (W/W_0)^2$$

where W is the mean wind velocity 2 meters above ground leve in miles per day or kilometers per hour, and W_0 = 100 miles per day or 6.7 kilometers per hour.

$$C_{h2} = 0.499 + 0.620\ (Hm/Hm_0) - 0.119\ (Hm/Hm_0)^2$$

where Hm is the mean relative humidity, expressed decimally (60 percent = 0.60), and H_0 = 0.60.

$$C_{s2} = 0.904 + 0.008\ (S/S_0) + 0.088\ (S/S_0)^2$$

where S is the percentage of possible sunshine, expressed decimally, and S_0 = 0.80.

The formula relating potential evapotranspiration to extraterrestrial radiation, Rt, and climatic factors can be expressed by the equation:

$$Etp = 0.324\ Rt\ C_{tt}\ C_{wt}\ C_{ht}\ C_{st}\ C_e$$

where

$$C_{tt} = 0.463 + 0.425\ (Tc/Tc_0) + 0.112\ (Tc/Tc_0)^2 .$$

The symbols for the climatic parameters are the same as for the previous formula.

$$C_{wt} = 0.672 + 0.406\ (W/W_0) - 0.078\ (W/W_0)^2$$

$$C_{ht} = 1.035 + 0.240\ (Hm/Hm_0)^2 - 0.275\ (Hm/Hm_0)^3$$

$$C_{st} = 0.340 + 0.856\ (S/S_0) - 0.196\ (S/S_0)^2$$

$$C_e = 0.970 + 0.030\ (E/E_0).$$

The formula relating potential evapotranspiration, Etp, to measured incoming radiation, Rs, as a base can be written:

$$Etp = 0.492\ Rs\ C_{tt}\ C_{wt}\ C_{ht}$$

where Rs is the measured incoming solar radiation expressed as equivalent depth of evaporation. The equations for the coefficients, C_{tt}, C_{wt}, and C_{ht} are the same as given before.

As stated by Christiansen and Hargreaves (1969), the measured incoming solar radiation is generally reported as Langleys per day, R_L, (calories per cm^2 per day). The equivalent depth of evaporation per day is obtained by dividing Langleys per day, R_L, by the latent heat of vaporization, L:

$$Rs = R_L/L.$$

At a temperature of 20^oC, L has a value of 584.8 calories per gram. For other temperatures in ^oC, the relation is

$$L - 595.9 = 0.55\ Tc$$

To obtain Rs for a month one must multiply the mean daily value of Rs by the number of days in the month, or use the total Langleys per month. Because of the small variation of L with temperature, the value for 20^oC is generally used except for computer computations.

Hargreaves Formulas

Hargreaves (1972) has developed several equations to estimate pan evaporation and potential evapotranspiration.

Evaporation from a Class A pan located in an irrigated grass area is given by the equation

$$EV = .43 \ RT \ CT \ CH \ CW \ CE \tag{3}$$

in which

EV = Class A pan evaporation

RT = extraterrestrial radiation reaching the earth's atmosphere computed from a solar constant of 2.0 calories per cm^2 expressed in equivalent depth of evaporation

$$CT = .40 + .024 \ TM \tag{3a}$$

(TM is mean temperature in ^oC)

$$CT = .140 + .555 \ (T - 32) \tag{3b}$$

(T is mean temperature in ^oF)

$$CH = .05 + 1.58 \ (1.00 - HM)^{1/2} \tag{3c}$$

(HM is mean relative humidity in percent expressed decimally)

$$CW = .68 + .04 \ W10 \tag{3d}$$

(W10 is wind at an elevation of 10 meters in Km/hr)

$$CW = .47 + .04 \ WP \tag{3e}$$

(WP is wind at the pan in Km/hr)

$$CW = .47 + .00276\ WPM \tag{3f}$$

(WPM is wind at pan in miles per day)

$$CE = 1.00 + .07 \times EL/1000 \tag{3g}$$

(EL is elevation in meters)

$$CE = 1.00 + .021 \times ELF/1000 \tag{3h}$$

(ELF is elevation in feet).

Potential evapotranspiration equivalent to that from a short, green, rapidly growing grass vegetation with a continuously adequate moisture supply is given by the equation

$$ETP = .82\ EVP\ CHTV\ CWTV\ CETV \tag{4}$$

in which

ETP is potential evapotranspiration

EVP is Class A pan evaporation in an irrigated area exposure

$$CHTV = .55 + .75\ HM \tag{4a}$$

$$CWTV = 1.08 - .01\ W10, \text{ or} \tag{4b}$$

$$CWTV = 1.03 - .01\ WP \tag{4c}$$

$$CETV = 1.00 - .04\ EL/1000. \tag{4d}$$

Crop coefficients to be used with either standardized evaporation or potential evapotranspiration are given in Table 1. Root depths in meters are also given in Table 1, Appendix A.

These equations have been tested for California, Arizona, Nicaragua, Venezuela, Ecuador and Iran with good results. According to

Hargreaves (1972) these are general equations and they should fit almost any irrigable area in the world, making the following considerations:

1. The coefficient CW is based on 24-hour wind data. Daytime wind velocities are higher, and therefore when daytime data are used, the value .43 should be correspondingly decreased.

2. The CE value is a function of advection which usually increases with elevation. But this is no valid for all locations, so in some cases this must be estimated.

IRRIGATION REQUIREMENTS

Irrigation water requirements is defined as the amount of water exclusive of precipitation needed to maintain a desired soil moisture and salinity level during a crop season (Pair, 1969). This definition contains the unique environments, existing for each crop, in each soil, locality, soil moisture level, cultural environment, and stage of growth which make irrigation requirements unique also.

Christiansen and Hargreaves (1970, 1971) proposed as an index of actual irrigation water requirements the term potential irrigation requirement, where the potential irrigation requirement on a monthly basis is the potential evapotranspiration less dependable precipitation. Dependable precipitation was defined by them as the mean amount of precipitation equaled or exceeded 75 percent of the time based on ranking distribution.

Consumptive use data are used in estimating the irrigation water requirements of existing or proposed projects and for crop production on individual farms. The actual irrigation water requirement is dependent not only on the total consumptive need but also on the amount of moisture contributed from such natural sources as effective growing-season rainfall, carryover soil moisture from winter rains, and sometimes any contributions from ground water.

Shockley (1966) has presented an equation through which it is possible to calculate irrigation water requirement and where the evapo-

transpiration is only one component of the equation which can be written as follows:

$$IR = 100\ ((Et + LR - Re - Mc - Mg) + Lc)/E$$

where

IR = irrigation water requirement

Et = evapotranspiration

LR = leaching requirement

Re = effective rainfall

Mc = carryover soil moisture

Mg = ground water contribution

E = field capacity efficiency

Lc = conveyance and operation losses.

The various factors vary greatly. In arid areas where the irrigation water contains appreciable amounts of salt, LR may be high and Re almost negligible. In areas where the water is relatively pure and rainfall sufficient for leaching, LR may be zero. If depths to ground water are in excess of the depth of the root zone, Mg can be disregarded.

Effective Precipitation

Effective precipitation supplies part of the evapotranspiration requirement of crops. It may be a very small part in an arid area, or it may be a major part in humid areas such as the south of Chile.

Since there are few records of effective precipitation available, it is necessary to utilize total precipitation records and estimate the percentage that is effective.

The factors affecting total precipitation effectiveness are:

1. Total precipitation.
2. Intensity of precipitation.
3. Intake rate of soil.
4. Water holding capacity of soil.
5. Evapotranspiration rate of crop.
6. Timing of precipitation in relation to irrigation.

The maximum effective precipitation for a month or season cannot exceed the evapotranspiration for that period plus water holding capacity of the soil. Storms occurring just after an irrigation or in rapid succession when the soil profile is filled with water may provide little effective water for evapotranspiration.

Where the intensity of the precipitation exceeds the intake rate of the soil, runoff will reduce the effectiveness of the total precipitation even though storage space is available in the root zone.

High water-holding capacity soils will hold more precipitation than soils with low water-holding capacities.

High evapotranspiration rates will deplete the soil moisture rapidly, thus providing storage capacity for subsequent precipitation.

Rainfall Probabilities

The Soil Conservation Service (1967) has concluded that because of the wide variation in the net irrigation requirements caused by the variation of the climatic factors and the irregular distribution of precipitation from year to year, the development of a dependable water supply cannot be based on average requirements, or computations of these requirements from average values of data available, since this would provide an adequate supply approximately half the time.

Methods Used for Computing Precipitation Probabilities

Several methods have been advanced to determine rainfall probability. Some are relatively simple and easy to apply, whereas others involve mathematical formulas that are time consuming to solve. An ideal method of estimating probability would: a) apply to any period of time such as a year, season, month, or week; b) provide reliable estimates for a return period of 50 to 100 years by extrapolation; and c) be easily and quickly computed. None of the probability methods now in common use meets all of these requirements.

The most common probability methods in use are: normal distribution, ranking distribution, and incomplete gamma function. Burchinal and Dickerson (1961) presented a good analysis of these methods.

Normal Distribution. This normal distribution is usually referred to as Gaussian Distribution. The function is completely determined by

two parameters: the mean value, $\overline{X}$, and the standard deviation, σ. It is symmetrical, tails out of the extreme values and has a shape resembling a bell. It is defined by the following equation:

$$F(x) = (2n\sigma)^{-1} \exp\left[-1/2\ (X-\overline{X})^2/\sigma^2\right].$$

The normal distribution provides a good fit for most climatological variables that are, for all practical purposes, unbound above and below such as temperature. Precipitation is bound on the lower end by zero but it is unbound at the upper end. According to Ramirez (1971) some distribution other than normal should be expected to provide the best fit for precipitation data.

Ranking Distribution (Determined by Kimball Equation). Burchinal and Dickerson (1961) show a good procedure to analyze the rainfall data using the Kimball equation.

The equations are:

$$F = m/(N + 1)$$

or

$$T = (N + 1)/m$$

where

F = percent frequency or probability

T = return period in years, or recurrence interval

m = rank number in an array of decreasing order of magnitude

N = number of years of record.

The procedure indicated by the aforementioned author is:

1. Tabulate the average annual rainfall.

2. Array the rainfall amounts in order of decreasing magnitude.

3. Compute and tabulate the plotting position, i.e., percent frequency or return period, by the formula.

4. Plot the arrayed rainfall amounts against the percent frequency on probability paper.

5. Draw the line of best fit by eye, giving less weight to single points that plot far out of line.

Incomplete Gamma Distribution Function. Barger and Thom (1949) made studies related with rainfall distribution based upon frequency histograms. They concluded analyzing that the normal distribution did not fit well for periods shorter than four months. This was because of the large number of weeks with zero rainfall. It has been proposed that the incomplete gamma distribution function may offer an appropriate model for weekly, monthly or seasonal rainfall.

Hardee (1971) and Ramirez (1971) made a study for Colombia and Venezuela, respectively, finding that the incomplete gamma distribution can give reliable information. Hardee concluded from an analysis of 103 years of precipitation records that a gamma distribution provides the best fit.

The incomplete gamma frequency as presented by Thom (1958) for random variable x is given by:

$$f(x) = \frac{e^{-x/\beta} x^{m-1}}{\beta^{m} \Gamma(m)}$$

in which

x = precipitation amount

β and m are parameters

$$m = \int_0^x e^{-x} x^{m-1} dx$$

$0 \leq x \leq \infty$, m 0.

The probability that precipitation will not exceed x amount as well as the precipitation associated with any probability can be found from

$$f(x) = \int_0^x \frac{e^{-x/\beta} x^{m-1}}{\beta^{m} \Gamma(m)}$$

where

x is the amount of precipitation (daily, weekly, monthly, annual, etc.).

Miller and Weaver (1968), using the incomplete gamma distribution for climatic division in Ohio, determined the monthly and annual precipitation amounts for the 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 95 percent probability levels. Rather than utilizing a desk calculator and the Thom monogram of Pearson's tables of the incomplete gamma distribution function (which are related to probability [absissa] and the ratio $\bar{x}/\beta$ [ordinate] [in Thom's graphs, the value of precipitation associated with a given probability and gamma parameter is the x term in the ratio $\bar{x}/\beta$]).

Weaver and Miller (1967) wrote a computer program for the purpose of computing precipitation associated with selected probabilities. This program calculated gamma and beta parameters. Precipitation, xi, for a given probability, P, is estimated from:

$$x\,i = x_j = \frac{x_j}{m}(S) - \frac{P(m)\,e^{x_j}}{x_j^{m-1}}$$

where

$$d = i - 1$$

$$S = 1 + \frac{x}{m+1} + \frac{x^2}{(m+1)(m+2)} + \frac{x^3}{(m+1)(m+2)(m+3)}$$

$$\beta = \bar{x}/m$$

$$m = \Gamma = \text{gamma.}$$

The gamma parameter, Γ, is found by solving for m in the quadratic equation:

$$12\,(\ln \bar{x} - 1/N\,\Sigma \ln x)\,m^2 - m - 1 = 0$$

or

$$12\,(\ln \bar{x} - 1/N\,\Sigma \ln x)^2 - 6\Gamma - 1 = 0.$$

If Γ is less than 36, the gamma function is caluclated by using an algorithm developed by Collinge (1961). If the r value is greater than 36, the gamma functions were found by linear interpolation of Pearson's gamma function table.

PROCEDURE

Evaporation Equation

Using Data from the Meteorological Office of Chile

The first step in the present study was to analyze climatological and evaporation data at eight different stations in Chile where the data was found to be complete enough for such use. These eight stations are listed below in Table 1 together with their latitude, longitude, and elevation.

Table 1. Chilean Meteorological Stations

Identification Number	Station	Latitude °S	Longitude °W	Elevation In Meters	Anemometer Height In Meters
2	Serena	29.90	71.25	32	9
4	Ovalle	30.36	71.20	250	9
10	Santiago	30.45	70.70	520	22
12	San Fernando	34.58	71.00	342	8
13	Curico	34.98	71.23	211	9
15	Linares	35.85	71.60	157	9
18	Los Angeles	37.47	72.35	160	9
20	Temuco	38.75	75.28	114	9

The data used were monthly means, with a total of 290 months. All data for a single month for a given station were punched onto one card. The data were obtained from the Chilean Meteorological Office. Com-

puter program 810 written in FORTRAN V language for the UNIVAC 9200 was used to process the data and analyze the results.

The following minumum information (for the eight stations) was required for the computations: wind velocity, relative humidity, temperature, precipitation, percentage of sunshine, and measured pan evaporation. Also the following was taken into consideration: latitude, longitude, elevation and extraterrestrial radiation.

The main limitation of the data was that they were not consistant for the winter periods, especially for stations that had high precipitation during this period.

Computer program 810 was used to relate the values of measured evaporation with the different climatic parameters that were measured at all of the stations. Following the method given by Christiansen (1968), and starting from a very general equation to calculate evaporation, every climatic parameter was related several times with the measured evaporation in order to develop a formula for average evaporation and climatic conditions.

The general equation for pan evaporation is

$$EVP = K_{ev} R_t C_t C_{hv} C_w C_e C_p C_s$$

in which

K_{ev} is an appropriate dimensionless constant for pan evaporation

R_t is the extraterrestrial radiation computed for the month and latitude, and expressed as equivalent evaporation by dividing the radiation (cal/cm^2/day) by the heat of vaporation at the mean temperature, TM, and converting to appropriate units, usually mm per day or per month (given in the tables).

With the exception of C_p, which is a coefficient for precipitation, all of the coefficients have been defined and described in a previous section.

The coefficients are dimensionless and most of them are of the general form:

$$C_X = A + B X + C X^n$$

where

C_X represents the coefficient for the specific parameter

X represents the ratio, X/X_0, where X is the parameter and X_0 is the standard value of the parameter, preferably an approximate mean value for the data used

n generally has a value of 2, but sometimes has other values.

The coefficients are written so that A + B + C = 1.00.

The ratios of measured evaporation to calculated evaporation were plotted against each of the climatological parameters in order to improve the corresponding coefficient and obtain a better fit. The absolute error, standard deviation and R square were used as a measure of how well the computed values compared with the measured pan evaporation.

Use of ENDESA Data

Due to the delay in obtaining the climatic data from the National Electrical Company (ENDESA), these data were analyzed separately. Program 810-A was written for this purpose. This computer program was basically a modification of program 810, and it is shown in Appendix B. The procedure followed was the same as for the data from the Meteorological Office. The only difference was that the equation already developed with the first data was introduced in the program to see how well it fit. This equation was modified because the measurements of pan evaporation corresponding to the ENDESA data were Class A pan evaporation (Weather Bureau), but apparently the other set of data was taken from a different type of evaporimeter. Unfortunately it was not possible to find out exactly the type of pan used, but it may have been a Wild type vaporimeter. Another difference was that the ENDESA data did not include sunshine measurements and maximum and minimum temperatures (only mean temperature was available); it was not possible, therefore, to use a coefficient for temperature difference, TD, which has a good correlation with sunshine.

The data used were monthly means, with a total of 272 months for six stations. They were found to be complete enough for the computations needed. These stations are listed below in Table 2 together with their latitude, longitude, and elevation.

Table 2. ENDESA Meteorological Stations

Identification Number	Station	Latitude °S	Longitude °W	Elevation In Meters	Anemometer Height In Meters
2	Desague Invernada	37.73	70.78	1325	.6
3	Polcura Embaseadero	37.32	75.53	740	.6
4	Armerillo	35.72	71.08	450	.6
5	Puente Arque do	34.28	71.35	199	.6
6	Quelantaro A Radio	34.03	71.58	260	.6

Evapotranspiration Equation

Using Chilean Evapotranspiration Data

There are very few data related to measured evapotranspiration in Chile. The only information available for this study was that obtained by Fritsch and Tosso (1969). This information consisted of a monthly average of three years of measured evapotranspiration for the following crops in Santiago Province: clover, alfalfa, corn, and wheat. Program 812 was written to analyze these data. The program is given in Appendix B.

The monthly average measured evapotranspiration for every crop was punched onto cards. The computer program related these values with the measured evaporation for the same place and months. The

climatological data for the corresponding months were also punched onto cards and printed out in order to relate these values with the ratios ET/EV for each crop. The purpose of this was to find an equation to compute the crop coefficients.

Evapotranspiration Equation Using Pruitt's Data

Using a program written by Professor Christiansen, data from experimental work at Davis, California, using a 6.1 meter diameter lysimeter planted to rye grass, were used to develop a formula for potential evapotranspiration. The procedure used is that given by Christiansen (1968). The equation is in the section on Results and Discussion.

Irrigation Requirements

Program 691-GV, Appendix B, was written to read the basic precipitation data to calculate the gamma distribution of precipitation data on a monthly and annual basis. The same program computes precipitation for different probability levels according to the normal distribution and ranking distribution. The gamma distribution is given at 13 different probability levels. A subroutine was used to calculate potential evapotranspiration using the formula developed in this study using Pruitt's data.

RESULTS AND DISCUSSION

New Evaporation Formulas

Using Data from the Meteorological Institute of Chile

The new formula developed to estimate pan evaporation using data from the Meteorological Institute is:

EVPT = KT RMM CWT CET CTT CHVT CTDT CPT

where

EVPT is evaporation, mm per month

KT = .328

RMM is extraterrestrial radiation in evaporation units, the same as EVPT (given in Table 2, Appendix A)

$CWVT = .41 + .92\ (W10C/10) - .33\ (W10C/10)^2$

If W10C (wind velocity in kilometers per hour at 10 meters height) is greater than 14.0, CWT = 1.06

$CET = .94 + .06\ (EL/1000)$

EL is elevation in meters

$CTT = .12 + .92\ (TM/15) - .04\ (TM/15)^2$

TM is mean temperature in ^{o}C

$CHVT = 1.13 - .13\ (HM/.70)^2$

HM is daytime relative humidity expressed in decimal form

$CTDT = .72 + .28\ (TD/15)^2$

TD is mean temperature difference (maximum temperature, minimum temperature

$$CPT = 1.05 - .05\ (P/100)$$

P is mean precipitation.

All of these coefficients have been calculated for the range of values that may be expected for Chile. These coefficients are presented in Table 5.

This formula was compared with Christiansen's formula that uses extraterrestrial radiation as a base and was given by Christiansen and Hargreaves (1969). The only modification to the original equation was the value of the constant .459 which was changed to .430.

Hargreaves' formula, as given in the literature review of this study, was also used for the same purpose. A modification of the wind coefficient was made by Hargreaves as follows:

Original: $CW = .68 + .04\ W10$

Modified: $CW = .82 + .0225\ W10$

The constant was also changed from .430 to .413.

The absolute error, standard deviation and R square were computed and used as a measure of how well the formulas fit the data. A comparison of these values are given in Table 4 which shows that the Tosso formula has the least error and standard deviation, and at the same time has the highest coefficient of correlation squared (R^2) with an overall value of .93. This indicates that 93 percent of the variance is predicted by the equation, leaving only 7 percent unexplained.

Using the same computer program with some slight modifications, Christiansen's formula (Christiansen and Hargreaves, 1969), and Hargreaves' formula (Hargreaves, 1972) were introduced in order to compare them with the new formula developed for Chile.

The Blaney-Criddle formula, as applied to pan evaporation, was also tried. For this purpose it was necessary first to compute mean monthly k values, which are pan coefficients, and which are different for every month. These k values were computed from the equation:

$$k = EVPM/f$$

in which

EVPM = measured pan evaporation

k = pan evaporation coefficient

f = the product of mean monthly temperature and monthly percent of daytime hours.

The mean monthly k values were then averaged for all stations for each month and then used in the computer program to calculate the pan evaporation from the Blaney-Criddle formula. The computed evaporation values were averaged for each station by months and for the year. Monthly ratios of EVPM/EVBC and the absolute errors were also computed and averaged.

The mean absolute errors for the Blaney-Criddle formula also appear in Table 4. In order to compare this formula with the new one developed in the present study, it was first necessary to obtain the average monthly k values as was explained in the section on Procedure.

The following are the average monthly k values computed from the data from the Meteorological Institute.

Table 3. Mean Monthly Values of k for the Blaney-Criddle Formula

Month	k	Month	k	Month	k
January	1.40	May	.56	September	.74
February	1.33	June	.42	October	.92
March	1.05	July	.41	November	1.11
April	.71	August	.56	December	1.28

Table 4. Comparison of Christiansen, Hargreaves, Blaney-Criddle, and Tosso Formulas Using Data from the Meteorological Institute

Station No.	Average Absolute Error			
	Christiansen	Hargreaves	Blaney-Criddle	Tosso
2	11.5	13.4	20.7	10.2
4	9.6	11.7	22.0	8.6
10	9.8	18.5	24.3	10.8
12	13.2	23.1	16.2	15.6
13	20.7	11.1	18.9	7.5
15	13.9	14.8	25.4	11.3
18	15.1	22.2	23.9	10.5
20	15.0	11.8	33.7	18.4
Overall Average	13.2	16.4	22.7	11.4
Standard Deviation	23.0	28.0		19.0
R Square	.89	.85		.93

TABLE 5. COEFFICIENTS FOR COMPUTING PAN EVAPORATION FOR CHILE

(FOR METEOROLOGICAL INSTITUTE DATA)

WID	CWVT	ELEV	CET	TM	CTVT	HM	CHVT	PREC	CPT	TD	CTD
0.	.410	0.	.940	0.	.120	.50	1.064	0.	1.050	0.	.720
1.	.433	100.	.945	1.	.181	.51	1.061	5.	1.047	1.	.739
2.	.591	200.	.952	2.	.247	.52	1.058	10.	1.045	2.	.757
3.	.656	300.	.958	3.	.302	.53	1.055	15.	1.043	3.	.776
4.	.725	400.	.964	4.	.362	.54	1.053	20.	1.040	4.	.795
5.	.797	500.	.970	5.	.422	.55	1.050	25.	1.038	5.	.813
6.	.843	600.	.976	6.	.482	.56	1.047	30.	1.035	6.	.832
7.	.877	700.	.982	7.	.541	.57	1.044	35.	1.032	7.	.851
8.	.935	800.	.988	8.	.599	.58	1.041	40.	1.030	8.	.869
9.	.971	900.	.994	9.	.658	.59	1.038	45.	1.028	9.	.888
10.	1.001	1000.	1.000	10.	.716	.60	1.034	50.	1.025	10.	.907
11.	1.023	1100.	1.006	11.	.773	.61	1.031	55.	1.023	11.	.925
12.	1.039	1200.	1.012	12.	.830	.62	1.028	60.	1.020	12.	.944
13.	1.048	1300.	1.018	13.	.887	.63	1.025	65.	1.017	13.	.963
14.	1.051	1400.	1.024	14.	.944	.64	1.021	70.	1.015	14.	.981
15.	1.047	1500.	1.030	15.	1.000	.65	1.018	75.	1.013	15.	1.000
16.	1.037	1600.	1.036	16.	1.056	.66	1.014	80.	1.010	16.	1.019
17.	1.020	1700.	1.042	17.	1.111	.67	1.011	85.	1.008	17.	1.037
18.	.997	1800.	1.048	18.	1.166	.68	1.007	90.	1.005	18.	1.056
19.	.967	1900.	1.054	19.	1.221	.69	1.004	95.	1.002	19.	1.075
20.	.930	2000.	1.060	20.	1.276	.70	1.000	100.	1.000	20.	1.093
21.	.937	2100.	1.066	21.	1.330	.71	.995	105.	.998	21.	1.112
22.	.937	2200.	1.072	22.	1.383	.72	.992	110.	.995	22.	1.131
23.	.796	2300.	1.078	23.	1.437	.73	.989	115.	.993	23.	1.149
24.	.717	2400.	1.084	24.	1.490	.74	.985	120.	.990	24.	1.168
25.	.643	2500.	1.090	25.	1.542	.75	.981	125.	.988	25.	1.187
26.	.571	2600.	1.096	26.	1.594	.76	.977	130.	.985	26.	1.205
27.	.433	2700.	1.102	27.	1.646	.77	.973	135.	.983	27.	1.224
28.	.399	2800.	1.108	28.	1.698	.78	.969	140.	.980	28.	1.243
29.	.303	2900.	1.114	29.	1.749	.79	.964	145.	.978	29.	1.261
30.	.250	3000.	1.120	30.	1.800	.80	.960	150.	.975	30.	1.280
31.	.091	3100.	1.126	31.	1.850	.81	.955	155.	.973	31.	1.299
32.	-.025	3200.	1.132	32.	1.901	.82	.952	160.	.970	32.	1.317
33.	-.148	3300.	1.138	33.	1.950	.83	.947	165.	.968	33.	1.336
34.	-.277	3400.	1.144	34.	2.000	.84	.943	170.	.965	34.	1.355
35.	-.413	3500.	1.150	35.	2.049	.85	.938	175.	.963	35.	1.373
36.	-.555	3600.	1.156	36.	2.099	.86	.934	180.	.960	36.	1.392
37.	-.704	3700.	1.162	37.	2.146	.87	.929	185.	.958	37.	1.411
38.	-.859	3800.	1.168	38.	2.194	.88	.925	190.	.955	38.	1.429

EVPT=.325*FMM*CWVT*CET*CTVT*CHVT*PREC*CPT*CTD

Using Data from ENDESA

The new formula developed to estimate Class A pan evaporation using the climatological information given by ENDESA is:

$$EVPT = KT\ RMM\ CWT\ CET\ CTT\ CHVT\ CPT$$

where

RMM is the extraterrestrial radiation as given in Table 2, Appendix A

$KT = .40$

$CWT = .18 + 1.10\ (W10C/10) - .28\ (W10C/10)^2$

If the wind velocity is greater than 19.4, $CWT = 1.27$

$CET = .94 + .06\ (EL/1000)$

$CTT = .50 + .18\ (TM/15) + .32\ (TM/15)^2$

$CHVT = 1.07 - .07\ (HM/.70)^8$

$CPT = 1.05 - .05\ (P/100)$.

All of these coefficients have also been calculated for the different values that are probable for Chile. These coefficients are presented in Table 6.

This equation is a modification of the formula developed using data from the Meteorological Institute for which every term has previously been defined.

Due to the fact that there were no data from which the coefficient for temperature difference, CTDT, could be computed, this coefficient was omitted. This has the same effect as making CTDT = 1.0.

TABLE 6. COEFFICIENTS FOR COMPUTING PAN EVAPORATION AND EVAPOTRANSPIRATION FOR CHILE

(FOR E N D E S A DATA)

WIN	CWVT	CWTT	ELEV	CET	TM	CTVT	CTTT	HM	CHVT	CHTT	PREC	CPT
0.	.190	1.120	0.	.940	0.	.500	.910	.50	1.065	.859	0.	1.050
1.	.237	1.108	100.	.946	1.	.513	.916	.51	1.064	.869	5.	1.047
2.	.330	1.096	200.	.952	2.	.530	.922	.52	1.064	.877	10.	1.045
3.	.485	1.084	300.	.958	3.	.549	.928	.53	1.062	.886	15.	1.043
4.	.575	1.072	400.	.964	4.	.571	.934	.54	1.061	.894	20.	1.040
5.	.650	1.060	500.	.970	5.	.596	.940	.55	1.060	.902	25.	1.038
6.	.739	1.048	600.	.976	6.	.623	.946	.56	1.058	.910	30.	1.035
7.	.813	1.036	700.	.982	7.	.654	.952	.57	1.056	.917	35.	1.032
8.	.881	1.024	800.	.988	8.	.687	.958	.58	1.054	.924	40.	1.030
9.	.943	1.012	900.	.994	9.	.723	.964	.59	1.052	.931	45.	1.028
10.	1.000	1.000	1000.	1.000	10.	.762	.970	.60	1.050	.937	50.	1.025
11.	1.051	.988	1100.	1.006	11.	.804	.976	.61	1.047	.944	55.	1.023
12.	1.097	.976	1200.	1.012	12.	.849	.982	.62	1.043	.949	60.	1.020
13.	1.137	.964	1300.	1.018	13.	.896	.988	.63	1.040	.955	65.	1.017
14.	1.171	.952	1400.	1.024	14.	.947	.994	.64	1.036	.960	70.	1.015
15.	1.200	.940	1500.	1.030	15.	1.000	1.000	.65	1.031	.965	75.	1.013
16.	1.223	.928	1600.	1.036	16.	1.056	1.006	.66	1.026	.969	80.	1.010
17.	1.241	.916	1700.	1.042	17.	1.115	1.012	.67	1.021	.974	85.	1.008
18.	1.253	.904	1800.	1.048	18.	1.177	1.018	.68	1.014	.977	90.	1.005
19.	1.259	.892	1900.	1.054	19.	1.241	1.024	.69	1.008	.981	95.	1.002
20.	1.260	.880	2000.	1.060	20.	1.309	1.030	.70	1.000	.984	100.	1.000
21.	1.255	.868	2100.	1.066	21.	1.379	1.036	.71	.992	.987	105.	.998
22.	1.245	.856	2200.	1.072	22.	1.452	1.042	.72	.982	.990	110.	.995
23.	1.229	.844	2300.	1.078	23.	1.528	1.048	.73	.972	.992	115.	.993
24.	1.207	.832	2400.	1.084	24.	1.607	1.054	.74	.961	.994	120.	.990
25.	1.180	.820	2500.	1.090	25.	1.689	1.060	.75	.948	.996	125.	.988
26.	1.147	.808	2600.	1.096	26.	1.773	1.066	.76	.935	.998	130.	.985
27.	1.109	.796	2700.	1.102	27.	1.861	1.072	.77	.920	.999	135.	.983
28.	1.066	.784	2800.	1.108	28.	1.951	1.078	.78	.904	.999	140.	.980
29.	1.015	.772	2900.	1.114	29.	2.044	1.084	.79	.886	1.000	145.	.978
30.	.960	.760	3000.	1.120	30.	2.140	1.090	.80	.866	1.000	150.	.975
31.	.899	.748	3100.	1.126	31.	2.239	1.096	.81	.845	1.000	155.	.973
32.	.833	.736	3200.	1.132	32.	2.340	1.102	.82	.822	.999	160.	.970
33.	.761	.724	3300.	1.138	33.	2.445	1.108	.83	.797	.999	165.	.968
34.	.683	.712	3400.	1.144	34.	2.552	1.114	.84	.769	.998	170.	.965
35.	.600	.700	3500.	1.150	35.	2.662	1.120	.85	.739	.996	175.	.963
36.	.511	.688	3600.	1.156	36.	2.775	1.126	.86	.707	.994	180.	.960
37.	.417	.676	3700.	1.162	37.	2.891	1.132	.87	.671	.992	185.	.958
38.	.317	.664	3800.	1.168	38.	3.010	1.138	.88	.633	.990	190.	.955

EVPT=.401*PHM*CWVT*CET*CTVT*CHVT*CPT

EVTT=.814*EVPT*CWTT*CTTT*CHTT

This formula was also compared with the Christiansen, Hargreaves and Blaney-Criddle formulas.

To obtain the same average value of the computed evaporation and the measured evaporation, the constant for the Christiansen formula changed from .459 to .562. The sunshine coefficient used was equal to 0.865, which was the mean value for the data from the Meteorological Institute. This was necessary because the ENDESA data did not include sunshine measurements.

The Hargreaves formula which did not include a sunshine coefficient was used in the same way as the Meteorological Institute data. For this comparison only the constant was changed from 0.430 to 0.480.

The mean monthly k values for the Blaney-Criddle formula obtained for ENDESA stations are given in Table 7.

Table 7. Mean Monthly k Values for the Blaney-Criddle Formula for ENDESA Stations

Month	k	Month	k	Month	k
January	1.60	May	.65	September	.94
February	1.43	June	.51	October	1.07
March	1.33	July	.53	November	1.33
April	.99	August	.69	December	1.50

A comparison of these formulas with the new formula developed to estimate Class A pan evaporation (Tosso formula) is given in Table 8. From this table it is possible to observe that the Christiansen

and Hargreaves formulas present relatively low absolute errors giving an overall error, standard deviation and coefficient of correlation squared pretty similar to that obtained with the Tosso formula. There appears to be no significant difference in the results from these three formulas, but the mean absolute errors for the Blaney-Criddle formula were much higher. Details of these results appear in Tables 3.1 to 3.5 in Appendix C.

Table 8. Comparison of Christiansen, Hargreaves, Blaney-Criddle and Tosso Formula Using Data Given by ENDESA

Station No.	Average Absolute Error			
	Christiansen	Hargreaves	Blaney-Criddle	Tosso
2	8.7	8.7	24.8	8.9
3	12.4	17.3	48.3	11.1
4	11.6	12.3	13.6	10.9
5	7.5	7.3	20.8	7.3
6	10.6	11.4	24.5	9.8
Overall Average	10.6	11.4	21.5	9.8
Standard Deviation	22.6	24.3		21.2
R Square	.94	.93		.95

New Evapotranspiration Formulas

Evapotranspiration Formulas Developed for Chilean Data

An analysis of the climatic data and measured evapotranspiration for the Santiago Province was made. There was information for four crops and they were analyzed individually.

As a result of this analysis a formula to estimate evapotranspiration for every crop was obtained.

Evapotranspiration for Clover (CL). The following formula to estimate actual evapotranspiration for clover was developed:

$$ETCL = EVPM\ CTCL\ CHCL$$

in which

ETCL = actual evapotranspiration for clover in the same units as EVPM

EVPM = pan evaporation

$CTCL = .82 - .20\ ((TM-10)/5) + .06\ ((TM-10)/5)^2$

M is mean temperature in ^{o}C

$CHCL = 1.18 - .795\ ((HM - .50)/.15) + .465\ ((HM - .50)/1.15)^2$

HM is mean relative humidity in percent expressed decimally.

The average absolute difference between the measured and calculated evapotranspiration from the above equation is 5 millimeters per month.

Evapotranspiration for Alfalfa. The following formula to estimate actual evapotranspiration for alfalfa was developed:

$$ETAL = EVPM\ CTAL\ CHAL$$

in which

ETAL = actual evapotranspiration for alfalfa in same units as EVPM

EVPM = pan evaporation

$CTAL = 1.18 - .18\ (TM/15)$

$$CHAL = 1.03 - .14((HM - .50)/.15) + .09((HM - .50)/.15)^2.$$

The average absolute difference between the measured and calculated evapotranspiration from the above equation is 7.2 millimeters per month.

Evapotranspiration for Corn. The following formula to estimate actual evapotranspiration for corn was developed:

$$ETCO = EVPM\ CLO$$

in which

ETCO = actual evapotranspiration for corn in the same units as EVPM

$$CCO = .72 + .38 \cos(1.047(XM - 12.2))$$

where for months preceding September,

$$XM = Month + 12$$

and for September to December,

$$XM = Month.$$

These values are given in the following tabulation:

Month	XM	Month	XM	Month	XM
January	13	May	17	September	9
February	14	June	18	October	10
March	15	July	19	November	11
April	16	August	20	December	12

The average absolute difference between the measured and calculated evapotranspiration from the above equation is 5.7 millimeters per month.

Evapotranspiration for Wheat. The following formula to estimate actual evapotranspiration for wheat was developed:

$$ETWH = EVPM\ CWH$$

in which

ETWH = actual evapotranspiration for corn in the same units as EVPM

EVPM = pan evaporation

$$CWH = .545 + .345 \cos (1.2548\ (XM - 10.5)).$$

The average absolute difference between the measured and calculated evapotranspiration from the above equation is 4.3 millimeters per month.

The measured and calculated values of evapotranspiration and some of the ratios are given in Table 3, Appendix A. The symbols used appear in Appendix A.

Potential Evapotranspiration Formula Developed from Pruitt's Data

From the analysis of Pruitt's data at Davis, California, the following formula to estimate potential evapotranspiration was developed:

$$EVTT = .81\ EV\ CH\ CT\ CW$$

in which

EVTT = potential evapotranspiration

EV = measured or computed Class A pan evaporation

$$CH = 2.0\ (HM/.80) - 1.0\ (HM/.80)^2$$

If HM is greater than .80, CH = 1.0

HM is daytime relative humidity expressed in decimal form

$CT = .91 + .09\ (TM/15)$

TM is mean temperature in ^{o}C

$CW = 1.12 - .12\ (W10/10)$

W10 is wind velocity in km/hours at 10 meters height.

Relating these values of measured evapotranspiration at Davis with those calculated from the above equation for the same period, an absolute error of 6.6 percent average was obtained.

Due to the reliability and the greater amount of data from which this equation was developed, and considering that the climatic conditions for Davis are, in general, similar to those of the irrigated areas of Chile, this equation was used in the gamma program as a base for the calculation of the potential irrigation requirement.

Irrigation Requirements

Potential Irrigation Requirements

To arrive at the actual irrigation requirements, two basic parameters need to be determined: effective precipitation and evapotranspiration. The amount of water used by a crop and the amount of water required for leaching are directly proportional to evapotranspiration. Part of this water used is supplied by effective precipitation and the remainder must be supplied by irrigation. Unfortunately it was not possible to obtain values of effective precipitation for this study because data related to intensity of precipitation, soil characteristics, drainage, and runoff were not available.

The gamma distribution analysis was used to compute precipitation probability values for stations. Potential evapotranspiration and potential irrigation requirements for 5 precipitation probability levels appears in Appendix D. The calculated value of potential evapotranspiration for each month and the annual value, which is the sum of the monthly values, are printed out. The potential irrigation requirement is obtained by subtracting from the values of evapotranspiration the precipitation at 5 probability levels. Positive values indicate that irrigation is required and negative values indicate that dependable precipitation exceeds the potential evapotranspiration, therefore irrigation may not be required.

Monthly and annual probabilities of receiving equal to or greater than a certain amount of precipitation for 13 probability levels were also calculated. The annual values do not correspond with the sum of the monthly values since they represent the distribution of the annual totals for each year of record. As an example, in Table 8.5 for Santiago we find under the 70 percentile column and for May the value 17. This indicates that in 7 years out of 10, the May precipitation total for Santiago is expected to be equal or greater than 17.0 millimeters, or alternatively, that 3 years out of 10 the May precipitation total is expected to be less than 17.0 millimeters.

In Appendix D also appear values of maximum and minimum precipitation for each month as well as the annual value, dependable precipitation, evapotranspiration deficit (ETDF) and moisture available index (MAI) at the 75 percent level of probability.

Actual Irrigation Requirements

As previously stated, actual irrigation requirements depend upon both crop and soil conditions as well as the climate. For this reason it is not possible to compute actual irrigations in this study. The information given here, however, provides a basis for estimating actual irrigation requirements on a specific project basis where crop to be grown and soil conditions are known or can be determined. Some appropriate precipitation, such as 75 percent, can be selected for this purpose and tabulated for each month. An analysis of the irrigation

requirement can then be made by first estimating the effective precipitation on a month to month basis by considering the probable runoff as related to soil infiltration rates and precipitation intensities. Using appropriate crop rooting depths, the amount of the precipitation that infiltrates into the soil and is retained in this rooting depth can be estimated and the carry-over moisture determined for each month. An irrigation efficiency percentage can be assumed for the method of irrigation to be used. Where the water quality may be relatively poor, the leaching requirement should be taken into consideration.

An example of such a detailed procedure for maise (corn) grown in the Santiago area would be as given in Table 9.

From a personal knowledge of the soils, precipitation intensities, and irrigation methods used, the following assumptions are made:

1. The furrow method of irrigation will be used for corn.

2. The irrigation efficiency is assumed to be 60 percent.

3. The maximum rooting depth for maise for the soils in this area will be taken as 120 cm. Since maise is an annual crop, the root development will occur simultaneously with the vegetative growth, so the monthly percentage of rooting depth will be assumed the same as the crop coefficient.

4. The carry-over moisture will be assumed to be that remaining in the total rooting depth.

5. A minimum values of actual evapotranspiration (Eta) of 20 mm was used for the six winter months.

Table 9. Analysis of Actual Irrigation Requirements for Corn in Chillan

Month	Dep. P (80%) mm	Est. Runoff mm	Infiltrated Prec. mm	ETP mm	Crop Coeff.	ETA mm	Moisture Carry-over	Deficit	IR	Excess Moisture
Jul	79	10	69	30	--	20	120	--	--	49
Aug	69	10	59	44	--	20	120	--	--	39
Sep	36	--	36	62	--	20	120	--	--	16
Oct	20	--	20	108	--	21	119	--	--	--
Nov	3	--	3	168	.40	47	75	--	--	--
Dec	--	--	--	223	1.10	249	--	174	250	--
Jan	--	--	--	254	.90	229	--	229	328	--
Feb	--	--	--	184	.50	92	--	92	131	--
Mar	--	--	--	137	--	27	--	27	39	--
Apr	11	--	--	81	--	20	--	--	--	--
May	73	10	63	35	--	20	43	--	--	--
Jun	116	16	100	24	--	20	120	--	--	3

Estimating Dependable Precipitation at 75% Probability Level

To calculate the Gamma Distribution the Univac 1108 computer was used. It seemed desirable that a simpler method be developed to estimate precipitation at the 75% probability level which is used in estimating water requirements for irrigation projects.

Eighteen stations with records verifying from 30 to 100 years were used for the development of this method. The monthly values of precipitation for the 75% probability level from the Gamma Distribution were plotted against the monthly mean values. A curve was fitted by eye to the plotted points and the equation for this curve was developed. The equation obtained was:

$$PD(75\%) = -7 + 31.5\,(PM/100) + 13.5\,(PM/100)^2$$

in which

PD(75%) is the dependable precipitation at 75% of probability level, in millimeters per month

PM is the mean precipitation from more than 10 years of records for a certain month, in millimeters.

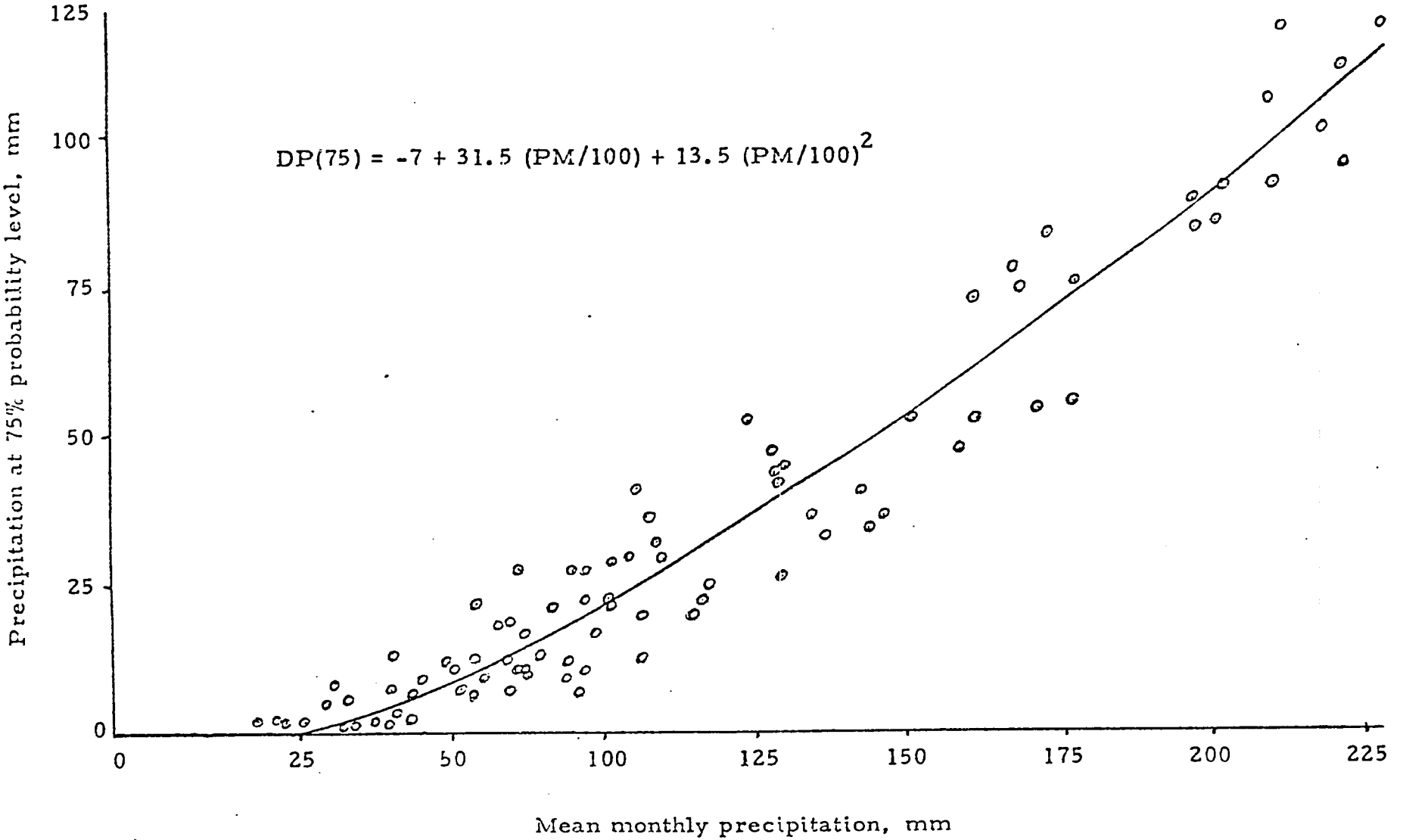

Figure 2. Relationship of Dependable Precipitation at 75% of Probability from a Gamma Distribution to Mean Monthly Precipitation

SUMMARY AND CONCLUSIONS

The objectives of this study were to:

1. Analyze the available climatic data for Chile and determine the best formula for estimating potential evapotranspiration.

2. Process the available monthly rainfall data to estimate the dependable and effective precipitation.

3. Relate the dependable precipitation with potential evapotranspiration to determine irrigation water requirements.

4. Choose what seems to be the best formula for potential evapotranspiration.

5. Combine this formula with dependable precipitation and make a complete study of potential irrigation requirements for 13 stations in Chile.

Two sets of data were analyzed to develop a formula to estimate pan evaporation. The first one was data from the Meteorological Institute of Chile. A total of 290 months of data from 8 stations was used.

A formula to estimate pan evaporation was obtained and compared with other formulas. The new formula developed gives the least absolute error.

Analyzing the second set of data obtained from ENDESA, with 272 months of data from 6 stations, a formula to estimate Class A pan

evaporation was also developed. This formula gives an overall absolute error equal to 9.6 percent. The new formula was also compared with others and it seems to be the most reliable.

An evapotranspiration study was made using measured evapotranspiration and climatic data from Santiago Province for 4 different crops. Formulas that relate evaporation and two climatic parameters were developed to estimate actual evapotranspiration for the 4 crops.

Using Pruitt's data from Davis, California, a formula to estimate potential evapotranspiration was developed. This formula was used for the study of potential irrigation requirements for the 13 stations.

Thirteen probability levels of precipitation were determined for the 13 stations, corresponding to 13 different provinces in Chile (Table 8.1 to 8.13, Appendix D).

Potential irrigation requirements for the same 13 stations were computed using the gamma distribution at 5 probability levels subtracted from the potential evapotranspiration.

An example of how the results from this study can be used in a practical way is given and summarized in Table 9.

A formula for computing precipitation at 75% probability level was developed based on a gamma distribution and average monthly value of the years of record available. The formula was tested and appears to be fairly reliable for estimating precipitation probability for Chile.

BIBLIOGRAPHY

Allen, B. J., and F. R. Crow. 1966. Predicting lake evaporation by the performance of evaporation ponds, pans, and tanks. Purdue University, W. Lafayette, Indiana.

Barger, G. L., and H. C. S. Thom. 1949. Evaluation of drought hazard. Agronomy Journal 11:519-527.

Burchinal, J. C., and W. H. Dickerson. 1961. Rainfall probability and its applications. West Virginia University Agricultural Experiment Station Bulletin 454 T. 26 p.

Christiansen, J. E. 1968. Pan evaporation and evapotranspiration from climatic data. Journal of Irrigation and Drainage Division. Proceedings of the American Soceity of Civil Engineers. pp. 243-265.

Christiansen, J. E. 1972. Personal communication, Utah State University, Logan, Utah.

Christiansen, J. E., and G. H. Hargreaves. 1969. Irrigation requirements from evaporation. International Commission on Irrigation and Drainage, Seventh Congress. Reprinted at Utah State University, February 7, 1970. 27 p.

Christiansen, J. E., and G. H. Hargreaves. 1970. Irrigation requirements in Latin American countries. Second World Congress of Engineers and Architects, December 14-18, 1970, Tel Aviv, Israel. 20 p. (Xeroxed)

Christiansen, J. E. and G. H. Hargreaves. 1971. Irrigation requirements and climatic evaluations for Venezuela. Department of Agricultural and Irrigation Engineering, Utah State University, Logan, Utah. 137 p. January.

Collinge, R. M. 1961. Gamma function. Association of Computing Machinery, Algorith 31. 15 p.

Criddle, W. D. 1952. Irrigated crops. American Society of Civil Engineers. Transactions. Consumptive Use of Water. A Symposium. Paper No. 2524.

Davidson, J. M., and D. L. Nielson. 1966. Determining evapotranspiration by profile sampling. Procedure, Evapotranspiration and its role in water resources management. Conference American Society of Agricultural Engineers.

Department of Water Resources. 1963. Vegetative water use studies 1954-1960. The Resources Agency of California. Bulletin No. 113. 120 p.

Department of Water Resources. 1967. Vegetative water us · studies. The Resources Agency of California. Bulletin No. 113-2. 78 p.

Ekern, P. C., J. R. Robins, and W. J. Staple. 1967. Soil and Cultural factors affecting evapotranspiration. Irrigation for Agricultural Lands. Agronomy No. 11. pp. 522-530.

Fritsch, N., and J. Tosso. 1969. Resumen de 3 anos de evapotranspiracion para diferentes cultivos. Instituto de Investigaciones Agropecuarias. Informetecnico. Santiago, Chile

Gates, D. M., and R. J. Hanks. 1967. Plant factors affecting evapotranspiration. Irrigation of Agricultural Lands. Agronomy 11. pp. 506-521.

Griffin, R. E. 1971. Letter sent to George H. Hargreaves.

Hanks, R. J. 1971. Unpublished mimeographed class notes, Utah State University, Logan, Utah. 127 p.

Hardee, J. E. 1971. Analysis of Colombian precipitation to estimate irrigation requirements. Department of Agricultural and Irrigation Engineering, College of Engineering. Utah State University and Utah Water Research Laboratory, Publication PRWG69-4.

Hargreaves, G. H. 1971. The evaluation of water deficiencies. Technical Report. Utah State University, Department of Agricultural and Irrigation Engineering. Logan, Utah. 12 p.

Hargreaves, G. H. 1972. Personal communication, Utah State University, Logan, Utah.

Israelsen, O. W., and V. E. Hansen. 1965. Irrigation principles and practices. Third Edition. John Wiley and Sons, Inc. New Yrok. 447 p.

Jensen, M. E. 1968. Water consumption by agricultural plants. Agricultural Research Service, USDA, Kimberly, Idaho.

Jensen, M. E. W. 1967. Evaluating irrigation efficiency. American Society of Civil Engineering. Eng. Proc. 93(IR1):83-99.

Jensen, Marvin E., and Howard R. Haise. 1963. Estimating evapotranspiration from solar radiation. American Society of Civil Engineers Proceedings, Journal of the Irrigation and Drainage Division 39(IR4):15-41.

Kohler, M. A., T. J. Northenson, and W. E. Fox. 1955. Evaporation from pans and lakes. U.S. Department of Commerce. Weather Bureau, Washington, D.C. Research Paper No. 38.

Miller, M. E., and C. R. Weaver. 1968. Monthly and annual precipitation probability for climatic divisions in Ohio. Ohio Research and Development Center. Research Bulletin 1005:1-11.

Nimmo, W. H. 1964. Measurements of evaporation by pan and tanks. Australian Meteorological Magazine No. 46. pp. 17-53.

Pardo, B. G. 1968. Study of sheltered evaporation in Colombia. Unpublished M.S. Thesis. Utah State University Library, Logan, Utah. 81 p.

Pair, H. C. (Ed.) 1969. Sprinkler irrigation. Third Edition. Sprinkler Irrigation Association. Washington, D. C. 20005. 444 p.

Penman, H. L., D. E. Angus, and C. H. M. van Vabel. 1967. Microclimatic factors affecting evaporation and transpiration. Irrigation of Agricultural Lands. Agronomy No. 11. pp. 483-505.

Politica Nacional de Riego. 1970. Instituto de Ingenieros de Chile Report. 229 p. December.

Pruitt, W. O. 1960. Relation of consumptive use of water to climate. Reprinted from the Transactions of ASAE. Vol. 3, No. 1, pp. 9, 10, 11, 12, 13.

Pruitt, W. O., and D. E. Angus. 1960. Large weighing lysimeter for measuring evapotranspiration. Transactions of ASAE. Vol. 3, No. 2, pp. 13, 14, 15 and 16, 1960.

Pruitt, W. O., and F. L. Lourence. 1968. Correlation of climatological data with water requirements of crops. Department of Water Science and Engineering, University of California, Davis. 59 p.

Ramirez, L. E. 1971. Development of a procedure for determining special and time variations of precipitation in Venezuela. Department of Agricultural and Irrigation Engineering. Utah Water Research Laboratory Publication PRWG69-3. 92 p.

Rose, C. W. Agricultural Physic. 1966. Printed in Great Britain by the Camelot Press Limited. First Edition. London and South Anpthol.

Rujirakul, S. 1970. Analysis of Venezuelan data to compare computed evaporation, potential evapotranspiration, and evapotranspiration deficit. Unpublished M.S. thesis. Utah State University Library, Logan. 106 p.

Shockley, D. G. 1966. Evapotranspiration and irrigation planning and management. Conference Proceedings: Evapotranspiration and its role in water resources management. American Society of Agricultural Engineers. pp. 4-5.

Soil Conservation Service. 1967. Irrigation water requirements. USDA, Engineering Division. Technical Release No. 21. Revised September 1970. 88 p.

Tanner, C. B. 1967. Measurement of evapotranspiration. Irrigation of Agricultural Lands. Agronomy No. 11. pp. 535-574.

Taylor, S. A., D. D. Evans, and W. D. Kemper. 1961. Evaluating soil water. Utah Agricultural Experimental Station. Bulletin No. 426. 67 p.

Thom, H. C. S. 1958. A note on the gamma distribution. Monthly Weather Review 86(4):117-122.

van Bavel, C. H. M., L. J. Fritschen, and W. E. Reeves. 1963. Transpiration by sudangrass as an externally controlled process. Reprinted from Science, Vol. 141, No. 3577, pp. 269-270.

Weather Bureau. 1962. Instructions for climatological observers. U.S. Department of Commerce. Chapter 4 from circular B, Eleventh Edition. 48 p.

Weaver, C. R., and Marvin Miller. 1967. A precipitation probability computer program. Ohio Agricultural Research and Development Center, Research Circular 155. 10 p.

Weaver, H. A., and J. C. Stephens. 1963. Relation of evaporation to potential evapotranspiration. Transactions of ASAE. Vol. 6, No. 1. pp. 55-56.

APPENDICES

APPENDIX A

Crop Coefficients and Extraterrestrial Radiation Tables

Table 1. Crop Coefficients, K

	Root Depth in Meters	Full Crop Cover		Seasonal K	
		Range in K	Average K	Range	Mean
Field and Oil Crops	1.00-1.30	.90-1.08	1.00	.60-.81	.73
Fruits and Grapes					
Grapefruit	1.20		.65		.65
Grapes	1.26	.69-.73	.71		.55
Naval Oranges	1.07		.53		.53
Peaches			.92		
Grain and Forage Crops	1.12-1.35	.89-1.39	1.12	.78-.95	.85
Grass and Hay Crops					
Alfalfa	1.83	1.07-1.10	1.09		1.09
Bermuda Lawn	1.19		.86		.86
Blue Panicium Grass	1.20		.91		.91
Green Manure Crops	.86-1.31	.79-1.00	.91	.70-.97	.79
Winter Vegetables	.64-.95	1.00-1.53	1.19	.70-.97	.83
Summer Vegetables	.86-.95	1.00-1.15	1.05	.67-.69	.68

Notes: Root depth is zone from which 90 percent of soil moisture depletion occurred. Coefficients are to be used with Class A pan evaporation from an irrigated area exposure, standardized and adjusted in order to compensate for differences in wind speed and humidity. Values of K x 1.22 may be used with computed values of potential evapotranspiration.

Source: Erie, French and Harris and Middleton, Pruitt, Crandall and Jensen.

TABLE 2. MEAN MONTHLY VALUES OF EXTRATERRESTRIAL RADIATION EXPRESSED AS EQUIVALENT EVAPORATION IN MILLIMETERS PER MONTH AT 15 DEGREES C.

LATITUDE DEGREES SOUTH	MONTH JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	AVERAGE ANNUAL
15	571.8	460.4	477.5	410.4	370.5	331.4	354.2	400.6	492.6	499.5	502.6	523.7	5295.5
16	574.5	461.2	475.8	406.4	354.6	325.0	347.9	395.6	439.9	499.8	524.7	526.9	5272.3
17	577.1	461.9	474.0	402.2	358.6	318.5	341.5	390.5	437.1	499.6	506.7	539.0	5247.7
18	579.5	462.4	472.1	397.9	352.5	312.0	335.0	385.3	434.2	499.2	508.5	533.0	5221.6
19	581.8	462.8	470.0	393.5	346.3	305.4	328.5	379.9	431.1	498.7	510.2	535.8	5194.1
20	583.9	463.1	467.7	389.0	340.1	299.8	321.8	374.5	427.9	498.1	511.8	538.5	5165.2
21	586.0	463.2	465.4	384.4	333.7	292.0	315.1	369.0	424.6	497.3	513.2	541.1	5134.9
22	587.8	463.3	462.9	379.5	327.3	285.2	308.3	363.3	421.1	496.3	514.5	543.5	5103.3
23	589.6	463.1	460.2	374.8	320.8	278.4	301.5	357.6	417.5	495.2	515.7	545.8	5070.2
24	591.2	462.9	457.4	369.8	314.2	271.5	294.6	351.7	413.8	494.0	516.7	547.9	5035.8
25	592.7	462.5	454.5	364.8	307.6	264.6	287.6	345.8	410.0	492.6	517.6	549.9	5000.1
26	594.0	462.0	451.4	359.6	300.9	257.6	280.6	339.8	406.1	491.1	518.3	551.8	4963.0
27	595.2	461.3	448.2	354.3	294.1	250.6	273.5	333.6	402.0	489.4	519.0	553.6	4924.6
28	596.2	460.5	444.8	348.9	287.2	243.5	266.4	327.4	397.8	487.6	519.4	555.2	4885.0
29	597.1	459.7	441.4	343.4	280.3	236.4	259.2	321.1	393.4	485.6	519.8	556.7	4844.0
30	597.9	458.5	437.7	337.9	273.3	229.2	251.9	314.7	389.0	483.5	520.0	558.0	4801.8
31	598.5	457.5	433.9	332.2	266.3	222.1	244.7	308.3	384.4	481.3	520.0	559.2	4758.4
32	599.0	456.2	430.1	326.4	259.2	214.9	237.3	301.7	379.8	478.9	520.0	560.3	4713.7
33	599.4	454.8	426.1	320.5	252.0	207.6	230.0	295.1	375.0	476.3	519.8	561.3	4667.9
34	599.6	453.2	422.0	314.6	244.8	200.4	222.6	288.4	370.1	473.7	519.5	562.1	4620.9
35	599.7	451.5	417.7	308.5	237.6	193.1	215.2	281.6	365.0	470.9	519.0	562.8	4572.7
36	599.7	449.5	413.3	302.4	230.3	185.9	207.6	274.8	359.9	468.0	518.4	563.4	4523.5
37	599.5	447.8	408.8	296.2	223.0	178.6	200.3	267.9	354.7	464.9	517.7	563.8	4473.1
38	599.3	445.8	404.1	289.9	215.6	171.3	192.8	260.9	349.3	461.7	516.8	564.2	4421.7
39	598.9	443.6	399.4	283.5	208.2	164.0	185.3	253.8	343.9	458.4	515.9	564.4	4369.2
40	598.3	441.4	394.5	277.0	200.8	156.7	177.8	246.7	338.3	454.9	514.8	564.4	4315.7
41	597.7	438.0	389.5	270.5	193.4	149.5	170.3	239.6	332.7	451.3	513.6	564.4	4261.3
42	596.9	436.5	384.4	263.9	185.9	142.2	162.8	232.4	326.9	447.6	512.2	564.3	4205.9
43	596.0	433.8	379.1	257.2	178.4	135.0	155.3	225.1	321.0	443.7	510.8	564.0	4149.6
44	595.0	431.1	373.8	250.4	170.9	127.8	147.8	217.8	315.1	439.8	509.2	563.7	4092.4
45	593.9	428.3	368.3	243.6	163.4	120.6	140.4	210.5	309.0	435.7	507.5	563.2	4034.4
46	592.7	425.3	362.7	236.7	155.9	113.5	132.9	203.1	302.9	431.4	505.8	562.5	3975.6
47	591.4	422.2	357.0	229.8	148.5	106.4	125.5	195.7	296.6	427.1	503.9	562.0	3916.0
48	589.9	419.1	351.2	222.8	141.0	99.4	118.1	188.2	290.3	422.7	501.9	561.2	3855.8
49	588.4	415.8	345.3	215.7	133.5	92.4	110.8	180.7	283.9	418.1	499.8	560.4	3794.9

SYMBOLS USED IN TABLE 3

TM = mean monthly temperature.

HM = mean monthly humidity.

W10 = mean monthly wind velocity.

EVPM = measured pan evaporation.

ETCL = measured evapotranspiration for clover.

R = indicates a ratio; i.e., RCLM = measured evapotranspiration for clover divided by measured pan evaporation for the same month.

ETHCL = calculated evapotranspiration for clover.

ER = indicates the error or the difference between the measured evapotranspiration and calculated evapotranspiration; i.e., ER TCL = ETCL - ETHCL.

TABLE 3. CROP COEFFICIENTS FOR FOUR CROPS AT SANTIAGO CHILE

STATION 2 SANTIAGO SANTIAGO LAT. 33 27 S LONG. 70 42 W ELEV. 520 M. AH. 22 M.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TM	20.5	19.4	16.7	13.7	11.3	7.7	7.6	9.0	10.9	14.0	17.1	19.0
HM	.524	.554	.633	.729	.744	.781	.789	.724	.710	.620	.570	.532
WIN	4.3	3.9	3.7	2.6	2.9	2.0	2.0	3.5	2.6	3.7	5.0	5.0
EVFM	204.	177.	125.	63.	38.	18.	25.	42.	65.	115.	157.	209.
EVFX	219.	151.	111.	61.	42.	21.	24.	43.	60.	110.	165.	201.
ETCL	149.	101.	77.	46.	34.	0.	0.	0.	0.	62.	90.	143.
RCLM	.779	.569	.620	.762	.897	.000	.000	.000	.000	.539	.573	.682
RTCL	1.096	.868	.940	1.081	1.162	.000	.000	.000	.000	.777	.873	1.043
RTCLT	1.029	.910	1.115	1.129	1.040	.000	.000	.000	.000	.917	.959	1.011
RHCL	1.110	.927	1.045	1.076	1.211	.000	.000	.000	.000	.917	.950	1.055
RHCLT	.997	.939	.959	.953	1.037	.000	.000	.000	.000	.824	.872	.955
ETHCL	144.5	110.8	69.5	46.6	32.8	.0	.0	.0	.0	67.6	93.9	141.1
ERTCL	4.7	-10.0	8.0	1.4	1.3	.0	.0	.0	.0	-5.6	-3.9	1.5
RELX	.673	.663	.698	.787	.812	.000	.000	.000	.000	.564	.545	.709
ETAL	167.	123.	84.	57.	37.	0.	0.	0.	0.	96.	129.	161.
RALM	.931	.695	.670	.905	.973	.000	.000	.000	.000	.836	.822	.771
RTAL	.968	.873	.895	1.096	1.010	.000	.000	.000	.000	1.028	1.088	.953
RHAL	1.063	.947	.916	1.047	1.063	.000	.000	.000	.000	1.157	1.179	1.013
RTALH	.953	.881	.907	1.068	.971	.000	.000	.000	.000	1.054	1.105	.979
ETHAL	174.8	120.9	90.3	53.3	38.3	.0	.0	.0	.0	91.2	116.7	164.7
ERTAL	-7.2	-11.7	-9.6	3.7	-1.1	.0	.0	.0	.0	4.9	12.3	-3.5
RELX	.764	.816	.754	.934	.896	.000	.000	.000	.000	.974	.787	.802
ETCO	201.	101.	50.	0.	0.	0.	0.	0.	0.	46.	138.	223.
RCOM	.788	.559	.397	.000	.000	.000	.000	.000	.000	.404	.879	1.058
RCO	.974	.603	.348	.000	.000	.000	.000	.000	.000	.466	.838	1.092
ETCOM	193.8	116.7	43.5	.0	.0	.0	.0	.0	.0	53.6	131.5	228.2
RCOMT	1.019	.945	1.139	.000	.000	.000	.000	.000	.000	.868	1.050	.978
ERCOM	2.7	-5.9	6.1	.0	.0	.0	.0	.0	.0	-7.1	6.5	-5.0
RCOX	.920	.668	.447	.000	.000	.000	.000	.000	.000	.423	.836	1.110
ETWH	28.	0.	0.	0.	0.	0.	0.	0.	0.	93.	129.	90.
RWHM	.137	.000	.000	.000	.000	.000	.000	.000	.000	.809	.822	.430
RWH	.200	.000	.000	.000	.000	.000	.000	.000	.000	.824	.824	.439
ETWHM	40.8	.0	.0	.0	.0	.0	.0	.0	.0	94.8	129.4	91.8
RWHMT	.684	.000	.000	.000	.000	.000	.000	.000	.000	.981	.997	.979
ERWHM	-12.9	.0	.0	.0	.0	.0	.0	.0	.0	-1.8	-.4	-1.9
RWHX	.127	.000	.000	.000	.000	.000	.000	.000	.000	.845	.782	.447

APPENDIX B

Computer Programs

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C     PROGRAM  810 TO ANALYZE CLIMATOLOGICAL DATA FROM CHILE
C     NSTS = NUMBER OF STATES
C     NSTAS = NUMBER OF STATIONS IN STATE
C     NSTA = STATION NUMBER
      DIMENSION DEC(15),FS(15),DER(15),X(29),SU(29),AA(29),NAME(10)
      DIMENSION A(29),SS(29), SX(29),AX(29),ABCK(12),IYP(8)
      DIMENSION TMI(8,12),WL(8,12),EV(8,12),HMI(8,12),PC(8,12),DM(12)
  101 FORMAT(5I3)
  102 FORMAT(12F6.3)
  103 FORMAT(12F6.5)
  104 FORMAT(I3,8X,F54)
  105 FORMAT(I5,4X,F45,F3.0,F2.0,F3.0,F2.0,F6.0,I4,F4.0)
  106 FORMAT(6X,I2,2X,12F5.1,/,10X,12F5.2,/,2(10X,12F5.1,/),10X,12F5.2)
  200 FORMAT(1H1,'TABLE    COMPARISON OF S WITH SC AND EVPM WITH EVPC, E
     1VPX AND EVPH, CHILEAN DATA',93X,'PAGE',F4.0)
  205 FORMAT(1H0,'STA. ',I4,5X,F45,' LAT. ',F7.2,'    LONG. ',F6.2,'    E
     1LEV. ',F5.0,'    ANEMOMETER HEIGHT',F5.1)
  211 FORMAT(1H0' MO YRS    TM    BCD    BCF  EVBC    HM     S   BCKM   RC
     1K   RRC  ERRC  WIDC  EVPM  EVPC  EVPH  EVPT  RCC  RCH  RCT  ERCC
     2ERCH  ERCT',/)
  219 FORMAT(1H )
  220 FORMAT(1H ,2I4,      8F6.1,5F6.3,6F6.1,3F5.2,3F6.1)
  221 FORMAT(1H ,4X,I4,'     NO RELIABLE DATA',/)
  222 FORMAT(1H0,2I4,8F6.1,5F6.3,6F6.1,3F5.2,3F6.1/)
  223 FORMAT(1H0,'ST M',I4,8F6.1,5F6.3,6F6.1,3F5.2,3F6.1)
  224 FORMAT(1H0,'OV M',I4,8F6.1,5F6.3,6F6.1,3F5.2,3F6.1)
  229 FORMAT(1H0,'NO OF MONTHS       XX        XXS        XXE        XXT
     1    XSC        XVC        XVH',/)
  230 FORMAT(12X,3F10.0,8F10.3)
  231  FORMAT(1H0,93X,'STANDARD DEVIATION',2X,3F6.2)
  232  FORMAT(1H0,93X,'R SQUARE',12X,3F6.2)
  299 FORMAT(1H1)
      DATA (DM(I),I=1,12)/31.,28.,31.,30.,31.,30.,31.,31.,30.,31.,30.,31
     1./
C----READ IN DATA
      READ(5,102) (DEC(M),M=1,12)
      READ(5,103) (FS(M),M=1,12)
      READ(5,102)(ABCK(M),M=1,12)
      READ(5,101)NSTS
C----TO INITIALIZE CERTAIN VALUES
      DO 18 I=1,29
   18 SX(I)=0.
      PG=0.
      SDCS=0.
      SDCC=0.
      SDCX=0.
      SSDV=0.
      XX=0.
      XXS=0.
      XXE=0.
      XXP=0.
C----OUTER DO LOOP
      DO 70 J=1,NSTS
      DO 19 I=1,29
   19 SS(I)=0.
      XN=0.
      XNS=0.
      XNE=0.
      XNP=0.
C----TO READ HEADER CARD AND COMPUTE LATITUDE AND LONGITUDE IN D
      READ(5,105)NST,(NAME(I),I=1,6),XLD,XLM,XLOD,XLOM,EL,NYP,AH
      XLA=XLD-XLM/60.
      XLO=XLOD+XLOM/60.
C----TO WRITE HEADINGS
      PG=PG+1.
      WRITE(6,200)PG
      WRITE(6,205)NST,(NAME(I),I=1,6),XLA,XLO,EL,AH
      WRITE(6,211)
C----READ ALL DATA IN FOR  NUMBER OF YEARS IN THE STATIONS DATA
      DO 100 IY=1,NYP
  100 READ(5,106)IYP(IY),(TMI(IY,M),M=1,12),
     1                (HMI(IY,M),M=1,12),
     1                ( EV(IY,M),M=1,12),
     1                ( WL(IY,M),M=1,12),
     1                ( PC(IY,M),M=1,12)
C----MIDDLE DO LOOP
      DO 63 K=1,12
      DO 20 I=1,28
   20 SU(I)=0.
      XM=0.
      XS=0.
      XE=0.
      PX=0.
      WIDC=0.
      NN=NYP
      M=K
C----INNER DO LOOP
      DO 80 KK=1,NYP
C----FOR EASE IN CALCULATION S. COMPUTATIONS ARE PERFORMED ON NO
C----VARIABLES
      TM=TMI(KK,M)
      HM=HMI(KK,M)
      WA=WL(KK,M)/(DM(M)*24.)
      PREC=PC(KK,M)
      EVPM=EV(KK,M)
      IF(TM.LE.-1.0)GO TO 49
      IF(HM.LE.0.) GO TO 43
      IF(EVPM.LE.-.01) GO TO 43
   49 CONTINUE
C----COMPUTATION OF RADIATION RHM (EXPRESSED AS EVAPORATION IN M
      DER(M)=(DEC(M))/57.2958
      Z=-TAN(XLA/57.2958)*TAN(DER(M))
      OM=ATAN(SQRT(1.0-Z*Z)/ABS(Z))
      DL=OM/0.1309
      IF (Z) 12,13,13
   12 DL=24.-DL
```

```
   13 SINO = SIN(OM)
      RLD=120.*(DL*SIN(XLA/57.2958)*SIN(DER(M))+3.8197*COS(XLA/57.2958)*
     1COS(DER(M))*2.*SINO)/FS(M)
      RMD=10.*RLD/(595.9-0.55*TM)
      RMM=RMD*DM(M)
C-----TO CORRECT WIND VELOCITY FOR DIFFERENT HEIGHTS OF ANNEMOMETERS
      WAMH=8.71*AH**.296
      XP=.579-.009*(WA/WAMH)+.126*(WA/WAMH)**2
      IF((WA/WAMH).GT.1.6) XP=.249
      W10=WA*(10./AH)**XP
      W10C=W10
   15 CONTINUE
C-----TO CORRECT DAYS IN FEBRUARY FOR LEAP YEAR
      IF((NYR/4)*4).EQ.NYR) DM(2)=29.
      DLM=DL*DM(M)
C----COMPUTATION OF EVBC (BLANEY-CRIDDLE)
      TF=1.8*TM+32.
      BCF=25.4*DL*DM(M)*TF/4380.
      BCK=EVPM/BCF
      BCKM=1.137*ABCK(M)
      EVBC=BCKM*BCF
      PBC=EVPM/EVBC
      ERBC=100.*ABS(EVPM-EVBC)/EVPM
C----COMPUTATION OF EVPC (CHRISTIANSEN)
      XKV=1.0
      XSC=1.0
      XVC=.562
      CTC=.393+.559*(TM/20.)+.048*(TM/20.)**2
      WDS=64*(0.6/AH)**XP
      CWC=0.705+.328*(WDS/8.)-.036*(WDS/8.)**2
      CHC=1.255-.242*(HM/.55)-.013*(HM/.55)**6
      CSC=.965
      CEC=.970+.030*(EL/305.)
      EVPC=XVC*RMM*CTC*CWC*CHC*CSC*CEC
      RCC=EVPM/EVPC
      ERCC=100.*ABS(EVPM-EVPC)/EVPM
C----COMPUTATION OF EVPH (HARGREAVES)
      XVHH=.880
      CTVH=.400+.028*TM
      CHVH=.050+1.58*SQRT(1.0-HM)
      CWVH=.92+.0225*W10C
      CEL=1.0+.0075*EL/1000.
      EVPH=XVHH*RMM*CTVH*CHVH*CWVH*CEL
      RCH=EVPM/EVPH
      ERCH=100.*ABS(EVPM-EVPH)/EVPM
C----COMPUTATION OF EVPT (TOSSO)
      XKT=.400
      CWT=.19+1.10*(W10C/10.)-.28*(W10C/10.)**2
      IF(W10C.GT.19.4) CWT=1.27
      CET=.94+.06*(EL/1000.)
      CTT=.50+.18*(TM/15.)+.32*(TM/15.)**2
      CHVT=1.07-.07*(HM/.70)**8
      CTDT=1.0
      CPT=1.05-.05*(PREC/100.)
      EVPT=XKT*RMM*CWT*CET*CTT*CHVT*CTDT *CPT
      RCT=EVPM/EVPT
      ERCT=100.*ABS(EVPM-EVPT)/EVPM
C----COMPUTATION OF STANDARD DEVIATIONS
      SDCC=(EVPM-EVPC)**2+SDCC
      SDCH=(EVPM-EVPH)**2+SDCH
      SDCT=(EVPM-EVPT)**2+SDCT
      SSDV=EVPM**2+SSDV
      XE=XE+1.
      XNE=XNE+1.
      XXE=XXE+1.
      XN=XN+1.
      XM=XM+1.
      XX=XX+1.
      PX=PX+1
      XNP=XNP+1.
      XXP=XXP+1.
   35 XS=XS+1.
      XNS=XNS+1.
      XXS=XXS+1.
   36 CONTINUE
      X(1)=TM
      X(2)=ABS(EVPM-EVBC)
      X(3)=BCF
      X(4)=EVBC
      X(5)=HM
      X(6)=0.
      X(7)=BCKM
      X(8)=BCK
      X(9)=RBC
      X(10)=ERBC
      X(11)=W10C
      X(12)=EVPM
      X(13)=EVPC
      X(14)=EVPH
      X(15)=EVPT
      X(16)=RCC
      X(17)=RCH
      X(18)=RCT
      X(19)=ERCC
      X(20)=ERCH
      X(21)=ERCT
      X(22)=ABS(EVPM-EVPC)
      X(23)=ABS(EVPM-EVPH)
      X(24)=ABS(EVPM-EVPT)
C-----SUMMATION OF X(I) VALUES
      DO 40 I=1,24
      SX(I)=SX(I)+X(I)
      SS(I)=SS(I)+X(I)
   40 SU(I)=SU(I)+X(I)
      NPREC=PREC
      IF(NPREC.EQ.-11) CP=1.0
      IF(NPREC.NE.-11) GO TO 42
   41 SX(4)=SX(4)-X(4)
      SS(4)=SS(4)-X(4)
      SU(4)=SU(4)-X(4)
      PX=PX-1.
      XNP=XNP-1.
      XXP=XXP-1.
   42 CONTINUE
```

```
   85 CONTINUE
   83 CONTINUE
   60 CONTINUE
      MX=XM
      IF(MX.EQ.0) GO TO 61
      IF(MX.EQ.1) GO TO 62
C----TO COMPUTE MONTHLY AVERAGES
      DO 22 I=1,15
   22 A(I)=SU(I)/XM
      A(4)=SU(4)/PX
      A(6)=SU(26)/XS
      A(09)=SU(12)/SU(04)
      A(10)=100.*SU(2)/SU(12)
      A(16)=SU(12)/SU(13)
      A(17)= A(12)/A(14)
      A(18)= A(12)/A(15)
      A(19)=100.*SU(22)/SU(12)
      A(20)=100.*SU(23)/SU(12)
      A(21)=100.*SU(24)/SU(12)
      WRITE(6,222)M,MX,(A(I), I=1,21)
      GO TO 63
   61 WRITE(6,221)M
      GO TO 63
   62 WRITE(6,219)
   63 CONTINUE
C----TO COMPUTE STATION MEANS
      DO 23  I=1,15
   23 AA(I)=SS(I)/XN
      AA(4)=SS(4)/XNP
      AA(6)=SS(26)/XNS
      AA(9)=SS(12)/SS(04)
      AA(10)=100.*SS(2)/SS(12)
      AA(16)=SS(12)/SS(13)
      AA(17)=AA(12)/AA(14)
      AA(18)=AA(12)/AA(15)
      AA(19)=100.*SS(22)/SS(12)
      AA(20)=100.*SS(23)/SS(12)
      AA(21)=100.*SS(24)/SS(12)
      NX=XN
      WRITE(6,223)NX,(AA(I),I=1,21)
   76 CONTINUE
C----TO COMPUTE OVERALL MEANS
      DO 30  I=1,15
   30 AX(I)=SX(I)/XXE
      AX(4)=SX(4)/XXP
      AX(6)=SX(26)/XXS
      AX(9)=SX(12)/SX(04)
      AX(16)=SX(12)/SX(13)
      AX(10)=100.*SX(2)/SX(12)
      AX(17)=AX(12)/AX(14)
      AX(18)=AX(12)/AX(15)
      AX(19)=100.*SX(22)/SX(12)
      AX(20)=100.*SX(23)/SX(12)
      AX(21)=100.*SX(24)/SX(12)
      NXE=XXE
      SSDV=(SSDV-SX(12)**2/XX)/(XX-1.)*(XX-6.)
      RSCC=1.-SDCC/SSDV
      RSCH=1.-SDCH/SSDV
      RSCT=1.-SDCT/SSDV
      SDCC=SQRT(SDCC/(XX -6.))
      SDCH=SQRT(SDCH/(XX -5.))
      SDCT=SQRT(SDCT/(XX-6.))
      WRITE(6,224)NXE,(AX(I),I=1,21)
      WRITE(6,231)SDCC,SDCH,SDCT
      WRITE(6,232)RSCC,RSCH,RSCT
      WRITE(6,229)
      WRITE(6,230)XX,XXS,XXE,XKT,XSC,XVC,XVHH
      WRITE(6,299)
      STOP
      END

END OF COMPILATION:        NO  DIAGNOSTICS.
```

PROGRAM 812 TO OBTAIN THE CROP COEFFICIENTS AT SANTIAGO

```
C     CL=CLOVER, AL=ALFALFA, CO=CORN, WH=WHEAT
      DIMENSION TM(12),W10(12),HM(12),EVPX(12),EVPM(12),CL(12),AL(12),
     1CO(12),WH(12),DM(12),RCLM(12),RCLX(12),RALM(12),RALX(12),RCOM(12),
     2RCOX(12),RWHM(12),RWHX(12),CALM(12),CALT(12),CCLM(12),CCLT(12),RTC
     3L(12),RHCL(12),RTAL(12),RHAL(12),CTAL(12),CHAL(12),RTALM(12),RHALT
     4(12),RTHAL(12),ERTAL(12),CCO(12),ETCOM(12),ERC
     5OM(12),RCOMT(12),CWH(12),ETWHM(12),RWHMT(12),ERWHM(12),RTCLM(12),R
     6HCLT(12),ETHCL(12),ERTCL(12),CTCL(12),CHCL(12)
  102 FORMAT(12F6.3)
  107 FORMAT(12F6.1)
  109 FORMAT(12F6.0)
  201 FORMAT(1H1,'TABLE    .CROP COEFFICIENTS FOR  FOUR CROPS AT SANTIA
     1GO CHILE')
  202 FORMAT(1H0,'STATION 2    SANTIAGO          SANTIAGO        LAT.  33
     1 27 S   LONG.  70 42 W   ELEV.  520 M.   AH.  72 M.')
  203 FORMAT(1H0,10X, 'JAN      FEB      MAR      APR      MAY      JUN      J
     1UL      AUG      SEP      OCT      NOV      DEC')
  204 FORMAT(1H1)
  205 FORMAT(1H ,'   TM',12F8.1)
  206 FORMAT(1H ,'   HM',12F8.3)
  207 FORMAT(1H ,'  W10',12F8.1)
  208 FORMAT(1H ,' EVPX',12F8.0)
  209 FORMAT(1H ,' EVPX',12F8.0)
  210 FORMAT(1H0,' RCLM',12F8.3)
  211 FORMAT(1H0,' RCLM',12F8.3)
  311 FORMAT(1H ,' RTCL',12F8.3)
  411 FORMAT(1H ,' RHCL',12F8.3)
  321 FORMAT(1H ,'RTCLT',12F8.3)
  511 FORMAT(1H ,'RHCLT',12F8.3)
  611 FORMAT(1H ,'ETHCL',12F8.1)
  811 FORMAT(1H ,'ERTCL',12F8.1)
  911 FORMAT(1H ,'CTCL',12F8.1)
  217 FORMAT(1H ,' RCLX',12F8.3)
  213 FORMAT(1H0,' ETAL',12F8.0)
  317 FORMAT(1H ,'ETHAL',12F8.1)
  413 FORMAT(1H ,'ERTAL',12F8.1)
  214 FORMAT(1H0,' RALM',12F8.3)
  314 FORMAT(1H ,' RTAL',12F8.3)
  324 FORMAT(1H ,'RTALM',12F8.3)
  414 FORMAT(1H ,' RHAL',12F8.3)
  614 FORMAT(1H ,'ERTAL',12F8.1)
  215 FORMAT(1H ,' RALX',12F8.3)
  216 FORMAT(1H0,' ETCO',12F8.0)
  217 FORMAT(1H0,' RCOM',12F8.3)
  227 FORMAT(1H ,'  CCO',12F8.3)
  237 FORMAT(1H ,'ETCOM',12F8.1)
  247 FORMAT(1H ,'ERCOM',12F8.1)
  257 FORMAT(1H ,'RCOMT',12F8.3)
  218 FORMAT(1H ,' RCOX',12F8.3)
  219 FORMAT (1H0,' ETWH', 12F8.0)
  220 FORMAT(1H0,' RWHM',12F8.3)
  230 FORMAT(1H ,' CWH ',12F8.3)
  240 FORMAT(1H ,'ETWHM',12F8.1)
  250 FORMAT(1H ,'RWHMT',12F8.3)
  260 FORMAT(1H ,'ERWHM',12F8.1)
  221 FORMAT(1H ,' RWHX',12F8.3)
      READ(5,102)(DM(M),M=1,12)
      READ(5,102)(HM(M),M=1,12)
      READ(5,107)(W10(M),M=1,12)
      READ(5,107)(TM(M),M=1,12)
      READ(5,108)(EVPM(M),M=1,12)
      READ(5,108)(EVPX(M),M=1,12)
      READ(5,107)(CL(M),M=1,12)
      READ(5,107)(AL(M),M=1,12)
      READ(5,107)(CO(M),M=1,12)
      READ(5,107)(WH(M),M=1,12)
      DO 16 M=1,12
      CL(M)=CL(M)*DM(M)
      AL(M)=AL(M)*DM(M)
      CO(M)=CO(M)*DM(M)
      WH(M)=WH(M)*DM(M)
      IF(CL(M).LT.0.1) GO TO 13
      RCLM(M)=CL(M)/EVPM(M)
      CCLT(M)=.82-.20*((TM(M)-10.)/ 5.0)+.06*((TM(M)-10.)/5.0)**2
      CCLH(M)=.70- .30*((HM(M)-.5)/.15)+ .20*((HM(M)-.5)/.15)**2
      RTCL(M)=RCLM(M)/CCLT(M)
      RHCL(M)=RCLM(M)/CCLH(M)
      CTCL(M)=1.75-1.15*(TM(M)/15.)+.50*(TM(M)/15.)**2
      CHCL(M)=1.18-.795*((HM(M)-.50)/.15)+.065*((HM(M)-.50)/.15)**2
      RHCLT(M)=RHCL(M)/CTCL(M)
      RTCLH(M)=RTCL(M)/CHCL(M)
      ETHCL(M)=EVPM(M)*CCLT(M)*CHCL(M)
      ERTCL(M)=CL(M)-ETHCL(M)
      RCLX(M)=CL(M)/EVPX(M)
   13 IF(AL(M).LT.0.1) GO TO 14
      RALM(M)=AL(M)/EVPM(M)
      CALH(M)=.81-.27*((HM(M)-.5)/.15)+.20*((HM(M)-.5)/.15)**2
      CALT(M)=1.08-.87*((TM(M)-10.)/5.)+.17*((TM(M)-10.)/5.)**2
      RTAL(M)=RALM(M)/CALT(M)
      RHAL(M)=RALM(M)/CALH(M)
      CTAL(M)=1.19-.18*(TM(M)/15.)
      CHAL(M)=1.03-.14*((HM(M)-.50)/.15)+.09*((HM(M)-.50)/.15)**2
      RHALT(M)=RHAL(M)/CTAL(M)
      RTALH(M)=RTAL(M)/CHAL(M)
      ETHAL(M)=EVPM(M)*CALT(M)*CHAL(M)
      ERTAL(M)=AL(M)-ETHAL(M)
      RALX(M)=AL(M)/EVPX(M)
   14 IF(CO(M).LT.0.1) GO TO 15
      RCOM(M)=CO(M)/EVPM(M)
      MO=M
      XM=M
      IF(MO.LT.9)XMO=XM+12.
      IF(MO.GT.8)XMO=XM
      CCO(M)=.72+.38*COS(1.007*(XMO-17.2))
      ETCOM(M)=EVPM(M)*CCO(M)
      RCOMT(M)=CO(M)/ETCOM(M)
      ERCOM(M)=CO(M)-ETCOM(M)
      RCOX(M)=CO(M)/EVPX(M)
   15 IF(WH(M).LT.0.1) GO TO 16
      RWHM(M)=WH(M)/EVPM(M)
      CWH(M)=.585+.395*COS(1.2588*(XMO- 10.5))
      ETWHM(M)=EVPM(M)*CWH(M)
      RWHMT(M)=WH(M)/(ETWHM(M))
      ERWHM(M)=WH(M)-ETWHM(M)
```

```
      RWHX(M)=WH(M)/EVPX(M)
   16 CONTINUE
      WRITE(6,201)
      WRITE(6,202)
      WRITE(6,203)
      WRITE(6,205)(TM(M),M=1,12)
      WRITE(6,206)(HM(M),M=1,12)
      WRITE(6,207)(W10 (M),M=1,12)
      WRITE(6,208)(EVPM(M),M=1,12)
      WRITE(6,209)(EVPX(M),M=1,12)
      WRITE(6,210)(CL(M),M=1,12)
      WRITE(6,211)(PCLM(M),M=1,12)
      WRITE(6,311)(PTCL(M),M=1,12)
      WRITE(6,371)(PTCLH(M),M=1,12)
      WRITE(6,411)(PHCL(M),M=1,12)
      WRITE(6,511)(PHCLT(M),M=1,12)
      WRITE(6,611)(ETHCL(M),M=1,12)
      WRITE(6,311)(ERTCL(M),M=1,12)
      WRITE(6,212)(PCLX(M),M=1,12)
      WRITE(6,213)(AL(M),M=1,12)
      WRITE(6,214)(PALM(M),M=1,12)
      WRITE(6,314)(PTAL(M),M=1,12)
      WRITE(6,414)(PHAL(M),M=1,12)
      WRITE(6,374)(PTALH(M),M=1,12)
      WRITE(6,313)(ETHAL(M),M=1,12)
      WRITE(6,614)(ERTAL(M),M=1,12)
      WRITE(6,215)(PALX(M),M=1,12)
      WRITE(6,216)(CC(M),M=1,12)
      WRITE(6,217)(PCOM(M),M=1,12)
      WRITE(6,227)(CCO (M),M=1,12)
      WRITE(6,237)(ETCOM(M),M=1,12)
      WRITE(6,257)(RCOMT(M),M=1,12)
      WRITE(6,247)(ERCOM(M),M=1,12)
      WRITE(6,218)(RCOX(M),M=1,12)
      WRITE(6,219)(WH(M),M=1,12)
      WRITE(6,220)(RWHM(M),M=1,12)
      WRITE(6,230)(CWH(M),M=1,12)
      WRITE(6,240)(ETWHM(M),M=1,12)
      WRITE(6,250)(RWHMT(M),M=1,12)
      WRITE(6,260)(ERWHM(M),M=1,12)
      WRITE(6,221)(RWHX(M),M=1,12)
      WRITE(6,204)
      STOP
      END

END OF COMPILATION:        NO  DIAGNOSTICS.
```

APPENDIX C

Comparison of Evaporation Equations

TABLE 3.1 Comparison of EVPM with EVBC, EVPC, EVPH and EVPT

STA. 7 MAULE DESAGUE L. INVERNADA LAT. -35.73 LONG. 70.78 E LEV. 1325. ANNEMOMETER HEIGHT .6

MO	YRS	TM	RCD	RCF	EVBC	HM	S	RCKM	RCK	RBC	ERBC	WIDC	EVPM	EVPC	EVPH	EVPT	RCC	RCH	RCT	ERCC	ERCH	ERCT
1	6	16.7	72.2	157.9	285.5	.500	.000	1.815	2.272	1.252	20.1	21.9	358.7	364.5	360.6	356.0	.98	.99	1.01	4.7	4.0	7.4
2	8	16.6	77.8	138.6	225.6	.482	.000	1.627	2.188	1.345	25.6	21.8	303.3	307.4	306.6	296.4	.99	.99	1.02	5.4	4.5	8.0
3	5	15.1	83.8	130.3	192.6	.470	.000	1.478	2.121	1.435	30.3	21.1	276.5	257.0	259.0	242.1	1.08	1.07	1.14	9.2	8.5	12.9
4	7	11.5	39.6	101.9	115.1	.497	.000	1.130	1.512	1.344	25.6	18.1	154.7	154.5	155.9	144.2	1.00	.99	1.07	6.9	7.5	10.8
5	6	8.6	32.9	86.5	63.6	.545	.000	.736	1.112	1.517	34.1	15.3	96.5	96.6	97.1	90.8	1.00	.99	1.06	12.1	12.9	13.0
6	5	3.1	17.9	63.1	36.2	.584	.000	.574	.769	1.343	25.5	14.7	48.6	56.7	58.4	56.1	.86	.83	.97	19.4	21.7	19.0
7	5	3.7	20.8	68.3	40.7	.576	.000	.597	.899	1.503	33.7	15.6	61.5	66.7	68.7	65.1	.92	.90	.94	13.2	14.4	13.3
8	5	4.5	29.9	77.3	60.5	.572	.000	.782	1.165	1.495	37.1	15.8	90.4	92.5	94.6	89.0	.98	.96	1.02	17.9	19.4	16.9
9	6	7.7	41.8	94.0	99.9	.525	.000	1.063	1.506	1.418	29.5	16.7	141.7	147.7	150.8	136.4	.96	.94	1.04	8.0	9.8	7.8
10	6	9.4	52.1	113.8	138.5	.530	.000	1.217	1.671	1.376	27.3	17.1	190.6	209.5	211.0	195.1	.91	.90	.98	9.9	10.7	5.5
11	6	13.5	86.2	136.1	205.7	.512	.000	1.511	1.869	1.234	19.0	19.1	253.8	289.9	287.8	276.9	.88	.88	.92	14.2	13.4	10.4
12	6	14.8	63.9	151.8	253.2	.555	.000	1.701	2.115	1.248	19.8	21.2	322.1	335.4	326.1	326.2	.96	.99	.99	5.8	5.6	3.6
ST M	67	10.5	47.6	110.5	149.4	.529	.000	1.191	1.603	1.330	24.8	18.2	192.0	199.1	198.8	190.2	.96	.97	1.01	8.7	8.7	8.9

TABLE 3.2 Comparison of EVPM with EVBC, EVPC, EVPH and EVPT

STA. 1 BIO-BIO POLUCRA EN BALSEADERO LAT. -37.32 LONG. 71.53 ELEV. 740. ANNEMOMETER HEIGHT .6

MO	YRS	TM	RCD	SCF	EVBC	HM	S	RCKM	BCK	RBC	ERBC	WIDC	EVPM	EVPC	EVPH	EVPT	RCC	RCH	RCT	ERCC	ERCH	ERCT
1	5	16.2	84.0	157.0	284.9	.662	.000	1.815	1.277	.705	41.8	5.7	200.9	192.8	204.3	180.6	1.04	.98	1.11	7.9	9.8	11.9
2	5	15.6	71.7	135.4	220.4	.660	.000	1.627	1.096	.675	48.2	5.8	148.7	158.8	168.7	147.0	.94	.88	1.01	10.0	14.9	11.8
3	5	13.0	63.3	122.3	180.8	.694	.000	1.478	.959	.650	53.9	5.4	117.4	119.3	127.6	103.8	.98	.92	1.13	4.2	8.7	11.6
4	5	9.9	38.4	95.7	108.1	.740	.000	1.130	.729	.645	55.0	5.2	69.8	70.8	75.6	58.7	.98	.92	1.19	10.7	13.3	19.3
5	5	7.4	20.4	81.7	60.1	.774	.000	.736	.483	.660	51.6	6.3	39.6	49.1	50.4	41.2	.81	.79	.96	23.8	27.1	22.2
6	5	3.9	9.1	63.9	35.7	.798	.000	.574	.429	.751	33.1	4.2	27.6	28.1	30.7	21.2	.98	.90	1.30	11.9	14.9	23.8
7	5	4.4	23.1	69.6	41.5	.796	.000	.597	.265	.443	125.8	3.1	18.4	31.3	34.2	19.3	.59	.54	.95	69.9	86.0	17.0
8	5	8.9	23.4	77.8	60.9	.776	.000	.782	.481	.615	52.5	5.0	37.4	47.2	51.4	37.9	.79	.73	.99	26.0	37.3	7.2
9	5	7.6	34.0	93.4	99.3	.746	.000	1.063	.701	.658	52.0	5.5	65.3	75.4	82.2	63.7	.85	.79	1.02	18.7	25.9	14.5
10	4	9.1	57.1	112.9	137.4	.717	.000	1.217	.773	.635	57.4	5.1	87.3	111.7	.4	91.1	.78	.72	.96	27.4	39.1	11.7
11	4	13.2	56.4	135.8	205.2	.665	.000	1.511	1.081	.715	39.8	6.5	146.8	166.3	175.9	152.3	.89	.83	.96	13.3	19.8	3.9
12	4	15.1	74.7	154.4	262.6	.677	.000	1.701	1.217	.717	39.4	6.1	188.3	190.4	200.0	181.0	.99	.94	1.04	4.5	7.2	3.9
STA	57	9.9	45.1	107.0	138.3	.727	.000	1.171	.779	.674	48.3	5.3	93.3	100.7	107.3	88.9	.93	.87	1.05	12.4	17.3	11.1

TABLE 3.3 Comparison of EVPM with EVBC, EVPC, EVPH and EVPT

STA. 4 MAULE ARMERILLO LAT. -35.72 LONG. 71.08 ELEV. 450. ANNEMOMETER HEIGHT .6

MO	YRS	TM	RCD	RCF	EVBC	HM	S	BCKM	BCK	RBC	ERBC	WIOC	EVPM	EVPC	EVPH	EVPT	RCC	RCH	RCT	ERCC	ERCH	ERCT
1	4	20.9	28.3	176.6	320.5	.605	.000	1.815	1.809	.996	8.8	9.7	319.4	279.5	270.2	320.0	1.14	1.18	1.00	15.9	17.8	9.4
2	6	19.7	19.9	151.4	245.4	.600	.000	1.627	1.623	.998	8.1	9.4	245.8	224.2	220.6	249.4	1.10	1.11	.99	11.2	13.2	7.6
3	7	17.7	28.7	140.5	201.7	.609	.000	1.478	1.626	1.098	12.6	10.0	228.2	188.3	189.2	203.3	1.21	1.24	1.12	17.5	19.3	12.0
4	7	14.1	21.1	111.0	125.5	.664	.000	1.130	1.180	1.049	16.0	9.9	131.6	115.7	117.5	118.7	1.14	1.17	1.11	12.1	14.6	9.8
5	7	11.2	10.0	98.9	69.8	.683	.000	.736	.821	1.119	12.8	9.9	78.1	77.8	76.1	76.7	1.00	1.03	1.02	8.6	8.9	7.4
6	6	9.1	8.0	78.0	44.8	.715	.000	.574	.650	1.132	15.7	10.4	50.7	53.4	52.7	51.2	.95	.96	.99	12.3	9.9	11.2
7	6	8.2	18.7	82.7	49.4	.657	.000	.597	.813	1.365	27.7	11.1	67.4	65.9	65.6	63.0	1.02	1.03	1.07	11.0	11.8	11.0
8	7	8.3	16.2	89.9	70.3	.663	.000	.782	.948	1.216	19.0	10.9	85.5	85.3	84.5	82.5	1.00	1.01	1.04	15.3	15.0	13.2
9	6	11.1	12.7	106.4	113.1	.652	.000	1.063	1.187	1.112	10.1	10.6	125.8	125.8	123.4	124.4	1.00	1.02	1.01	2.1	3.5	1.5
10	7	13.1	22.6	129.1	157.1	.680	.000	1.217	1.281	1.053	13.7	11.0	165.4	174.5	167.5	179.2	.95	.99	.92	7.3	7.3	10.3
11	7	16.6	29.0	149.6	226.1	.657	.000	1.511	1.405	.930	13.8	10.6	210.3	222.7	219.2	240.0	.94	.98	.88	12.2	9.6	19.4
12	6	18.5	47.2	168.6	286.8	.657	.000	1.701	1.558	.920	17.9	9.5	263.9	252.4	241.8	280.6	1.05	1.09	.94	9.2	9.7	12.3
STM	76	13.7	21.6	121.5	154.2	.655	.000	1.166	1.224	1.032	13.6	10.3	159.1	151.3	147.1	160.4	1.05	1.08	.99	11.6	12.3	10.9

TABLE 3.4 Comparison of EVPM with EVBC, EVPC, EVPH and EVPT

STA. 6 RAPEL OUTLANTARO ANTENA RADIO LAT. -34.03 LONG. 71.58 E LEV. 260. ANNEMOMETER HEIGHT .6

NO	YRS	TP	RCD	RCF	EVBC	HM	S	BCKM	BCK	RBC	ERBC	WIDC	EVPM	EVPC	EVPH	EVPT	RCC	RCH	RCT	ERCC	ERCH	ERCT
1	3	20.0	10.6	171.0	310.2	.583	.000	1.815	1.850	1.019	3.3	10.7	316.2	275.0	270.9	310.9	1.15	1.17	1.02	13.0	14.3	6.4
2	3	19.8	6.4	150.7	245.2	.627	.000	1.627	1.667	1.024	2.5	9.8	251.1	221.7	214.0	252.5	1.13	1.17	.99	11.7	14.8	4.7
3	3	17.4	10.7	139.2	205.8	.663	.000	1.478	1.556	1.052	4.9	9.0	216.4	169.9	166.8	183.4	1.27	1.30	1.18	21.5	22.9	15.2
4	3	14.9	23.6	114.2	129.1	.737	.000	1.130	1.218	1.082	16.9	16.2	139.7	130.2	119.9	139.7	1.07	1.16	1.00	6.8	14.1	3.8
5	3	12.3	7.3	99.7	73.4	.773	.000	.735	.706	.962	10.4	9.4	70.6	73.8	69.5	74.9	.96	1.02	.94	9.3	5.9	9.6
6	3	9.8	5.5	84.5	48.5	.810	.000	.574	.510	.887	12.9	10.2	43.1	53.5	49.1	52.5	.81	.88	.82	24.2	14.1	22.0
7	3	8.8	5.4	95.8	51.2	.797	.000	.597	.534	.896	11.8	9.1	45.9	54.8	52.5	53.0	.84	.87	.87	19.5	14.5	15.6
8	3	9.6	6.2	95.2	74.4	.783	.000	.782	.717	.917	9.0	8.0	68.3	71.2	69.9	67.6	.96	.98	1.01	10.9	6.6	15.0
9	3	11.6	12.6	108.5	115.3	.743	.000	1.063	.947	.891	12.3	8.2	102.7	106.2	104.5	103.3	.97	.98	.99	13.4	7.8	18.6
10	3	13.4	9.8	130.0	158.2	.677	.000	1.217	1.151	.946	6.6	7.4	149.6	153.3	156.7	146.3	.98	.95	1.02	14.9	10.1	24.6
11	3	16.4	16.3	147.6	223.0	.647	.000	1.511	1.515	1.004	7.3	8.5	223.9	203.4	204.0	208.5	1.10	1.10	1.07	9.1	8.9	11.5
12	3	18.7	15.2	167.8	285.4	.620	.000	1.701	1.724	1.013	5.2	9.3	289.0	250.3	249.1	274.5	1.15	1.16	1.05	13.4	13.8	6.4
ST M	36	14.4	10.8	124.5	160.0	.705	.000	1.186	1.175	.998	6.8	9.6	159.7	146.9	143.9	155.6	1.09	1.11	1.03	13.3	13.[illegible]	10.6
OV M	272	12.4	32.3	116.8	150.3	.650	.000	1.178	1.185	.999	21.5	10.6	150.3	149.7	150.2	149.2	1.00	1.00	1.01	10.6	11.4	9.8
																STANDARD DEVIATION				22.55	24.35	21.20
																R SQUARE				.94	.93	.95

NO OF MONTHS	XX	XXS	XXE	XKT	XSC	XVC	XVH
	272.	272.	272.	.400	1.000	.562	.480

TABLE 3.5 Comparison of EVPM with EVBC, EVPC, EVPH and EVPT

STA. S PAPEL FUENTE ARQUEADO LAT. -34.28 LONG. 71.35 E LEV. 199. ANNEMOMETER HEIGHT .6

MO	YRS	TM	RCD	RCF	EVRC	HH	S	RCKM	RCK	RRC	ERRC	WIDC	EVPM	EVPC	EVPH	EVPT	RCC	RCH	RCT	ERCC	ERCH	ERCT
1	3	20.7	62.9	174.5	316.7	.610	.000	1.815	1.453	.801	24.8	7.3	253.8	239.6	248.9	264.4	1.06	1.02	.96	5.6	2.6	4.2
2	3	20.0	43.7	151.7	245.7	.610	.000	1.627	1.340	.823	21.5	6.5	203.0	191.1	203.1	201.4	1.06	1.00	1.01	5.3	2.6	2.5
3	3	17.4	41.6	139.5	206.2	.647	.000	1.478	1.181	.798	25.3	6.3	164.6	150.3	159.8	150.7	1.10	1.03	1.09	8.7	2.9	8.5
4	3	14.5	31.6	112.7	127.4	.690	.000	1.130	.847	.752	33.0	6.0	95.8	95.1	101.3	89.7	1.01	.95	1.07	5.0	5.8	6.4
5	3	11.6	15.4	97.4	71.6	.737	.000	.736	.578	.785	27.4	5.7	56.2	62.4	65.2	56.3	.90	.85	1.00	10.3	17.7	6.4
6	3	9.2	11.6	82.3	47.3	.780	.000	.574	.433	.755	32.5	5.3	35.7	42.6	45.2	36.1	.84	.79	.99	19.4	26.6	8.3
7	3	9.1	9.4	86.6	51.7	.783	.000	.597	.488	.818	22.2	7.0	42.3	50.5	51.6	47.1	.84	.82	.90	19.4	22.0	15.0
8	3	10.3	17.0	97.5	76.3	.760	.000	.782	.607	.777	28.7	6.7	59.3	69.6	72.2	65.3	.85	.82	.91	17.4	21.8	15.3
9	3	12.8	17.1	113.0	120.2	.723	.000	1.063	.911	.857	16.6	6.9	103.0	105.6	109.1	103.4	.98	.94	1.00	4.4	6.7	2.9
10	3	14.4	18.8	134.0	163.0	.653	.000	1.217	1.076	.885	13.0	7.2	149.2	156.5	165.3	154.8	.92	.87	.93	8.5	14.6	7.3
11	3	17.8	29.8	153.8	232.5	.620	.000	1.511	1.317	.872	14.7	7.8	202.7	208.7	215.9	221.5	.97	.94	.91	6.2	6.5	11.7
12	3	19.6	37.0	172.2	292.8	.610	.000	1.701	1.488	.874	24.5	7.9	255.9	243.1	250.1	267.3	1.05	1.02	.96	6.2	5.1	8.7
STM	36	14.8	28.0	126.3	162.7	.685	.000	1.186	.977	.828	20.8	6.7	134.7	134.6	140.7	138.2	1.00	.96	.97	7.5	7.3	7.3

APPENDIX D

Precipitation and Potential Irrigation Requirements

Based on Gamma Distribution

TABLE 8. 1 PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION, IN MM.

STATION NAME COPIAPO COPIAPO SER. NO. 1
LAT. -27 21. LONG. 70 21. ELEV. 380. YEARS OF DATA 57

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN*	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	281.	281.	281.	281.	281.	281.
FEB	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	236.	236.	236.	236.	236.	236.
MAR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	204.	204.	204.	204.	204.	204.
APR	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	130.	130.	130.	130.	130.	130.
MAY	0.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	4.	11.	18.	90.	90.	90.	90.	90.	90.
JUN	9.	0.	0.	0.	0.	0.	0.	1.	2.	5.	7.	11.	26.	46.	64.	64.	64.	64.	64.	64.
JUL	5.	0.	0.	0.	0.	0.	0.	1.	2.	3.	5.	7.	16.	26.	71.	71.	71.	71.	71.	70.
AUG	8.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	5.	12.	21.	96.	96.	96.	96.	96.	96.
SEP	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	2.	131.	131.	131.	131.	131.	131.
OCT	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	1.	3.	6.	183.	183.	183.	183.	183.	183.
NOV	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	219.	219.	219.	219.	219.	219.
DEC*	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	240.	240.	240.	240.	240.	240.
ANN	24.	0.	0.	1.	2.	3.	6.	10.	16.	25.	31.	39.	65.	93.	1945.	1949.	1943.	1943.	1942.	1939.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMDA	.0001	16.1662	1.0725	.2962	.0534	.0209	.0423	.0451	.4287	.1565	1.0725	.0000	.0197
D	********	.284	.188	.171	.187	.177	.219	.175	.188	.172	-.188	**********	.467
LMDA	.0001	1.1549	1.5886	1.6867	1.5927	1.6543	1.4285	1.6672	1.5894	1.6911	1.5886	.0000	.6409

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	0.	1.	10.	20.	32.	75.	40.	62.	12.	19.	10.	0.	95.
PMIN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
P075	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ETDF	281.	236.	204.	130.	90.	64.	71.	96.	131.	183.	219.	240.	2.
MAI	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	1943.
													.001

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	19.8	19.8	18.2	15.7	13.4	11.4	11.1	12.2	13.1	15.0	16.7	17.7	15.4
HUM	.53	.65	.68	.72	.73	.74	.72	.72	.70	.69	.66	.65	.70
WIND	15.6	16.1	14.6	12.7	11.6	10.2	10.6	11.2	13.2	14.3	15.5	16.1	13.6
PREC.DAYS	0.	0.	0.	0.	0.	1.	1.	0.	0.	0.	0.	0.	2.
SUNSHINE	.61	.00	.70	.00	.66	.63	.00	.00	.00	.00	.00	.00	.22

* INDICATES MISSING DATA

TABLE 8. 2 PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION, IN MM.

STATION NAME SERENA COQUIMBO SER. NO. 2
LAT. -29 59. LONG. 71 15. ELEV. 32. YEARS OF DATA 50

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	157.	157.	157.	157.	157.	157.
FEB	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	1.	4.	7.	122.	122.	122.	122.	122.	122.
MAR	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	3.	5.	96.	96.	96.	96.	96.	96.
APR	2.	0.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	6.	11.	58.	58.	58.	58.	58.	58.
MAY	10.	0.	0.	0.	0.	0.	1.	3.	7.	13.	19.	27.	57.	93.	28.	28.	28.	28.	28.	27.
JUN	30.	0.	0.	1.	2.	3.	6.	11.	19.	30.	38.	49.	85.	125.	31.	31.	30.	29.	28.	25.
JUL	22.	0.	0.	1.	2.	3.	5.	9.	15.	23.	29.	36.	61.	88.	28.	28.	27.	27.	26.	23.
AUG	19.	0.	0.	0.	1.	1.	3.	5.	10.	18.	23.	30.	57.	86.	40.	40.	39.	39.	38.	37.
SEP	6.	0.	0.	0.	0.	0.	0.	1.	2.	4.	6.	8.	17.	28.	60.	60.	60.	60.	60.	59.
OCT	3.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	5.	10.	16.	86.	86.	86.	86.	86.	86.
NOV	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	1.	3.	4.	104.	104.	104.	104.	104.	104.
DEC	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	2.	4.	160.	160.	160.	160.	160.	160.
ANN	106.	21.	30.	46.	53.	60.	74.	90.	107.	129.	141.	157.	202.	244.	969.	939.	924.	917.	910.	895.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMBA	1.3501	.1297	.2010	.0895	.0124	.0135	.0706	.0170	.0416	.0712	.2526	.2131	.0205
P	.216	.183	.173	.186	.235	.405	.457	.330	.239	.229	.212	.175	2.167
LNGAM	1.4925	1.7376	1.6780	1.6003	1.3518	.7836	.6675	.9962	1.3584	1.3792	1.4617	1.6667	.0795

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	2.	54.	33.	30.	213.	113.	112.	109.	60.	42.	11.	17.	271.
PMIN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	8.
PDYS	0.	0.	0.	0.	0.	2.	2.	1.	0.	0.	0.	0.	53.
ETDF	157.	122.	96.	58.	28.	29.	27.	39.	60.	86.	104.	160.	917.
MAI	.000	.000	.000	.000	.005	.059	.069	.016	.001	.000	.000	.000	.055

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	17.0	16.5	15.3	14.0	12.1	10.9	10.5	10.6	11.2	12.4	14.1	17.0	13.5
HUM	.79	.81	.84	.85	.86	.83	.84	.83	.83	.81	.81	.79	.82
WIND	10.8	10.3	9.5	7.8	4.1	5.8	4.8	5.5	7.4	7.6	7.6	10.1	7.6
PREC.DAYS	0.	0.	0.	0.	3.	6.	4.	3.	1.	0.	0.	0.	17.
SUNSHINE	.60	.56	.47	.51	.43	.58	.51	.54	.51	.59	.53	.50	.53

* INDICATES MISSING DATA

TABLE 8. PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION, IN MM.

STATION NAME OVALLE COQUIMBO SER. NO. 4
LAT. -30 36. LONG. 71 12. ELEV. 250. YEARS OF DATA 47

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN*	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	250.	250.	250.	250.	250.	250.
FEB	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	1.	3.	6.	209.	209.	209.	209.	209.	209.
MAR	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	2.	4.	172.	172.	172.	172.	172.	172.
APR	3.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	4.	10.	17.	97.	97.	97.	97.	97.	97.
MAY	29.	0.	0.	0.	0.	1.	2.	5.	10.	19.	26.	35.	72.	114.	63.	63.	63.	63.	63.	61.
JUN	40.	0.	1.	3.	4.	5.	11.	18.	28.	43.	53.	65.	107.	151.	49.	48.	46.	45.	43.	38.
JUL	25.	0.	0.	1.	1.	2.	5.	9.	15.	25.	32.	41.	72.	105.	49.	49.	48.	48.	47.	44.
AUG	26.	0.	0.	1.	1.	2.	5.	9.	15.	25.	32.	41.	73.	108.	69.	69.	68.	67.	66.	64.
SEP	5.	0.	0.	0.	0.	0.	0.	1.	1.	3.	5.	7.	16.	28.	102.	102.	102.	102.	102.	102.
OCT	3.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	4.	10.	18.	154.	154.	154.	154.	153.	153.
NOV	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	2.	196.	196.	196.	196.	196.	196.
DEC	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	1.	3.	6.	245.	245.	245.	245.	245.	245.
ANN	130.	35.	49.	66.	75.	83.	99.	116.	135.	157.	170.	186.	231.	273.	1655.	1608.	1589.	1580.	1572.	1556.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMBA	.0000	.1328	.2292	.0548	.0109	.0130	.0157	.0151	.0360	.0535	.3999	.1386	.0230
P	*********	.155	.156	.176	.262	.513	.396	.390	.193	.180	.179	.159	2.986
LNGAM	.0000	1.7901	1.7224	1.6583	1.2370	.5469	.8060	.8240	1.5608	1.6354	1.6433	1.7650	.6802

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	0.	52.	30.	53.	257.	158.	114.	139.	91.	32.	13.	27.	346.
PMIN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	18.
P075	0.	0.	0.	0.	0.	4.	1.	1.	0.	0.	0.	0.	75.
ETDF	250.	209.	172.	97.	63.	45.	48.	67.	102.	154.	196.	245.	1580.
MAI	.000	.000	.000	.000	.005	.086	.030	.070	.000	.000	.000	.000	.045

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	19.2	19.3	17.2	14.6	12.5	12.0	10.6	11.4	12.2	14.1	16.1	18.1	14.7
HUM	.60	.62	.64	.68	.72	.76	.78	.77	.72	.67	.65	.69	.66
WIND	12.9	12.1	11.9	8.6	8.0	8.6	8.7	9.4	10.6	11.0	12.0	13.2	10.6
PREC.DAYS	0.	0.	0.	0.	4.	7.	5.	5.	1.	0.	0.	0.	22.
SUNSHINE	.72	.72	.67	.56	.55	.57	.68	.66	.67	.71	.79	.72	.67

* INDICATES MISSING DATA

TABLE 8. * PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION. IN MM.

STATION NAME VALPARAISO VALPARAISO SER. NO. 9
LAT. -33 1. LONG. 71 38. ELEV. 41. YEARS OF DATA 60

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN	2.	0.	0.	0.	0.	0.	0.	0.	0.	1.	2.	2.	6.	10.	200.	200.	200.	200.	200.	200.
FEB	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	2.	4.	7.	154.	154.	154.	154.	154.	154.
MAR	4.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	5.	11.	19.	122.	122.	122.	122.	122.	122.
APR	18.	0.	0.	0.	0.	0.	1.	3.	7.	14.	19.	26.	54.	86.	68.	68.	68.	68.	68.	67.
MAY	91.	1.	2.	8.	12.	16.	27.	43.	63.	91.	110.	134.	212.	294.	46.	44.	38.	34.	30.	19.
JUN	117.	3.	17.	33.	40.	49.	67.	87.	112.	143.	162.	186.	257.	328.	32.	15.	-0.	-8.	-17.	-35.
JUL	86.	7.	12.	29.	29.	35.	49.	64.	82.	105.	119.	136.	189.	241.	33.	20.	9.	3.	-3.	-16.
AUG	56.	4.	8.	17.	21.	26.	36.	48.	62.	80.	91.	105.	148.	190.	51.	43.	35.	30.	26.	15.
SEP	28.	0.	0.	1.	2.	3.	7.	12.	19.	29.	36.	46.	77.	112.	75.	75.	74.	73.	72.	69.
OCT	12.	0.	0.	0.	0.	1.	1.	3.	6.	11.	14.	19.	36.	56.	120.	120.	120.	120.	120.	119.
NOV	5.	0.	0.	0.	0.	0.	0.	0.	1.	3.	4.	7.	16.	27.	157.	157.	157.	157.	157.	157.
DEC	3.	0.	0.	0.	0.	0.	0.	0.	1.	2.	2.	4.	9.	15.	192.	192.	192.	192.	192.	192.
ANN	424.	157.	197.	254.	278.	302.	347.	393.	449.	502.	536.	576.	691.	796.	1252.	1055.	998.	974.	951.	905.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMDA	.0250	.1307	.0511	.0142	.0073	.0104	.0141	.0169	.0161	.0247	.0363	.0618	.0107
A	.179	.174	.190	.253	.593	1.216	1.200	1.119	.450	.304	.187	.180	4.524
LNGAM	1.5417	1.5697	1.5780	1.2736	.4004	-.0900	-.0820	-.0578	.6769	1.0803	1.5976	1.6339	2.4875

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL.

PMAX	92.	30.	40.	102.	452.	458.	360.	324.	175.	105.	66.	33.	1245.
PMIN	0.	0.	0.	0.	0.	0.	3.	2.	0.	0.	0.	0.	62.
PDES	0.	0.	0.	0.	12.	40.	29.	21.	2.	0.	0.	0.	278.
ETCF	200.	154.	122.	68.	38.	-8.	3.	30.	73.	120.	157.	192.	974.
MSI	.000	.000	.000	.003	.251	1.262	.903	.413	.030	.002	.000	.000	.272

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	17.7	17.4	16.1	14.3	13.1	11.9	11.2	11.8	12.1	14.1	15.3	16.8	14.3
HUM	.76	.78	.80	.83	.83	.89	.85	.84	.83	.81	.77	.76	.81
WIND	14.6	14.3	12.4	9.7	9.1	8.4	8.2	10.7	13.0	15.3	16.8	16.7	13.1
PREC.DAYS	0.	0.	0.	3.	12.	15.	12.	10.	5.	2.	1.	0.	60.
SUNSHINE	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

* INDICATES MISSING DATA

TABLE 8. 5 PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION. IN MM.

STATION NAME SANTIAGO SANTIAGO SER. NO. 10
LAT. -33 27. LONG. 70 42. ELEV. 520. YEARS OF DATA 104

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	2.	4.	8.	185.	185.	185.	185.	185.	185.
FEB	2.	0.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	7.	12.	134.	134.	134.	134.	134.	134.
MAR	4.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	5.	11.	20.	102.	102.	102.	102.	102.	102.
APR	15.	0.	0.	0.	0.	0.	1.	3.	6.	12.	16.	22.	44.	69.	49.	49.	49.	49.	48.	47.
MAY	58.	2.	4.	10.	13.	17.	26.	37.	51.	69.	81.	95.	147.	189.	24.	20.	15.	11.	7.	-2.
JUN	81.	7.	13.	24.	29.	35.	48.	52.	78.	99.	112.	128.	175.	222.	13.	-0.	-11.	-17.	-22.	-35.
JUL	73.	5.	9.	18.	2	28.	39.	52.	68.	88.	101.	116.	164.	212.	18.	9.	-0.	-5.	-10.	-21.
AUG	57.	3.	7.	14.	18.	21.	30.	40.	53.	69.	79.	91.	129.	166.	30.	23.	16.	12.	6.	-1.
SEP	29.	0.	1.	3.	5.	6.	11.	15.	23.	33.	40.	48.	75.	103.	50.	49.	47.	45.	43.	39.
OCT	14.	0.	0.	0.	1.	1.	2.	4.	8.	13.	17.	22.	39.	59.	88.	88.	87.	87.	87.	86.
NOV	6.	0.	0.	0.	0.	0.	0.	1.	2.	4.	5.	8.	17.	29.	134.	134.	134.	134.	134.	134.
DEC	4.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	5.	13.	23.	175.	175.	175.	175.	175.	175.
ANN	344.	132.	164.	209.	229.	248.	284.	321.	361.	407.	434.	466.	556.	639.	1001.	838.	792.	772.	759.	718.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMBDA	.1245	.0742	.0513	.0187	.0139	.0160	.0149	.0188	.0218	.0261	.0373	.0406	.0138
P	.176	.173	.195	.274	.814	1.297	1.083	1.071	.640	.356	.213	.171	4.745
LNGAM	1.6597	1.6801	1.5517	1.1905	.1391	-.1377	-.0973	-.0372	.3395	.9156	1.4586	1.6987	2.8030

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	41.	85.	40.	131.	268.	433.	353.	313.	250.	102.	57.	60.	800.
PMIN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	66.
P075	0.	0.	0.	0.	13.	29.	23.	18.	5.	1.	0.	0.	229.
ETDF	185.	134.	102.	49.	11.	-17.	-5.	12.	45.	87.	134.	175.	772.
MAT	.000	.000	.000	.005	.546	2.298	1.271	.590	.095	.007	.000	.000	.229

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	21.2	20.0	17.7	14.5	11.3	8.5	8.1	9.5	11.4	14.4	17.4	19.8	14.5
HUM	.52	.56	.61	.67	.74	.79	.80	.75	.70	.65	.57	.53	.66
WIND	5.2	4.5	3.9	2.5	1.8	1.3	2.3	2.6	3.1	3.8	4.8	5.3	3.4
PREC.DAYS	0.	0.	0.	2.	9.	12.	11.	9.	5.	2.	1.	0.	51.
SUNSHINE	.76	.76	.65	.57	.48	.33	.33	.45	.47	.50	.62	.70	.55

* INDICATES MISSING DATA

TABLE B. 6 PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION. IN MM.

STATION NAME SAN FERNANDO O'HIGGINS SER. NO. 12
LAT. -34 35. LONG. 71 0. ELEV. 342. YEARS OF DATA 49

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN	5.	0.	0.	0.	0.	0.	0.	0.	1.	3.	4.	7.	19.	34.	276.	276.	276.	276.	276.	276.
FEB	5.	0.	0.	0.	0.	0.	0.	0.	1.	3.	4.	6.	16.	28.	177.	177.	177.	177.	177.	177.
MAR	10.	0.	0.	0.	0.	0.	0.	1.	3.	6.	9.	13.	30.	51.	150.	150.	150.	150.	150.	150.
APR	34.	0.	0.	1.	1.	2.	4.	9.	17.	30.	40.	53.	100.	153.	65.	64.	64.	63.	63.	60.
MAY	134.	11.	21.	38.	47.	57.	77.	100.	128.	163.	185.	211.	291.	370.	38.	17.	-0.	-10.	-19.	-39.
JUN	204.	37.	55.	84.	98.	112.	141.	171.	206.	248.	274.	305.	395.	482.	22.	-32.	-62.	-76.	-90.	-118.
JUL	152.	13.	24.	44.	55.	65.	89.	115.	146.	186.	210.	240.	330.	419.	26.	2.	-18.	-28.	-39.	-62.
AUG	109.	3.	15.	29.	36.	45.	61.	80.	103.	132.	150.	172.	240.	307.	36.	21.	7.	-0.	-8.	-25.
SEP	58.	1.	2.	7.	4.	13.	20.	31.	44.	62.	74.	89.	138.	188.	67.	65.	60.	58.	54.	46.
OCT	31.	0.	0.	2.	3.	4.	8.	13.	21.	33.	40.	50.	84.	120.	110.	110.	109.	108.	106.	102.
NOV	23.	0.	0.	0.	0.	1.	2.	5.	11.	20.	27.	36.	70.	108.	170.	170.	169.	169.	169.	167.
DEC	7.	0.	0.	0.	0.	0.	0.	1.	2.	5.	7.	10.	22.	35.	227.	227.	227.	227.	227.	227.
ANN	770.	347.	415.	510.	549.	587.	658.	730.	807.	896.	947.	1007.	1175.	1327.	1364.	949.	855.	815.	778.	706.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMBDA	.0296	.0317	.0206	.0098	.0094	.0099	.0084	.0108	.0123	.0156	.0124	.0296	.0084
[illegible]	.153	.167	.205	.322	1.256	2.020	1.278	1.174	.665	.978	.292	.212	6.437
LNGAM	1.9056	1.7155	1.9979	1.0227	-.0997	.0085	-.1041	-.0775	.3053	.6164	1.1245	1.4607	5.5492

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	77.	108.	53.	169.	466.	625.	469.	301.	308.	142.	146.	51.	1618.
PMIN	0.	0.	0.	0.	1.	7.	10.	0.	0.	0.	0.	0.	164.
PC75	0.	0.	0.	1.	47.	98.	55.	36.	9.	3.	0.	0.	549.
ETDF	276.	177.	150.	63.	-10.	-76.	-78.	-0.	58.	108.	169.	227.	815.
MAT	.000	.000	.000	.016	1.254	4.376	2.076	1.011	.139	.026	.003	.000	.403

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	20.1	18.9	16.7	12.6	10.0	7.3	6.5	7.4	9.8	12.5	15.9	17.7	13.2
HUM	.70	.74	.74	.79	.83	.85	.82	.82	.79	.78	.75	.71	.77
WIND	13.1	9.2	10.5	7.6	8.9	8.9	8.2	7.3	8.7	9.4	10.0	12.0	9.0
PREC.DAYS	1.	1.	1.	6.	17.	22.	18.	14.	9.	6.	4.	1.	100.
SUNSHINE	.68	.79	.63	.42	.36	.28	.30	.45	.46	.46	.61	.43	.49

* INDICATES MISSING DATA

TABLE A. 7 PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION, IN MM.

STATION NAME CURICO CURICO STP. NO. 13
LAT. -34 59, LONG. 71 14, ELEV. 211, YEARS OF DATA 43

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN	8.	0.	0.	0.	0.	0.	0.	0.	1.	4.	6.	9.	24.	43.	291.	291.	291.	291.	291.	291.
FEB	5.	0.	0.	0.	0.	0.	0.	0.	1.	3.	4.	7.	15.	29.	221.	221.	221.	221.	221.	221.
MAR	13.	0.	0.	0.	0.	0.	1.	2.	4.	8.	13.	18.	38.	63.	145.	145.	145.	145.	145.	145.
APR	43.	0.	0.	1.	2.	3.	7.	14.	24.	41.	53.	69.	123.	183.	71.	70.	69.	69.	67.	63.
MAY	119.	6.	12.	26.	34.	42.	51.	82.	109.	140.	165.	192.	275.	359.	27.	15.	1.	-7.	-15.	-33.
JUN	185.	36.	52.	80.	92.	105.	130.	158.	189.	226.	249.	276.	356.	437.	16.	-36.	-63.	-76.	-88.	-116.
JUL	187.	18.	24.	48.	58.	64.	87.	112.	142.	180.	203.	231.	317.	401.	19.	-6.	-25.	-36.	-46.	-68.
AUG	113.	14.	22.	37.	44.	51.	66.	83.	102.	126.	141.	159.	211.	263.	38.	16.	1.	-6.	-13.	-28.
SEP	57.	2.	4.	10.	13.	17.	25.	35.	47.	64.	74.	87.	128.	169.	70.	66.	60.	57.	53.	45.
OCT	37.	0.	1.	4.	5.	7.	12.	18.	26.	37.	45.	54.	84.	115.	123.	122.	119.	118.	116.	111.
NOV	12.	0.	0.	0.	0.	1.	2.	5.	9.	16.	22.	29.	56.	85.	197.	197.	197.	197.	197.	195.
DEC	11.	0.	0.	0.	0.	0.	0.	1.	3.	7.	10.	15.	33.	55.	265.	265.	265.	265.	265.	265.
ANN	740.	350.	414.	503.	533.	574.	640.	706.	777.	857.	904.	958.	1111.	1248.	1484.	1069.	981.	944.	910.	844.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMBA	.0204	.0345	.0183	.0086	.0083	.0115	.0099	.0156	.0161	.0195	.0163	.0193	.0096
P	.161	.181	.231	.367	.991	2.130	1.315	1.613	.860	.637	.309	.211	7.121
LAMAM	1.7539	1.6278	1.3094	.8265	.0052	.0603	-.1105	-.1108	.0985	.3438	1.0655	1.4698	6.8066

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	78.	88.	84.	219.	431.	513.	398.	294.	226.	131.	73.	68.	1302.
PMIN	0.	0.	0.	0.	0.	10.	3.	5.	0.	0.	0.	0.	123.
P075	0.	0.	0.	2.	34.	92.	54.	84.	13.	5.	0.	0.	539.
ETDF	291.	221.	145.	69.	-7.	-76.	-36.	-6.	57.	118.	197.	265.	944.
MAT	.000	.000	.000	.028	1.249	5.681	2.911	1.157	.186	.043	.002	.000	.363

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	19.9	18.5	15.6	12.3	9.1	7.3	6.9	8.1	9.8	12.3	15.7	18.2	12.8
HUM	.62	.65	.70	.79	.88	.91	.91	.87	.82	.78	.71	.67	.78
WIND	19.7	13.8	9.5	8.5	8.3	9.4	10.4	11.2	10.9	12.1	13.8	15.8	11.9
PREC.DAYS	1.	1.	2.	7.	15.	21.	18.	14.	8.	6.	3.	2.	98.
SUNSHINE	.88	.85	.68	.50	.31	.23	.39	.38	.44	.49	.59	.73	.54

* INDICATES MISSING DATA

TABLE 8. A PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION. IN MM.

STATION NAME LINARES LINARES SER. NO. 15
LAT. -35 51. LONG. 71 36. ELEV. 157. YEARS OF DATA 44

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN	15.	0.	0.	0.	0.	0.	0.	1.	3.	7.	12.	18.	45.	81.	239.	239.	239.	239.	239.	239.
FEB	11.	0.	0.	0.	0.	0.	0.	1.	3.	7.	10.	14.	32.	54.	154.	154.	154.	154.	154.	153.
MAR	23.	0.	0.	0.	0.	0.	1.	3.	7.	16.	27.	32.	70.	116.	107.	107.	107.	107.	107.	106.
APR	58.	1.	3.	9.	13.	17.	26.	38.	54.	75.	89.	106.	160.	216.	28.	24.	19.	15.	11.	1.
MAY	199.	39.	51.	75.	84.	94.	112.	132.	153.	179.	194.	212.	265.	314.	18.	-35.	-57.	-66.	-76.	-94.
JUN	209.	56.	75.	104.	118.	130.	155.	182.	211.	246.	267.	291.	362.	428.	14.	-61.	-91.	-104.	-117.	-142.
JUL	172.	36.	52.	77.	89.	100.	123.	148.	176.	210.	230.	254.	325.	392.	11.	-40.	-66.	-77.	-89.	-112.
AUG	136.	31.	44.	64.	73.	82.	100.	118.	140.	165.	180.	198.	251.	300.	28.	-16.	-35.	-44.	-53.	-71.
SEP	87.	12.	19.	31.	36.	42.	54.	67.	82.	101.	112.	126.	167.	206.	48.	30.	18.	12.	6.	-6.
OCT	49.	2.	4.	9.	12.	16.	23.	32.	43.	58.	67.	79.	115.	151.	87.	83.	79.	75.	72.	64.
NOV	27.	0.	0.	0.	1.	1.	4.	7.	14.	24.	32.	43.	80.	123.	145.	145.	144.	144.	143.	141.
DEC	23.	0.	0.	0.	0.	0.	1.	3.	8.	16.	23.	33.	70.	114.	212.	212.	212.	212.	212.	211.
ANN	955.	574.	643.	734.	771.	805.	869.	932.	998.	1072.	1115.	1163.	1298.	1416.	1092.	449.	358.	321.	287.	222.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMBA	.0112	.0198	.0095	.0113	.0135	.0147	.0133	.0185	.0207	.0185	.0116	.0100	.0143
P	.170	.210	.221	.729	2.895	3.001	2.266	2.516	1.707	.893	.318	.232	13.696
LNMAN	1.5936	1.4742	1.4195	.2271	.5988	.6942	.1455	.2960	-.0943	.0675	1.0356	1.3680	21.7638

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	93.	130.	196.	267.	271.	598.	505.	294.	270.	139.	117.	141.	1506.
PMIN	0.	0.	0.	0.	4.	24.	20.	14.	4.	0.	0.	0.	476.
P075	0.	0.	0.	13.	84.	118.	89.	73.	36.	17.	1.	0.	771.
ETDF	239.	154.	107.	15.	-66.	-104.	-77.	-44.	12.	75.	144.	212.	321.
MAI	.000	.000	.000	.858	4.697	8.576	7.911	2.566	.749	.182	.005	.000	.706

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE.ETCH

TEMP	18.4	18.1	15.8	12.3	9.1	7.8	7.0	7.9	9.8	12.4	15.2	17.7	12.6
HUM	.65	.66	.72	.80	.88	.89	.91	.86	.82	.79	.74	.69	.78
WIND	10.8	6.4	5.4	1.7	4.1	5.7	4.1	6.1	5.6	6.3	7.7	9.3	6.1
PREC.DAYS	3.	2.	4.	10.	18.	22.	20.	17.	12.	8.	5.	4.	125.
SUNSHINE	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

* INDICATES MISSING DATA

TABLE NO. 9 PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION. IN MM.

STATION NAME CHILLAN NUBLE SER. NO. 16
LAT. -36 36. LONG. 72 26. ELEV. 144. YEARS OF DATA 47

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS												
JAN	13.	0.	0.	0.	0.	0.	0.	2.	4.	10.	15.	23.	55.	95.
FEB	13.	0.	0.	0.	0.	1.	2.	4.	8.	15.	21.	28.	55.	86.
MAR	23.	0.	0.	0.	1.	2.	4.	8.	15.	25.	34.	48.	82.	124.
APR	67.	2.	4.	11.	14.	18.	28.	40.	55.	74.	87.	103.	152.	202.
MAY	176.	31.	47.	73.	85.	97.	121.	148.	178.	215.	237.	264.	343.	419.
JUN	215.	69.	85.	115.	129.	142.	168.	195.	225.	260.	280.	305.	375.	441.
JUL	177.	37.	53.	79.	91.	103.	125.	152.	181.	215.	236.	261.	334.	403.
AUG	143.	35.	48.	69.	78.	88.	105.	125.	147.	173.	188.	206.	260.	310.
SEP	80.	17.	24.	35.	41.	46.	57.	68.	81.	97.	106.	117.	150.	181.
OCT	57.	8.	12.	20.	23.	27.	35.	43.	53.	65.	72.	81.	107.	133.
NOV	32.	0.	1.	3.	5.	7.	11.	17.	25.	36.	43.	52.	82.	113.
DEC	28.	0.	0.	0.	1.	2.	4.	8.	15.	26.	39.	45.	83.	127.
ANN	1033.	678.	744.	831.	865.	897.	957.	1015.	1075.	1142.	1181.	1224.	1344.	1445.

MONTH	ETT	IRRIGATION REQUIREMENTS 90.	80.	75.	70.	60.
JAN	259.	254.	254.	254.	254.	254.
FEB	184.	184.	184.	184.	184.	183.
MAR	137.	137.	137.	136.	135.	133.
APR	81.	77.	71.	67.	63.	53.
MAY	35.	-12.	-38.	-50.	-62.	-86.
JUN	24.	-60.	-91.	-105.	-118.	-144.
JUL	30.	-23.	-49.	-61.	-73.	-97.
AUG	44.	-4.	-25.	-35.	-44.	-62.
SEP	62.	38.	27.	21.	16.	5.
OCT	109.	97.	89.	85.	82.	74.
NOV	168.	166.	164.	163.	161.	156.
DEC	223.	223.	223.	222.	221.	219.
ANN	1351.	607.	521.	486.	454.	394.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMDA	.0103	.0154	.0119	.0130	.0113	.0154	.0129	.0187	.0290	.0320	.0196	.0115	.0186
C	.188	.285	.335	.815	1.937	3.321	2.279	2.672	2.303	1.698	.619	.328	19.161
LNGAM	1.5918	1.1896	.9812	.1380	-.0014	1.0087	.1415	.4123	.1567	-.0962	.3691	1.0030	36.8647

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	131.	83.	133.	272.	431.	571.	565.	350.	255.	200.	122.	184.	1563.
PMIN	0.	0.	0.	0.	9.	56.	9.	25.	7.	3.	0.	0.	482.
PD75	0.	0.	1.	14.	85.	129.	91.	78.	41.	23.	5.	1.	865.
ETDF	258.	194.	135.	67.	-50.	-105.	-61.	-35.	21.	85.	163.	222.	486.
MAT	.000	.002	.007	.177	2.424	5.311	3.044	1.790	.658	.214	.029	.009	.640

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	18.6	17.8	15.8	13.3	9.3	8.0	7.2	7.9	9.5	11.0	15.0	17.1	12.5
HUM	.58	.57	.60	.69	.80	.85	.87	.80	.75	.72	.68	.64	.71
WIND	18.3	11.5	9.1	9.0	7.8	11.7	11.7	10.8	7.7	10.3	11.4	12.6	10.6
PREC.DAYS	3.	3.	5.	10.	20.	22.	20.	17.	11.	8.	6.	5.	130.
SUN.SHINE	.71	.77	.72	.52	.49	.22	.32	.43	.48	.56	.59	.62	.53

* INDICATES MISSING DATA

TABLE 8.10 PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION, IN MM.

STATION NAME CONCEPCION CONCEPCION SER. NO. 17
LAT. -36 50. LONG. 73 2. ELEV. 10. YEARS OF DATA 46

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN	15.	0.	0.	0.	0.	1.	2.	4.	8.	14.	19.	25.	48.	74.	196.	196.	196.	195.	195.	194.
FEB	21.	0.	0.	1.	1.	2.	4.	7.	13.	20.	26.	33.	58.	85.	156.	156.	155.	155.	154.	152.
MAR	40.	3.	5.	10.	13.	15.	22.	29.	37.	49.	56.	64.	91.	117.	122.	117.	112.	110.	107.	101.
APR	97.	9.	15.	26.	32.	38.	50.	65.	81.	102.	114.	130.	176.	221.	66.	51.	40.	34.	28.	16.
MAY	215.	48.	67.	99.	113.	127.	156.	186.	220.	261.	285.	314.	400.	480.	36.	-32.	-63.	-78.	-92.	-120.
JUN	257.	103.	127.	160.	174.	188.	214.	240.	269.	302.	321.	344.	408.	466.	25.	-102.	-136.	-150.	-163.	-189.
JUL	239.	67.	90.	124.	139.	154.	183.	214.	248.	288.	312.	340.	421.	497.	29.	-61.	-95.	-110.	-125.	-154.
AUG	197.	51.	70.	99.	111.	124.	149.	175.	204.	238.	259.	283.	354.	420.	40.	-33.	-58.	-71.	-84.	-108.
SEP	99.	23.	32.	47.	53.	59.	72.	86.	101.	119.	130.	143.	181.	217.	69.	37.	22.	16.	10.	-3.
OCT	61.	10.	15.	24.	28.	32.	41.	50.	61.	74.	82.	91.	120.	147.	111.	95.	87.	83.	79.	70.
NOV	57.	0.	1.	4.	6.	9.	16.	26.	39.	57.	70.	85.	137.	192.	149.	147.	144.	142.	139.	132.
DEC	31.	0.	0.	1.	2.	2.	5.	10.	18.	30.	39.	50.	89.	133.	187.	186.	186.	185.	184.	181.
ANN	1310.	995.	972.	1045.	1090.	1132.	1210.	1286.	1365.	1453.	1509.	1562.	1720.	1858.	1185.	253.	140.	95.	63.	-25.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMBA	.0187	.0196	.0271	.0169	.0113	.0201	.0129	.0195	.0258	.0307	.0107	.0119	.0116
P	.304	.402	1.086	1.407	2.422	5.169	3.096	2.852	2.539	1.855	.553	.373	17.852
LNGAM	1.0923	.7927	-.0440	-.1200	.2313	3.4364	.7340	.5608	.3129	-.0592	.4743	.8690	33.0824

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	93.	78.	183.	237.	516.	564.	537.	490.	377.	191.	363.	133.	1345.
PMIN	0.	0.	1.	3.	29.	90.	24.	27.	13.	2.	0.	0.	666.
P075	0.	1.	13.	32.	113.	174.	139.	111.	53.	28.	5.	2.	1030.
ETDF	195.	155.	110.	34.	-78.	-150.	-110.	-71.	16.	83.	142.	185.	95.
MAI	.002	.008	.103	.486	3.166	7.077	4.775	2.768	.769	.252	.043	.008	.920

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	16.8	15.5	14.3	12.2	10.7	9.5	8.6	8.9	9.9	11.0	14.3	15.6	12.2
HUM	.70	.73	.76	.81	.85	.87	.84	.84	.79	.75	.74	.71	.78
WIND	21.5	17.3	16.2	13.8	13.0	15.7	18.8	17.7	13.1	14.8	21.4	21.2	16.6
PREC.DAYS	3.	4.	7.	12.	22.	24.	24.	21.	13.	9.	8.	5.	153.
SUNSHINE	.68	.77	.64	.50	.40	.34	.40	.47	.51	.59	.62	.66	.55

* INDICATES MISSING DATA

TABLE 8.11 PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION, IN MM.

STATION NAME LOS ANGELES BIO- BIO SER. NO. 18
LAT. -37 28. LONG. 72 21. ELEV. 160. YEARS OF DATA 46

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN	27.	0.	0.	0.	0.	0.	1.	3.	7.	16.	22.	32.	69.	115.	235.	235.	235.	235.	234.	234.
FEB	26.	0.	0.	0.	1.	1.	3.	7.	13.	23.	31.	41.	78.	119.	184.	184.	184.	183.	183.	181.
MAR	49.	1.	2.	6.	9.	11.	18.	26.	36.	51.	60.	72.	108.	146.	154.	151.	148.	145.	142.	136.
APR	84.	6.	12.	23.	29.	35.	47.	62.	80.	103.	117.	134.	186.	238.	79.	67.	56.	50.	44.	31.
MAY	129.	42.	59.	83.	101.	114.	140.	167.	198.	236.	258.	285.	363.	437.	42.	-17.	-46.	-59.	-72.	-97.
JUN	254.	92.	116.	150.	165.	179.	207.	235.	265.	301.	327.	347.	417.	482.	22.	-99.	-124.	-143.	-157.	-185.
JUL	219.	53.	73.	104.	118.	131.	159.	188.	229.	259.	282.	309.	388.	463.	23.	-50.	-81.	-95.	-109.	-136.
AUG	195.	49.	66.	93.	105.	117.	140.	164.	191.	223.	242.	265.	331.	392.	43.	-28.	-50.	-62.	-74.	-97.
SEP	105.	18.	27.	42.	49.	57.	72.	88.	106.	129.	142.	159.	207.	254.	76.	49.	34.	26.	19.	4.
OCT	76.	9.	13.	23.	29.	34.	46.	59.	74.	93.	105.	119.	163.	205.	124.	111.	100.	95.	90.	78.
NOV	51.	1.	3.	7.	10.	13.	21.	30.	43.	59.	70.	83.	126.	170.	169.	167.	162.	159.	156.	148.
DEC	42.	0.	0.	1.	2.	3.	7.	13.	23.	40.	51.	67.	122.	183.	226.	226.	225.	224.	223.	219.
ANN	1208.	872.	919.	1032.	1077.	1119.	1197.	1278.	1353.	1442.	1493.	1551.	1710.	1849.	1375.	956.	393.	297.	256.	177.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMBA	.0097	.0118	.0157	.0141	.0121	.0171	.0126	.0156	.0181	.0178	.0145	.0089	.0134
O	.222	.313	.726	1.189	2.351	4.348	2.685	2.887	1.911	1.357	.735	.353	17.419
LNGAM	1.8113	1.0500	.2306	-.0821	.1852	2.2960	.9229	.5918	-.0151	-.1160	.2197	.9260	31.8505

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	137.	158.	218.	420.	458.	586.	507.	490.	374.	703.	217.	303.	1812.
PMIN	0.	0.	0.	1.	13.	71.	27.	35.	4.	6.	0.	0.	683.
P075	0.	1.	9.	29.	101.	165.	118.	105.	49.	29.	10.	2.	1077.
ETDF	235.	183.	145.	50.	-59.	-143.	-95.	-62.	26.	95.	159.	224.	297.
MAT	.000	.004	.055	.359	2.392	7.606	5.148	2.465	.651	.232	.060	.008	.784

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	19.0	17.9	15.9	12.5	9.9	7.7	7.0	7.9	9.3	11.6	14.6	17.1	12.6
HUM	.59	.59	.66	.76	.78	.87	.87	.82	.76	.72	.67	.63	.73
WIND	23.1	22.2	18.9	13.6	12.8	14.3	13.5	18.2	17.5	18.2	21.3	20.0	17.8
PREC.DAYS	4.	5.	7.	12.	21.	24.	22.	21.	14.	11.	8.	7.	156.
SUNSHINE	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

* INDICATES MISSING DATA

TABLE 8.12 PRECIPITATION AND POTENTIAL IRRIGATION REQUIREMENTS FOR GIVEN PROBABILITY LEVELS BASED ON GAMMA DISTRIBUTION, IN MM.

STATION NAME PANCAGUA O'HIGGINS SER. NO. 19
LAT. -34 10. LONG. 70 45. ELEV. 500. YEARS OF DATA 46

PROBABILITY		95.	90.	80.	75.	70.	60.	50.	40.	30.	25.	20.	10.	5.		90.	80.	75.	70.	60.
MONTH	MEAN	PRECIPITATION AT VARIOUS PROBABILITY LEVELS													ETT	IRRIGATION REQUIREMENTS				
JAN	8.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	4.	11.	19.	259.	259.	259.	259.	259.	259.
FEB	3.	0.	0.	0.	0.	0.	0.	0.	1.	1.	2.	3.	8.	14.	193.	193.	193.	193.	193.	193.
MAR	8.	0.	0.	0.	0.	0.	0.	1.	2.	4.	7.	10.	23.	39.	148.	148.	148.	148.	148.	148.
APR	21.	0.	0.	0.	0.	1.	2.	5.	10.	18.	24.	33.	63.	99.	81.	81.	80.	80.	80.	78.
MAY	73.	2.	8.	11.	16.	20.	32.	45.	63.	87.	102.	121.	181.	243.	45.	41.	34.	30.	25.	14.
JUN	107.	16.	25.	40.	47.	54.	68.	85.	103.	125.	140.	156.	205.	253.	26.	1.	-14.	-21.	-28.	-43.
JUL	79.	9.	14.	25.	30.	36.	47.	60.	75.	95.	106.	120.	163.	205.	29.	15.	4.	-1.	-7.	-18.
AUG	59.	7.	13.	22.	27.	32.	42.	54.	67.	84.	95.	107.	146.	183.	46.	33.	24.	19.	14.	4.
SEP	30.	1.	3.	6.	8.	10.	14.	20.	27.	36.	42.	49.	71.	93.	77.	75.	72.	70.	68.	63.
OCT	17.	0.	0.	1.	2.	3.	5.	8.	12.	18.	22.	27.	45.	63.	128.	128.	127.	126.	125.	123.
NOV	9.	0.	0.	0.	0.	0.	1.	2.	3.	6.	9.	13.	26.	42.	194.	194.	194.	194.	194.	193.
DEC	5.	0.	0.	0.	0.	0.	0.	0.	1.	3.	4.	7.	16.	28.	247.	247.	247.	247.	247.	246.
ANN	419.	187.	225.	276.	298.	318.	358.	397.	440.	488.	517.	550.	692.	726.	1473.	1248.	1196.	1175.	1158.	1115.

PARAMETERS FOR GAMMA DISTRIBUTION

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
LAMBA	.0979	.0696	.0257	.0137	.0105	.0174	.0185	.0207	.0302	.0313	.0287	.0334	.0150
P	.159	.174	.195	.294	.772	1.795	1.937	1.427	.905	.520	.249	.179	6.305
LNGAM	1.7019	1.6701	1.5514	1.1159	.1602	-.0721	-.1212	-.1209	.0629	.5345	1.2923	1.6933	5.3168

MAX.AND MIN.PRECIP. AND A SUMMARY OF DEPENDABLE PREC. EVAPOTRANSPIRATION DEFICIT AND MOISTURE AVAILABILITY AT THE 75 P.C.PROB.LEVEL

PMAX	41.	88.	67.	123.	250.	423.	257.	205.	206.	73.	69.	40.	859.
PMIN	0.	0.	0.	0.	0.	2.	3.	2.	0.	0.	0.	0.	82.
P75	0.	0.	0.	0.	16.	47.	30.	27.	8.	2.	0.	0.	238.
ETDF	259.	193.	148.	80.	30.	-21.	-1.	19.	70.	126.	194.	247.	1175.
MAI	.000	.000	.000	.006	.347	1.801	1.039	.588	.100	.014	.000	.000	.202

CLIMATIC DATA USED TO COMPUTE COEFFICIENTS WHICH TOGETHER WITH ELEVATION AND SOLAR RADIATION DETERMINE ETCH

TEMP	19.8	19.6	15.8	12.5	9.8	7.3	6.9	7.9	9.8	12.6	15.9	18.4	12.9
HUM	.59	.61	.66	.72	.78	.81	.83	.79	.75	.72	.66	.61	.71
WIND	10.9	10.0	9.6	8.4	8.2	6.9	8.0	8.1	9.2	10.4	12.0	11.6	9.4
PREC.DAYS	0.	0.	1.	4.	11.	14.	11.	10.	6.	3.	1.	1.	62.
SUNSHINE	.89	.87	.69	.63	.50	.37	.46	.53	.52	.53	.75	.79	.63

* INDICATES MISSING DATA

VITA

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Master of Science

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