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Richard H. Cuenca

Regionalized variable analysis has been used to study a number of meteorological and hydrological variables including precipitation (Delhomme and Delfinier, 1973), streamflow (Villeneuve et al., 1979) and hydraulics of groundwater aquifers (Gambolati and Volpi, 1979). In the research work reported in this thesis, an attempt was made to characterize the spatial variability of evapotranspiration over the state of Oregon using methods of Geostatistics.

Application of the geostatistical concept of semivariograms was required to describe spatial variation of a variable as a function of distance. The semivariogram models were derived from reference evapotranspiration rates computed from data at 175 weather stations during May through September of 1979.

The resulting semivariograms for all months but September were anisotropic and indicated that the rate of

change in reference evapotranspiration was higher in the east-west direction than in north-south direction. The semivariograms were fitted by spherical models and applied to perform interpolation of evapotranspiration using the geostatistical technique of kriging. Kriging estimates of evapotranspiration were made at approximately 1,600 locations where no weather data existed, corresponding to corners of a 12.8 km by 12.8 km square grid system laid over the state of Oregon. Using computer plotting routines, the estimates were transformed into contour maps of evapotranspiration and of contour maps of kriging variance. The contour curves of reference evapotranspiration agreed with the general distribution of climatological and topographical features over the state of Oregon. A self-validation test performed on the semivariograms revealed the existence of a certain bias which could be removed by deriving individual semivariograms for climatic subregions within the state.

The results of this research indicate that the spatial variability of reference evapotranspiration over large geographical areas can be described by semivariogram models and this information can be used to predict evapotranspiration rates by means of kriging. Such a procedure could be effectively applied to increase the efficiency of water resources utilization in the arid regions.

APPLICATION OF GEOSTATISTICS TO REGIONAL EVAPOTRANSPIRATION

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Head of Department of Civil Engineering

Redacted for privacy

Dean of Graduate School

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Application of Geostatistics to Regional Evapotranspiration

1. INTRODUCTION

1.1 Statement of the Problem

Since the 1950's, agricultural scientists and engineers have been increasingly concerned with the quantification of crop water requirements, especially in arid and semi-arid irrigated areas of the world. Crop water requirements are defined by Doorenbos and Pruitt (1977) as "the depth of water needed to meet the water loss through evapotranspiration (ET_{crop}) of disease-free crops, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment". The determination of crop water requirements is essential when an irrigation system must be designed to supply water for growing crops.

Crop water requirements may be measured directly by lysimeter or estimated from a suitable evapotranspiration formula using meteorological data. Evapotranspiration is termed reference evapotranspiration when it is estimated for a reference crop under a set of standard conditions. Doorenbos and Pruitt (1977) defined reference evapotranspiration (ET_r) as "the rate of evapotranspiration from an extensive surface of 8 to 15 centimeters tall green grass cover of uniform height, actively growing, completely shading the ground, and not short of water". Earlier, Jensen et al. (1971) proposed that reference evapotranspiration be defined as "the upper limit or maximum evapotranspiration that occurs under given climatic conditions with a field having a well-watered agricultural crop with an aerodynamically rough surface, such as alfalfa with 30 to 45 cm of top growth". Reference evapotranspiration may be considered as a meteorological or climatic variable which varies in response to atmospheric conditions. When the meteorological parameters used in an ET_r estimation are representative of a single location, the estimated value is termed the local estimate of reference evapotranspiration. Seguin (1977) used the words local and regional evapotranspiration to apply for about 100 square kilometers and 10,000 square kilometers, respectively. These numbers are simple averages which can be modified according to the evaporating surface roughness and heterogeneity.

When irrigation systems are designed to supply water required for growing crops in a given region, the ET_r used is one locally estimated from a meteorological station considered as representative of the project site. The fields to be irrigated may be hundreds or thousands times larger than the supposedly representative weather station site.

ET_r estimates from weather station sites are therefore extrapolated to larger fields. This same extrapolation is implicitly assumed when a water resources balance has to be made over a region perhaps hundreds of square kilometers in area and possibly several kilometers away from a weather station from which data are taken for the evapotranspiration estimate. Such an approximation incorporates errors which may cause crops to be overirrigated or underirrigated and water storage reservoirs to be overdesigned or underdesigned.

Worldwide problems of energy and water scarcity and/or relatively high cost justify an effort to improve the accuracy of regional ET_r estimates and to quantify the error associated with the application of a local ET_r estimate to a region a certain distance away from the meteorological station. A model of ET_r spatial variability will take into consideration the change in ET_r with respect to geographic coordinates and the distance between project site and weather stations where data are collected. Such a model will provide estimates based on the variation of ET_r as a function of distance between measurement points. As a consequence, the model will provide a more accurate estimate of ET_r at locations where no climatic data are available compared to a method which does not take into consideration the structure of ET_r variability. An accurate model of ET_r spatial variability could improve the efficiency of irrigation scheduling by providing a means of determining more precisely when to irrigate and how much water to apply at locations where no weather data exist. The relationship determined between error and station density could be used by engineers to determine required hydrometric station density as a function of desired accuracy. MacMahon and Cronin (1980) provided curves relating standard errors of hydrologic estimates to gaging station density and studied the marginal cost and benefit associated with increasing network density. The work proposed in this thesis would aid in such an analysis.

1.2 Alternative Methods of Approach

This thesis is not the first attempt to model regional evapotranspiration. Recent progress in remote sensing techniques has encouraged some scientists to derive evapotranspiration formulas using the crop canopy temperature. The soil-plant canopy temperature sensed by satellite or by other remote sensing instruments was used in combination with ground based parameters measured from traditional weather stations. Although the resulting formulas offered promising results, their validity has not been adequately verified with respect to soil moisture and cloudy sky conditions to allow operational estimates of regional ET_r (Schmugge, 1978; Bernard et al., 1981). The most direct procedure (Baier, 1979) consists of applying local models to small homogeneous units and to weight resulting values according to the relative surface area in order to compute an overall regional evapotranspiration. To obtain reliable regional ET estimates in such methods, it is necessary to equip a large number of data collection sites.

Recently, a theory termed the Theory of Regionalized Variables was developed by Matheron (1965) in France. This theory was partially based on a practical statistical method designed by Krige (1960) to estimate metal grade in gold mines. This theory, which will be extensively explained in the next chapter, was first used by geologists and mining engineers to estimate metal grade in ore deposits. According to Journel and Hujbregts (1978), a regionalized variable can be characterized by the correlation between neighboring measurements.

As was stated by Henly (1981), the Theory of Regionalized Variables, or Geostatistics, can be applied to a large variety of fields including geophysics, meteorology, ecology, geography and oceanography. This method has also been applied to ground water level and soil characteristics mapping, and even to investigate air pollution. In all these applications, the method uses the correlation between neighboring measurements to construct a model which characterizes the structure of spatial variation of the parameter under study. This theory has been applied to estimate variables at locations where few or no measurements were available. The method has also provided a tool to quantify the error of estimation. It has aided in detecting to what degree a variable is heterogeneous or anisotropic. A regionalized variable is isotropic if it exhibits the same behavior in every direction. The variable will be anisotropic if it changes at a different rate from one direction to another.

In water resources planning, it is beneficial to be able to describe reference evapotranspiration quantitatively over a large geographic area. In irrigation scheduling, it is advantageous to be able to predict crop water requirements at locations where no weather stations are available and to quantify the error associated with the predicted values. In the design of hydrometeorological networks, it is useful to be able to relate the station density to errors associated with estimations based on those densities.

During the preliminary studies of regional water resources development, it would be convenient and time-saving to be able to rapidly access a map of evapotranspiration contour curves on a weekly, monthly or annual basis. Such maps can be made relatively rapidly if a model of spatial interpolation exists which can be translated into computer language and routinely used to perform interpolation based on the structure of evapotranspiration spatial variability. Although some of the benefits mentioned above can be reached using classical statistics methods based on random sampling, Geostatistics offers the advantage for dealing with data not necessarily randomly sampled. A classical regression between locally estimated periodic ET_r and the geographic coordinates of sampling locations can be used, but this method is not necessarily accurate because the least squares regression method does not exactly reproduce the measured values previously included for the model derivation (Neter and Wasserman, 1974). On the contrary, the geostatistical estimation method termed kriging, which will be explained in the next chapter, is a least squares method which is also an exact estimation method. This property was described by Journel and Hujbregts (1978) who noted that the kriged surface passed through the experimental data points.

1.3 Thesis Objectives and Scope

This thesis is an attempt to study how well the Theory of Regionalized Variables can be applied to evapotranspiration. There are five objectives which are:

1. To characterize the spatial variability of regional evapotranspiration. This can be done by relating the change in evapotranspiration to geographic variables using a geostatistical feature termed the semivariogram. This term is defined in the next chapter.
2. To apply regionalized variable analysis to evapotranspiration at sampling locations and compare the estimated variables to the original data. This operation constitutes a test for the validity of the spatial variability model obtained in the first objective.
3. To estimate reference evapotranspiration where no weather data are available using the model tested in the second objective.
4. To use regionalized variable analysis to quantify the error associated with an estimation of evapotranspiration using such a model.
5. To represent, by contour curves, the spatial variation of reference evapotranspiration and the error of estimation over a region.

The scope of the objectives is limited to the State of Oregon, where local reference evapotranspiration rates will be estimated at 175 locations for 1979 during the months of May through September. For each month, ET_r data will be used with the geographic coordinates of their locations to compute parameters which characterize the spatial variability in terms of geostatistics. Once the spatial variability model is tested for its agreement with the measured data, the analysis will be carried on through the fifth objective. The final result will be computer plots of reference evapotranspiration and maps of the error of ET_r estimation.

2. LITERATURE REVIEW

This chapter focuses on the changing concepts of evaporation through human history and recent advances in regional evapotranspiration. Later, the theory of regionalized variables will be reviewed along with the specific methodology applied in this study.

2.1 Advances in Reference Evapotranspiration

Recent studies on reference evapotranspiration rates, measured by highly accurate lysimeters and compared to estimates based on formulas, revealed that 95 percent of variability in the rate of reference evapotranspiration can be correctly accounted for by certain estimating formulas. Doorenbos and Pruitt (1977) compared lysimeter-measured evapotranspiration for grass at Davis, California, to evapotranspiration predicted from four different climatic data-based estimating methods. In each case, a very high correlation coefficient was found ($r \geq 0.97$) between measured and estimated evapotranspiration. This result, among others, indicates how accurately evapotranspiration can be currently estimated. Such success has not been reached without many philosophical debates, laborious experiments, and an accumulation of scientific knowledge since antiquity.

2.1.1 Historical Development of Local Evapotranspiration Estimates

Brutsaert (1982) wrote an overview of the progress of the evapotranspiration concept through history. A great deal of the material presented in this section was based on his book, Evaporation into the Atmosphere. Scientists showed limited interest in evapotranspiration formulation before Penman (1948) published the first scientifically sound equation to estimate the evaporation rate of water vapor from a free water surface into the atmosphere. Penman relied on Dalton's (1802) formulation of water vapor flow as the product of water vapor deficit and a conductivity coefficient which was a function of wind velocity. Dalton's efforts were the first step in the quantitative theory of evaporation. Before Dalton (1802), most of the scientific and philosophic works on the subject were intended to clarify concepts on the causes and effects of the evaporation process.

Among the peoples of antiquity, the Greeks contributed the most to explain the relationship between the sun, the clouds and the rain. The views of Anaximander of Miletos (565 B.C.) on the phenomenon of evaporation were summarized by Aetius in Diels (1934):

"Wind is a stream of air, of the finest in it and of the moistest, which are moved or dissolved by the sun."

According to Aetius in Diels (1934), Xenophanes of Colophon (570-460 B.C.) said that:

". . . what happens in the sky is caused by the heat of the sun; for, when the moisture is drawn up out of the sea, the sweat part, which is distinguished by its fine texture, forms a cloud, and drips out as rain . . ."

Later, Aristotle (384-332 B.C.) developed Herakleito's concept of dual exhalation:

". . . the sun not only draws up the moisture on the earth's surface, but also heats and so dries the earth itself; and this must produce exhalations which are of the two kinds we have described, namely vaporous and smoky. The exhalation containing the greater amount of moisture is, ..., the origin of rain: the dry exhalation is the origin and natural substance of winds . . ."

Aristotle agreed that the moist exhalation required solar radiation, but contrary to Anaximander, he denied any connection between evapotranspiration and the wind except that both are separate exhalations and were caused by the sun. Aristotle's opposition to the fact that wind may also be a cause of evaporation constituted a setback that influenced the understanding of the causes and effects of evaporation through the era of the Roman Empire, the Middle Ages, and up to the 17th century. Descartes (1637) broke partially away from Aristotle's views in his book The Meteors, where he said:

". . . although the winds are caused nearly only by the vapors, they are not composed only of vapors . . ."

Later, Perrault (1674), based on experimental results he obtained from the first evaporation experiments on record, broke completely away from the concept that wind is not a cause of evaporation. He wrote:

"Although Aristotle and all the other philosophers give only one cause for the evaporation of water, namely heat, I would be able to find two more, one the cold, its contrary, and the other the movement of the particles of air."

Further experiments conducted by Halley (1691) showed that evaporation is only caused by heat and wind.

Le Roy (1751) introduced the concept of "degree of saturation" of air in order to characterize the moisture content of the air. A major contribution to thermodynamics was made by Dalton (1801, 1802) who clearly expressed the laws of partial pressures known as Dalton's Law; that is the partial pressure of a gas in a mixture of gases is independent of the presence of the others. From this point, a large horizon was opened to the quantitative theories of evaporation.

Dalton's (1802) contribution to the quantification of evaporation was expressed in the following terms:

> "The quantity of any liquid evaporated in the open air is directly as the force of stream from such liquid as its temperature . . ."

> "Evaporation is greater where there is a stream of air than where the air is stagnant."

These concepts were formulated as:

$$E = f_D(\bar{u})(e_s' - e_a) \qquad (2.1)$$

where:

E = the evaporation rate

$f_D(\bar{u})$ = a wind function

$\bar{u}$ = mean wind speed

e_s' = saturation vapor pressure at the evaporating surface

e_a = vapor pressure in the air.

Due to the fact that the Dalton equation included $f_D(\bar{u})$, a wind function, it was called an aerodynamic equation. Earlier in the eighteenth century, it was well known that wherever evaporation took place, it was accompanied by a cooling process. The discovery of the latent heat of vaporization by Black, around 1760, made it clear that evaporation required heat. The discovery by Pouillet (1838) of the solar constant by means of a pyrheliometer, an instrument used to measure direct solar radiation, helped Daubree (1847) establish a numerical relationship between the amount of water evaporated from the earth's surface and the amount of solar energy received at the outer boundary of the atmosphere. Later, Homen (1897) conducted experiments to give a detailed analysis of the energy budget at the earth's surface. Homen's works were partially based on the understanding of radiation from the discovery by Stefan (1879) and Boltzmann (1884) concerning radiant flux:

$$F = \sigma T^4 \tag{2.2}$$

where:

F = radiant flux density $(W \cdot m^{-2})$

σ = Stefan-Boltzmann constant =

$5.67 \times 10^{-8} \ W \cdot m^{-2} \cdot {}^{o}K^{-4}$

T = absolute temperature, ^{o}K (degree Kelvin)

Later, Bowen (1926) and others contributed the energy budget approach to the estimation of local evaporation.

$$R_n = E + H + G \tag{2.3}$$

where:

R_n = specific flux of net incoming radiation

E = the rate of evaporation

H = specific flux of sensible heat into the atmosphere

G = specific flux of heat conducted into the earth.

It can be noticed that Eq.2.1 and Eq.2.3 are two different approaches to the evaluation of the evaporation rate (E). However, each of them contains a term difficult to either measure or estimate. They are e_s' in Eq.2.1 and H in Eq.2.3. A major contribution to science was made by Penman (1948), who combined the two equations into a single formula by discovering the link between vapor pressure deficit, $e_s' - e_a$, and the sensible heat, H. He applied the law of Fourier on heat transfer, Fick's Law on mass transfer, and Newton's Law on viscous shear stress. He also used Reynold's (1874) analogy on the similarity of the wind functions involved in heat transfer and mass transfer. According to Reynolds, the transport mechanisms of heat and momentum in turbulent flow might be similar. Using the laws recalled above, the components of the energy budget equation can be written as follows (Thom et al., 1981):

$$H = \gamma \cdot f_h(\bar{u}) \cdot (T_s - T_a) \qquad (2.4)$$

where

$f_h(\bar{u})$ = wind function for sensible heat transfer

$\bar{u}$ = mean wind speed for the period considered

γ = psychrometric constant

T_s = temperature at the evaporating surface

T_a = air temperature

From the Reynolds' analogy (1874),

$$f_h(\bar{u}) = f_D(\bar{u}) \qquad (2.5)$$

Replacing $f_D(\bar{u})$ in Dalton's equation, Eq.2.1, gives:

$$E = f_h(\bar{u})(e'_s - e_a) \qquad (2.6)$$

Using the Taylor expansion series, the term $(e'_s - e_a)$ can be developed as follows:

$$e'_s = e'(T_s) = e'(T_a) + \left(\frac{\partial e'}{\partial T}\right)_a (T_s - T_a) + \varepsilon \qquad (2.7)$$

$\left(\frac{\partial e'}{\partial T}\right)_a$ is the value of the first derivative of $e'(T)$ at the air temperature T_a. It can be replaced by Δ, the slope of the saturation vapor pressure curve at air temperature, T_a, which can be obtained in equation form (Burman et al., 1983), from the psychrometric chart or from tables. The term ε is negligible since it contains the second derivative of $e'(T)$. Therefore, equation (2.6) can be written:

$$E = f_h(\bar{u}) \; [e'(T_a) + \Delta \cdot (T_s - T_a) - e_a] \qquad (2.8)$$

This gives:

$$(T_s - T_a) = \frac{E}{\Delta \cdot f_h(\bar{u})} - \frac{e'(T_a) - e_a}{\Delta} \qquad (2.9)$$

Substitution of Eq.2.9 in Eq.2.4 gives:

$$H = \gamma \cdot f_h(\bar{u}) \; [\frac{E}{\Delta \cdot f_h(\bar{u})} - \frac{e'(T_a) - e_a}{\Delta}] \qquad (2.10)$$

where:

$e'(T_a)$ = saturation vapor pressure at T_a measured at the surface where $\bar{u}$ is measured.

Substitution of this value of H in Eq.2.3 gives:

$$R_n - G = E + \frac{\gamma}{\Delta} \cdot E - \frac{\gamma}{\Delta} \cdot f_h(\bar{u}) \; [e'(T_a) - e_a] \qquad (2.11)$$

Rearranging to solve for E:

$$E = \frac{\Delta}{\gamma+\Delta} \cdot (R_n - G) + \frac{\gamma}{\gamma+\Delta} \cdot f_h(\bar{u}) \; [e'(T_a) - e_a] \qquad (2.12)$$

Over a period of one day the heat storage in the ground, G, is negligible. Eq.2.12 then becomes:

$$E = \frac{\Delta}{\gamma+\Delta} \cdot R_n + \frac{\gamma}{\gamma+\Delta} \cdot f_h(\bar{u}) \; [e'(T_a) - e_a] \qquad (2.13)$$

Eq.2.13 was developed by Penman (1948). It is often termed the combination equation because it contains an energy balance component and an aerodynamic component. This formula is based on theory but it contains a certain degree of empiricism because of the empirical formulation of the wind function $f(\bar{u})$. $f(\bar{u})$ was a straight line equation fitted to a few observations of evaporation losses versus wind velocity. The Penman formula, although originally developed to estimate evaporation from a free water surface, was used to estimate evapotranspiration of water from a soil and plant canopy surface. This was done by using in the Penman equation a net radiation, R_n, representative of the net radiation at the specific soil-canopy surface.

In 1965, Monteith developed a fully rigorous equation which models evapotranspiration from vegetated areas in terms of the meteorological conditions and plant physiological factors:

$$E = \frac{\Delta \cdot R_n + \rho \cdot C_p \cdot (e'(T_a) - e_a)/r_a}{\Delta + \gamma \cdot (1 + r_s/r_a)} \qquad (2.14)$$

where:

ρ = density of air

C_p = specific heat of air

r_a = aerodynamic resistance to the diffusion of water from the evaporating surface to the same reference level above where vapor pressure is e_a; it is also termed aerodynamic resistance to water vapor transfer

r_s = aerodynamic resistance to the diffusion of water through the evaporating surface; it is also termed canopy resistance to water vapor transfer.

Monteith (1965) gave details on the derivation of Eq.2.14. Eq.2.14 is the Monteith version of Penman equation. It is original in the sense that it gives a more theoretical expression of the wind function than that empirically determined in the Penman equation. Monteith included canopy, r_s, and aerodynamic, r_a, resistances to water vapor transfer in order to eliminate the empiricism of the wind function. However, for practical purposes Eq.2.14 is difficult to use because of the difficulty in determining r_s.

2.1.2 Practical Methods of Computing Local Evapotranspiration

Since Penman (1948), several equations have been developed to model evapotranspiration. Some are more theoretical versions of Penman equation, such as Businger's (1956), Monteith's (1965) and Van Bavel's (1966). They attempted to replace the empirical wind function with more theoretical relations. These scientists included in the Penman equation theoretical expressions for the resistance of water diffusion through and from the evaporating surface. Other methods were more practical than the Penman method. The authors were concerned with practical considerations and wanted to design simple methods which could yield the best estimate from the data available. These empirical methods are widely used by engineers for project design.

Erpenbeck (1981) identified seventeen empirical ET methods. Seven of these methods used air temperature only as the primary weather parameter. Some of them were calibrated using secondary weather data. Ten methods used most of the data available at a relatively complete weather station, including solar radiation, windspeed, and saturation deficit of the air.

Primary weather data refer to values available for each day or month in each year. Secondary weather parameters are long-term values for the period of record, taken on a monthly basis. The secondary weather parameters allow for adjustment based on the general climatic conditions. Such an adjustment has been termed local calibration. Doorenbos and Pruitt (1977) showed consistently improved reference ET estimates by applying local calibration or at least an adjustment that considers the general climatic conditions. Details on different empirical methods were given by Erpenbeck (1981). Erpenbeck evaluated and compared the seventeen ET methods at fourteen meteorological sites in the state of Washington. The FAO-modified Blaney-Criddle method (Doorenbos and Pruitt, 1977) was selected as the best state-wide ET method. The selection was based on the weather data available throughout the state and on statistical ranking using the coefficient of determination for each estimating method compared to lysimeter measurements. Allen and Brockway (1982) compared four FAO-modified methods (i.e. FAO Blaney-Criddle, FAO Penman, FAO Makkink, FAO Pan methods), Jensen-Haise, SCS-modified Blaney-Criddle, standard Penman and Wright modified Penman methods. The comparison was done using daily weather data from the USDA Snake River Water Conservation Laboratory at Kimberly, Idaho. The FAO-modified Blaney-Criddle method was selected as the best state-wide ET method for Idaho based on accuracy, responsiveness of the evaluation, and the primary data requirement of air temperature only. For the state of Oregon, no such comparative study of ET methods has been done to date because no lysimeter is available. However, the climate in western Oregon is like the climate in western Washington, while the climate in central and eastern Oregon is like the arid climate of Idaho. Of the seventeen methods compared by Erpenbeck (1981), only the FAO Blaney-Criddle method will be described. From Doorenbos and Pruitt (1977):

$$f = (8.13 + 0.46\ T_a)p \qquad (2.15)$$

where:

f = Blaney-Criddle "f" factor.

T_a = air temperature (^oC)

p = daily percentage of annual daytime hours (percent)

$$p = 100\ (h_d / h_{an}) \tag{2.16}$$

$$h_{an} = \sum_{j=1}^{an} (h_d)_j \tag{2.17}$$

where:

h_{an} and h_d are the annual and daily daytime hours (hr), respectively

an = number of days per year.

Doorenbos and Pruitt (1977) published a modified version of the Blaney-Criddle method for a green grass reference crop. The following formula was derived:

$$ET_{r-BC} = a + b \cdot f \tag{2.18}$$

where:

$$a = -1.41 + 0.0043\ RH_{min} - n/N \tag{2.19}$$

RH_{min} is the minimum relative humidity (percent)

n/N is the ratio of actual to maximum possible sunshine hours

b is a function of RH_{min}, n/N, and U_2. U_2 is the daytime wind speed (m/s) at 2 meters height. Doorenbos and Pruitt (1977) published calibration curves for Blaney-Criddle ET. Those curves are functions of RH_{min}, n/N, and U_2. Burman et al. (1983) gave a regression equation for b as follows:

$$b = a_0 + a_1 RH_{min} + a_2 n/N + a_3 U_2$$

$$+ a_4 RH_{min} n/N + a_5 RH_{min} U_2 \qquad (2.20)$$

Frevert et al. (1982) determined the numerical values of the regression coefficients

$a_o = 0.81914$, $a_1 = -0.0040322$. $a_2 = 1.0705$,

$a_3 = 0.06546$, $a_4 = 0.0059684$, $a_5 = -0.0005987$

Allen and Brockway (1982) verified in Idaho the recommendation made by Doorenbos and Pruitt (1977) to make a ten percent upward adjustment of the FAO Blaney-Criddle ET estimate for every 1000 meters altitude above sea level.

2.1.3 Estimation of Regional Evapotranspiration

There is a large gap of available methods to make the transformation between local and regional ET estimates. In order to reduce this gap, several possibilities have been examined. These require either extension of local methods or development of new procedures.

A representation of weather condition on a large scale by a single parameter implicitly involves smoothing out the heterogeneities which exist at elementary scales. Such a homogenization is assumed when local estimates are lumped together to represent an estimate at a larger scale or when a representative value of the large scale is measured directly. Fig. 1 (Seguin, 1978) illustrates the heterogeneities that must be smoothed out in order to pass from one scale to a larger one. The reference evapotranspiration, ET_r, corresponds to homogenization at scale D, since in the theory ET_r corresponds to measurement made from a lysimeter surrounded by a mimimun of 100 meters diameter of homogeneous cropping conditions identical to the conditions which prevail on the lysimeter (Jensen, 1973). The regional evapotranspiration, ETR, corresponds to a homogenization at scale E.

Bouchet (1963) showed that variations of regional actual evaporation, ETR, which is an experimental value, lead to simultaneous variations of potential evapotranspiration, ETP, which is the theoretical demand of water due only to the climate. The reason is that any modification of regional ETR due to the reduction of water supply at a regional scale results in an increase in the remaining solar energy available for evaporating water in terms of ETP at any neighboring surface where no water restriction has been imposed. Bouchet (1963) proposed the following equation:

$$ETR + ETP = 2\ ETP_0$$

$$\text{or} \quad ETP - ETP_0 = ETP_0 - ETR \qquad (2.21)$$

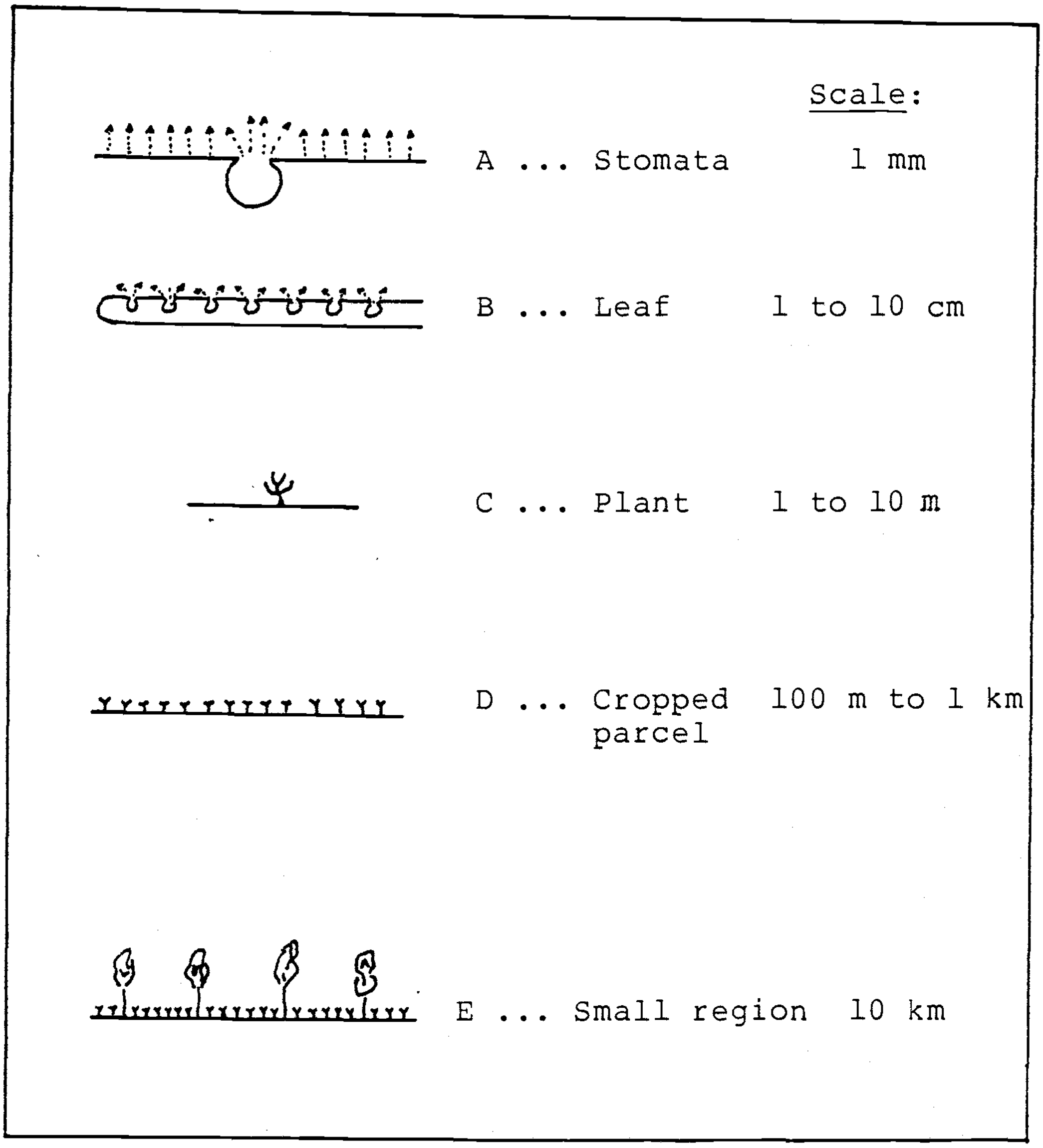

Figure 1. Reconstitution of homogeneous evaporating surfaces by moving from small to larger scales.

where ETP_0 is the potential evapotranspiration from either a local or regional surface when the supply of water is not limited. Eq.2.21 neglected the effect of advection on ETP. In fact, this effect depends on the size of the evaporating surface. Seguin (1975) used the definition sketch in Fig. 2 to illustrate the relationship between ETP and ETR using their corresponding evaporating surface sizes. The following relationship was established (Seguin, 1975):

$$ETP(s) - ETP_0 = [f(x/L,\ L/Z_0)] \cdot (ETP_0 - ETR(S)) \qquad (2.22)$$

where:

Z_0 = surface roughness parameter (m)

$ETP(s)$ = potential evapotranspiration from a surface of size s, with extension x, which is not short of water

ETP_0 = potential evapotranspiration where there is no advection and no water shortage

$ETR(S)$ = actual regional evapotranspiration from surface S, with extension L, where water shortage has been imposed.

Seguin (1975) demonstrated the following:

$$f(x/L,\ L/Z_0) = f(x/L) \quad \text{for} \quad 10^6 \leq L/Z_0 \leq 10^7 \qquad (2.23)$$

Eq.2.22 becomes independent of the surface roughness parameter, Z_0, as L/Z_0 is between 10^6 and 10^7. Seguin (1975) assumed Z_0 = 1 cm, which is equivalent to grass 7.5 centimeters tall as specified by Brutsaert

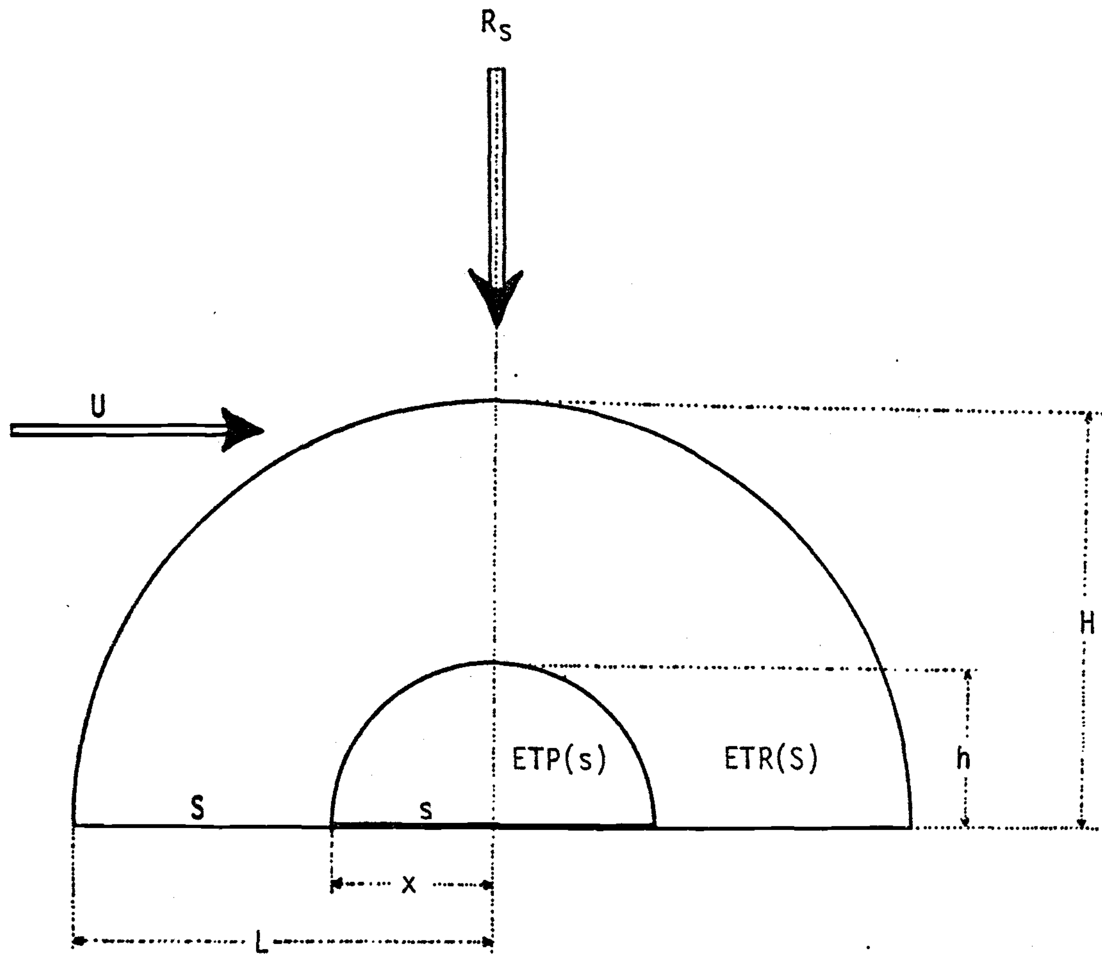

Fig. 2. Regional (S) and local (s) scales of evaporating surfaces.

U = windspeed

R_S = global solar radiation

H and h are thicknesses of boundary layers for surfaces S at the regional scale and s at the local scale.

(1982). For Z_0 = 1 cm, L lies between 10 and 100 kilometers.

Seguin (1978) gave in Fig. 4 an illustration of latent heat flux homogenization as one moved from local to regional scales. Fig. 3 shows the elementary boundary layers produced individually by elementary homogeneous surfaces. If measurements of weather data are made very close to the earth's surface at one specific location, they will represent that particular location. The computation of evapotranspiration from each of these measurements will not represent the whole surface at regional scale. However, if the same measurements are made at a higher altitude outside the elementary boundary layers, the corresponding flux will better represent an average of the elementary fluxes and therefore be more representative of the regional evapotranspiration. One of the applications of remote sensing is to measure representative weather conditions for surfaces at the regional scale.

In the United States, research on regional evapotranspiration has tended to estimate the variation of locally calibrated evapotranspiration as it changes from one location to another. Jensen (1974) found that the peak monthly ET rate at Brawley, California, an arid inland location, is 2.5 times that at a coastal location at Lompoc, California. Earlier, Nixon et al. (1963)

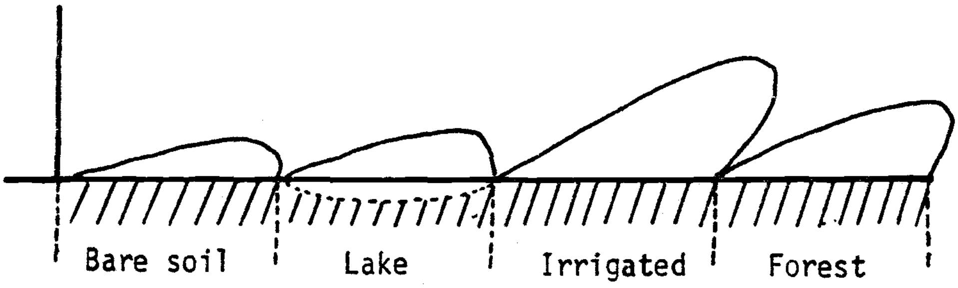

Figure 3. Juxtaposition at regional scale of homogeneous surfaces each developing an internal boundary layer.

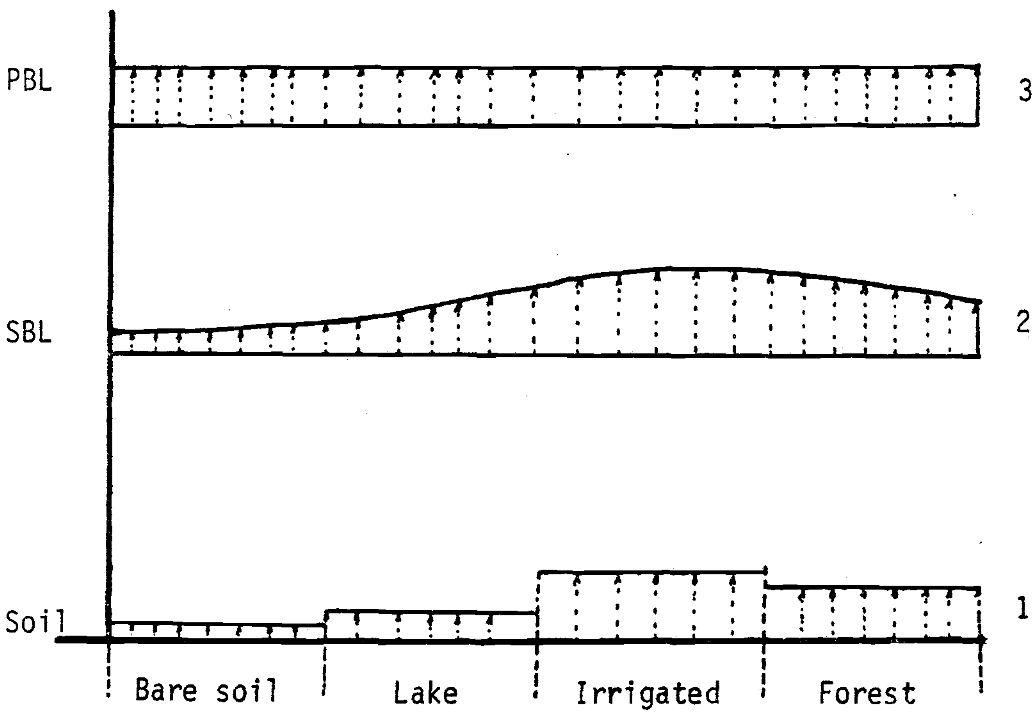

Figure 4. Homogenization of latent heat flux at regional scales 2 and 3 above elementary surfaces in 1, using measurements made at evaporating surface (soil), surface boundary layer (SBL), and planetary boundary layer (PBL).

found in a California coastal valley that ET 37 kilometers (23 miles) inland was more than 1.5 times that 21 kilometers (13 miles) nearer the ocean. Trimmer (1980) concluded that within 100 kilometers radius of weather station, the ET data were representative of the crop water use in the Nebraska High Plains, a relatively flat area. There is no clean-cut difference between the local scale and regional scale on a practical basis. However, it has been customary to assume that at distances greater than 16.5 km (10 miles) away from a weather station, adjustment may have to be made to ET estimates in order to take into consideration the variability due to distance, surface heterogeneity and micro-climatic modifications.

Seguin et al. (1982) stated that two main criteria must be used to design techniques for estimating regional ET. Those estimates must be representative of the whole surface and hence take into consideration the heterogeneity of elementary surfaces which compose the regional scale. The techniques also must be simple enough to be used routinely for practical purposes using traditional weather station networks. The local estimation methods cannot be used for regional estimates because the local estimates have been designed for a homogeneous surface and under very exclusive conditions as specified in the ET_r definition (Jensen et al., 1971;

Doorenbos and Pruitt, 1977). The three main techniques used are summarized below.

The classical approach is to delimit small homogeneous units for which local methods may apply, compute the local estimate of ET for each elementary homogenous surface then make a weighted average of these elementary fluxes. Seguin et al. (1982) noticed it is difficult to equip the required large number of sites. If a catalog of soil and vegetation parameters can be made available, this method can be used in connection with a hydrologic water balance model to derive the regional evapotranspiration.

Brutsaert and Mawdsley (1976) extended the Penman aerodynamic method to the planetary boundary layer. For surfaces larger than 5 to 10 kilometers, the aerodynamic boundary layer over the surface penetrates the atmospheric boundary layer. This requires measurement of weather data (e.g. wind velocity) at 50 to 100 meters height by airplane, balloons or poles. Some successful results have been obtained, but only on a monthly basis. Difficulties arise also from the inadequacy of radiosonde networks and errors in recording upper air data. Other models were based on the measurement of weather data in the lower atmospheric boundary layer (e.g. traditional weather stations) at grid corners to compute surface fluxes. The most difficult problem was to define a parameter that could represent the surface wetness at grid corners (Brunet, 1982).

One approach described as the equilibrium evaporation approach is to approximate regional ET by the global radiative term of Penman's equation. Rouse and Stewart (1972) estimated regional ET with a 10 percent precision, compared to Penman's local ET estimate, using this method for hourly and daily values on moderately dry days. Working with wheat, Perrier et al. (1980) established that equilibrium evapotranspiration accounted for 10 percent of observed ET variation. Davies and Allen (1973) proposed to extend the Priestley-Taylor formulation by using a parameter α which depends upon soil moisture conditions. The Priestley-Taylor formula for equilibrium ET is given as follows:

$$ET_{pt} = \frac{\alpha \cdot \Delta}{\Delta + \gamma} R_n \qquad (2.24)$$

The terminology equilibrium ET refers to the assumption that the evaporating surface is saturated and advective effects are minimal. This assumption allows one to neglect the aerodynamic component of evapotranspiration. In Eq.2.24, α is an empirical coefficient found to be 1.26 (Erpenbeck, 1981) and $\Delta/(\Delta+\gamma)$ is as defined in Eq.2.13.

Another approach consists of using the Bouchet (1963) relationship, Eq.2.21. Bouchet's formula appears as valid as the equilibrium evaporation method (Seguin et al., 1982). A difficulty in using this formula is that it does not apply for ET_r estimates in windy regions subject to large scale advection. Besides the difficulties inherent to each individual approach and for which improvements are possible, all these methods of regional estimation provide only global values and their precision with respect to the surface size has not been defined.

Remote sensing can be used to collect, more rapidly and on different scales, weather and surface parameters needed for ET estimates. Due to recent progress in technology (resolution, frequency of passes, stability of measuring systems) and associated techniques (data treatment, image analysis, atmospheric corrections), remote sensing now appears as a useful tool to improve methods of local and regional evapotranspiration estimation, especially by using thermal infrared or microwave imagery. Using the basic energy balance equation, Eq.2.3, Bartholic et al (1970) derived the rate of evapotranspiration as follows:

$$E = \frac{R_n - G}{1 + \gamma \cdot (T_a - T_c)/[e_s'(T_a) - e_s'(T_c)]} \qquad (2.25)$$

In Eq. 2.25 T_c is canopy temperature measured by remote sensing and $e_s'(T_c)$ is the saturated vapor pressure obtained as a function of T_c. All other terms are defined as in the Penman equation Eq.2.13. Brown and Rosenberg (1973) eliminated $e_s'(T_a) - e_s'(T_c)$ from Eq.2.25 using the aerodynamic resistance to water vapor transfer, r_a, and the specific heat capacity of air, C_p. This method is formulated as follows:

$$E = (R_n - G) + [\rho C_p (T_c - T_a)/r_a] \qquad (2.26)$$

where:

ρ = the air density

Stone and Horton (1974) found that Bartholic's method yielded smaller estimates, by 17 percent, than the other typical predictions of local ET_r, whereas the Brown-Rosenberg method produced estimates 22 percent larger than the traditional models (i.e., Penman method). Besides these difficulties which are related to local estimates, the main problem concerns the methodology of incorporating remote sensing data, T_c and $e_s'(T_c)$, and combining them with ground based parameters in order to derive ET_r. The use of microwave techniques to remotely sense T_c in case of cloudy conditions requires more research in order to define the exact significance of those data relative to surface soil moisture.

2.2 Theoretical Fundamentals of Geostatistics

The purpose of this section is to present the main geostatistical tools, termed the semivariogram, estimation variance, and kriging, used by geostatisticians to characterize spatial variability and to estimate regionalized variables. Elements of the theory of regionalized variables will be covered. In the next chapter, this theory will be applied to identify the spatial structure and variability of reference evapotranspiration. The theory will therefore be explained using reference evapotranspiration as an example variable.

2.2.1 The Semivariogram

Matheron (1962-1963) published his treatise on the theory of Regionalized Variables, after the empirical work done by Krige in South Africa to estimate ore reserve in gold mines. The development and applications of this theory for mining industries led to the popular name Geostatistics. The application of Geostatistics to the estimation of ore reserves in mining is its most well-known use. However, it has been emphasized (Clark, 1979) that this estimation technique can be used wherever a continuous measure is made on a sample at a particular location in space or time (i.e. where a sample value is expected to be affected by its position and its relationship with its neighbors). Such a continuous variable which is expected to take different values at different sampling locations is termed a regionalized variable. All the realizations ($z(x_i)$, i=1,...n) at n locations in a given domain or geographical region constitute a random variable.

According to this definition, the different values of the reference evapotranspiration in a given region at the same time or during the same period of time can be considered as local realizations of a regionalized random variable. In addition, the variable reference evapotranspiration is continuous over space and its realizations from one location to the next location a certain distance away are random (i.e. not determined a priori). The random character of evapotranspiration is due to the randomness of the variables it was derived from. In fact, temperature, relative humidity, wind velocity, and solar radiation are each a random variable from one location to another during the same period of time. Reference evapotranspiration, as well as any other spatial variable such as soil permeability, topographic elevation, population density, tree diameter in a forest, rainfall or temperature in a watershed, sediment mean size distribution in an alluvial deposit, is a <u>regionalized variable</u>. Those variables have a spatial characteristic defined by what is called the semivariogram.

Most of the following explanation on the semivariogram definition and characteristics was taken from a review of David (1977) and Journel and Hujbregts (1978). The material was greatly simplified in order to present only the notions and properties which can be applied to the spatial variability of evapotranspiration.

Let us assume a spatial variable, z(x), measured or observed at N locations, x_i (i=1,2,...,N), to be represented by $z(x_1)$, $z(x_2)$,..., $z(x_N)$. One way to compare two values z(x) and z(x + h), separated by h kilometers, is to compute their difference z(x) - z(x + h). This difference can be positive, negative or zero. If one is just interested in the absolute value of the difference, then the value to be considered is |z(x) - z(x + h)|. If the main interest is not just to compare two single observations but all the n(h), n(h) < N, observations separated by the distance h kilometers, then it makes more sense to compute the average of the quantity [z(x) - z(x + h)]. This average can be written as follows:

$$D(h) = \frac{1}{n(h)} \sum_{i=1}^{n(h)} [z(x_i) - z(x_i + h)] \qquad (2.27)$$

D(h) is the estimate of the mathematical expectation of the difference $[z(x_i) - z(x_i + h)]$. The plot of D(h) for different values of h is termed the drift and its departure from zero indicates how much the region is heterogeneous with respect to the property z(x). If the difference D(h) is zero for all values of h over the region considered, the regionalized random variable z(x) is said to have first order stationarity (i.e. there is no drift). First order stationarity also indicates there is no trend (Clark, 1979). For variables which exhibit first order stationarity,

$$E\ \{z(x) - z(x + h)\} = 0 \qquad (2.28)$$

The drift, D(h), can be positive, negative or zero. However, in geostatistics one is interested in the absolute value of changes as functions of distance. One way to avoid dealing with the sign of D(h), without being encumbered by the calculation of means of absolute values, is to compute the mathematical expectation of the squared difference of $z(x_i) - z(x_i + h)$ which is defined as:

$$2\gamma(h) = E\ \{[z(x_i) - z(x_i + h]^2\} \qquad (2.29)$$

In its computational form, Eq. 2.29 is written as follows:

$$2\gamma(h) = \frac{1}{n(h)} \sum_{i=1}^{n(h)} [(z(x_i) - z(x_i + h)]^2 \qquad (2.30)$$

where:

$2\gamma(h)$ is termed the variogram

$n(h)$ is the number of pairs separated by the distance h

$\gamma(h)$ is termed the semivariogram and is written:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z(x_i) - z(x_i + h)]^2 \tag{2.31}$$

2.2.2 Stationarity Assumptions

It can be intuitively demonstrated that the realizations of a regionalized variable constitute a random function as they contain a certain degree of randomness. According to Matheron (1976a), it is not possible to consider any experiment which would conclude that a mining deposit is not a realization of a random function. This same statement can be made of any climatic variable which varies with location (e.g. evapotranspiration). Some assumptions have to be introduced about this type of random function. Since the purpose of geostatistical analysis is to characterize the variability of a parameter as a function of geographic location, one should look for a stationary random function, a natural property which remains invariant under spatial translation. The realization of the function should be allowed to change from one location to another, but the mathematical expression of the underlying function should be stable. This property is called stationarity. Going from the most restrictive to the more general, three possible assumptions on stationarity can be made in geostatistics (David, 1977).

Weak Stationarity (Second Order Stationarity): This assumption consists of two conditions seldom found in natural phenomena:

The expected value of the regionalized variable z(x) is the same over the entire field of interest. This is the first order stationarity written as follows:

$$E\{z(x)\} = m$$

or

$$E[z(x) - z(x + h)] = 0 \qquad (2.32)$$

where (x + h) is obtained from x through a vectorial translation using the vector distance h.

For each pair of random variables {z(x), z(x + h)}, the covariance exists and depends on the separation h.

$$\begin{aligned} cov(x, x + h) &= E\{[z(x) - m][z(x + h) - m]\} \\ &= C(h) \end{aligned} \qquad (2.33)$$

The stationarity of the covariance implies the stationarity of the variance or of the variogram. Thus:

$$Var\{z(x)\} = E\{[z(x) - m]^2\} = C(0) \qquad (2.34)$$

From Eq. 2.29, it follows:

$$\gamma(h) = \frac{1}{2} E\{[z(x) - z(x + h)]^2\} \tag{2.35}$$

Adding and subtracting m and expanding, Eq. 2.35 becomes:

$$\gamma(h) = \frac{1}{2} E\{[z(x) - m]^2 - 2[z(x) - m][z(x + h) - m] + [z(x + h) - m]^2\} \tag{2.36}$$

In case of first order stationarity,

$$E\{z(x)\} = E\{z(x + h)\} = m \tag{2.28}$$

therefore:

$$\gamma(h) = \frac{1}{2}\{C(0) - 2C(h) + C(0)\} \tag{2.37}$$

$$\gamma(h) = C(0) - C(h) \tag{2.38}$$

Relation (2.38) indicates that, under the hypothesis of second order stationarity, the covariance and the semi-variogram are two equivalent tools for characterizing the auto-correlations between two variables $z(x)$ and $z(x + h)$ separated by h. A third tool termed the correlation, $\rho(h)$, can be derived from Eq. 2.38 as follows:

$$\rho(h) = \frac{C(h)}{C(0)} = 1 - \frac{\gamma(h)}{C(0)} \tag{2.39}$$

Second order stationarity supposes a priori existence of variance, $C(0)$, and covariance, $C(h)$, independent of x. However, according to Journel and Huijbregts (1978), there are several natural phenomena and random functions which have an infinite capacity for dispersion, i.e., which have neither a priori variance nor a covariance, but for which a variogram can be defined. The intrinsic hypothesis can be made where the second order stationarity is not rigorously applicable.

Intrinsic Hypothesis: A random function is said to satisfy the intrinsic hypothesis when:

The mathematical expectation of z(x) exists and does not depend on the location x,

$$E\{z(x)\} = m \qquad (2.32)$$

For all vectors h, the increment [z(x) - z(x + h)] has a finite variance which does not depend on x,

$$\mathrm{Var}\{[z(x) - Z(x + h)]\} = E\{[z(x) - z(x + h)]^2 = 2\gamma(h) \qquad (2.40)$$

Eq. 2.38 and Eq. 2.40 indicate that second order stationarity implies the intrinsic hypothesis, but the converse is not true.

Quasi-Stationarity (Hypothesis of Universal Kriging): This hypothesis is less restrictive than the two previous ones. It assumes the second moment, Var{[z(x) - z(x + h)]}, has some stationarity within a vicinity of restricted size and that the expectation E{[z(x)]}, which is no longer stationary, varies in a regular manner in a vicinity b_0. If x and x + h are taken in such a vicinity, so that $|h| \leq b_0$, then these relations follow:

$$E[z(x)] = m(x)$$

$$E[z(x + h)] = m(x + h) \tag{2.41}$$

$$D(h) = E[z(x) - z(x + h)] \neq 0 \tag{2.42}$$

D(h) can be statistically derived by a linear regression technique and used for kriging, which in the case where a drift is present, is termed universal kriging. The universal kriging is possible only if the drift D(h) is a linear combination of simple known functions (Journel and Hujbregts, 1978) and if the semivariogram $\gamma(h)$ of the original z(x), defined by Eq. 2.31, is accessible. More details on universal kriging can be found in David (1977). According to Journel and Hujbregts (1978), quasi-stationarity is a compromise between data availability and a strict stationarity because it is always possible by reducing the vicinity b_0 to produce a zone so small that the stationarity is verified. However, this reduction would not always be possible because of economical constraints related to station density for data collection. If no limitation is made on data availability, the stationarity of a continuous random variable can always be verified as the vicinity is adequately reduced. Because of this fact, a theoretical test could never refute the hypothesis of stationarity of a continuous random function (Journel and Hujbregts, 1978).

2.2.3 Properties of the Semivariogram

A semivariogram function represents all the possible values of $\gamma(h)$ as h varies. To compute a semivariogram function, one uses Eq. 2.31 for all possible h. The graphical representation of all the computed $\gamma(h)$ is termed the experimental semivariogram. This curve is obtained by fitting a smooth curve to the cloud of points representing the pairs $\{h, \gamma(h)\}$. In almost all publications on geostatistics, the term semivariogram is indifferently used to refer to the computational value $\gamma(h)$ for a given h and its graphical representation. In order to avoid adding to the confusion, this paper will not use any specific new term to make a distinction between those concepts.

Ideal Semivariogram Function: Although an experimental semivariogram can exhibit a large variety of shapes, an ideal semivariogram plots as shown in Fig. 5. An ideal semivariogram is expected to maintain the following properties:

The semivariogram is always a positive quantity, expected to go to zero as the distance h goes to zero.

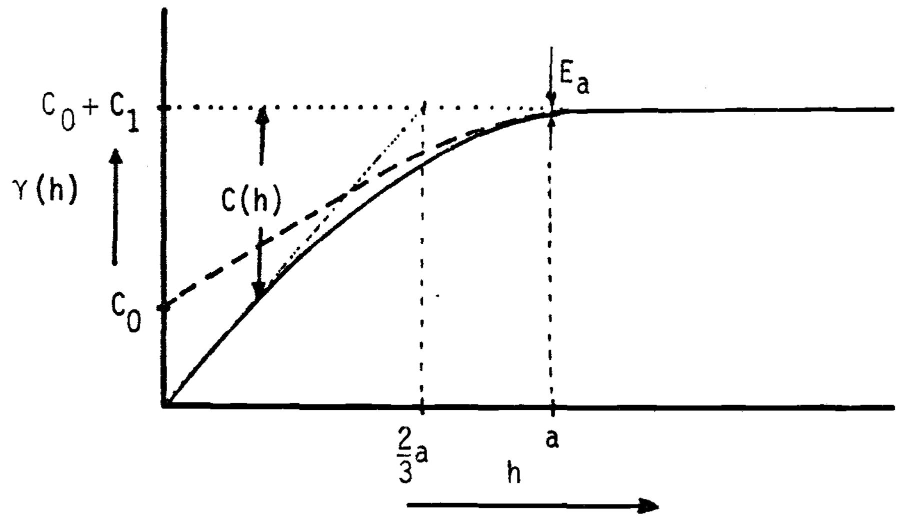

Figure 5. Ideal semivariogram curve.

Hence:

$$\gamma(h) = \gamma(-h) > 0 \quad \text{and} \quad \gamma(0) = 0 \qquad (2.43)$$

In practice, due to the difficulty to make h as small as possible, it may occur that:

$$\gamma(0) = C_0 \neq 0 \qquad (2.44)$$

C_0 is termed nugget effect. It represents half the squared error that one must account for when estimating the variable z(x) within a distance less than the sample distance.

The semivariogram, in case of second order stationarity, will approach asymptotically a maximum value which is the sample variance, Var[z(x)], as shown in Fig. 5. The maximum value is termed the sill value, $C_0 + C_1$, and is written:

$$C_0 + C_1 = \gamma(\infty) \tag{2.45}$$

When the nugget effect C_0 is zero, the sill value becomes C_1. Beyond a certain distance, a,

$$\gamma(a) = C_0 + C_1 - E_a \tag{2.46}$$

where E_a is a negligible quantity. a is termed the range. It represents the distance beyond which the spatial structure of the variable no longer exists. It is also termed the range of influence in the sense that it represents the zone within which the semivariogram can be used to represent a spatial correlation and to interpolate between data locations. Beyond distance a, the random variables z(x) and z(x + h) are no longer correlated.

Isotropic Models of Semivariogram: When a semivariogram function γ(h) depends only on the absolute value |h|, the natural phenomenon it describes is said to be isotropic and the corresponding semivariogram is termed an isotropic semivariogram. No matter how well an experimental semivariogram fits the points which represent the computed γ(h), the experimental semivariogram cannot describe perfectly the variability of a natural phenomenon in a region.

According to Gambolati and Volpi (1979) "the true semivariogram (which resides in God's mind) will never be known." However, experience has proven that almost all the semivariograms observed in Geostatistics fall in the following four categories:

(1) Linear model:

$$\gamma(h) = C_0 + b \cdot h \qquad 0 \le h \le a$$
$$\gamma(h) = C_0 + C_1 \qquad h > a \qquad (2.47)$$

where b is the slope

(2) Spherical model or Matheron model:

$$\gamma(h) = C_0 + C_1 \left[\frac{3}{2}\left(\frac{h}{a}\right) - \frac{1}{2}\left(\frac{h}{a}\right)^3\right] \qquad 0 \le h \le a$$
$$\gamma(h) = C_0 + C_1 \qquad \text{for} \quad h > a \qquad (2.48)$$

This model is the most commonly chosen one in Geostatistics. According to David (1977), it has been possible to estimate a hundred ore deposits with only the spherical and the exponential model and the tendency is now to use only the spherical model. This model was mentioned for the first time by Matheron.

(3) Exponential model:

$$\gamma(h) = C_0 + C_1 \left[1 - \exp\left(-3\frac{h}{a}\right)\right] \qquad 0 \le h \le a$$
$$\gamma(h) = C_0 + C_1 \qquad \text{for} \quad h > a \qquad (2.49)$$

In practice, a is such that $\gamma(a)$ = 95 percent of the sill value at the range (Vieira, 1983).

(4) Gaussian model:

$$\gamma(h) = C_0 + C_1[1 - \exp(-\frac{3h^2}{a^2})] \qquad (2.50)$$

where a is the distance after which the semivariogram becomes visually stable.

Anisotropic Models of Semivariogram: A property is said to be anisotropic when its variability is not the same in every direction. The structural function $\gamma(h)$ which characterizes its spatial variability depends on the direction of the vector distance h. When anisotropy is suspected, a semivariogram function must be experimentally determined for each direction where the characteristics (i.e. isotropic model, nugget effect, C_0, sill value, $C_0 + C_1$, and range, a) are suspected of changing. When anisotropy exists, a single isotropic semivariogram can no longer be used to characterize the spatial variability of the property in all directions. Two types of anisotropy have been identified in Geostatistics: Geometric anisotropy and zonal anisotropy.

A semivariogram $\gamma(x, y, z)$ in tridimensional space has a geometric anisotropy when the anisotropy can be reduced to isotropy by a linear transformation of the vector distance h as follows:

$$\gamma(h) = \gamma'(\sqrt{x'^2 + y'^2 + z'^2}) \qquad (2.51)$$

where:

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = [A] \begin{bmatrix} x \\ y \\ z \end{bmatrix} \qquad (2.52)$$

[A] represents the matrix of transformation of the coordinates (x, y, z) into the new coordinates (x', y', z'). Details on the derivation of matrix [A] will be found in David (1977) and Journel and Hujbregts (1978).

Any anisotropy which cannot be reduced by a simple linear transformation of coordinates is termed zonal anisotropy. It is identified by a significant difference between the sills of the individual unidirectional semivariograms. A unique model of zonal anisotropy can be derived for the whole domain as follows (David 1977):

$$\gamma(h) = \gamma_{iso}(|h|) + \gamma_{zon}(|h_z|) \qquad (2.53)$$

In the case of zonal anisotropy, the total variability $\gamma(h)$ can always be decomposed into an isotropic component $\gamma_{iso}(|h|)$ and a zonal component $\gamma_{zon}(h_z)$. For vector distance h within the region:

$|h|$ is the absolute value of h

$|h_z|$ is the component of h in the direction of zonal anisotropy.

The direction of anisotropy is chosen on basis of experience, configuration of the region, and the specific property under study. As a general rule, an anisotropic semivariogram $\gamma(h)$ can always be decomposed into a sum of p isotropic semivariograms $\gamma_i(|h_i|)$. As formulated by Journel and Hujbregts (1978):

$$\gamma(h) = \sum_{i=1}^{p} \gamma_i(|h_i|) \tag{2.54}$$

2.2.4 Simple Kriging

Kriging is a local estimation technique which provides the best linear unbiased estimator (abbreviated to BLUE) of the unknown characteristic studied (David, 1977). The name kriging appeared around 1960 to designate that estimation technique which was created in France by Matheron. D.G. Krige (1951) was probably the first to make use of spatial correlation and BLUE in the field of mineral resources evaluation.

Given a property $z(x)$ observed at n locations $x_i (i=1,...,n)$ in a region where the semivariogram function is available, the best linear unbiased estimate of $z(x)$ can be made at a location x_0 where no observations $z(x_0)$ are available. The term "point kriging" refers to estimation by the BLUE technique of $z(x)$ at a single location x_0. "Block kriging" refers to the estimation by the BLUE technique of the mean value of z(x) over a block or subregion. A block is a surface or volume smaller than the whole region or domain from which data are collected. The term "simple kriging" is used to indicate kriging in case of second order stationarity. "Universal kriging" is application of the BLUE technique which takes into account the existence of a drift (i.e. non stationarity).

In many applications of kriging, such as geochemistry, hydrology contour mapping (Clark, 1979), or local estimation of evapotranspiration, all that is needed is point kriging on a regular grid system. Given n observations of $z(x_i)$ at locations $x_i (i=1,...,n)$ in a region where a semivariogram function has been defined, a kriging system of linear equations can be derived to provide, at location x_0, a kriging estimate $z^*(x_0)$ expressed by David (1977) as follows:

$$z^*(x_0) = \sum_{i=1}^{n} w_i \; z(x_i) \tag{2.55}$$

where:

$z(x_i)$ $\{i=1,...,n\}$ are observed data at location x_i

$z^*(x_0)$ is the kriging estimate at location x_0.

w_i are weights that will be obtained from the kriging system, Eq. 2.65. Eq. 2.55 shows $z^*(x_0)$ is a linear estimate using $z(x_i)$ and $w_i (i=1,...,n)$. The weights w_i are computed to agree with the following two conditions:

(1) Non-bias Condition: This condition implies the kriging estimate $z^*(x_i)$ at a data location is exactly equal to the observation $z^*(x_i)$ at that location. This condition is formulated as follows:

$$E[z^*(x_0) - z(x_0)] = 0 \quad (2.56)$$

Replacing $z^*(x_0)$ by its expression in Eq. 2.55 gives:

$$E\{[\sum_{i=1}^{n} w_i \; z(x_i)] - z(x_0)\} = 0 \quad (2.57)$$

Because E{ } is a linear operator, Eq. 2.57 becomes:

$$E\{z(x_i)\} \sum_{i=1}^{n} w_i = E\{z(x_0)\} = m \quad (2.58)$$

Using the first order stationarity assumption stated by Eq. 2.31,

$$E\{z(x_i)\} = E\{z(x_0)\} = m \quad (2.59)$$

Therefore:

$$\sum_{i=1}^{n} w_i = 1 \quad (2.60)$$

Eq. 2.60 is another expression of the non-bias condition.

(2) The Minimum Estimation Variance: This condition is written as follows:

Minimize $E\{[z^*(x_0) - z(x_0)]^2\}$ (2.61)

Replacing $z^*(x_0)$ by its value from Eq. 2.55 gives:

$$E\{[\sum_{i=1}^{n} w_i\ z(x_i) - z(x_0)]^2\} \quad (2.62)$$

Using the linear property of the operand E{ },

$$E\{z^*(x_0) - z(x_0)]^2\} = E\{z^*(x_0)]^2\}$$

$$+ E\{[z(x_0)]^2\} - 2\ E\{[z^*(x_0)]\ [z(x_0)]\} \quad (2.63)$$

<u>Kriging System of Equations</u>: The kriging system of linear equations is based on the non-bias and minimum estimation variance conditions. Developing the right hand side of Eq. 2.63 term by term and using Eq. 2.33 leads to:

$$E\{[z^*(x_0)]^2\} = E\{[\sum_{i=1}^{n} w_i\ z(x_i)]^2\}$$

$$= \sum_{i=1}^{n} \sum_{j=1}^{n} w_i\ w_j\ E\{z(x_i)\ z(x_j)\}$$

$$= \sum_{i=1}^{n} \sum_{j=1}^{n} w_i\ w_j\ [C(x_i,\ x_j) + m^2] \quad (2.64)$$

where:

$$\sum_{j=1}^{n} w_j = 1 \quad (2.60)$$

$$E\{[z(x_0)]^2\} = E\{z(x_0)\ z(x_0 + 0)\}$$

$$= C(x_0, x_0) + m^2 \qquad (2.65)$$

$$2E\{[z^*(z_0)][z(x_0)]\} = 2E\{[\sum_{i=1}^{n} w_i\ z(x_i)\ z(x_0)]\}$$

$$= 2 \sum_{i=1}^{n} w_i\ E\{[z(x_i)\ z(x_0)]\} \qquad (2.66)$$

$$= 2 \sum_{i=1}^{n} w_i\ C(x_i, x_0) + 2m^2$$

Substituting Eq. 2.64 through Eq. 2.66 into Eq. 2.63 gives:

$$E\{[z^*(x_0) - z(x_0)]^2\} = \sum_{i=1}^{n} \sum_{j=1}^{n} w_i\ w_j\ [C(x_i, x_j) + m^2]$$

$$+ C(x_0, x_0) + m^2 - 2 \sum_{i=1}^{n} w_i\ C(x_i, x_0) - 2m^2$$

$$E\{[z^*(x_0) - z(x_0)]^2\} = C(x_0, x_0) \qquad (2.67)$$

$$+ \sum_{i=1}^{n} \sum_{j=1}^{n} w_i\ w_j\ C(x_i, x_j) - 2 \sum_{i=1}^{n} w_i\ C(x_i, x_0)$$

where:

$C(x_0, x_0)$ is the covariance of $z(x)$ at x_0

$C(x_0, x_0)$ is zero if there is no nugget effect

$C(x_0, x_i)$ is the covariance of $z(x)$ at x_0 and the sampling point x_i

$C(x_i, x_j)$ is the covariance of $z(x)$ at sampling points x_i and x_j.

$$C(x_i, x_j) = 0 \quad \text{for } i = j$$
$$C(x_i, x_j) \neq 0 \quad \text{for } i \neq j \qquad (2.68)$$

Eq. 2.67 is to be minimized under conditions of Eq. 2.61. The condition of minimum variance set in Eq. 2.62, and the condition of unbias expressed by Eq. 2.60 may be combined in a single mathematical expression using the Lagrangian parameter λ as follows:

$$\frac{\partial F}{\partial w_i} = 0 \qquad (2.69)$$

where:

$$F = E\{[z^*(x_0) - z(x_0)]^2\} + 2\lambda\{(\sum_{i=1}^{n} w_i) - 1\} \qquad (2.70)$$

The last term in { } in Eq. 2.70 is equal to zero. The factor 2 in front of λ has been chosen in order to avoid non integer coefficients in the anticipated expression of $\partial F/\partial w_i$. Substituting Eq. 2.67 and Eq. 2.70 into Eq. 2.69,

$$\frac{\partial F}{\partial w_i} = \frac{\partial}{\partial w_i}\{C(x_0, x_0)\} + \frac{\partial}{\partial w_i}\{\sum_{i=i}^{n}\sum_{j=1}^{n} w_i w_j C(x_i, x_j)\}$$
$$- \frac{\partial}{\partial w_i}\{2\sum_{i=1}^{n} w_i C(x_i, x_0)\} + \frac{\partial}{\partial w_i}\{2\lambda[(\sum_{i=1}^{n} w_i) - 1]\}$$
$$(2.71)$$

Analyzing each term of Eq. 2.71 gives Eqs. 2.72 through 2.75 as follow:

$$\frac{\partial}{\partial w_i} \{C(x_0, x_0)\} = 0 \tag{2.72}$$

$$\frac{\partial}{\partial w_i} \{ \sum_{i=1}^{n} \sum_{j=1}^{n} w_i w_j C(x_i, x_j)\} = 2 \sum_{j=1}^{n} w_i C(x_i, x_j) \tag{2.73}$$

The factor 2 is mathematically justified by the fact that:

$$\sum_{i=1}^{n} w_i = \sum_{j=1}^{n} w_j$$

$$\frac{\partial}{\partial w_i} \{2 \sum_{i=1}^{n} w_i C(x_i, x_0)\} = 2C(x_i, x_0) \tag{2.74}$$

$$\frac{\partial}{\partial w_i} \{2\lambda[(\sum_{i=1}^{n} w_i) - 1]\} = 2\lambda \tag{2.75}$$

Adding up Eqs. (2.72) through (2.75), Eq. 2.69 becomes:

$$\sum_{i=1}^{n} w_j C(x_i, x_j) + \lambda = C(x_i, x_0) \qquad (i=1,2,\ldots,n)$$

$$\sum_{i=1}^{n} w_i = 1 \tag{2.76}$$

The system of linear equations given by Eq. 2.76 is termed kriging system. It has n+1 equations and n+1 unknowns. In matrix form it is written:

$$[K][W] = [R] \tag{2.77}$$

where:

$$[K] = \begin{bmatrix} C(x_1, x_1) & C(x_1, x_2) & \ldots & C(x_1, x_n) & 1 \\ C(x_2, x_1) & C(x_2, x_2) & \ldots & C(x_2, x_n) & 1 \\ \vdots & & & & \vdots \\ C(x_n, x_1) & C(x_n, x_2) & \ldots & C(x_n, x_n) & 1 \\ 1 & 1 & \ldots & 1 & 0 \end{bmatrix} \tag{2.78}$$

[K] is termed the kriging matrix.

$$[W] = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \\ \lambda \end{bmatrix} \qquad [R] = \begin{bmatrix} C(x_0, x_1) \\ C(x_0, x_2) \\ \vdots \\ C(x_0, x_n) \\ 1 \end{bmatrix} \tag{2.79}$$

Solving Eq. 2.76 which is a system of n+1 equations and n+1 unknowns, w_i (i=1,...,n) and λ, provides weights w_i needed to compute the kriging estimate $z^*(x_0)$ given by Eq. 2.55. The kriging estimation variance is defined as follows:

$$\sigma_K^2(x_0) = E\{[z^*(x_0) - z(x_0)]^2\} \tag{2.80}$$

Rearranging Eq. 2.76:

$$\sum_{i-1}^{n} w_j \, C(x_i, x_j) = C(x_i, x_0) - \lambda \tag{2.81}$$

and estimating the results into Eq. 2.67 gives:

$$\begin{aligned}\sigma_K^2(x_0) &= C(x_0, x_0) + \sum_{i=1}^{n} w_i \, C(x_i, x_0) - \sum_{i=1}^{n} w_i \, \lambda \\ &\quad - 2 \sum_{i=1}^{n} w_i \, C(x_i, x_0) \\ &= C(x_0, x_0) + \sum_{i=1}^{n} w_i \, C(x_i, x_0) - \lambda \sum_{i=1}^{n} w_i \\ &\quad - 2 \sum_{i=1}^{n} w_i \, C(x_i, x_0) \\ &= C(x_0, x_0) - \sum_{i=1}^{n} w_i \, C(x_i, x_0) - \lambda\end{aligned} \tag{2.82}$$

The kriging estimation variance is given by:

$$\sigma_k^2(x_0) = C(x_0, x_0) - \sum_{i=1}^{n} w_i\, C(x_0, x_i) - \lambda \tag{2.83}$$

The kriging system given by Eq. 2.76 assumes second order stationarity (i.e. stationary of the covariance). In case of the intrinsic hypothesis, only the stationarity of the variance is assumed. The kriging system should then be modified in order to be written in terms of semivariograms. According to David (1977), this can be done using Eq. 2.38 which gives:

$$C(h) = C(0) - \gamma(h) \tag{2.84}$$

Eq. 2.84 can be written using a more general notation which keeps track of the coordinates present in the kriging system:

$$\begin{aligned} C(x_0, x_i) &= C(x_0, x_0) - \gamma(x_0, x_i) \\ C(x_i, x_j) &= C(x_0, x_0) - \gamma(x_i, x_j) \end{aligned} \tag{2.85}$$

Replacing $C(x_0, x_i)$ and $C(x_i, x_j)$ in Eq. 2.66 through Eq. 2.76 gives the following formulas used in case of kriging under the condition of the intrinsic hypothesis:

$$\sum_{j=1}^{n} w_j \gamma(x_i, x_j) + \mu = \gamma(x_0, x_i) \qquad (i=1,2,\ldots,n)$$

$$\sum_{i=1}^{n} w_i = 1 \qquad (2.86)$$

where μ replaces λ in Eq. (2.71).

Therefore, substituting Eq. 2.85 into Eq. 2.83, it follows that (Rendu et al., 1978):

$$\sigma_K^2(x_0) = C(x_0, x_o) - \sum_{i=1}^{n} w_i C(x_0, x_0) + \sum_{i=1}^{n} w_i \gamma(x_0, x_i) + \sum_{i=1}^{n} w_i \gamma \qquad (2.87)$$

which reduces to:

$$\sigma_k^2(x_0) = \sum_{i=1}^{n} w_i \gamma(x_i, x_0) + \mu \qquad (2.88)$$

where μ has replaced λ.

If h_{ij} and h_{0i} are vectors defined by the couples of points (x_i, x_j) and (x_0, x_i),

$$\gamma(x_i, x_j) = \gamma(h_{ij})$$

$$\gamma(x_0, x_i) = \gamma(h_{0i})$$

Eq. 2.86 can then be developed as follows:

$$w_1\ \gamma(h_{11}) + w_2\ \gamma(h_{12}) + \ldots + w_n\ \gamma(h_{1n}) + \mu = \gamma(h_{01})$$

$$w_2\ \gamma(h_{21}) + w_2\ \gamma(h_{22}) + \ldots + w_n\ \gamma(h_{2n}) + \mu = \gamma(h_{02})$$

$$\vdots$$

$$w_n\ \gamma(h_{n1}) + w_2\ \gamma(h_{n2}) + \ldots + w_n\ \gamma(h_{nn}) + \mu = \gamma(h_{0n})$$

$$w_1 \qquad w_2 + . \quad . \quad . + w_n \qquad + 0 = 1.0 \tag{2.89}$$

Solving the system of linear equation 2.89 will provide the weights w_i needed in Eq. 2.55 to obtain:

$$z^*(x_0) = \sum_{i=1}^{n} w_i\ z(x_i) \tag{2.55}$$

According to David (1977), the system given by Eq. 2.89 has proven to be true even when $C(x_0, x_0) = \gamma(\infty)$ does not exist (i.e. if the semivariogram does not have a sill value).

2.2.5 Universal Kriging

When a drift is present which is not equal to zero, some geostatisticians recommend to include it in the kriging matrix. For simple drift represented by a second degree polynominal, David (1977) recommended the following kriging system in matrix form:

$$[K_2][W] = [R_2] \tag{2.90}$$

where:

$$[K_2] = \begin{bmatrix} \gamma(h_{11}) & \gamma(h_{12}) & \cdots & \gamma(h_{1n}) & 1 & X_1 & Y_1 & X_1^2 & Y_1^2 & X_1Y_1 \\ \gamma(h_{21}) & \gamma(h_{22}) & \cdots & \gamma(h_{2n}) & 1 & X_2 & Y_2 & X_2^2 & Y_2^2 & X_2Y_2 \\ \vdots & & & & \vdots & & & & & \vdots \\ \gamma(h_{n1}) & \gamma(h_{n2}) & \cdots & \gamma(h_{nn}) & 1 & X_n & Y_n & X_n^2 & Y_n^2 & X_nY_n \\ 1 & 1 & \cdots & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ X_1 & X_2 & \cdots & X_n & 0 & 0 & 0 & 0 & 0 & 0 \\ Y_1 & Y_2 & \cdots & Y_n & 0 & 0 & 0 & 0 & 0 & 0 \\ X_1^2 & X_2^2 & \cdots & X_n^2 & 0 & 0 & 0 & 0 & 0 & 0 \\ Y_1^2 & Y_2^2 & \cdots & Y_n^2 & 0 & 0 & 0 & 0 & 0 & 0 \\ X_1Y_1 & X_2Y_2 & \cdots & X_nY_n & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (2.91)$$

and [W] and $[R_2]$ are given by:

$$[W] = \begin{bmatrix} w_1 \\ w_2 \\ \cdot \\ \cdot \\ w_n \\ \mu_0 \\ \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \end{bmatrix} \qquad [R_2] = \begin{bmatrix} \gamma(h_{01}) \\ \gamma(h_{02}) \\ \\ \gamma(h_{0n}) \\ 1 \\ \bar{X}_0 \\ \bar{Y}_0 \\ \bar{X}_0^2 \\ \bar{Y}_0^2 \\ \overline{X_0 Y_0} \end{bmatrix} \tag{2.92}$$

where:

$$\bar{X}_0 = \frac{1}{n} \sum_{j=1}^{n} X_j$$

$$\bar{Y}_0 = \frac{1}{n} \sum_{j=1}^{n} Y_j$$

$$\bar{X}_0^2 = \frac{1}{n} \sum_{j=1}^{n} X_j^2 \tag{2.93}$$

$$\bar{Y}_0^2 = \frac{1}{n} \sum_{j=1}^{n} Y_j^2$$

$$\overline{X_0 Y_0} = \frac{1}{n} \sum_{j=1}^{n} X_j Y_j$$

where:

X_j and Y_j are the coordinates of x_j with respect to $x_0(X_0, Y_0)$.

The universal kriging may be done successfully only if the main trend m(x) is known a priori. Otherwise, there is no certainty it will improve the estimates (Volpi and Gambolati, 1978). The choice between simple kriging and universal kriging is sometimes a matter of experience and how much the main trend is known a priori. The use of kriging with drift is still a matter of research. More detail on universal kriging can be found in David (1977).

3. PROCEDURE AND DATA SELECTION

In order to design a model suitable for the study of evapotranspiration spatial variability, the state of Oregon was chosen as the geographic base. This chapter explains the procedure followed to select meteorological data for ET calculations and to estimate missing data. It also explains the computation of local evapotranspiration at weather stations and states the assumptions on which the computations of the geostatistical characteristics were based.

3.1 Selection of Evapotranspiration Data and Method

From the literature review, it is clear that weather data such as solar radiation, windspeed, and air vapor pressure are necessary for estimating evapotranspiration using any theoretically-based method such as Penman's or Monteith's. However, these data were available at only a select number of weather stations in Oregon. Therefore, the only alternative left was to look for a convenient empirical method. The choice of such an empirical method was made after the inventory of the available data. The weather data used to support this research were collected during the 1979 growing season, from May through September.

3.1.1 Available Weather Data

From the official publications of NOAA (National Oceanic and Atmospheric Administration), weather data have been provided regularly for most of the 284 weather stations listed for the state of Oregon in the monthly Climatological Data bulletins (NOAA, 1979). Of these stations, 175 provided the daily primary data of maximum and minimum air temperatures, T_x and T_m, respectively. In 1979, eighteen stations provided daily windspeed data. At sixteen stations, daily maximum and minimum relative humidity were available, while the solar radiation direct measurements or estimates were available at thirteen stations only. Some of these data were provided by Oregon State Experiment Stations, and others by the Weather National Service, mainly for aviation and public information purposes. This study has been limited to the state of Oregon data base constituted by 175 stations which recorded temperature data. Twenty-two of these stations are listed in Table 1. These 22 stations were equipped to record at least one of the three secondary weather data described above.

3.1.2 Choice of an Evapotranspiration Method

The reasons for selecting the FAO Blaney-Criddle method as the ET method for the states of Washington and Idaho were presented in the previous chapter. Methods

Table 1. Secondary Weather Data Stations

Weather Stations	R_s	ID#	WRUN	ID#	RH_{min}	ID#
Astoria	Y	01	Y	01	Y	01
Bend	Y	02	N		N	
Burns	Y	03	Y	03	Y	03
Coos Bay	Y	04	N		N	
Corvallis (Hyslop)	Y	05	Y	05	Y	05
Eugene	Y	06	Y	06	Y	06
Hermiston	Y	07	Y	07	Y	07
Hood River	N		Y	08	N	
Illahe (near Agnes)			Y	09	N	
Klamath Falls (near Kingsley Field)	Y	10	Y	10	Y	10
La Grande	Y	11	N		N	
Malheur Exp. Sta. (near Boise)	N		Y	12	Y	12
Medford	Y	13	Y	13	Y	13
Moro	N		Y	14	Y	14
North Willamette	N		Y	15	Y	15
Pendleton Exp. Sta.	Y	16	Y	16	Y	16
Portland	Y	17	Y	17	Y	17
Redmond	N		Y	18	Y	18
Salem	N		Y	19	Y	19
Union Exp. Sta.	N		Y	20	Y	20
Sexton Summit	N		Y	21	Y	21
Whitehorse Ranch	Y	22	N		N	
Number of Stations		13		18		16

Y and N: data available (Y) and not available (N)

R_s: daily solar global radiation (langley/day)

WRUN: daily wind run (miles/day)

RH_{min}: daily minimum relative humidity (percent) more sophisticated than the FAO Blaney-Criddle method could be used at specific sites where the data requirements were met in the state of Oregon. However, no option was left other than choosing, for the whole state, a temperature-based method -- since only temperature data were available throughout the state. The fact that researchers in the adjacent states of Washington and Idaho have adopted the FAO Blaney-Criddle method as the best state-wide ET method, provided some confidence in the choice of that method. The different variables required by the FAO Blaney-Criddle method were given in Eqs. (2.15) to (2.20). A computer program termed MAIN was written in FORTRAN to provide the FAO Blaney-Criddle ET estimate for all 175 locations, given the following input data for each location: monthly average maximum and minimum daily temperatures, TMAX and TMIN, monthly minimum relative humidity, RHMIN, monthly average solar radiation, RS, monthly average wind run, WRUN, monthly average day to night wind ratio, WRTIO, height of anemometer, HWIND, longitude, LONG, latitude, LAT, and altitude, ALT.

Program MAIN is listed in Appendix A. It provided the following parameters in tabular form: clear sky solar radiation, RRAN, and the monthly percentage of annual daytime hours, PP, as a function of latitude and month, and a local calibration table from Doorenbos and

Pruitt (1977) used to determine the factor b. The a coefficient was calculated from Eq. 2.19. A second adjustment was made for topography, which allowed a ten percent increase of ET for every 1000 meters in altitude above sea-level (Allen and Brockway, 1982). Once this final adjustment was made, the local reference ET was computed for all 175 locations, along with the longitude and latitude (in Cartesian coordinates). After execution, program MAIN provided an output file which could then be used as input to compute the geostatistical characteristics of ET spatial variability.

3.1.3. Estimation of Missing Weather Data

Missing Primary Data (Temperature): All 175 stations which defined the weather data base for local ET estimation were equipped to provide at least the daily temperature. However, sometimes data were not recorded during one or more days. Missing data were due to instrument breakdown or failure to record measurements. In such cases, a day by day moving average was performed to provide for the missing data. The number of observations used to estimate each missing data depended on the number of consecutive days when the observations were not available. Longer missing-data periods required a greater number of observations to estimate one datum. When only one observation was missing, it was replaced by the average of two observations, one before and one after the missing observation. When two consecutive observations were missing, the first was replaced by the average of two observations before and one observation after the set of missing data; the second missing datum was replaced by the average of one observation before and two observations after the set of missing data.

<u>Missing Secondary Weather Data</u>: As indicated in the previous section, only 22 stations were equipped to measure data other than air temperature on a daily basis. This suggested the use of a temperature-based method calibrated by secondary weather parameters which in general are estimated. In the case where the FAO Blaney-Criddle method is used, these secondary parameters are estimated from available minimum relative humidity, RH_{min}, solar radiation, R_s, and wind speed, U. It has been found convenient to use the secondary data only for adjusting the ET estimates for the local climate. Solar radiation and minimum relative humidity were not expected to change considerably over a short distance. This was not true for windspeed. Windspeed could change dramatically over short distances, depending on topographic and surface roughness variations. The decision of which secondary weather data should be used at a specific primary weather station, where such a secondary weather data was not available, was based on

empiricism, consideration of terrain, and advice from Weather Service representatives. Field trips were required to visit some of the weather stations, observe their topographic and floral environments, and discuss meteorological data needs with weather data technicians and specialists who have some experience with the local climate. Such an investigation helped determine similarities and dissimilarities between primary data stations and their neighboring secondary data stations.

The main topographical features which affect climate in Oregon are two predominantly north-south mountain ranges, the Coastal Range and the Cascades, separated by approximately 144 kilometers (90 miles) in the western part of the state, and the high plateau and highlands which are east of the Cascades. West of the Cascades, the climate is generally humid, with annual precipitation on the order of 1,000 millimeters (40 inches) in the inter-mountain valley. East of the Cascades, semi-arid to arid conditions prevail, with annual precipitation on the order of 250 millimeters (10 inches) or less. Topographic features and local meteorological conditions have led to the state of Oregon being divided into the five climatic regions, as indicated in Fig. 6. These are labeled as A) coastal, B) north inter-mountain valley, C) south inter-mountain valley, D) north high plateau, and E) south high plateau. Although the different climatic

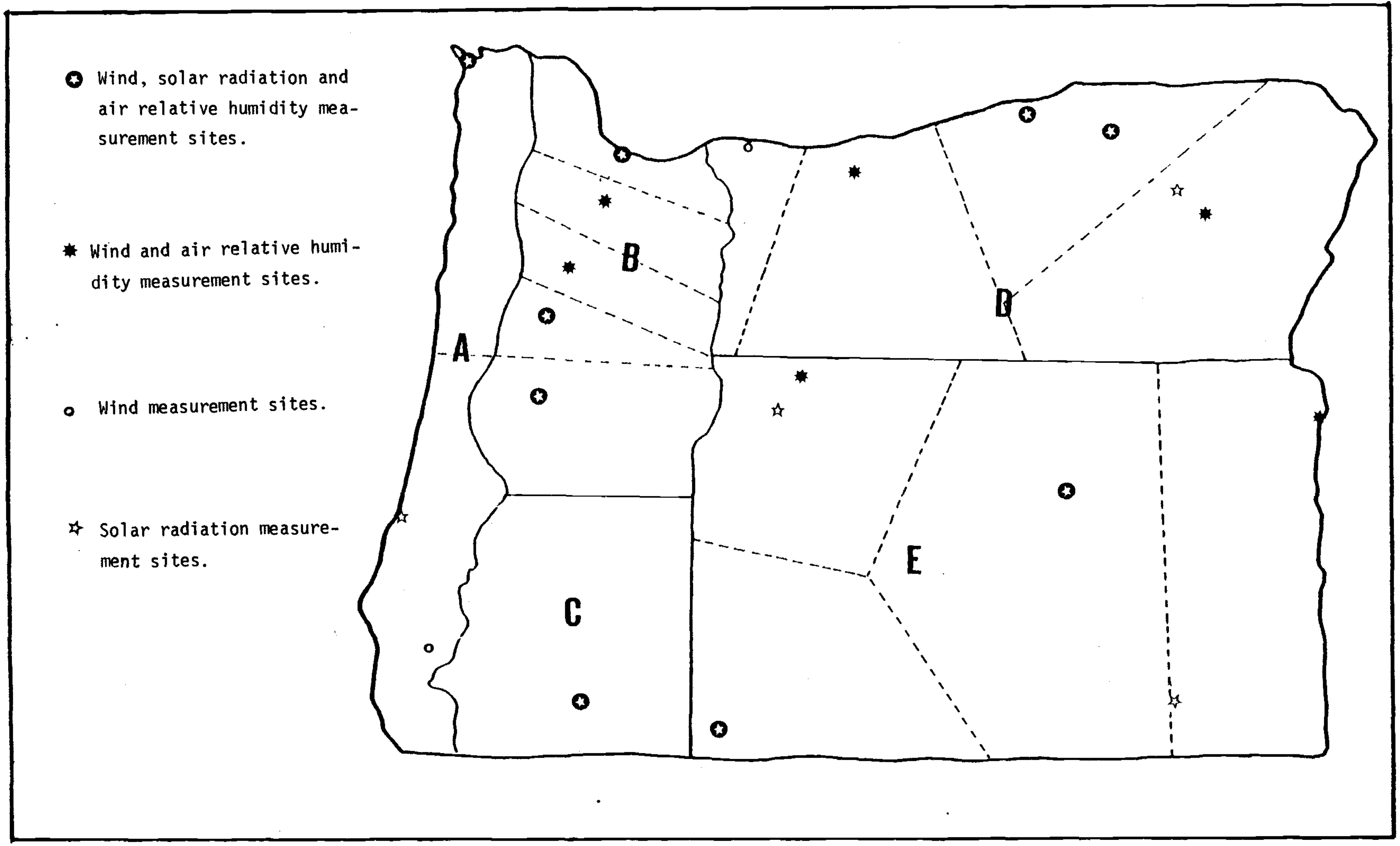

Figure 6. Secondary weather stations, and subdivision of the state of Oregon into climatic subregions (solid lines) and windspeed zones of influence (dashed lines).

subregions are not separated in nature by straight lines, such delineations were made as a first approximation for allocating secondary weather data from secondary stations to the primary stations. Each climatic subregion was subdivided into secondary weather data zones of influence, using the technique of Thiessen polygons, by drawing bisectors between secondary weather stations. All the primary data stations which fell in a given Thiessen polygon received the same secondary weather data corresponding to that polygon of influence. Such a subdivision is shown in Fig. 6 for the windspeed zones of influence. When no specific reasons based on experience existed for not doing so, the same criteria governed the assignment of solar radiation, R_s, and minimum relative humidity, RH_{min}, data to the primary weather stations. One station, Sexton Summit, has not been indicated on Fig. 6 because its data were missing during May and June. Because of this inconsistency, the wind and relative humidity data for Sexton Summit were used only for that station whenever they were available.

3.2 Organization of Geostatistical Computations

The geostatistical computations involved the semivariograms, kriging estimates, and kriging estimation variances. The method used for constructing semivariograms was based on the spatial configuration of the available data. Journel and Hujbregts (1978) stated that various cases could be distinguished according to whether or not the data were aligned and whether or not they were regularly spaced along these alignments. In the state of Oregon, weather stations were not aligned nor regularly spaced.

3.2.1 Procedure for Computing ET Semivariograms

Since ET data were scattered throughout the state, it was found convenient to group them into distance and angle classes as is illustrated in Fig. 7. According to David (1977), such scattered data can be grouped into classes using polar coordinates (h, θ). This technique allowed the computation of experimental semivariograms $\gamma^*(\theta, h)$ without losing too many data and with a sufficient number of data pairs. The star (*) adjacent to γ indicated that $\gamma^*(\theta, h)$ was a computed value, different from the theoretical semivariogram. Since the ET data were not continuously observed throughout the state, discrete distances, h_j, angles, θ_i, tolerance distances, Δh, and tolerance angles, $\Delta\theta$, were used to group them into distance and angle classes. The intersection of the two regions $(h_j \pm \frac{\Delta h}{2})$ and $(\theta_i \pm \frac{\Delta\theta}{2})$ defined a class of data which could be treated as located at (θ_i, h_j). Given a direction θ_i, all the semivariograms $\gamma^*(\theta_i, h_j)$ were

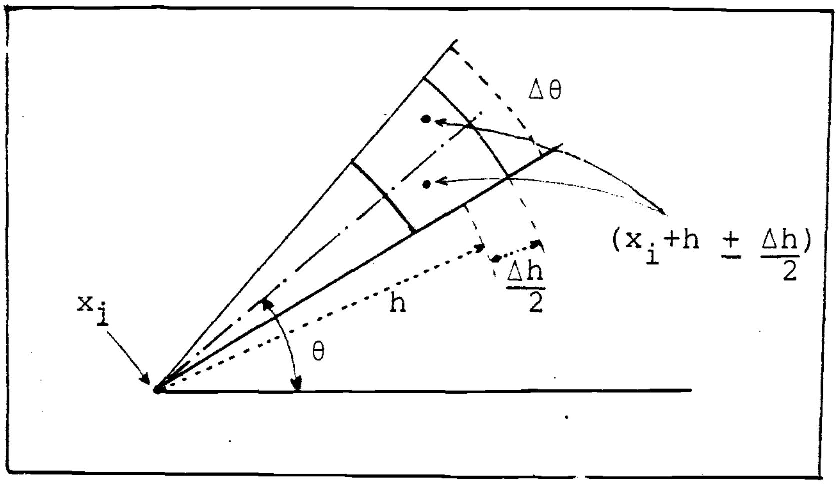

Figure 7. Grouping data into distance and angle classes.

computed and plotted as the semivariogram curve for the direction θ_i. h_j represented the preselected jth lag distance.

A computer program named VARIO was written in FORTRAN to compute the quantities $\gamma^*(\theta_i, h_j)$. For each direction θ_i, the program performed the computations step by step. h_{j+1} is obtained by adding h_0 to h_j. The quantities h_0 and Δh were termed basic lag distance and distance tolerance. After these computations were completed for one direction, $\theta_i \pm \frac{\Delta\theta}{2}$, the direction was changed to $\theta_{i+1} \pm \frac{\Delta\theta}{2}$ and the same computations of the quantities $\gamma^*(\theta_{i+1}, h_j)$ were repeated. For the basic lag distance, h_0, 12.87 kilometers (8.00 miles) was chosen, based on the ranges of regional ET scales previously discussed in the literature review. The tolerance distance was 3.22 km

(2.00 miles), so that samples separated by a distance 12.87 ± 3.22 kilometers belonged to the same semivariogram $\gamma^*(\theta, 12.87)$. Moving radially outward in the same angle class, samples which were separated by the distance 2(12.87) ± 3.22 kilometers, belonged to the same semivariogram defined as $\gamma^*[\theta, 2(12.87)]$, and so forth.

The topographic configuration of the state of Oregon, where a more pronounced climatic change exists in the east-west direction than in the north-south direction, suggested that an anisotropy of ET spatial variability could be expected. To confirm or deny this assumption, it was necessary to plot at least two directional semivariograms, one for the east-west direction and another for the north-south direction. The program VARIO was written in a general form in order to provide the plot of two other diagonal semivariograms, i.e. NE/SW and NW/SE. In the program, θ_i could take the values 0, $\pi/4$, $\pi/2$, and $-\pi/4$, while the angle tolerance $\Delta\theta$ was allowed to take any value. For this project, $\Delta\theta$ was chosen to be $\pi/8$ in order to allow enough margin between angle classes and to allow most of the data to fall in one or another class. Along with the plot of the semivariogram, the program VARIO could compute and plot the drift, $D(\theta_i, h_j)$, previously defined by Eq. 2.27, in each direction using the same lag distance and distance tolerance. The reason for plotting the drift was that it could be used to confirm or deny the first order stationarity. The shape of the semivariogram could also be used to identify not only second order stationarity but also first order stationarity. Moreover, the semivariogram plot could help detect the vicinity within or the extent to which secondary order stationarity was applicable. Program VARIO is listed in Appendix A. It used, as input, local reference ET data and the Cartesian coordinates of their locations. Its outputs were mainly the semivariograms and drifts plots.

The next step was to fit one of the theoretical models of semivariograms presented in the literature review to each direction, and evaluate its range, a, and sill value, $C_0 + C_1$. The comparison of these characteristics could help identify the existence of any anisotropy. These characteristics had to be combined in order to derive a unique semivariogram model of anisotropy which could take into account not only the variability due to the distances between weather stations, but also that due to their directional relationships. When anisotropy is present, the directional semivariograms can be combined into one single anisotropic model. In the case where the directional semivariograms are spherical with no nugget effect, a unique anisotropic model can be derived from

Eq. 2.48 as follows (David, 1977):

$$\gamma(h) = C_y\{\frac{3}{2}\left[(\frac{X}{a_x})^2 + (\frac{Y}{a_y})^2\right]^{0.5} - \frac{1}{2}\left[(\frac{X}{a_x})^2 + (\frac{Y}{a_y})^2\right]^{1.5}\}$$

$$+ (C_x - C_y)\{\frac{3}{2}\frac{|X|}{a_x} - \frac{1}{2}(\frac{|X|}{a_x})^3\} \qquad (3.1)$$

where:

C_x and a_x are the sill value and range of influence in East-West direction

C_y and a_y are the sill value and range of influence in North-South direction

X and Y are the Cartesian components of vector h which links two locations x_i and x_j.

In Eq. 3.1, X corresponds to the direction of anisotropy. It is associated with the direction of highest variability (i.e., highest sill value). Eq. 3.1 is governed by the following boundary conditions:

$X = a_x$	if	$X \geq a_x$
$Y = a_y$	if	$Y \geq a_y$

$$\left[(\frac{X}{a_x})^2 + (\frac{Y}{a_y})^2\right]^{0.5} = 1 \quad \text{if} \quad \left[(\frac{X}{a_x})^2 + (\frac{Y}{a_y})^2\right]^{0.5} \geq 1 \qquad (3.2)$$

3.2.2 Fitting a Spherical Semivariogram Model

Geostatisticians, such as M. Armstrong (Verly et al., 1983), advise against the systematic use of the least squares method to fit a theoretical semivariogram model, $\gamma(h)$, to the computed semivariogram, $\gamma^*(h)$. Such a technique assumes the observations are random while the purpose of the Geostatistics is to account for the spatial correlation between observations. Another reason for not systematically using the least squares method is that it generally leads to models different from the simple theoretical ones described in the literature review, and which are suitable for the kriging with the underlying assumption that there is a certain stationarity of the semivariogram. The spherical model has been the most commonly selected semivariogram model in applications in hydrology. The following steps are used to fit the spherical model to the computed semivariogram, $\gamma^*(h)$, based on the illustration shown in Fig. 5.

1. Fit a straight line to the first few points represented by $(\gamma^*(h), h)$.
2. The intercept of this straight line with the $\gamma(h)$ axis is the nugget effect C_0.
3. Draw a horizontal line representing the sill value, $C_1 + C_0$, which is given by the sample variance as follows:

$$C_1 + C_0 = \frac{1}{N-1} \sum_{i=1}^{N} (z(x_i) - M)^2 \qquad (3.3)$$

where:

M is the mean of all the N observations.

4. The intersection of the line drawn in step 1 with the line drawn in step 3 is assumed to represent a distance 2a/3 from the origin of h axis and this result is used to compute the range, a.

If there is zonal anisotropy, the highest sill value is taken equal to the sample variance and any other sill values are fitted visually. The small errors associated with the sill values and the range when such a visual fit is made do not make significant difference in the kriging estimates (David, 1977).

3.2.3 Kriging for Mapping ET Contour Curves

The most convenient means of displaying the distribution of evapotranspiration over a geographic region (e.g. the state of Oregon), was by using computerized contour plotting routines, such as COMPLOT, available in some form in most mainframe computer packages. A computer program was written in FORTRAN to draw the contour curves of ET. It used a subprogram, PLOTLIB, of the COMPLOT package. Such plotting programs normally require that data be available at uniformly spaced grid corners for efficient plotting of contours.

It became necessary to divide the state of Oregon into a square grid system 12.87 kilometers (8.00 miles) on a side, as it is shown in Fig. 8. The elementary grid size was selected to conform with the 12.87 kilometers (8.00 miles) previously chosen for the basic lag distance h_0. The grid size could be modified, depending on the desired distance between contour curves. Grid corners located at points where no meteorological data existed were termed unoccupied grid corners and were to be provided with kriged estimates of evapotranspiration, ETK, and a kriging variance, ERK.

A computer program named KRIGX was written in FORTRAN to compute the kriging estimates. This program is listed in Appendix A. It received as input the characteristics of the directional semivariograms and a file of ET data and the Cartesian coordinates of their locations. Program KRIGX used the IMSL (International Mathematical and Statistical Library) routine named LUDATF to solve the system of linear equations given by Eq. 2.89 as the kriging system. To estimate ET at each unoccupied grid corner, the eight nearest weather stations were selected and their corresponding semivariogram values used to build a system of nine linear equations which conformed to the kriging system given by Eq. 2.89.

It was decided to use eight weather stations because whenever the data are regularly spaced and anisotropy is

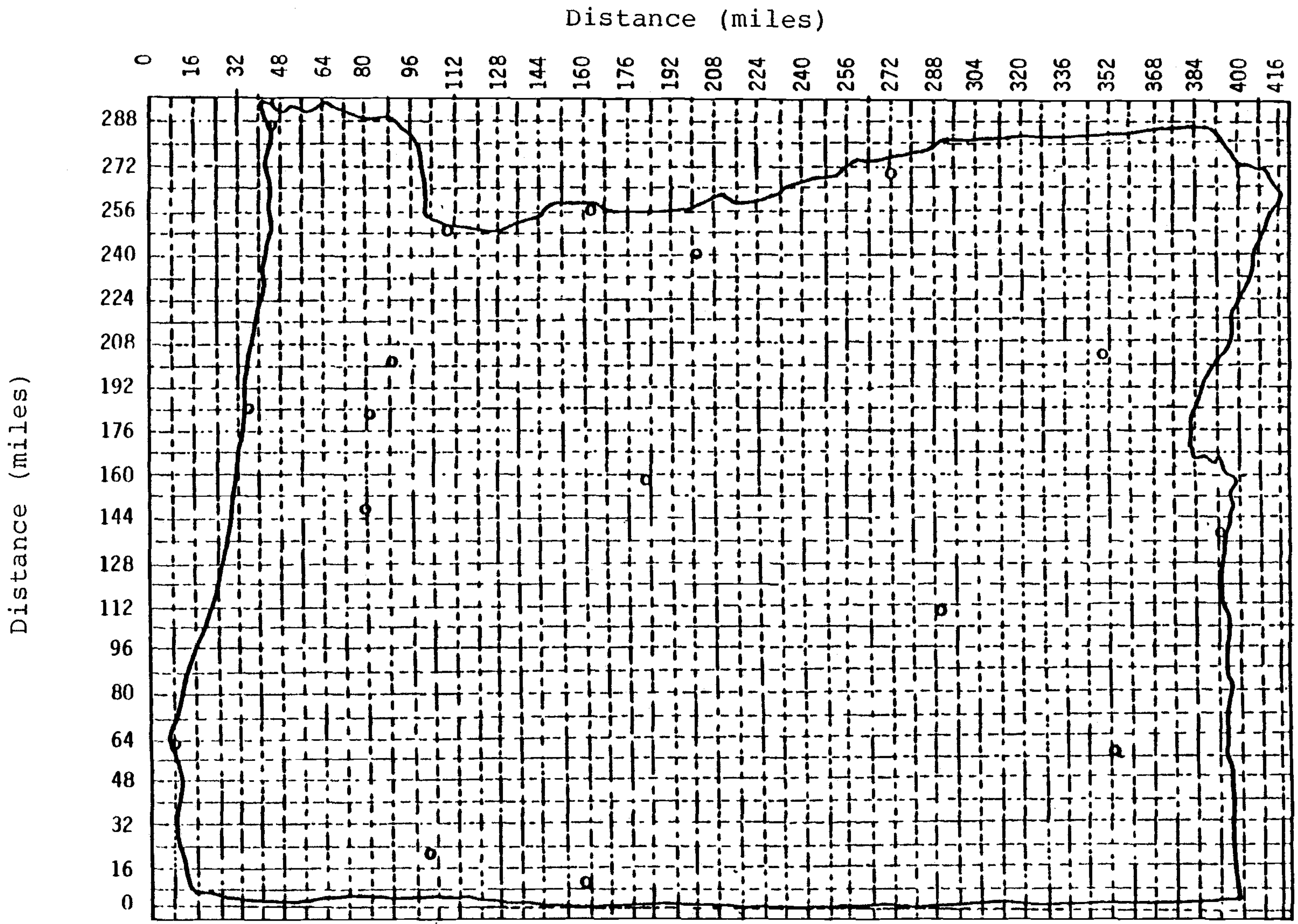

Figure 8. Superimposition of a (8x8 mi) grid system over the state of Oregon.

expected, a certain bias is avoided by selecting multiples of four in order to equally incorporate the variability in the two orthogonal directions. In the analysis it was noticed that using eight points instead of four improved the kriging results, while increasing the number of points to 12 was not only costly in terms of computer execution time, but did not improve the kriging results. The limitation of the estimation improvement as more points are added is due to a screening effect explained by Matheron (1965) and by David (1977). The existence of zonal anisotropy is also a reason for not using too many points.

A subprogram of KRIGX, named GAMMA, computed the semivariogram $\gamma(\theta_i, h_j)$ for each couple (θ_i, h_j) using the semivariogram model for anisotropy. Program KRIGX was written to output the kriging estimates, ETK, and the kriging variance, ERK, along with the Cartesian coordinates of their locations. Program KRIGX was written to perform simple kriging. However, it could be slightly modified to perform universal kriging if a drift existed that had to be taken into account.

3.3 Modeling Semivariograms with Insufficient Data

It has been a crucial problem in Geostatistics to decide whether all the data available on a large and heterogeneous region should be taken together to compute the semivariograms, or whether it is better to consider separately each subregion and derive its semivariogram using only the few data available for that subregion. The advantage of restricting a semivariogram to a small homogeneous subregion was that the stationarity assumptions were better sustained. However, a semivariogram derived from too few data points may not be reliable.

For this project, an iterative method was designed and a computer program written to search for the optimum semivariogram in each subregion. The optimum semivariogram was the one that produced kriging estimates closest to the original data and kriging variances, σ_k^2, closest to the the variances of the error, $z(x_i) - z^*(x_0)$. The trial-and-error technique developed involved the following steps:

1. Compute the sample variance. By definition it is equal to the sill value, $C_0 + C_1$. It is reduced to C_1, if the nugget effect, C_0, is zero. Assuming a zero nugget effect agrees with the fact mentioned by Journel and Hujbregts (1978) that the existence of nugget effect is due both to measurement errors and the discontinuity in the property at very small distances. Because of its continuous nature, evapotranspiration cannot be discontinuous at very small distances.

2. Assume a range of influence, a.
3. Assume the spherical model since the tendency has been to use only this model for kriging estimation (David, 1977). This model is entirely defined by C_1 and a, given that C_0 is zero.
4. At each step, delete one of the observed data, $z(x_i)$, and use the assumed semivariogram to estimate its value $z^*(x_i)$ by kriging. Repeat this operation for all data locations. A similar technique has been termed jacknifing (Vieira, 1983) and used to validate the kriging and semivariogram model.
5. Test the reduced errors for normal distribution. The reduced error, $R(x_i)$, is defined as follows:

$$R(x_i) = [z(x_i) - z^*(x_i)] / \sigma_k(x_i) \tag{3.4}$$

where:

$\sigma_k(x_i)$ is the kriging standard diviation, commonly termed kriging standard error, and computed from the kriging variance $\sigma_k^2(x_i)$.

This test is performed by testing if the mean and variance of the reduced error are $m_R = 0$ and $\sigma_R^2 = 1$. The mean of the reduced errors, m_R, is given by:

$$m_R = E\{R(x_i)\} = \frac{1}{n} \sum_{i=1}^{n} R(x_i) \qquad (3.5)$$

The variance, σ_R^2, of the reduced errors, $R(x_i)$, is given as follows:

$$\sigma_R^2 = Var\{R(x_i)\} = \frac{1}{n-1} \sum_{i=1}^{n} [R(x_i) - m_R]^2 \qquad (3.6)$$

This method for testing the normality of the reduced errors was suggested by Delhomme (1976) and used by Vieira (1983). It agreed also with Snedecor and Cochran (1967).

In order to verify how efficient this trial and error procedure could be, ET data from each of the five subregions shown in Fig. 6 were used separately to generate subregional semivariogram curves. For example, it was meaningless to fit a semivariogram curve to the semivariograms computed from the 41 ET data in the Willamette Valley because the number of data pairs which contributed to each semivariogram $\gamma(h_i)$ computation were too small to be used for modeling a semivariogram. Journel and Huijbregts (1978) suggested 30 pairs as an order of magnitude although fewer number of pairs have been used by other geostatisticians (Verly et al., 1983). In the Willamette Valley, as in the other subregions, most of the numbers of data pairs were fewer than 15. A computer program named VALID was written in FORTRAN to compare the original ET_r to the kriging estimates ETK and to compute m_R and σ_R^2. It could also be used to test the goodness of kriging estimation as described in the next section.

3.4 Method for Testing Goodness of Estimation

The iterative technique described above could be used to validate any semivariogram model, including the case in which the model was derived from a sufficient number of data. In the case of sufficient data, what was required was not to modify the semivariogram model by iteration until the optimum model was found, but to test whether or not the estimation method was unbiased (i.e. did not result in systematic errors). According to Delhomme (1976), the goodness of the estimation method could be verified through two conditions:

1. The mean of the reduced errors, m_R, must be close to zero.
2. The variance, σ_R^2, of the reduced errors, $R(x_i)$, must be close to 1.

Verification of the two conditions above meant that the estimation method was unbiased. The test on the reduced errors does not reveal how close the kriging estimates are to the observed evapotranspiration, ET_r. Such information could be obtained by testing the mean, m_E, of the deviations, ET_r - ETK, for the null hypothesis:

$$H_0: \ m_E = 0 \quad \text{against the alternative } H_a: \ m_E \neq 0$$

It could be assumed that the data are statistically paired, since ETK and ET_r correspond to the same location. Program VALID includes the computation of m_E and σ_E^2, the variance of the deviations ET_r - ETK. The next chapter will give the results obtained when following the procedures presented in this chapter.

4. RESULTS AND DISCUSSION

This chapter presents results obtained using procedures described in the previous chapter with the climatic data collected throughout the state of Oregon. Occasionally, intermediate results were needed to modify previous assumptions and to obtain more satisfactory results.

4.1 Local Estimates of Reference Evapotranspiration

The local estimates of reference evapotranspiration using the FAO modified Blaney-Criddle method were made available for 175 locations. The individual values of monthly ET_r given in mm/day at each location were computed for May through September. The results for the month of June as an example are listed in Appendix B. The weather data are shown for the same month in Appendix B. In order to reveal the existence of any trend of ET_r throughout the growing season, the monthly ET_r were plotted in Fig. 9 for five locations, each one chosen inside one of the five climatic subregions shown in Fig. 6. Those locations were Astoria in subregion A, Corvallis in subregion B, Medford in subregion C, Hermiston in subregion D, and Malheur Branch Station in subregion E. The plot confirmed the earlier results published by Cuenca et al. (1981) which indicated the parabolic shape of ET_r variation throughout the

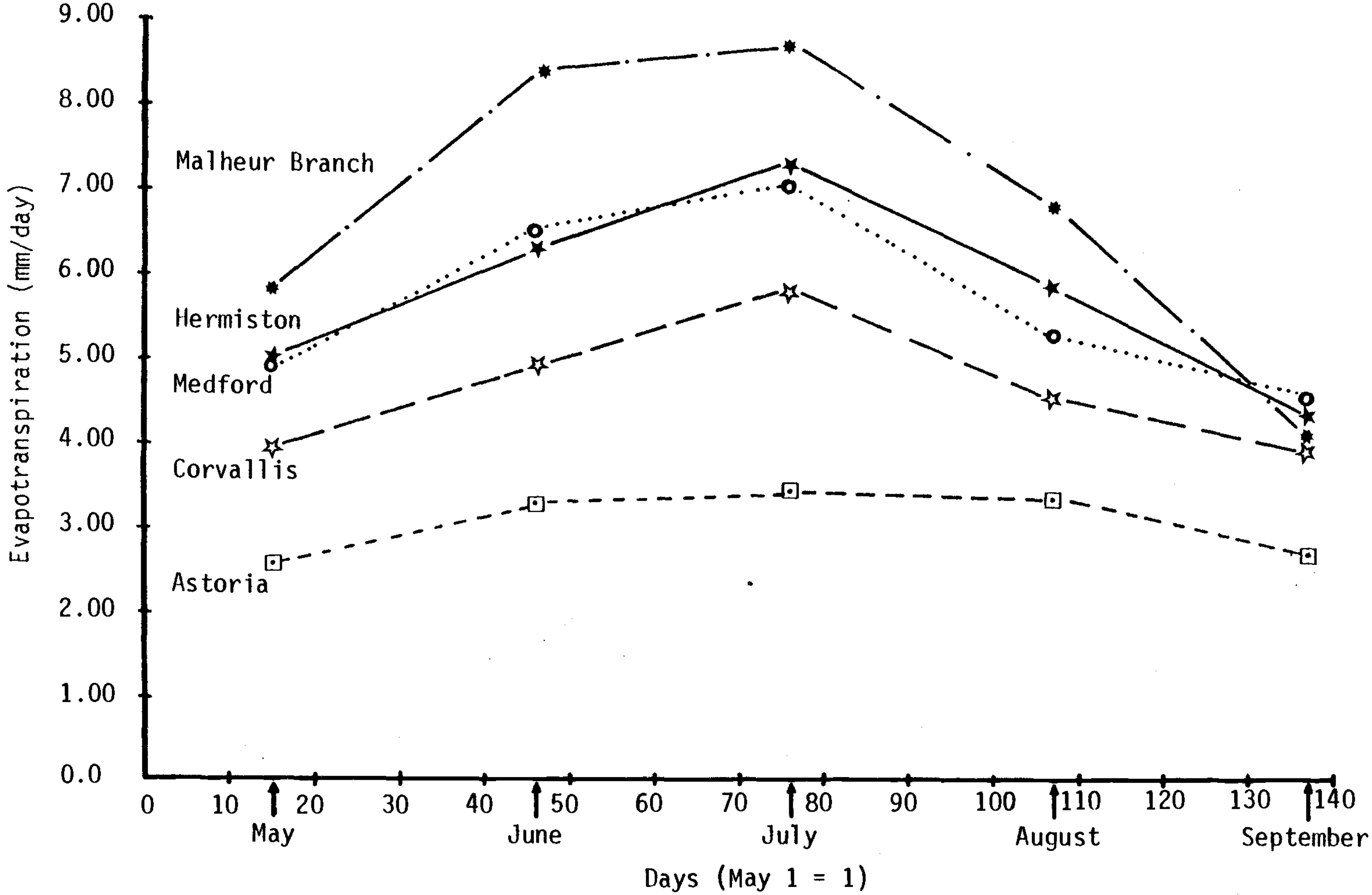

Figure 9. Monthly variations of daily evapotranspiration throughout 1979 growing season.

growing season. Table 2 shows the monthly average of daily reference evapotranspiration for weather stations where all the climatic data needed were measured in each of the 5 climatic subregions represented in Fig. 6. These data plotted in Fig. 9 indicate that significant variations in ET_r could be expected at the same location throughout the growing season. For this reason, it was decided to study the spatial variability of ET_r for each month separately. Fig. 9 indicates a general increase of reference evapotranspiration as one moves from Astoria on the West Coast to Malheur Branch Station in semi-arid Eastern Oregon.

4.2 Evaluation of the Stationarity Assumptions

It became clear from the literature review that first order stationarity could be revealed by the plot of the drift D(h) defined in Eq.2.27. The plot of the drifts are shown for June in Fig. 10. They have a trend similar to the ones shown by Vauclin et al. (1982) for soil surface temperature. Fig. 10 is presented as an example of the trend in the drift. Such a trend also existed for the other four months. Adequacy of the assumption of second order stationarity could also be made apparent if the semivariogram function $\gamma(h)$ defined by Eq.2.35 was plotted. Figures 11 to 15 indicate plots of the semivariograms for each month using data from all 175

Table 2. FAO modified Blaney-Criddle monthly reference evapotranspiration (mm/day) for the climatic subregions in 1979.

Climatic Subregions	Location	May	June	July	August	Sept.
A	Astoria	2.538	3.266	3.403	3.305	2.613
B	Corvallis Exp. Sta.	3.910	4.878	5.784	4.461	3.866
C	Medford Exp. Sta.	4.878	6.461	7.000	5.224	4.467
D	Hermiston Exp. Sta.	4.973	6.244	7.241	5.776	4.289
E	Malheur Branch Sta.	5.796	8.387	8.638	6.708	4.009

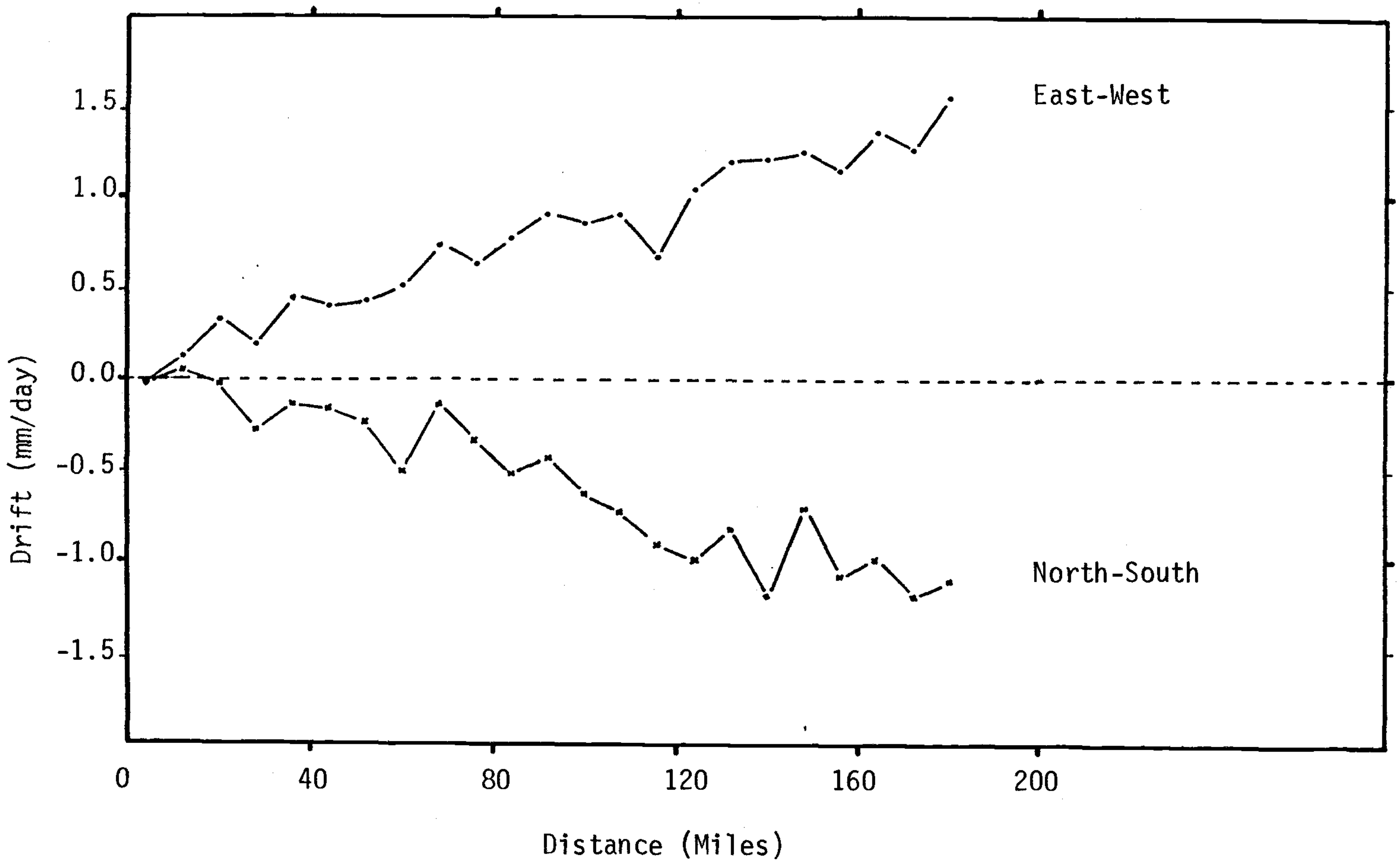

Figure 10. Drifts in reference evapotranspiration for June 1979.

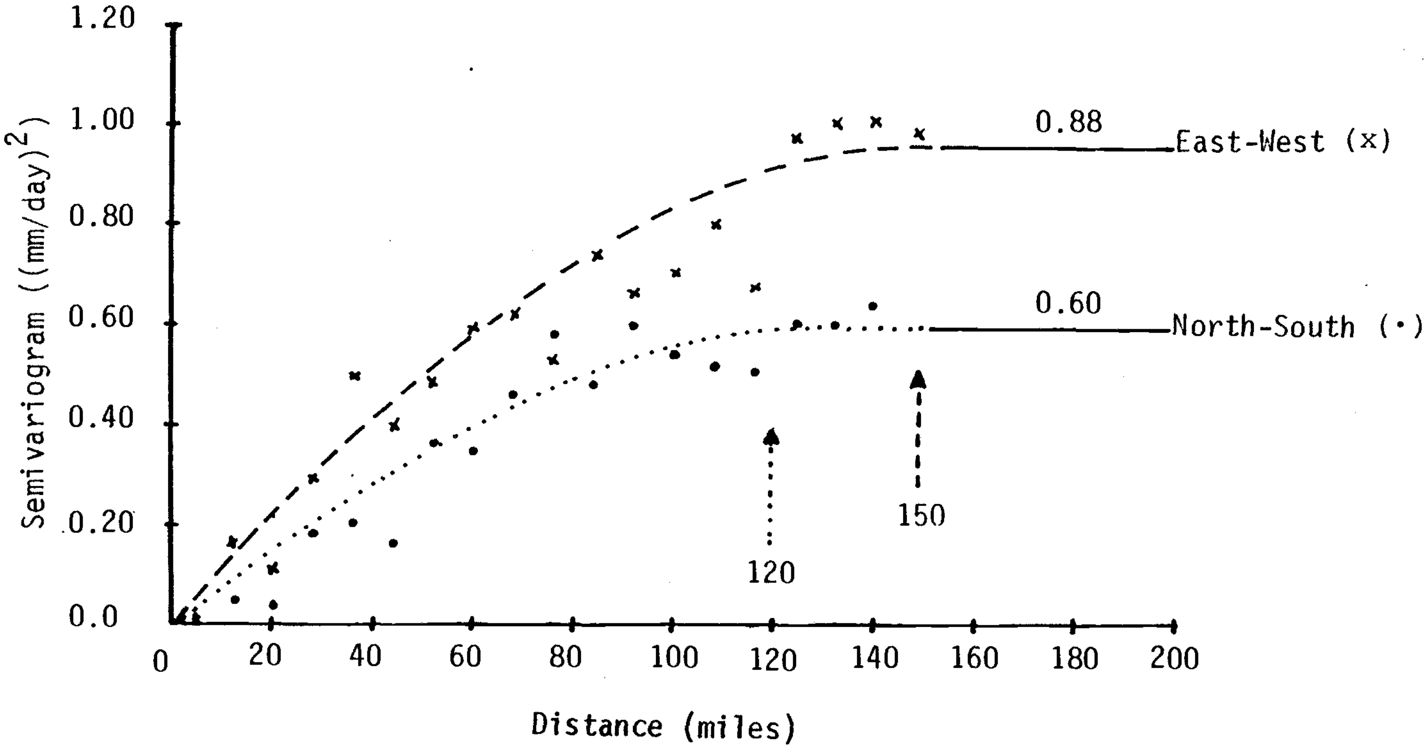

Figure 11. Semivariograms of reference evapotranspiration for May 1979.

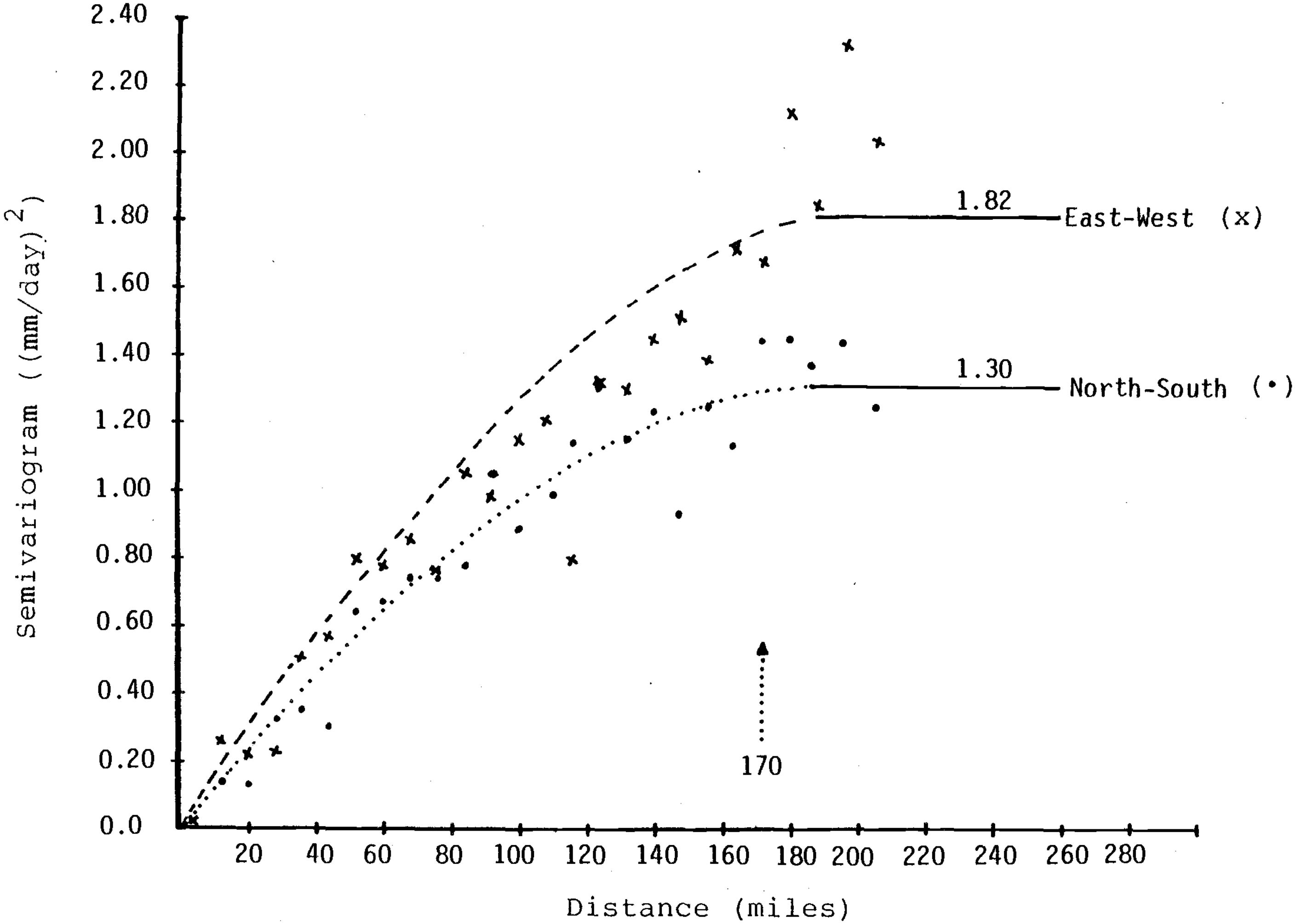

Figure 12. Semivariograms of reference evapotranspiration for June 1979.

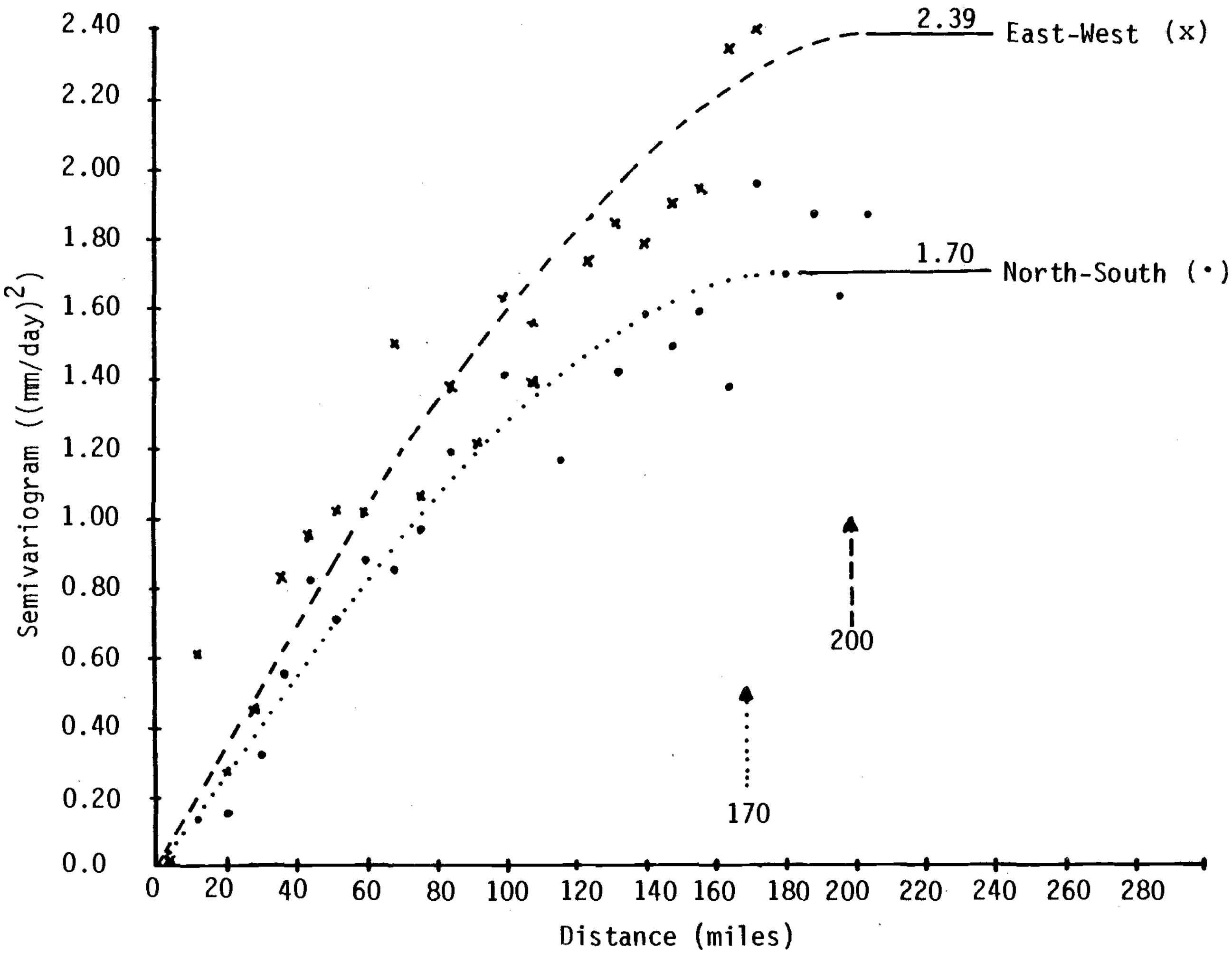

Figure 13. Semivariograms of reference evapotranspiration for July 1979.

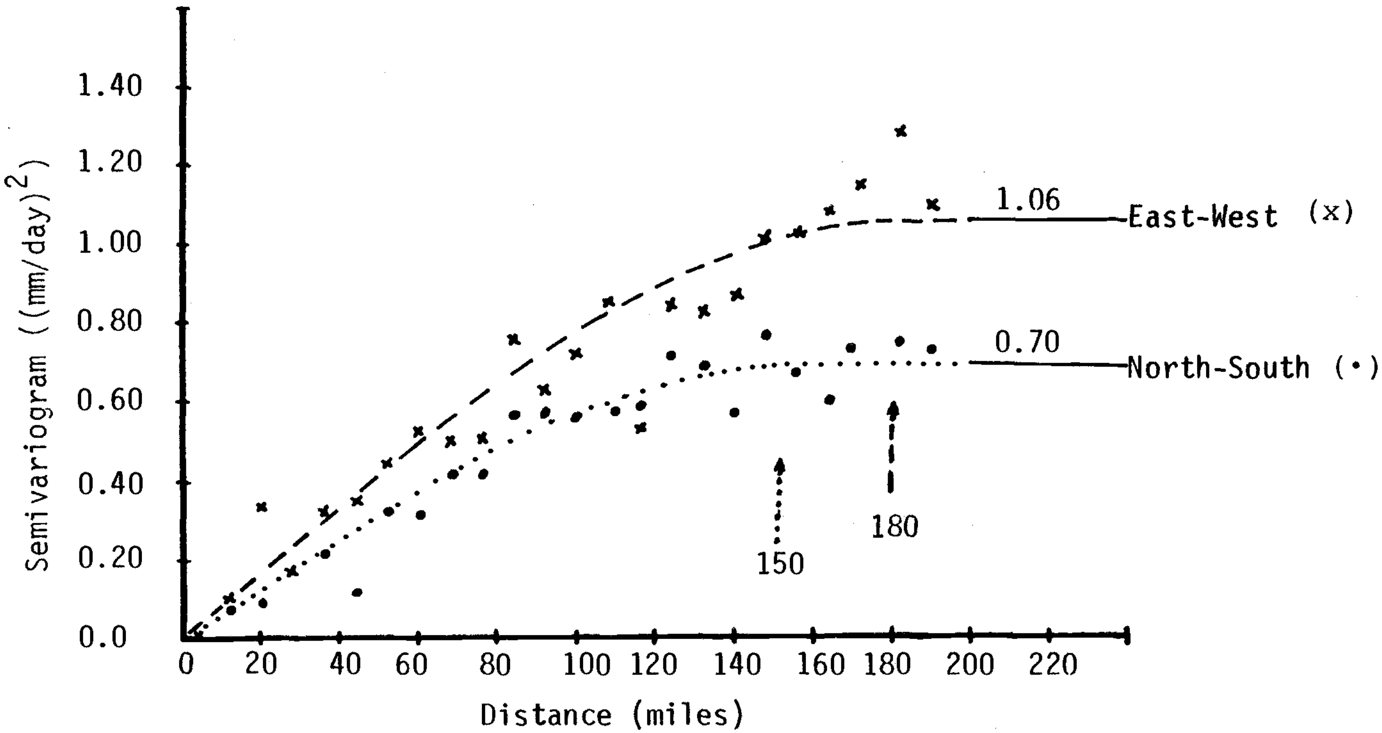

Figure 14. Semivariograms of reference evapotranspiration for August 1979.

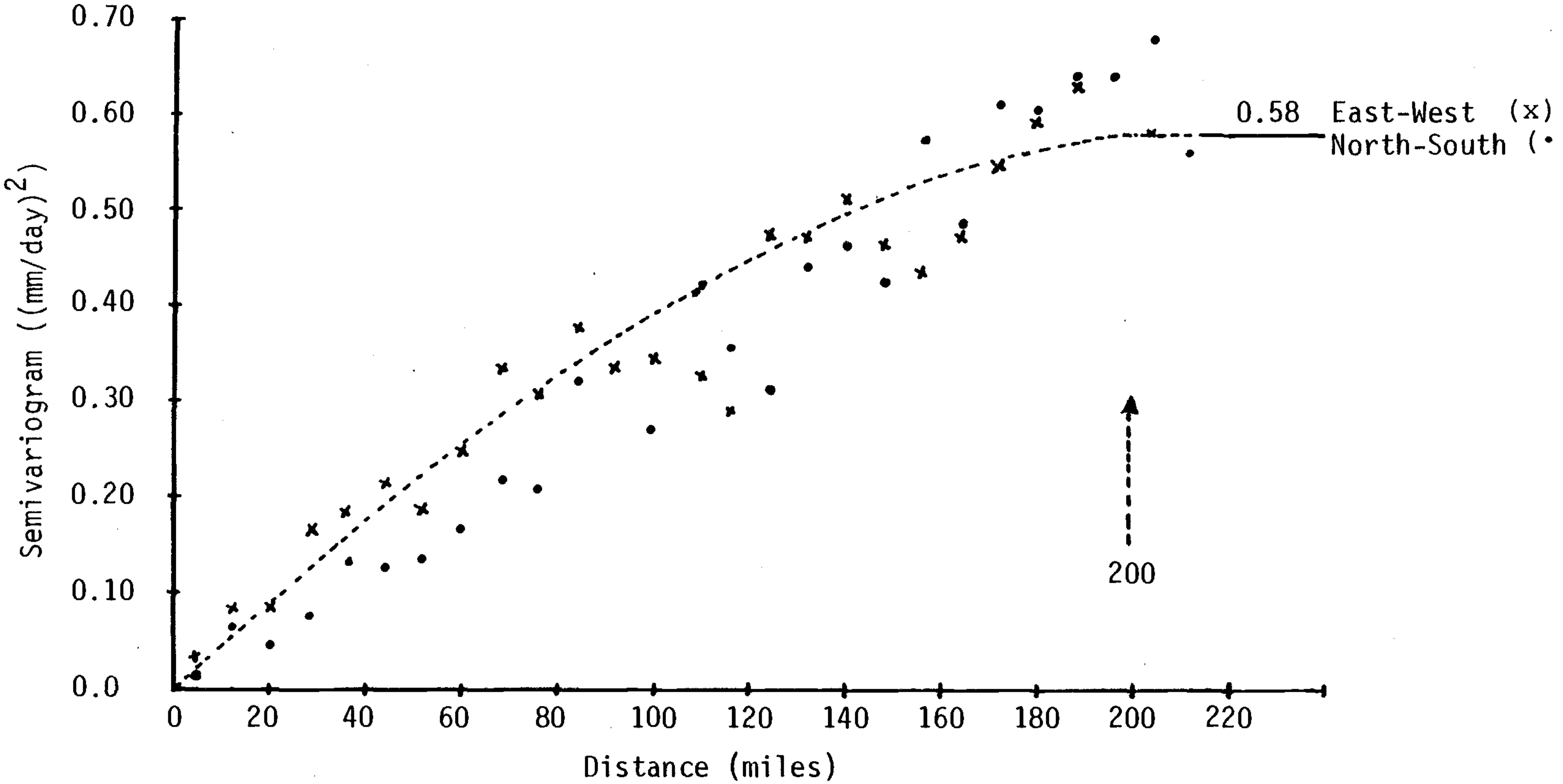

Figure 15. Semivariogram of reference evapotranspiration for September 1979.

weather stations lumped together. The procedure for fitting these semivariogram models was described in the previous chapter. Other than September, each month showed a zonal anisotropy, revealed by the difference between the sill values of the north-south and the east-west semivariograms. Table 3 indicates these differences as well as the ranges and characteristics of the anisotropic models of semivariograms.

The plot of the drifts shown for June in Fig. 10 departed systematically from the zero axis. This indicated a lack of stationarity. Obviously, kriging on the basis of the derived semivariograms would not yield unbiased estimates. A certain error should be expected on the average when each observation is intentionally deleted and the kriging estimate performed for that location using the neighboring observations. This lack of precision always occurs whenever a lack of first order stationarity has been ignored (Volpi and Gambolati, 1978). However, the most important criterion on which the semivariogram models could be accepted was how well the kriging estimates agreed with the observations. More details on this verification is given following discussion of the kriging estimates.

The indicated semivariograms could be used to design weather station networks for ET estimates. This could be done using the relationship which has been found, through

Table 3. Semivariogram characteristics

Month	North - South			East - West		
	C_y	a_y(mi)	a_y(km)	C_x	a_x(mi)	a_x(km)
May	0.60	120	192	0.88	150	240
June	1.30	170	272	1.82	170	272
July	1.70	170	272	2.39	200	320
August	0.70	150	240	1.06	180	288
September	0.58	200	320	0.58	200	320

C_x and C_y = sill values ((mm/day)^2)

a_x = range of influence in miles (mi) and in kilometers (km) in the direction east-west.

a_y = range of influence in miles (mi) and in kilometers (km) in the direction north-south.

the semivariogram, between error and station density. If one is interested in designing a station network in order to estimate ET with an average error of ΔET, the following can be done:

1) Compute $\gamma(h) = (\Delta ET)^2/2$.
2) Read the corresponding h_{EW} value on east-west semivariogram.
3) Read the corresponding h_{NS} value on the north-south semivariogram.
4) On the average, the distances between adjacent stations would be h_{EW} and h_{NS}.

Such a procedure assumed the stationarity of the drift D(h) and of the semivariogram $\gamma(h)$, as discussed in the literature review. When there is a lack of stationarity, the station density is expected to vary from one subregion to another. (This can be verified if Table 3 is compared to Table 5 for the semivariogram characteristics. Table 5 corresponds to the subregional semivariograms and is described in Section 4.6).

4.3 Kriging Estimates of Evapotranspiration

Kriging estimates of evapotranspiration were performed at each unoccupied grid corner represented in Figure 8. For each estimation, the eight nearest weather stations were selected. The semivariogram characteristics shown in Table 3 were used for kriging. The geographical coordinates of the weather station locations and their original evapotranspiration rates were used to perform the kriging estimates of the evapotranspiration and the kriging variances at the unoccupied grid corners. The kriging estimates are listed in Appendix B for the month of June, 1979. It should be noticed that the kriging estimate of ET is identical to the original ET wherever the grid corner corresponds exactly to a weather station. The slight differences which might be noticed when Figure 8, showing the coordinates of the locations, is used to check this identity, came from errors due to tranforming longitudes and latitudes into Cartesian coordinates x and y. It should also be noticed that all the kriging estimates of ET lie between the lowest and highest computed evapotranspiration rates at occupied grid corners during the same month. This is an additional attribute of using kriging as an interpolation technique.

4.4 Estimates of Kriging Variances

Kriging techniques not only provide an estimation of the regionalized variable, but they also provide the kriging variance for each location. The kriging variance was computed using Eq. 2.88 by the program KRIGX along with the computation of kriging estimates, ETK, at each grid corner of Fig. 8. Whenever the grid corner coincides with a weather station, the kriging variance $\sigma_k^2(x_i)$ is identical to zero. On the contrary, $\sigma_k^2(x_i)$ is large when the grid corner is far away from the weather stations. These properties could be verified in Appendix B, which lists the kriging variances for the month of June, 1979.

The kriging variances near the borders of the state of Oregon were high because they corresponded to estimates which were made far from the weather stations. This is consistent with the expectation that the error should be high for any estimation made using observations collected far away. The square root of the kriging variance is an estimator of the error made when using, for a given location x_0, the kriging estimator $z^*(x_0)$ instead of $z(x_0)$, which could not be known unless measurements were made at that location.

4.5 Self-Validation of the Semivariogram Models

This test was described in Section 3.4 of the previous chapter. It is a means of evaluating how close the kriging estimates, based on the derived semivariogram, are to the observations. It is a test not only for $z^*(x_0)$ but also for $\sigma_k^2(x_0)$. Table 4 gives the means of the reduced errors, m_R, and their variances, σ_R^2, using the semivariogram models represented by Figs. 11 through 15. Table 4 is a summary

Table 4. Results of statewide semivariogram validation tests.

	Month				
	May	June	July	August	September
C_x	0.88	1.82	2.39	1.06	0.58
C_y	0.60	1.30	1.70	0.70	0.58
a_x	240	272	320	288	320
a_y	192	272	272	240	320
m_R	-0.02	-0.01	-0.01	0.002	-0.01
σ_R^2	1.44	1.09	1.44	2.31	1.80
m_E	-0.01	-0.008	-0.009	0.00009	-0.006
σ_E^2	0.22	0.28	0.45	0.27	0.13
$\lvert t_E \rvert$	0.28	0.20	0.18	0.003	0.22

C_x and C_y are sill values in east-west and north-south directions ($(mm/day)^2$)

a_x and a_y are ranges of influence in east-west and north-south directions (10^3 meters)

m_E and m_R are means of errors and reduced errors (mm/day)

σ_E^2 and σ_R^2 are variances of errors and reduced errors ($(mm/day)^2$)

$\lvert t_E \rvert$ is the parameter of Student's t-test for ET_r - ETK.

of the semivariogram models validation tests. It shows low values of m_R, which are very close to zero, while the values of σ_R^2, besides the month of June, are not close enough to 1.0 to confirm a lack of bias. On the other hand, the mean error, m_E, of the deviation ET_r - ETK are very small. The results of Student's t-test shows the mean m_E can be considered null at 5% level of significance for each of the five months analyzed during 1979. The negative signs are indications that kriging slightly underestimates ET_r on the average.

4.6 Subregional Models of Semivariogram

It was explained in the previous chapter how a semivariogram model could be derived for the case where only a few observations are available. There were too few observations in each subregion, taken separately, to compute a subregional semivariogram. A computer program named VALID was written in FORTRAN to compute the parameters m_R and σ_R^2 needed for the validation test. It also provided the mean, m_E, and variance, σ_R^2, of the differences, ET_r - ETK. The application of the jacknifing technique to the ET data available for June 1979 provided the results shown in Table 5 for the five subregions. Table 5 shows only the characteristics of the subregional semivariograms retained as the "best". The term "best" semivariogram, in this thesis,

Table 5. Characteristics of the subregional semi-variograms derived by jackknifing.

Subregion	C_1	a	m_R	σ_R^2	m_E	σ_E^2	$\lvert t_E \rvert$
A	0.138	52	-0.017	1.005	-0.003	0.078	0.011
B	0.302	27	-0.072	1.017	-0.04	0.266	0.078
C	0.137	12	-0.088	1.149	-0.04	0.175	0.096
D	0.65	73	-0.015	1.008	-0.014	0.247	0.028
E	1.57	150	-0.018	1.006	-0.026	0.380	0.042

C_1 = Sill value $((mm/day)^2)$

a = Range of influence (miles)

m_R = Mean of the reduced errors (mm/day)

σ_R^2 = Variance of the reduced errors $((mm/day)^2)$

m_E = Mean of the deviation (mm/day)

σ_E^2 = Variance of the deviation $((mm/day)^2)$

$\lvert t_E \rvert$ = The parameter of Student's t-test for ET_r - ETK is associated with the semivariogram for which m_R and σ_R^2 are the closest to zero and one, respectively. The results of these tests also revealed the subregional semivariograms were isotropic because the magnitudes of their ranges of influence and sill values do not depend on the direction.

Table 5 and the column for June in Table 4 reveal that the variances, σ_R^2, for four out of the five subregional semivariograms were closer to 1.0 than those computed using the state-wide semivariogram. This indicated that, on the average, kriging with the subregional semivariogram is less biased. The Student's t_E parameters were at least three times lower for all the subregional semivariograms than for the state-wide semivariogram. This is an indication that kriging estimates using the subregional semivariograms are closer to the original data values than kriging estimates using the state-wide semivariogram. Detailed results of the subregional semivariogram validation tests which support this conclusion are shown in Appendix C. The state-wide semivariogram for June results in the lowest variance of reduced errors, σ_R^2, when compared to the other state-wide semivariograms for the other months. Results using the subregional semivariograms for the other months should therefore also be expected to be better compared with those obtained using the corresponding state-wide semivariograms.

These results are partially explained by the realization by Journel and Huijbregts (1978) that the stationarity assumption is more and more verified as the vicinity from where the data are taken to compute the semivariograms and the drifts is reduced. This attribute was described in Section 2.2.2 of the literature review as quasi-stationarity.

4.7 Comparison of Semivariogram Models with Least Square Models

The 175 computed reference evapotranspiration data previously used for kriging have been regressed with respect to the Cartesian coordinates, X, Y, and Z, the altitude of the weather stations. A stepwise linear regression analysis was performed starting with 9 parameters, X, Y, Z, X^2, Y^2, Z^2, XY, XZ, and YZ. Table 6 shows a summary of the model retained for each month. The highest coefficient of determination, R^2, was 0.76 and corresponded to June. This indicates the regression models cannot explain at least 24 percent of the variabilities in ET_r. The residuals means and variances are shown along with the regressions coefficients in Table 6. Comparing Tables 4 and 6 shows that the variances, σ_E^2, for the kriging models are lower than the ones found for the least squares models.

Table 6. Linear regression models.

Regression coefficient	May	June	July	August	September
b_1	3.062	3.484	3.582	3.819	2.667
b_X	0.025	0.029	0.041	0.013	0.019
b_Y	-0.0077	0	-0.0059	-0.0049	-0.0031
b_{XX}	-3.02×10^{-5}	-2.89×10^{-5}	-3.85×10^{-5}	0	-3.37×10^{-5}
b_{YY}	0	-2.40×10^{-5}	0	0	0
b_{XY}	0	0	-3.15×10^{-5}	0	0
b_{XZ}	-1.88×10^{-6}	-1.57×10^{-6}	-2.64×10^{-6}	-1.51×10^{-6}	0
R^2	0.71	0.76	0.75	0.68	0.70
m_E	0	0	0	0	0
σ_E^2	0.24	0.37	0.59	0.32	0.16

The mean error from the linear regression analysis was always zero, which compared with the values of the mean error close to zero in Table 4. In addition, kriging models contain only two independent variables (X, Y), while the least squares model for each month contains at least 5 parameters. For the reasons above, the kriging model was preferred to the least squares model as a better method for interpolating between the available data.

Other traditional interpolation techniques, such as moving average, inverse distance, and inverse squared distance methods, have not been compared to kriging in this research work, since they are well known to be biased (Henley, 1981; Journel and Huijbregts, 1978).

4.8 Comparision of Simple Kriging with Universal Kriging

Universal kriging, as explained in the literature review, is kriging which takes the non-zero drift into account. It has been noticed from Fig. 10 that the drift is almost linear. This allows to drop the second degree and interaction terms, X^2, Y^2, XY in Eq. 2.91. The results of the self-validation test, using such a kriging system along with the semivariograms shown in Figs. 11 through 15, are presented in Table 7. Comparison of these results to those obtained for simple kriging, shown in Table 4, indicates that simple kriging is a better

Table 7. Self-validation of universal kriging models for the state of Oregon in 1979.

	Month				
	May	June	July	August	September
m_R	-0.089	-0.095	-0.045	-0.060	-0.060
σ_R^2	1.640	1.304	1.781	2.423	2.098
m_E	-0.339	-0.050	-0.029	-0.025	-0.019
σ_E^2	0.238	0.312	0.510	0.263	0.147
$\lvert t_E \rvert$	9.19	1.18	0.54	0.64	0.66

m_R = Mean of the reduced errors (mm/day)

σ_R^2 = Variance of the reduced errors ((mm/day)^2)

m_E = Mean of the deviation ET_r - ETK (mm/day)

σ_E^2 = Variance of the deviation ((mm/day)^2)

$\lvert t_E \rvert$ = The parameter of Student's t-test for ET_r - ETK model. In fact, the means of the reduced errors are closer to zero for the simple kriging, while their variances are consistently closer to one. The means and variances of the deviations, ET_r - ETK, are also respectively closer to zero and one. The Student's t-tests mentioned in the previous chapter also favored the simple kriging. The Student's t, here t_E, is calculated as follows:

$$t_E = m_E \cdot \sqrt{N} / \sigma_E \quad (4.1)$$

where N is the sample size (N = 175).

Two main reasons could be applied to explain why simple kriging performed better than universal kriging, while theory indicates it should be the opposite. First, the drift function, D(h), represents an average of the difference, z(x) - z(x + h), over the state of Oregon while h is maintained constant for each computed D*(h). This averaging process included different magnitudes of z(x) - z(x + h). However, when the eight nearest weather stations are selected for kriging, most of these stations could belong to a very homogeneous zone where the drift is negligible. Performing universal kriging using the same drift function for the whole state might remove too much drift in some locations and too little drift in other locations.

A second reason could be the use of a state-wide semivariogram derived from data which are not detrended. The question which arises is how to detrend a semivariogram when the local drift is not known. David (1977) suggested an iterative technique which consisted of applying the jacknifing technique described in Section 3.3 and using Eq. 2.90 for universal kriging. This technique is expected to be very expensive in computer time. Such a technique has been written into computer programs such as BLUE PACK. The cost of using such a technique for plotting ET contour curves should be evaluated in comparison with the gain in precision of the estimates. This cost and resulting precision should be contrasted with that required for kriging with subregional semivariograms. The use of subregional semivariograms for mapping over a region requires additional research on how to define the semivariograms that should be used for the transition zones between two adjacent subregions.

4.9 Contour Maps of Reference Evapotranspiration

The reference evapotranspiration rates shown in Appendix B were estimated at unoccupied grid corners using simple kriging on the basis of the semivariograms shown in Figs. 11 through 15. Chapter 3 discussed the computer programs and routines used to generate the iso-ET_r contour curves over the state of Oregon.

Figs. 16 through 20 show such maps. As expected, the contour levels of ET_r increase generally from the relatively humid West Coast to semi-arid Eastern Oregon. The general north-south orientation of the reference ET curves agreed with the reference ET curves manually drawn for California using lysimeter and pan evaporation data (Cuenca et al., 1981). Beside this general trend which is consistent from May through September, there are singularities which depend on the time of year and topographical configurations. South-east of Hood River lies Mount-Hood where the reference evapotranspiration rates are lower than expected from the general trend of increasing ET_r from West to East. This same singularity is noticed for the region which corresponds to the Cascades. It is also shown for the mountainous region lying east and north of Baker. The recorded daily temperatures in that region were not very much different from the adjacent zones where the ET rates were higher. The explanation for these low ET rates is due to the low wind runs recorded at Union Experiment Station. The climatological data bulletins showed relatively low wind runs compared to nearby Pendleton throughout the growing season. This same explanation holds for Escadia mid-way between Salem and Hood River. The wind runs used for that subregion were low and corresponded to the ones recorded at North Willamette Experiment Station. Another

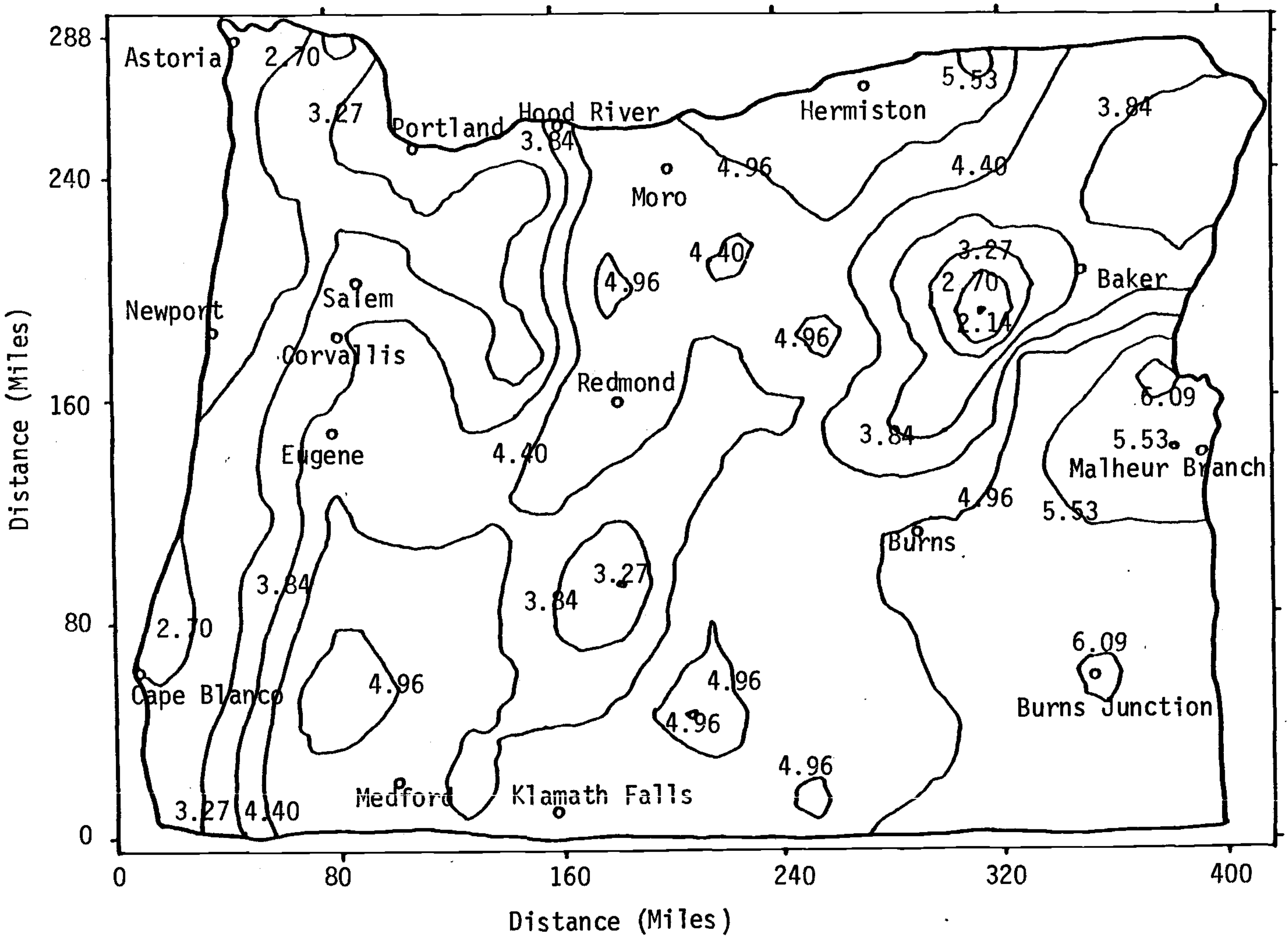

Figure 16. Contour map of reference evapotranspiration (mm/day) for May 1979.

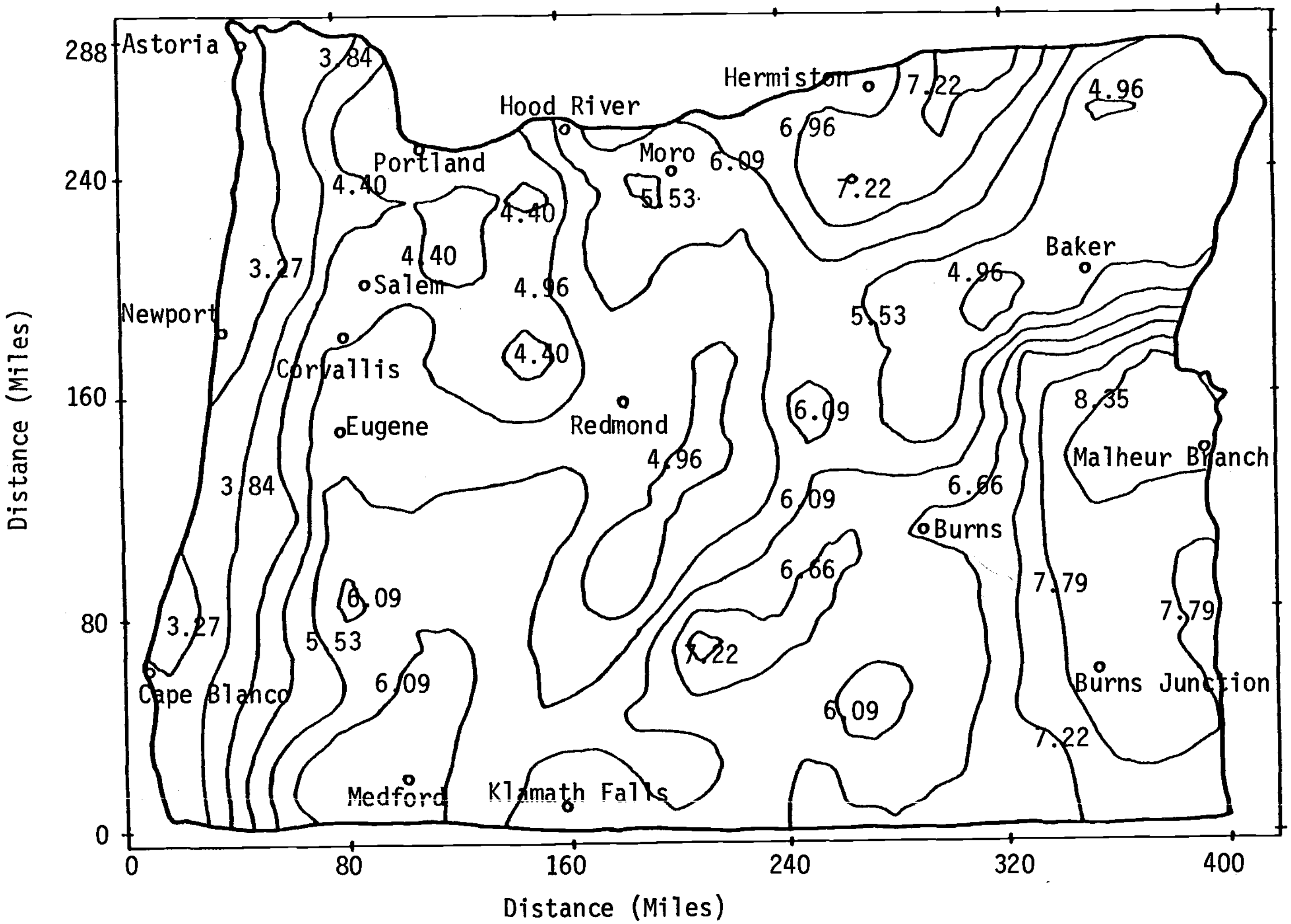

Figure 17. Contour map of reference evapotranspiration (mm.day) for June 1979.

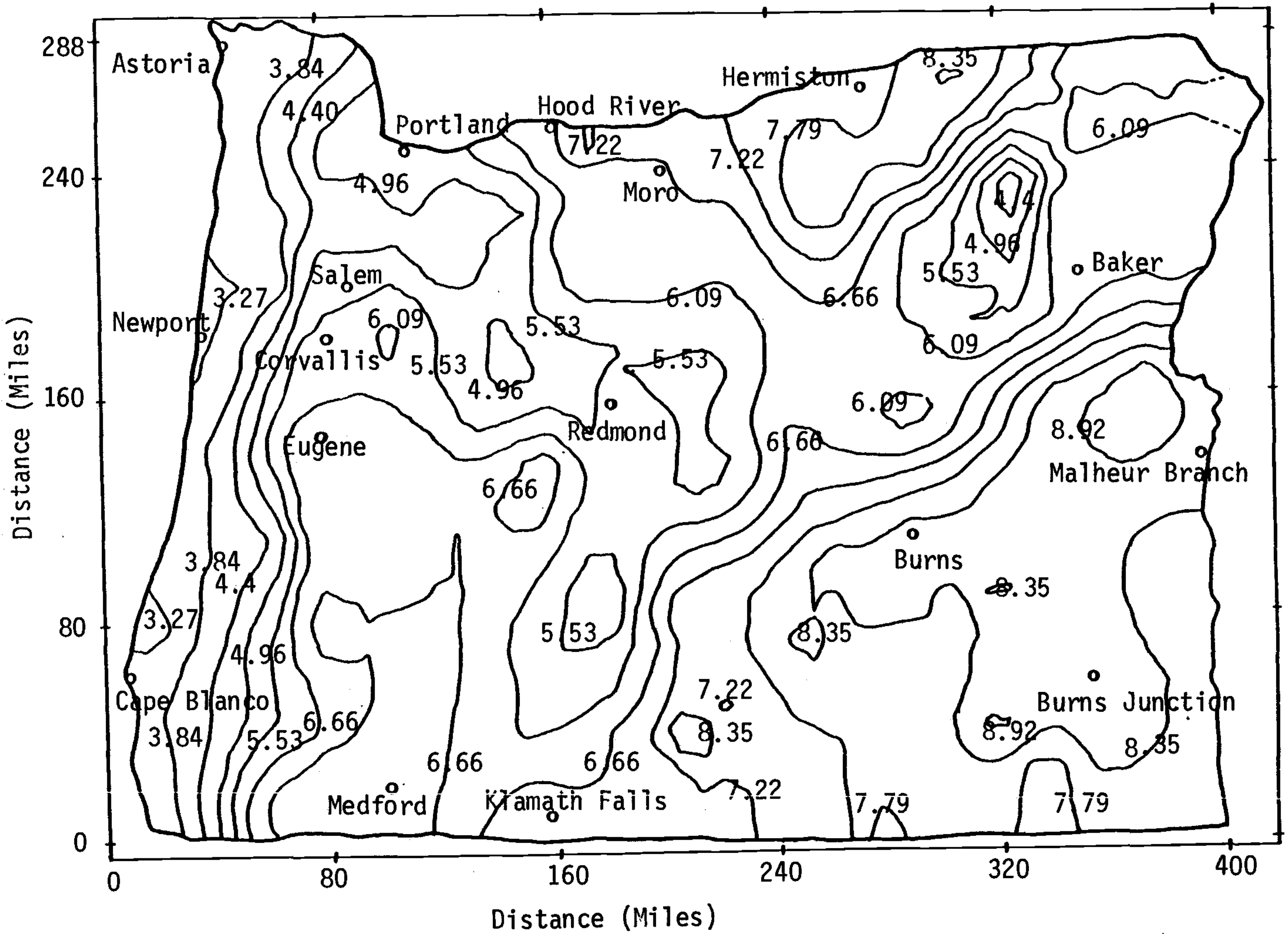

Figure 18. Contour map of reference evapotranspiration (mm/day) for July 1979.

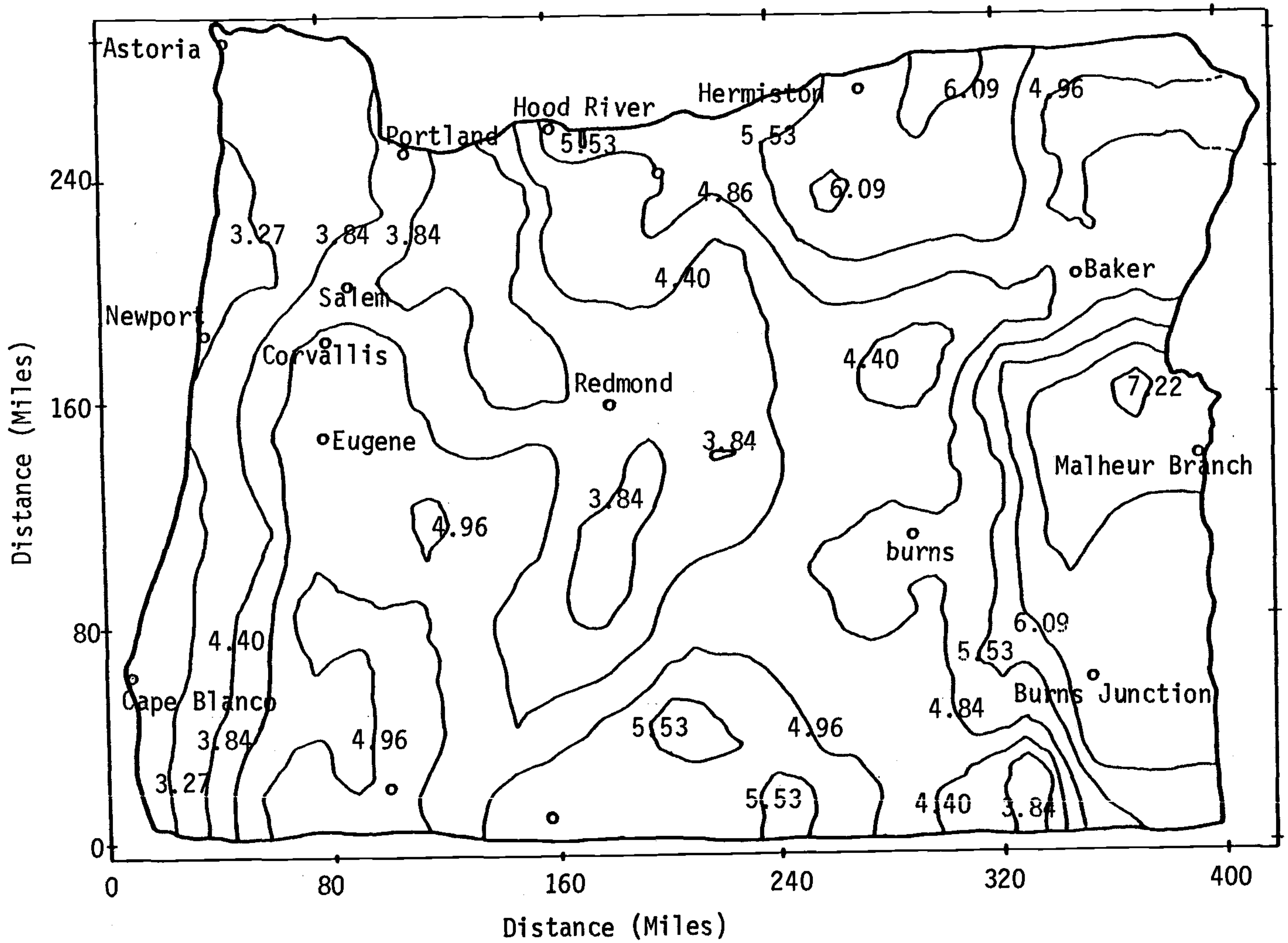

Figure 19. Contour map of reference evapotranspiration (mm/day) for August 1979.

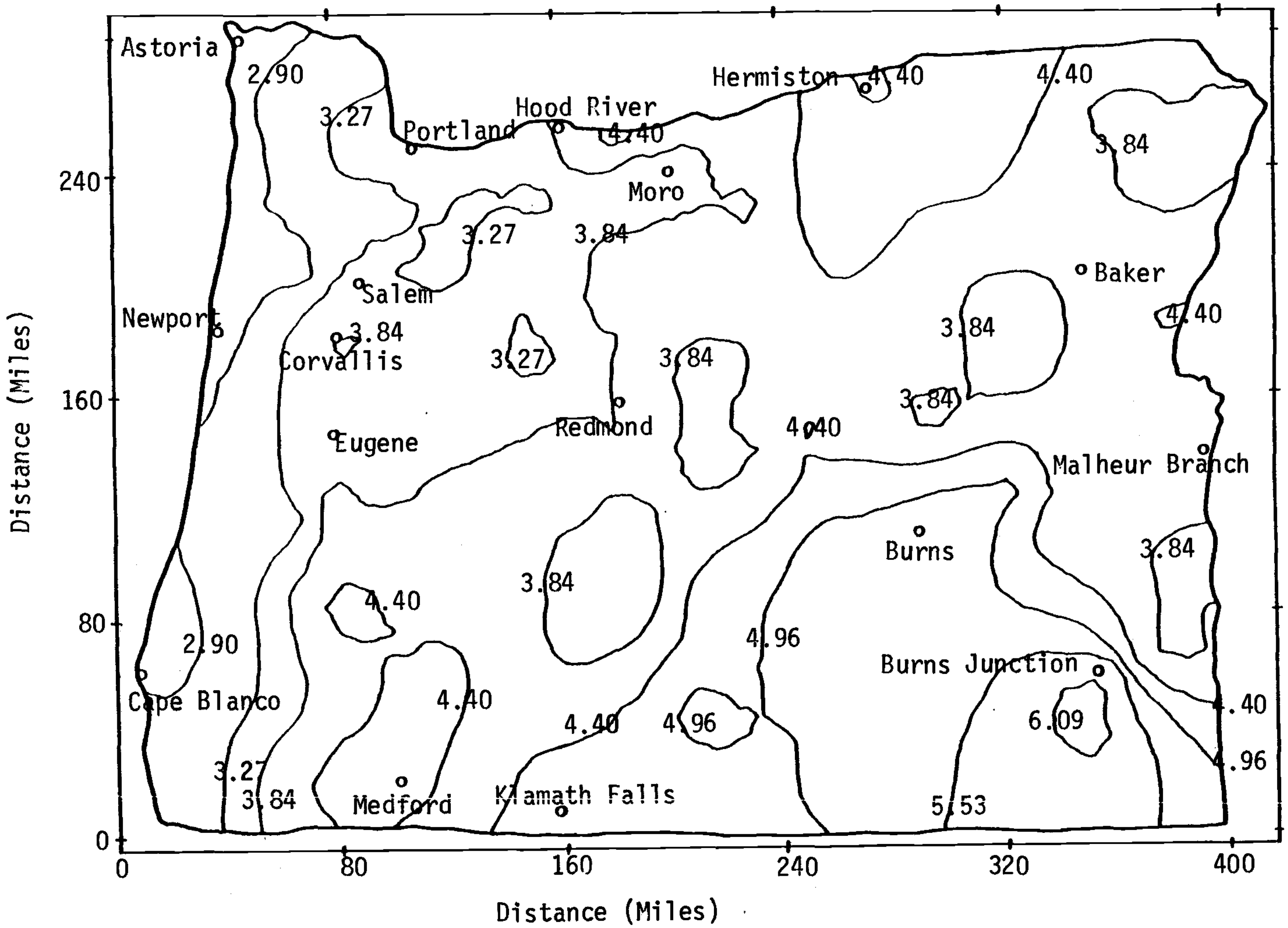

Figure 20. Contour map of reference evaptranspiration (mm/day) for September 1979.

explanation could come from the high sensitivity of the FAO-modified Blaney-Criddle estimated reference ET to temperature (Allen and Brockway, 1982). Since temperature decreases with altitude, in general, this change produces higher decreases in evapotranspiration than the 1 percent per 100 meters upward correction suggested by Doorenbos and Pruitt (1977). The overall change is therefore a decrease in reference evapotranspiration with the altitude. In the north of the state, the contour curves tend to depart from their general north-south orientation because of the influence of the Columbia Gorge, which is expected to increase the relative humidity.

The contour maps are shown with few contour levels in order to make the maps less crowded and thus easier to read. However, the plotting routine was designed to provide more contour levels if they are asked for. The changes in evapotranpiration rates from one month to another are also revealed by the contour maps of ET. The maps, Figs. 16 through 20, show that the reference evapotranspiration rates for the same location increase from May to July, then decrease through September. This observation agrees with the reference evapotranspiration trends shown by Fig. 9.

For the reasons given above, the contour maps appear to be a good illustration of the general spatial variability of evapotranspiration over the state of Oregon. It should be emphasized that the ET contour maps shown represent the monthly means of the daily evapotranspiration rates. The use of these maps should be restricted to the description of ET variability over the state of Oregon on a monthly basis. For project design at a specific location, it is recommended to refer to Appendix B where the kriging estimates of ET are given at each 12.8 km by 12.8 km grid corner. The values indicated compare very well with the original ET data, while the maps are less precise because of the small number of contour levels and possibly the lack of adjustment when computer plots of the contours were laid over a separate drawing of the state of Oregon. Beside those manipulation errors, the contour maps could be used to demonstrate, better than any other work done so far, the spatial variability of the monthly average of the daily evapotranspiration rate over the state of Oregon during the months and year indicated.

4.10 Contour Maps of Kriging Variances

Kriging variances were computed by program KRIGX along with the kriging estimates of ET. The variances were plotted by computer and are shown as contour maps of kriging variances in Figs. 21 through 25. These maps show the distribution of estimation variances over the

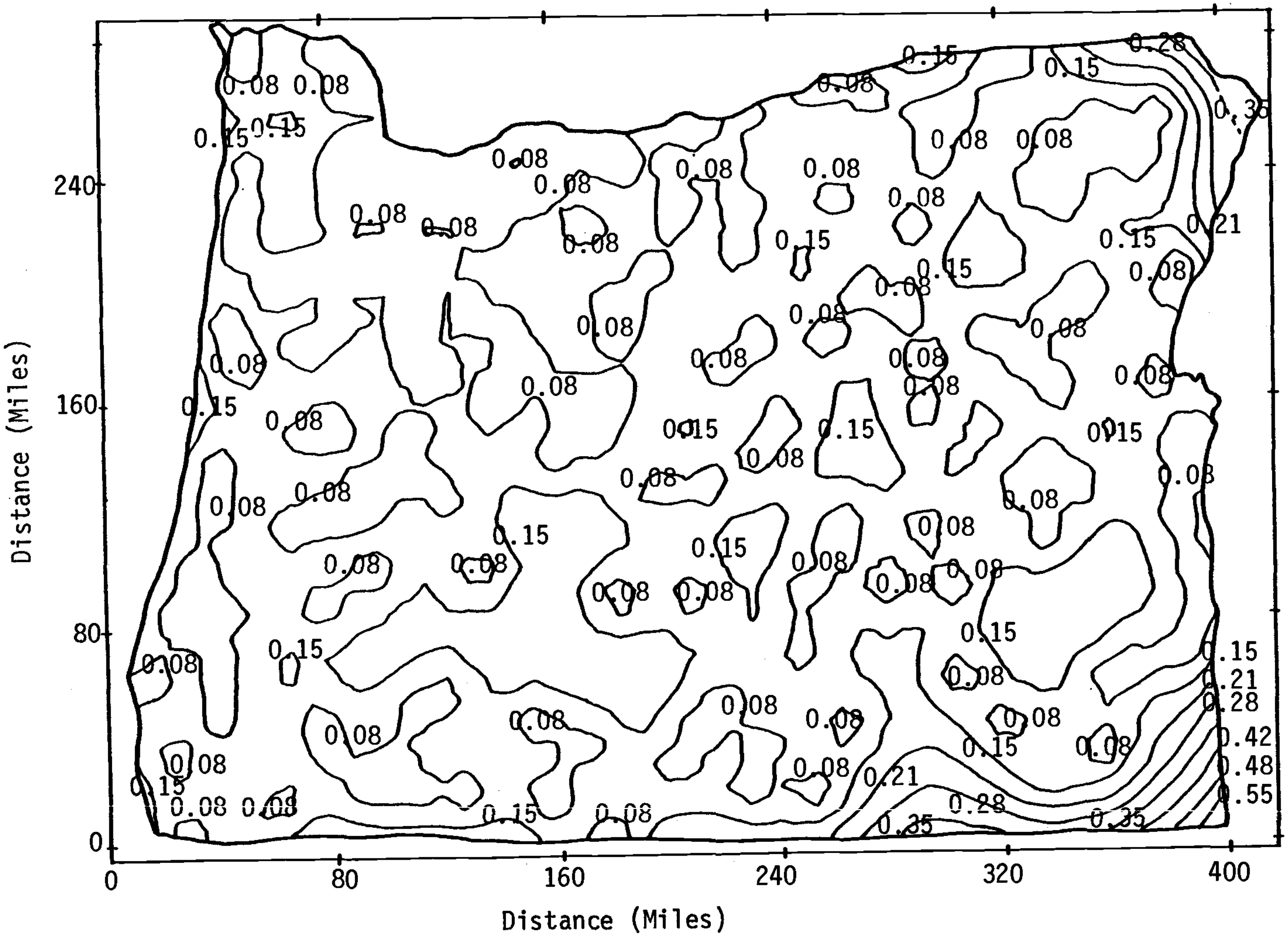

Figure 21. Contour map of kriging variance ($(mm/day)^2$) for May 1979.

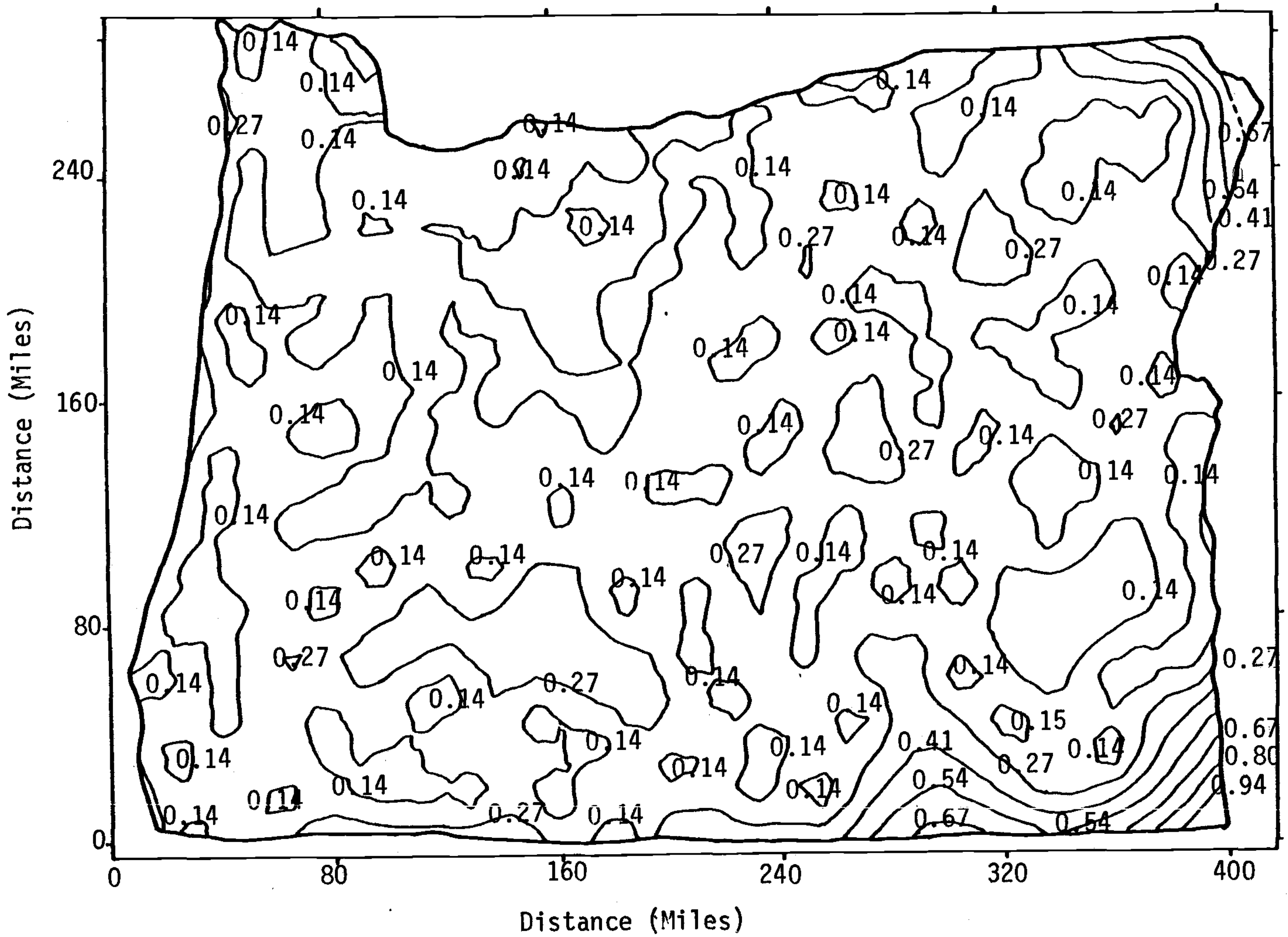

Figure 22. Contour map of kriging variance ($(mm/day)^2$) for June 1979.

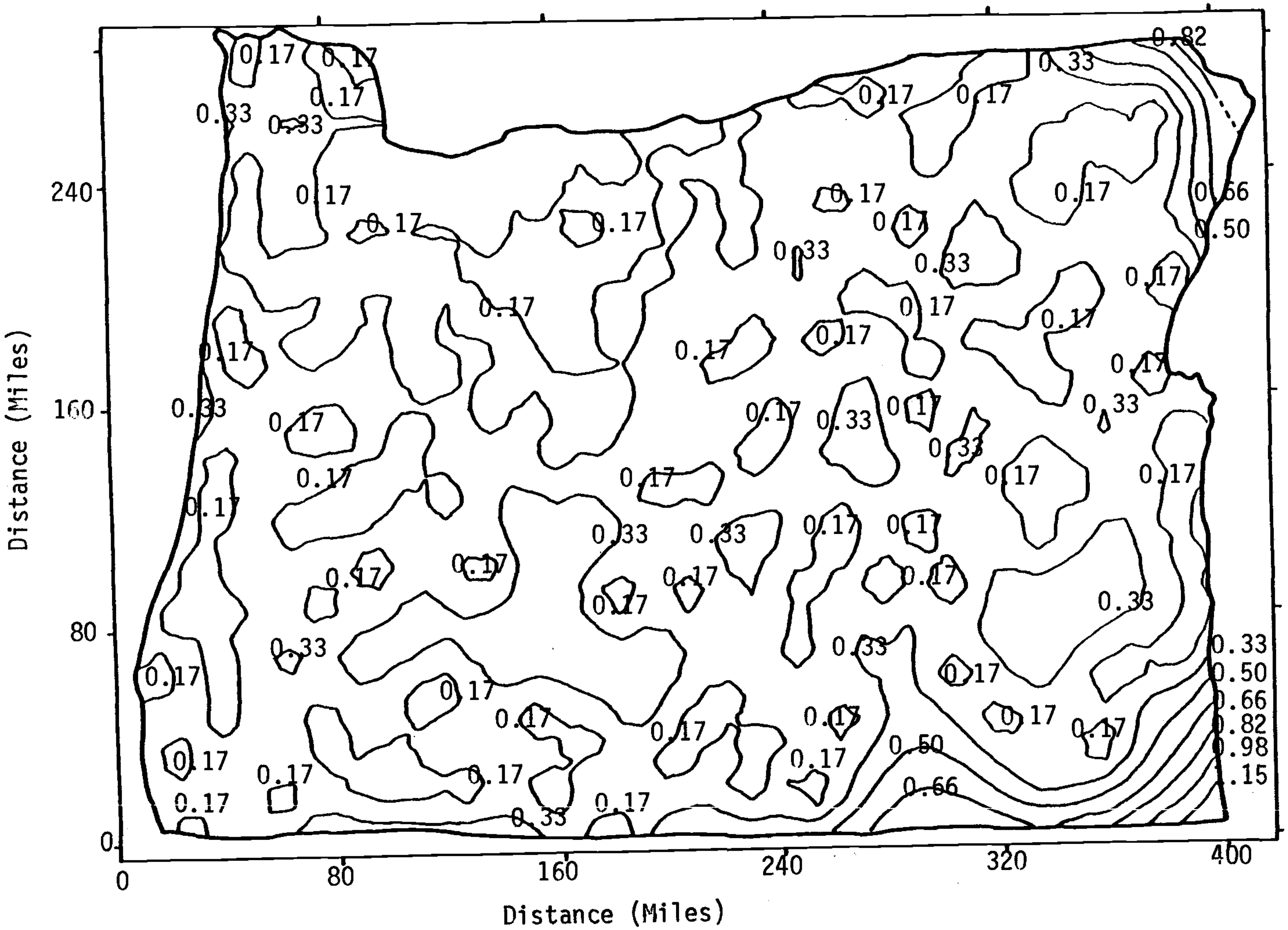

Figure 23. Contour map of kriging variance ((mm/day)^2) for July 1979.

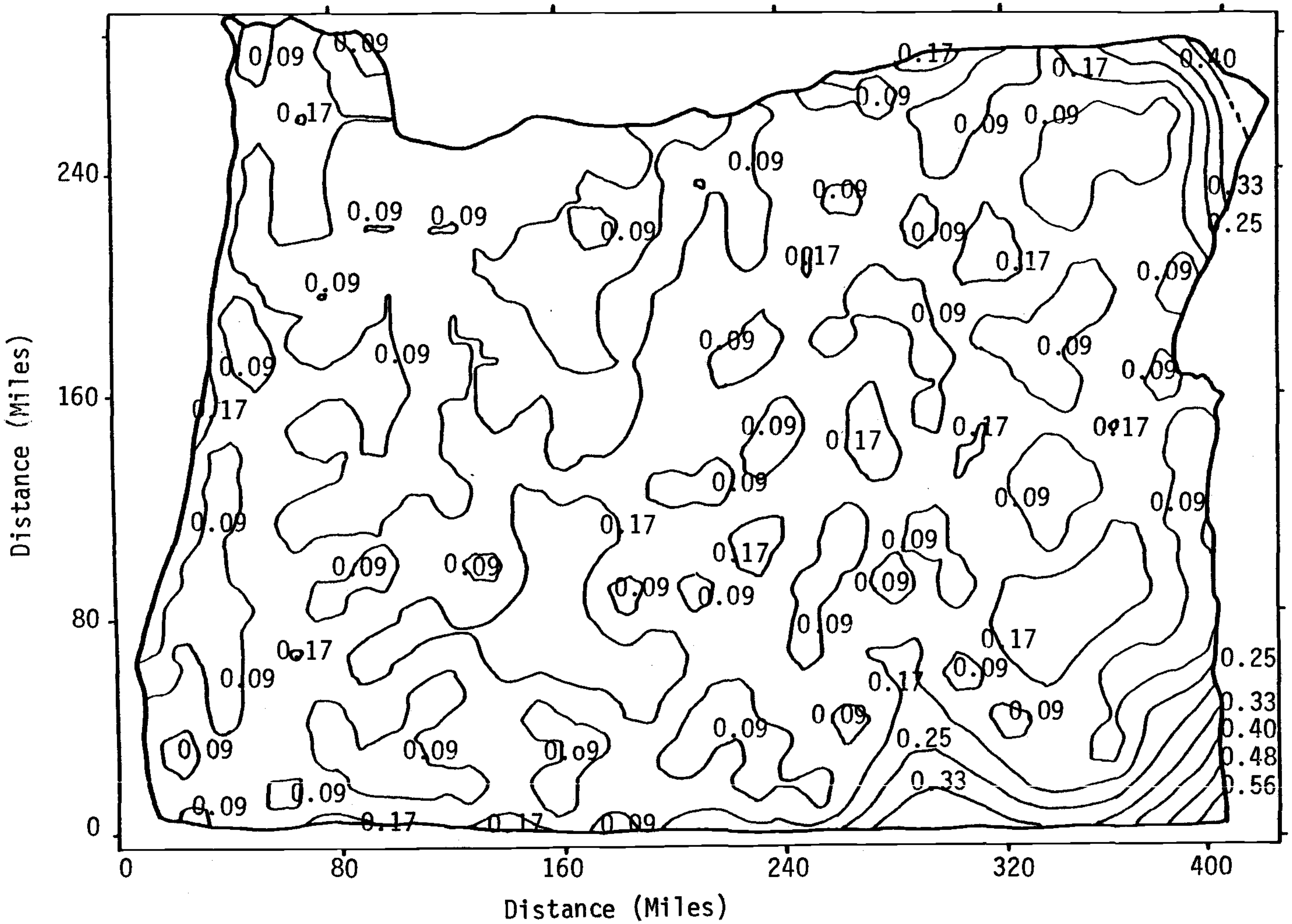

Figure 24. Contour map of kriging variance ((mm/day)^2) for August 1979.

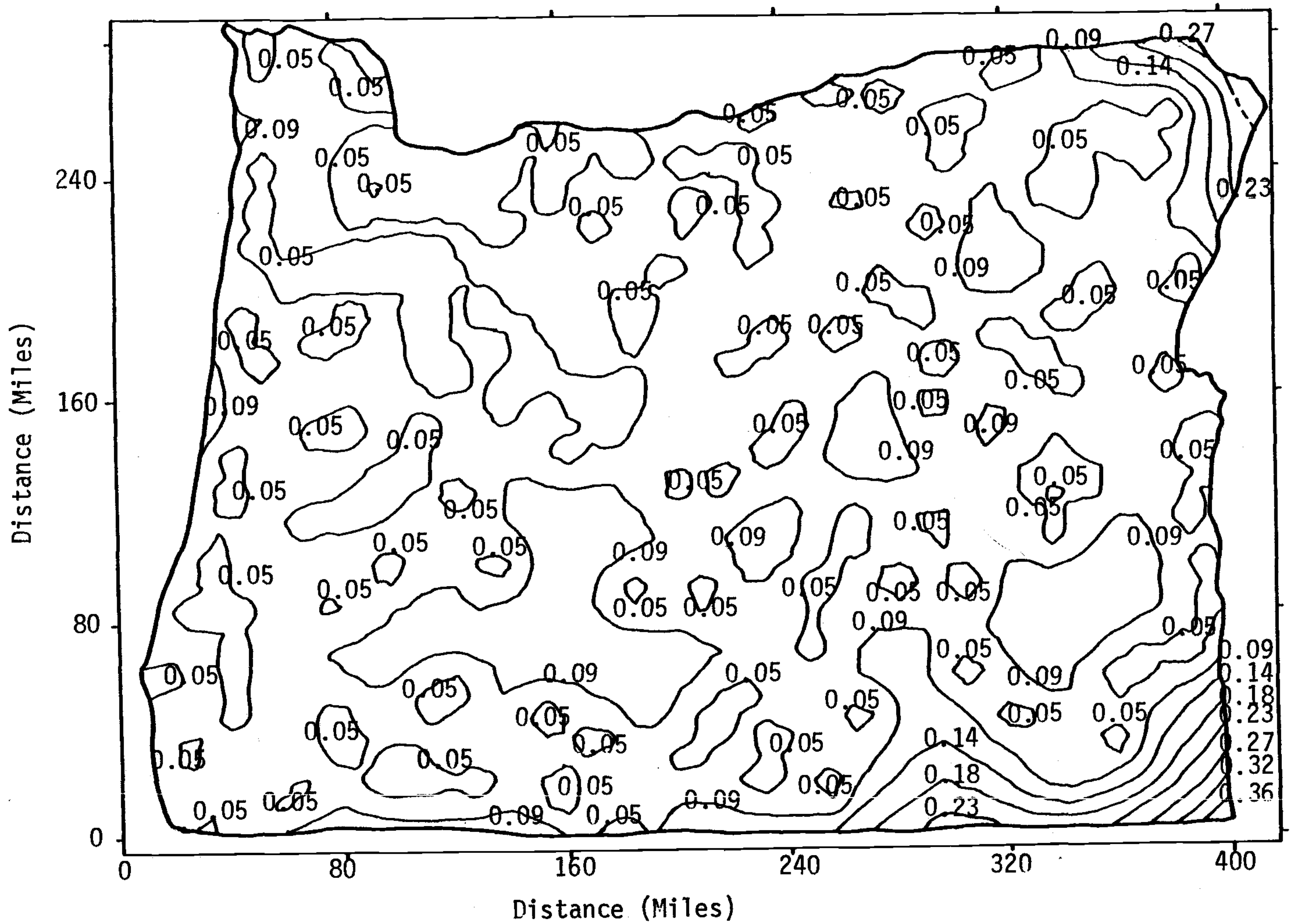

Figure 25. Contour map of kriging variance $((mm/day)^2)$ for September 1979.

state. The kriging variances, which are the estimates of the squared errors, increase from May to July and then decrease through September. The variance levels are generally low where there is a combination of high station density and low heterogeneity. However, because simple kriging (which assumes stationarity) was used, the variances depended only on the station density. Subregions of high station density such as the Willamette Valley are covered by low contour levels while those near the state boundaries such as in the north-east and south-east where the station densities are low, exhibit higher contour levels of kriging variances. The interest of such maps of contour variances is to show how much the estimation could be improved when additional weather stations were added to the network. This subject was discussed in detail by Hughes and Lettenmaier (1981). Few contour levels are shown to make the maps easy to read. More detail is provided by Appendix B, where the numerical values of kriging variance are listed.

The shapes of the variance contour curves were conserved from one month to the next while they changed for the evapotranspiration rates through the same period. This consistency in the shape of the variance contour curves is an indication that the relative changes in kriging variances do not depend on the absolute values of the observations, but rather on the station density and the semivariogram model. The months which have higher sill values produced, in general, higher contour levels of kriging variances.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Weather data were collected from 175 stations over the state of Oregon during the 1979 growing season. These data were used to estimate the monthly reference evapotranspiration rates, ET_r, by the FAO-modified Blaney-Criddle method. This ET_r estimation method was selected among others because of its compatibility with the weather data available throughout the state of Oregon.

The 175 ET_r rates were used to compute semivariograms to which spherical (or Matheron's) semivariogram models were fitted. For all months but September, the semivariograms were anisotropic and revealed that the rate of change in ET_r was higher in the north-south than in the east-west directions. These semivariogram functions described the relationship between the reference evapotranspiration variability and the distance between the weather stations.

For each month, the semivariogram models were used to estimate the reference evapotranspiration rates, by kriging technique, at locations where no weather data were available. Such a technique was verified to provide better estimates of ET_r rates than the ordinary linear regression models. The comparison was made on the basis of the number of parameters included in the model, and the mean and variance of the residuals.

The use of jacknifing to test the model validation revealed that simple kriging performed better than the universal kriging.

The kriging estimates and the estimation of kriging variances were made at approximately 1,600 locations over the state of Oregon. These estimates were translated into contour maps of evapotranspiration which agreed with the general distribution of the climate over the state of Oregon. The contour curves of the kriging variance also agreed with the change in the weather station density. Subregions of low station density corresponded to high contour levels of kriging variance and vice-versa.

5.2 Recommendation for Future Research

The results of this research could be improved by the use of subregional semivariograms for estimating the reference evapotranspiration rates within each subregion. Such a method would incorporate a means of modifying the subregional semivariograms for their use in the transition zones between subregions. The subregional semivariograms derived by jacknifing for June constitute the initial approach which must be improved.

This thesis assumed the constancy of wind velocity inside each zone of influence. A relationship could be found between the few secondary weather data and the much larger number of temperature data available. Additional research is required to express such a relationship. Cokriging might be a way to approach this problem. Cokriging is an unbiased estimation method of poorly sampled variables, using the spatial correlation between these variables and the ones abundantly sampled. In any case, an effort could be made to add automatic recording weather stations which could be moved from one location to another and even to remote sites.

Other traditional interpolation techniques such as moving average, inverse distance and inverse squared distance interpolation methods could be used and compared to the results of the semivariogram models. These methods have the weakness of assuming a priori a spatial variability function. However, they have the advantage of being simpler than the kriging technique. Their use to obtain estimates of secondary weather data at primary weather stations may improve the local estimates of the reference evapotranspiration at those stations.

Additional research is required on the relationship between geographical configuration and the stationarity of the drift, and the semivariogram before the kriging variances could be used for designing station density. The general approach has been explained assuming stationarity of the drift and stationarity of the semivariogram. Any efficient design of weather station density, using such an approach, should be based on a long-term mean semivariogram curve and take into account its calibration based on the local topographical characteristics.

The ultimate goal of this research was efficient, timely, computerized plotting of evapotranspiration contours over large regions. Such contours could be drawn for different probabilities based on long historical records of meterological variables for water resources system and irrigation system design. Contours could also be drawn for data collected in the previous 24 to 48 hours for irrigation scheduling. The application of a method which accounts for the spatial structure of evapotranspiration over a region could prove to be beneficial for improving the productivity in irrigated agriculture and water resources development.

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APPENDICES

APPENDIX A

MAIN: Program for estimating the local reference evapotranspiration rates at weather stations.

VARIO: Program for computing and plotting the semivariograms.

KRIGX: Program for interpolating by kriging the reference evapotranspiration rates between weather stations.

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE1,TAPE3)
C
C.....................................................................
C
C          PROGRAM NAME: MAIN
C          WRITTEN BY  : KODJO AMEGEE, GRADUATE STUDENT
C                        AT OREGON STATE UNIVERSITY
C
C     THIS PROGRAM COMPUTES THE FAO MODIFIED BLANEY
C     AND CRIDDLE REFERENCE EVAPOTRANSPIRATION ESTIMATES
C     ALONG WITH THE CONVERSION OF THEIR SITES LONGITUDES
C     AND LATITUDES INTO CARTESIAN COORDINATES.
C
C INPUT VARIABLES:
C     ID        : WEATHER STATION NAME
C     IYEAR, MONTH: YEAR AND MONTH OF DATA COLLECTION
C     TMAX,TMIN    : MAXIMUM AND MINIMUM DAILY TEMPERATURES IN
C                    DEGREES FARENHEIT
C     RHMIN    : MINIMUM DAILY RELATIVE HUMIDITY IN PERCENT
C     RS       : DAILY GLOBAL SOLAR RADIATION IN LANGLEY
C     WRUN     : DAILY WIND RUN IN MILES/DAY
C     HWIND    : ANEMOMETER HEIGHT IN METERS
C     WRTIO    : RATIO OF DAY BY NIGHT WIND RUNS
C     ALT      : ALTITUDE OF WEATHER SATION IN FEET
C     LAT      : WEATHER STATION LATITUDE
C     LONG     :   "        "    LONGITUDE
C
C OUTPUT VARIABLES:
C    X  : CONVERSION OF LONG INTO CARTESIAN COORDINATE IN FEET
C    Y  :      "        LAT    "           "            "
C    ET : EVAPOTRANSPIRATION ESTIMATE IN MM/DAY
C
C.....................................................................
C
      REAL LAT,LONG,NRATIO
      DIMENSION BB(6,6,6),PP(11,12),RRAN(11,12)
      DIMENSION ET(175),X(175),Y(175)
      READ(1,100) ZONE,CWIND,CSOLAR
  100 FORMAT(2A10/F6.0,T16,F5.0,/)
      WRITE(3,150)
  150 FORMAT('STAT  DATE     F         ET         X         Y
     +  ALT')
      DO 22 I=1,175
      READ(1,200) ID,IYEAR,MONTH,TMAX,TMIN,RHMIN,RS,WRUN,
     +            HWIND,WRTIO,ALT,LAT,LONG
  200 FORMAT(A7,2I2,2F5.0,4F6.0,F5.0,2F6.0,F7.0)
C     PRINT*,TMAX,TMIN,LAT,MONTH
      TAVG=(TMAX+TMIN)/2.
```

```
      TAVG=(TAVG-32.)/1.8
      RHIAG=RHMIN
      U2MAVG=WRUN*WRTIO/(WRTIO+1.)*CWIND*1000./3600./12.*
     +(2.0/HWIND)**0.22
C TABLE OF MONTHLY PERCENT OF DAYLIGHT PP TO COMPUTE P AND THEN F
      DATA PP
     1 / .267,.264,.261,.257,.252,.246,.239,.231,.220,.209,.195,
     2   .269,.268,.266,.264,.261,.257,.253,.248,.243,.236,.228,
     3   .269,.269,.269,.269,.269,.269,.268,.268,.268,.267,.266,
     4   .269,.270,.272,.275,.278,.282,.286,.291,.297,.303,.310,
     5   .271,.273,.276,.281,.287,.294,.303,.312,.322,.334,.346,
     6   .274,.280,.285,.291,.298,.307,.316,.328,.341,.355,.371,
     7   .275,.281,.287,.293,.299,.305,.313,.321,.330,.341,.354,
     8   .274,.278,.282,.287,.291,.295,.300,.304,.309,.315,.322,
     9   .271,.277,.280,.281,.281,.281,.281,.281,.281,.281,.281,
     A   .270,.269,.268,.267,.264,.261,.258,.254,.250,.245,.240,
     B   .269,.267,.264,.260,.254,.247,.240,.231,.222,.211,.200,
     C   .268,.264,.262,.257,.250,.242,.232,.221,.209,.195,.180 /
      LL=INT(LAT/5)*5
      IF(LAT.GT.50.0) LL=50
      L1=LL/5+1
      L2=L1+1
      IF(L2.GT.11) L2=11
      FACP=(LAT-LL)/5.0
      P=PP(L1,MONTH)+FACP*(PP(L2,MONTH)-PP(L1,MONTH))
C     PRINT*,L1,MONTH,FACP,L2,P
      F=P*(0.46*TAVG+8.13)
      RS=RS*CSOLAR
C  THIS IS TO CALCULATE RA THEORETICAL SOLAR RADIATION
C     REACHING EARTH SURFACE IN ABSENCE OF ATMOSPHERE
C             FOR 12 MONTHS AND LATITUDE 0 TO 50 NORTH
      DATA RRAN
     1 / 15.8,14.1,13.2,12.2,11.2,10.1,08.9,07.6,06.4,05.1,03.8,
     2   15.5,14.9,14.3,13.5,12.7,11.7,10.7,09.6,08.5,07.3,06.1,
     3   15.7,15.6,15.3,14.9,14.4,13.7,13.0,12.2,11.3,10.3,09.3,
     4   15.3,15.5,15.6,15.7,15.6,15.5,15.2,14.7,14.2,13.5,12.7,
     5   14.4,15.0,15.5,16.8,16.3,16.4,16.5,16.4,16.3,16.1,15.7,
     6   13.9,14.6,15.2,15.8,16.3,16.7,17.0,17.2,17.3,17.3,17.2,
     7   14.1,14.7,15.3,15.8,16.3,16.6,16.7,16.0,16.7,16.6,16.4,
     8   14.6,15.2,15.5,15.8,15.9,15.8,15.7,15.5,15.1,14.6,14.0,
     9   15.3,15.3,15.3,15.1,14.8,14.5,13.9,13.2,12.5,11.7,10.9,
     A   15.4,15.1,14.6,14.1,13.4,12.6,11.7,10.7,09.6,08.5,07.2,
     B   15.1,14.4,13.6,12.7,11.7,10.6,09.5,08.2,07.0,05.6,04.3,
     C   14.8,13.9,13.0,11.9,10.8, 9.5,08.3,07.0,05.7,04.3,03.9 /
      FACR=(LAT-LL)/5.0
      RA=RRAN(L1,MONTH)+FACR*(RRAN(L2,MONTH)-RRAN(L1,MONTH))
      NRATIO=2.0*(RS/RA-0.25)
      IF(NRATIO.GT.1.0) NRATIO=0.999
      IF(NRATIO.LT.0.0) NRATIO=0.0
C THIS SECTION INTERPOLATES ET1 USING A,B,AND F
```

```
      DATA BB
     1 / 0.84,0.80,0.74,0.64,0.52,0.38, 1.03,0.95,0.87,0.76,0.63,0.48,
     2   1.22,1.10,1.01,0.88,0.74,0.57, 1.38,1.24,1.13,0.99,0.85,0.66,
     3   1.54,1.37,1.25,1.09,0.94,0.75, 1.68,1.58,1.36,1.18,1.04,0.84,
     4   0.97,0.90,0.81,0.68,0.54,0.40, 1.19,1.08,0.96,0.84,0.66,0.50,
     5   1.41,1.26,1.11,0.97,0.77,0.60, 1.60,1.42,1.25,1.09,0.89,0.70,
     6   1.79,1.59,1.39,1.21,1.01,0.79, 1.98,1.74,1.52,1.31,1.11,0.89,
     7   1.08,0.98,0.87,0.72,0.56,0.42, 1.33,1.18,1.03,0.87,0.69,0.52,
     8   1.56,1.38,1.19,1.02,0.82,0.62, 1.78,1.56,1.34,1.15,0.94,0.73,
     9   2.00,1.74,1.50,1.28,1.05,0.83, 2.19,1.90,1.64,1.39,1.16,0.92,
     A   1.18,1.06,0.92,0.74,0.58,0.43, 1.44,1.27,1.10,0.91,0.72,0.54,
     B   1.70,1.48,1.27,1.06,0.85,0.64, 1.94,1.67,1.44,1.21,0.97,0.75,
     C   2.18,1.86,1.50,1.34,1.09,0.85, 2.39,2.03,1.74,1.46,1.20,0.95,
     D   1.26,1.11,0.96,0.76,0.60,0.44, 1.52,1.34,1.14,0.93,0.74,0.55,
     E   1.79,1.56,1.32,1.10,0.87,0.66, 2.05,1.76,1.49,1.25,1.00,0.77,
     F   2.30,1.96,1.66,1.39,1.12,0.87, 2.54,2.14,1.82,1.52,1.24,0.98,
     G   1.29,1.15,0.98,0.78,0.61,0.45, 1.58,1.34,1.17,0.96,0.75,0.56,
     H   1.86,1.61,1.36,1.13,0.89,0.68, 2.13,1.83,1.54,1.28,1.03,0.79,
     I   2.39,2.03,1.71,1.43,1.15,0.89, 2.63,2.22,1.86,1.56,1.27,1.00 /
      XX=RHIAG
      YY=NRATIO
      Z=U2MAVG
C     PRINT*,XX,YY,Z
      I1=INT(XX/20.)+1
      I2=I1+1
      IF(I2.GT.6) I2=6
      J1=INT(YY/0.2)+1
      J2=J1+1
      IF(J2.GT.6) J2=6
      K1=INT(Z/2)+1
      K2=K1+1
      IF(K2.GT.6) K2=6
      IF(K1.GT.6) K1=6
      X1=(I1-1)*20
      X2=(I2-1)*20
      Y1=(J1-1)*0.2
      Y2=(J2-1)*0.2
      Z1=(K1-1)*2
      Z2=(K2-1)*2
      FACX=0.0
      FACY=0.0
      FACZ=0.0
      IF(K1.NE.K2) FACZ=(Z-Z1)/(Z2-Z1)
      C11  = BB(I1,J1,K1)+FACZ*(BB(I1,J1,K2)-BB(I1,J1,K1))
      C12  = BB(I1,J2,K1)+FACZ*(BB(I1,J2,K2)-BB(I1,J2,K1))
      C21  = BB(I2,J1,K1)+FACZ*(BB(I2,J1,K2)-BB(I2,J1,K1))
      C22  = BB(I2,J2,K1)+FACZ*(BB(I2,J2,K2)-BB(I2,J2,K1))
C     PRINT*,PP(3,5),RRAN(10,8),BB(3,4,5)
C     PRINT*,X1,Y1,Z1
      IF(J1.NE.J2) FACY=(YY-Y1)/(Y2-Y1)
```

```
      IF(I1.NE.I2) FACX=(XX-X1)/(X2-X1)
C     PRINT*,FACZ,FACY,FACX,C11,C12,C21,C22
      D1  = C11 + FACY*(C12 - C11)
      D2  = C21 + FACY*(C22 - C21)
      BP = D1+FACX*(D2-D1)
      AP=0.0043*XX-YY-1.41
C     PRINT*,U2MAVG,D1,D2,BP
      ET(I)=AP+BP*F
C        CORRECTING FOR ALTITUDE
      ET(I)=ET(I)*(1.+ALT*0.305/10000.)
C  CONVERSION OF LATITUDE AND LONGITUDE INTO
C   X AND Y COORDINATES (WITH SALEM AS ORIGIN
C              SLONGO AND  SLATO)  IN MILES
      SLATO = 42.0
      SLONGO = 124.50
      LATO=INT(SLATO)
      LONGO=INT(SLONGO)
      NLAT=INT(LAT)
      NLONG=INT(LONG)
      IF(NLAT-45) 101,102,103
  101 FLAT= 68.993 + 0.061*(NLAT-40)/5.0
      FLON= 53.063 - 4.068*(NLAT-40)/5.0
      GOTO 104
  102 FLAT= 69.054
      FLON= 48.995
      GOTO 104
  103 FLAT= 69.054 + 0.061*(NLAT-45)/5.0
      FLON= 48.995 - 4.443*(NLAT-45)/5.0
  104 X(I)=-FLON*((NLONG-LONGO)+(LONG-SLONGO+LONGO-NLONG)*100./60.)
      Y(I)=FLAT*((NLAT-LATO)+(LAT-SLATO+LATO-NLAT)*100./60.)
      WRITE(3,400) ID,IYEAR,MONTH,F,ET(I),X(I),Y(I),ALT
  400 FORMAT(A6,2I2,5F10.3)
   22 CONTINUE
      STOP
      END
```

```
      PROGRAM VARIO(INPUT,OUTPUT,TAPE2,TAPE3)
C
C .................................................
C
C     PROGRAM NAME: VARIO
C     WRITTEN BY  : KODJO AMEGEE, GRADUATE STUDENT
C                   AT OREGON STATE UNIVERSITY.
C
C        SEMI-VARIOGRAM IN TWO DIMENSIONS
C  IRREGULAR GRID.THERE MAY BE MISSING DATA.
C  CALCULATION BY CLASS OF ANGLE AND DISTANCE.
C
C ....PARAMETERS
C  VR(ND)     DATA ARRAY
C  X(ND),Y(ND)   X AND Y COORDINATES OF POINTS
C  ND         NUMBER OF POINTS
C  KMAX       MAXIMUM NUMBER OF COMPUTATION LAGS
C  PAS        LENGTH OF BASIC LAG
C  DP         WIDTH OF DISTANCE CLASS.IF DP=0.
C                  DP=PAS/2. IS TAKEN
C  NDI        NUMBER OF DIRECTIONS
C  ALP(NDI)   ANGLES DEFINING DIRECTIONS (WITH
C               RESPECT TO X AXIS IN DEGREES)
C  DA         WIDTH OF ANGLE CLASS.IF DA=0. THEN
C               DA=45. DEGREES IS TAKEN
C  NC(KMAX*NDI) NUMBER OF COUPLES/LAG/DIRECTION
C  G(KMAX*NDI)  VARIOGRAM VALUES/LAG/DIRECTION
C  D(KMAX*NDI)  AVERAGE DISTANCE/LAG/DIRECTION
C  U          AVERAGE  /
C  V          VARIANCE / OF DATA .GT.TEST
C  N          NUMBER
C
C ....OPTIONS
C  IS.NE.1 RESULTS ARE PRINTED
C
C ....COMMONS
C
C  TEST       INFERIOR BOUNDARY OF EXISTING DATA
C     IF VR.LE.TEST MISSING OR ELIMINATED DATUM
C
C
C .................................................
C
```

```
C DIMENSIONS AND PARAMETERS SPECIFICATIONS
      REAL U,V,H
      INTEGER N,ND,KMAX,KD,KR
      CHARACTER REGION*30,STA*20,HEAD*4,TICK4*4,TICK5*5
      CHARACTER*1 STAR,DOT,PLUS,BLANK
      CHARACTER LINE1(0:44)*45,LINE2(-10:10)*21
      PARAMETER(KMAX=62,ND=175)
      DIMENSION SCALE(0:11),D(KMAX),KMAX1(4),CAN(4),SAN(4),ALP(4)
      DIMENSION G(KMAX),DR(KMAX),NC(KMAX),VR(ND),X(ND),Y(ND)
      DATA (ALP(KD),KD=1,4) /0.,45.,90.,-45./
      BLANK=' '
      DOT='.'
      STAR='*'
      PLUS='+'
      TICK4='+...'
      TICK5='+....'
C
      PRINT*,'PAS=?,DP=?,DA=?,TEST=?,IS=?'
      READ*,PAS,DP,DA,TEST,IS
      PRINT*,'REGION NAME?'
      READ(*,8)REGION
    8 FORMAT(A30)
      PRINT*,'REGION LIMITS:XW,XE,YS,YN'
      READ*,XW,XE,YS,YN
C
C            INITIALIZE
C
      PI=3.14159265
      IF(DA.LE.0)DA=45.
      IF(DP.LE.0)DP=PAS/2.
C
      DO 9 KD=1,4
      ALPHA=PI*ALP(KD)/180.
      CAN(KD)=COS(ALPHA)
      SAN(KD)=SIN(ALPHA)
    9 CONTINUE
      THETA=PI*DA/180.
      CDA=COS(THETA)
C READING IN THE ET DATA
      NCOUNT=0
      READ(2,99) HEAD
   99 FORMAT(A)
      DO 5,I=1,175
        READ(2,100) STA,ET,XX,YY
  100   FORMAT(A20,3(F10.3))
        IF(XX.LE.XE.AND.XX.GE.XW) THEN
          IF(YY.LE.YN.AND.YY.GE.YS) THEN
            NCOUNT=NCOUNT+1
```

```
            VR(NCOUNT)=ET
            X(NCOUNT)=XX
            Y(NCOUNT)=YY
          ELSE
          ENDIF
        ENDIF
    5 CONTINUE
C
C INITIALIZATIONS CONTINUE
C
      N=1
      U=VR(1)
      V=VR(1)*VR(1)
C
C COMPUTATIONS FOR EACH DIRECTION
C
      KMAX1(1)=(XE-XW)/PAS+1
      KMAX1(3)=(YN-YS)/PAS+1
      DMAX=SQRT((XE-XW)*(XE-XW)+(YN-YS)*(YN-YS))
      KMAX1(2)=KMAX1(4)=DMAX/PAS+1
      DO 50,KD=1,4
        DO 40,KK=1,KMAX1(KD)
          NC(KK)=0
          D(KK)=0.
          DR(KK)=0.
          G(KK)=0.
   40   CONTINUE
        DO 30,I=1,NCOUNT
            I1=I+1
            IF(I1.GT.NCOUNT) GOTO 30
            IF(VR(I1).LE.TEST) GOTO 30
            IF(KD.EQ.1) THEN
              N=N+1
              U=U+VR(I1)
              V=V+VR(I1)*VR(I1)
            ELSE
            ENDIF
            DO 20,J=I1,NCOUNT
            IF(VR(J).LE.TEST) GOTO 20
            DX=X(I)-X(J)
            DY=Y(I)-Y(J)
            H=SQRT(DX*DX+DY*DY)
            IF(H.LT.1.E-03)GOTO 20
            COSD=(DX*CAN(KD)+DY*SAN(KD))/H
            COSD1=ABS(COSD)
            IF(COSD1.GT.CDA) THEN
              REST=MOD(H,PAS)
                KR=H/PAS
```

```
                IF(KR.LT.KMAX1(KD)) THEN
                  IF(REST.LE.3.*DP/2.AND.REST.GE.DP/2.)THEN
                  IK=KR+1
                ELSE
                  GOTO 20
                ENDIF
                  IF(COSD1.EQ.0.)THEN
                    VRR=VR(I)-VR(J)
                  ELSE
                    VRR=COSD*(VR(I)-VR(J))/COSD1
                  ENDIF
                  NC(IK)=NC(IK)+1
                  D(IK)=D(IK)+H
                  DR(IK)=DR(IK)+VRR
                  G(IK)=G(IK)+.5*VRR*VRR
                ELSE
                  GOTO 20
                ENDIF
              ENDIF
 20         CONTINUE
 30       CONTINUE
C
C PRINT ALL THE KMAX1 RESULTS FOR EACH DIRECTION
C
        IF(KD.EQ.1)THEN
          V=(V-U*U/N)/N
          U=U/N
          WRITE(3,2000) REGION,XW,XE,YS,YN
          WRITE(3,2001) U,V,N
          WRITE(3,2003)
        ELSE
        ENDIF
        IF(V.GT.0.5.AND.V.LE.1.0) SINCR=0.10
        IF(V.GT.1.0.AND.V.LE.1.5) SINCR=0.15
        IF(V.GT.1.5.AND.V.LE.2.0) SINCR=0.20
        IF(V.GT.2.0.AND.V.LE.2.5) SINCR=0.25
      DO 35,J=0,11
  35    SCALE(J)=J*SINCR
      WRITE(3,3001) KD,(SCALE(KK),KK=0,11)
      WRITE(3,3011)(TICK4,J=1,11),(TICK5,L=1,4)
      DO 45,IK=1,KMAX1(KD)
        IF(NC(IK).GT.1)THEN
          D(IK)=D(IK)/NC(IK)
          DR(IK)=DR(IK)/NC(IK)
          G(IK)=G(IK)/NC(IK)
        ELSE
        ENDIF
        IF(NC(IK).GE.1.AND.G(IK).LT.11.*SINCR)THEN
```

```
          DO 43,J=0,44
            LINE1(J)=BLANK
            LINE1(0)=DOT
 43       CONTINUE
          DO 44,J=-10,10
            LINE2(J)=BLANK
            LINE2(-10)=LINE2(0)=LINE2(10)=DOT
 44       CONTINUE
          MG=G(IK)*40./(SINCR*10.)+.5
          IF(MG.GT.44) MG=44
          LINE1(MG)=STAR
          IF(DR(IK).EQ.0.)THEN
            MD=0
          ELSE
            MD=DR(IK)*5.+.5*DR(IK)/ABS(DR(IK))
          ENDIF
          IF(MD.GT.10)MD=10
          IF(MD.LT.-10)MD=-10
          LINE2(MD)=STAR
          WRITE(3,3003)IK,NC(IK),D(IK),G(IK),IK,
     1                 LINE1,DR(IK),IK,LINE2
        ELSE
          WRITE(3,3002)IK,NC(IK),D(IK),G(IK),IK,DR(IK),IK
        ENDIF
   45 CONTINUE
   50 CONTINUE
C         PRINT IF IS.NE.0
      IF(IS.EQ.0) GO TO 6
 3001 FORMAT(//,'DIRECTION',I2,24X,12(F3.1,1X),11X,
     1'-2.0 -1.0  0.0 +1.0 +2.0')
 3011 FORMAT(34X,'0 ',11A4,'+',15X,4A5,'+')
C
 2000 FORMAT(1H ,5X,A30,2X,'IRREGULAR GRID 2 DIMENSIONS',3X,
     1'ET..SEMI-VARIOGRAM',3X,'AND DRIFT'/1H ,5X,'XW = ',F7.2,2X,
     2'XE = ',F7.2,2X,'YS = ',F7.2,2X,'YN = ',F7.2,8X,
     3'******************',3X,'*********')
 2001 FORMAT(1H ,'AVERAGE = ',F7.4,6X,'VARIANCE = '
     1,F7.4,' NUMBER OF DATA = ',I5)
 2003 FORMAT(1H ,' LAG   NC   AVD',6X,'1/2VAR',55X,'DRIFT    LAG')
 3003 FORMAT(1H ,I3,2X,I4,2X,F7.3,2X,F6.3,5X,I3,1X,45A1,2X,F6.3,
     13X,I3,1X,21A1)
 3002 FORMAT(1H ,I3,2X,I4,2X,F7.3,2X,F6.3,5X,I3,1X,'.',
     146X,F6.3,3X,I3,1X,'.')
C
    6 STOP
      END
```

```
      PROGRAM KRIGX(INPUT,OUTPUT,TAPE5,TAPE6)
C
C.......................................................
C
C          PROGRAM NAME: KRIGX
C          WRITTEN BY  : KODJO AMEGEE, GRADUATE STUDENT
C                        AT OREGON STATE UNIVERSITY
C
C     THIS PROGRAM PERFORMS KRIGING ESTIMATES AND KRIGING
C     VARIANCES OF EVAPOTRANPIRATIONS AT GRID CORNERS
C     USING FEW OBSERVATIONS, SEMIVARIOGRAM CHARACTERIS-
C     TICS, AND GEOGRAPHICAL COORDINATES.
C
C INPUT VARIABLES:
C     X(ID)       : EAST-WEST DISTANCE FROM A REFERENCE
C     Y(ID)       : NORTH-SOUTH  "   FROM THE SAME    "
C
C INPUT PARAMETERS:
C     NSAMP       : NUMBER OF SAMPLES FOR EACH ESTIMATION
C     SILLX       : SILL VALUE FOR EAST-WEST DIRECTION
C     SILLY       : SILL VALUE FOR NORTH-SOUTH DIRECTION
C     RANGX       : RANGE FOR EAST-WEST SEMIVARIOGRAM
C     RANGY       : RANGE FOR NORTH-SOUTH SEMIVARIOGRAM
C     NDAT        : TOTAL NUMBER OF OBSERVATIONS
C     NSYS        : DIMENSION OF THE KRIGING LINEAR SYSTEM
C
C OUTPUT VARIABLES
C     ETK(IY,IX) : KRIGING ESTIMATE OF "ET" AT (IY,IX)
C     ERK(IY,IX) : KRINGING VARIANCE AT GRID CORNER
C                  IDENTIFIED BY THE ID. NUMBERS (IY,IX)
C
C SUBROUTINES AND FUNCTIONS
C     GAM(      ) : COMPUTES SEMIVARIOGRAM BETWEEN POINTS
C     SOLVE(    ) : SOLVES FOR KRIGING WEIGHTS X USING THE
C                   KRIGING SYSTEM OF LINEAR EQUATIONS
C     LUDATF,LUELMF: ARE COMPUTER ROUTINES FROM IMSL USED
C                    TO PERFORM MATRIX TRANSFORMATIONS ON
C                    THE KRIGING SYSTEM.
C
C.......................................................
C
      CHARACTER STA(175)*10,HEAD*4
      INTEGER NSAMP,NSYS,IER,NX,NY
```

```
      REAL SILLX,SILLY,RANGX,RANGY,XEW,YSN,XO,YO
      PARAMETER(NDAT=175,NSAMP=8)
      PARAMETER(NSYS=NSAMP+1)
      REAL A(NSYS,NSYS),B(NSYS),WEIG(NSYS)
      REAL X(NDAT),Y(NDAT),ET(NDAT),DIS(NDAT)
      REAL SX(NSAMP),SY(NSAMP),ETR(NSAMP)
      REAL ETK(40,55),ERK(40,55),ALT(NDAT)
      COMMON /VARIO/ SILLX,SILLY,RANGX,RANGY
C
C READ THE DATA FROM VARIOGRAM AND FROM TAPE5
C
      PRINT*,'SILLX=?,SILLY=?,RANGX=?,RANGY=?'
      READ*,SILLX,SILLY,RANGX,RANGY
C READ REGION LIMITS AND GRID DISTANCES
      PRINT*,'XLW=?,XLE=?,YLS=?,YLN=?'
      READ*,XLW,XLE,YLS,YLN
      PRINT*,'DX=?,DY=?'
      READ*,DX,DY
      NX=(XLE-XLW)/DX+1
      NY=(YLN-YLS)/DY+1
C MAKE THE UPPER LEFT KRID CORNER THE ORIGINE OF X AND Y
      READ(5,15)
   15 FORMAT(A4)
      DO 10,I=1,NDAT
        READ(5,20) STA(I),DUM,ET(I),X(I),Y(I),ALT(I)
        Y(I)=Y(I)-YLS
        X(I)=X(I)-XLW
   10 CONTINUE
   20 FORMAT(A10,5F10.3)
C
C SEARCH FOR NSAMP LOCOTIONS IN KRINGING NEIGHBORHOOD
C
      DO 50,IY=1,NY
        YC=(IY-1)*DY
        DO 50,IX=1,NX
          XC=(IX-1)*DX
          DO 27,I=1,NDAT
            XS=X(I)-XC
            YS=Y(I)-YC
            DIS(I)=XS*XS+YS*YS
   27     CONTINUE
          DO 22,I=1,NSAMP
            ID=1
            DO 21,J=2,NDAT
              IF(DIS(J).LT.DIS(ID)) ID=J
   21       CONTINUE
            SX(I)=X(ID)
```

```
            SY(I)=Y(ID)
            ETR(I)=ET(ID)
            DIS(ID)=9.0E20
   22     CONTINUE
C COMPUTATION OF KRIGING SYSTEM
          DO 35,I=1,NSAMP
            A(I,NSYS)=A(NSYS,I)=1.0
            B(I)=GAM(XC,YC,SX(I),SY(I))
            DO 33,J=1,I
              A(I,J)=GAM(SX(I),SY(I),SX(J),SY(J))
              A(J,I)=A(I,J)
   33       CONTINUE
   35     CONTINUE
          A(NSYS,NSYS)=0.
          B(NSYS)=1.0
          IF(IY.EQ.2.AND.IX.EQ.3) THEN
C           PRINT*,A
C           PRINT*,B
C           PRINT*,'A(2,3)=',A(2,3),'A(3,2)=',A(3,2)
          ENDIF
          CALL SOLVE(A,B,WEIG,IER)
          IF(IER.NE.129) GOTO 37
          ETK(IY,IX)=-9.99
          ERK(IY,IX)=-8.88
          GOTO 50
   37     SS1=0.
          SS2=0.
          DO 40,I=1,NSAMP
            SS1=SS1+WEIG(I)*ETR(I)
            SS2=SS2+WEIG(I)*B(I)
   40     CONTINUE
          ETK(IY,IX)=SS1
          ERK(IY,IX)=SS2+WEIG(NSYS)
   50   CONTINUE
C       PRINT*,'ETK=',ETK
C       PRINT*,'ERK=',ERK
C
C PRINT THE ET ESTIMATES AND KRIGING ERRORS
C
      K1=INT(XLW)
      K2=INT(XLE)
      K3=INT(DX)
      WRITE(6,200)
  200 FORMAT(/,' KRIGING EVAPOTRANSPIRATION ESTIMATES',/)
      WRITE(6,350)(K,K=K1,K2,K3)
      NTICY=INT(YLN+DY)
      DO 60,IY=NY,1,-1
```

```
          NTICY=NTICY-INT(DY)
          WRITE(6,400) NTICY,(ETK(IY,IX),IX=1,NX)
   60 CONTINUE
      WRITE(6,300)
  300 FORMAT(/,' KRIGING ESTIMATION ERRORS',/)
      WRITE(6,350)(K,K=K1,K2,K3)
      NTICY=INT(YLN+DY)
      DO 70,IY=NY,1,-1
        NTICY=NTICY-INT(DY)
        WRITE(6,400) NTICY,(ERK(IY,IX),IX=1,NX)
   70 CONTINUE
  350 FORMAT(7X,24(I4,1X))
  400 FORMAT(I4,3X,24(F5.2))
      END
C
C FUNCTION GAM TO COMPUTE SEMIVARINCES
      FUNCTION GAM(XC,YC,XS,YS)
      REAL SILLX,SILLY,RANGX,RANGY
      COMMON /VARIO/ SILLX,SILLY,RANGX,RANGY
C
C CONSIDERING GEOMETRIC AND ZONAL ANISOTROPY
      DSILL=SILLX-SILLY
      SCX=ABS(XC-XS)
      SCY=ABS(YC-YS)
      IF(SCX.GE.RANGX) SCX=RANGX
      IF(SCY.GE.RANGY) SCY=RANGY
      SCD=SQRT(SCX**2+(SCY*RANGX/RANGY)**2)
      IF(SCD.GE.RANGX) SCD=RANGX
      G=1.5*SCD/RANGX-0.5*(SCD/RANGX)**3
      DG=1.5*SCX/RANGX-0.5*(SCX/RANGX)**3
      GAM=SILLY*G+DSILL*DG
      SILL=MAX(SILLX,SILLY)
      IF(GAM.GE.SILL) GAM=SILL
C     PRINT*,'SCX=',SCX,' SCY=',SCY,' SCD=',SCD,' G=',GAM
      RETURN
      END
C
C SUBROUTINE SOLVE TO SOLVE SYSTEM OF LINEAR EQUATIONS
C
      SUBROUTINE SOLVE(A,B,X,IER)
      INTEGER N,IER,IA,IDGT
      PARAMETER(N=9)
      REAL A(N,N),LU(N,N),D1,D2
      REAL EQUIL(N),X(N),B(N)
      REAL RES(N),IPVT(N),DX(N),WA
      IDGT=3
      IA=N
```

```
      CALL LUDATF(A,LU,N,IA,IDGT,D1,D2,IPVT,EQUIL,WA,IER)
      CALL LUELMF(LU,B,IPVT,N,IA,X)
C     PRINT*,X
      RETURN
      END
```

APPENDIX B

Monthly reference evapotranspiration rates (mm/day) for June 1979.

Kriging estimates of monthly reference evapotranspiration rates (mm/day) for June 1979 at each (8x8 mi) grid corner over the state of Oregon.

Estimates of kriging variances ($(mm/day)^2$) at the grid corners mentioned above.

Results of self-validation test of state-wide semivariogram models for June 1979.

REFERENCE EVAPOTRANSPIRATION FOR OREGON, JUNE 1979

STA	DATE	F	ET	X	Y	ALT
ASTORI79	6	5.182	3.266	45.701	286.625	8.000
BANDON79	6	4.925	2.894	21.936	79.384	20.000
BROKIN79	6	5.108	3.695	28.290	2.301	70.000
CAPBLC79	6	4.617	3.177	13.716	57.515	188.000
CLODAL79	6	5.078	3.175	45.729	222.124	80.000
COQUIL79	6	5.091	3.670	32.061	81.685	23.000
DORA2W79	6	5.399	4.009	42.185	80.535	90.000
ELKTON79	6	5.643	4.275	63.278	110.447	120.000
GOLBEC79	6	4.975	3.549	21.432	27.607	50.000
HONEPA79	6	4.984	3.565	37.123	133.457	115.000
ILLAHE79	6	5.687	4.353	40.291	43.711	348.000
LAURMT79	6	4.743	3.185	63.091	201.372	3740.000
NEWPOR79	6	4.854	2.974	39.017	181.810	154.000
NBENDF79	6	4.967	3.535	29.530	97.792	6.000
OTIS2N79	6	5.087	3.189	44.096	209.464	150.000
PORFOR79	6	5.095	3.677	22.957	51.763	45.000
POWERS79	6	5.361	3.985	39.434	60.965	230.000
REDSPO79	6	5.180	3.770	36.279	117.350	60.000
SEASID79	6	5.122	3.210	44.912	275.065	10.000
TIDWAT79	6	5.318	3.392	46.488	166.851	50.000
TLAMOK79	6	4.885	2.991	47.362	238.236	10.000
VALSET79	6	5.179	3.375	58.110	196.769	1155.000
BONDAM79	6	5.773	4.876	141.269	250.896	60.000
CASDIA79	6	5.272	4.725	117.050	165.700	860.000
COROSU79	6	5.495	4.878	81.354	181.810	225.000
CORWSO79	6	5.478	4.912	68.902	173.755	592.000
COTGRO79	6	5.244	5.043	89.433	123.103	650.000
CGRODA79	6	5.467	5.366	90.276	118.501	831.000
DOREDA79	6	5.392	5.265	94.495	123.103	820.000
EUGENE79	6	5.382	5.181	80.524	146.138	364.000
FERIDA79	6	5.472	5.302	76.373	146.138	386.000
FDRGRO79	6	5.588	5.015	84.925	243.991	180.000
LACOMB79	6	5.494	5.352	105.428	180.659	520.000
LEABUR79	6	5.530	5.425	107.088	144.988	675.000
LOPODA79	6	5.503	5.395	104.619	132.307	712.000
NOTI1N79	6	5.336	5.132	68.072	142.686	445.000
SCREFA79	6	5.234	4.290	108.749	197.920	1350.000
BEVETO79	6	5.659	4.771	98.807	241.689	215.000
CHYROV79	6	5.384	4.034	77.575	235.935	650.000
CKLANI79	6	5.405	3.480	74.565	283.171	92.000
DALLAS79	6	5.670	4.798	75.543	202.523	325.000
ESCADA79	6	5.516	4.142	123.304	225.576	410.000
FOSTDA79	6	5.484	4.914	107.919	166.851	550.000

STA	DATE	F	ET	X	Y	ALT
HPTLDW79	6	5.521	4.690	131.470	238.236	748.000
HILBOR79	6	5.660	4.764	90.641	242.840	160.000
MMINVI79	6	5.533	4.221	80.842	223.275	148.000
NLAMET79	6	5.675	4.372	102.073	226.727	150.000
ORECIT79	6	5.432	4.613	109.422	231.331	4136.000
PTLDWS79	6	5.904	5.017	109.422	248.594	21.000
SHELEN79	6	5.743	4.850	98.807	267.009	100.000
SALEMW79	6	5.565	4.509	90.486	201.372	195.000
SCODAM79	6	5.677	4.811	80.025	240.538	355.000
SCOMIL79	6	4.969	4.102	114.560	203.673	2315.000
SILVER79	6	5.658	4.640	101.256	207.162	408.000
TRODAL79	6	5.889	5.002	119.221	246.293	29.000
VNONIA79	6	5.210	4.319	80.842	267.009	625.000
ASHLAN79	6	5.649	6.410	108.872	14.954	1780.000
CAVEJC79	6	5.559	6.181	60.008	11.503	1280.000
DRAIN 79	6	5.730	6.252	76.777	115.049	292.000
GRTPAS79	6	5.784	6.453	78.011	29.908	925.000
HOARDA79	6	4.891	5.669	126.875	14.954	4567.000
IDLPAR79	6	5.337	5.810	94.495	94.340	1080.000
LEMLAK79	6	5.104	5.943	132.461	94.340	4077.000
LCREDA79	6	5.657	6.385	110.587	46.012	1580.000
MEDFOD79	6	5.723	6.461	101.157	20.705	1457.000
MEDFWS79	6	5.831	6.598	101.157	25.306	1312.000
PROSPC79	6	5.486	6.284	119.160	50.613	2482.000
ROSBUR79	6	5.721	6.272	75.090	82.836	465.000
RUCH 79	6	5.645	6.361	92.584	16.104	1550.000
SSUMIT79	6	5.096	5.258	75.439	42.561	3836.000
BELKNA79	6	5.337	4.511	139.464	158.796	2152.000
DTRODA79	6	5.425	4.490	128.672	187.564	1220.000
GVTCAM79	6	4.699	4.110	151.068	227.878	3980.000
MARION79	6	5.273	4.477	143.615	179.509	2475.000
MKENZI79	6	5.704	4.842	135.313	150.741	1478.000
OKRIDG79	6	5.530	5.522	120.650	120.802	1275.000
SANTPA79	6	4.650	3.988	147.766	166.851	4748.000
TRELYN79	6	5.412	4.615	135.553	215.218	1120.000
CHEMUL79	6	4.864	4.256	182.240	85.137	4760.000
RONGRO79	6	4.903	5.804	203.171	23.006	4888.000
SUMLAK79	6	5.465	7.613	208.315	65.567	4192.000
WIKIDA79	6	5.090	5.877	159.460	116.200	4358.000
ANTELO79	6	5.380	5.493	195.084	201.372	2690.000
ALINTO79	6	6.358	6.403	227.010	256.651	285.000
BORDMA79	6	6.303	6.611	251.508	264.707	300.000
CONDON79	6	5.456	5.622	227.827	223.275	2830.000
DUFUR 79	6	5.508	5.456	181.282	238.236	1330.000
HEPPNE79	6	5.803	7.442	259.673	226.727	3240.000
HERMIS79	6	5.988	6.244	271.922	263.556	624.000
HODRIV79	6	5.697	5.905	162.500	254.349	500.000
KENT 79	6	5.478	5.635	202.513	220.973	2720.000

STA	DATE	F	ET	X	Y	ALT
MIKALO79	6	5.986	6.141	219.661	239.387	1550.000
MILTON79	6	6.197	7.597	314.385	272.763	970.000
MORO 79	6	5.582	5.643	201.696	240.538	1870.000
PAKDAL79	6	5.409	5.745	159.234	241.689	1930.000
PDLTON79	6	5.784	7.053	303.769	256.651	1487.000
PDLTON79	6	6.047	7.474	293.153	254.349	1492.000
PILOT179	6	5.813	7.146	294.787	240.538	1720.000
PINGRO79	6	5.607	5.735	169.849	215.218	2220.000
THEDAL79	6	6.381	6.767	178.015	248.594	102.000
ADEL 79	6	5.613	6.909	253.750	12.653	4580.000
ALKALA79	6	5.381	6.694	248.606	66.717	4332.000
ADREMI79	6	5.667	7.261	323.188	37.960	4780.000
BARNST79		5.150	5.116	233.706	134.608	3970.000
BEND 79	6	5.237	5.190	175.160	142.686	3650.000
BROTHE79	6	4.931	4.903	214.301	124.253	4640.000
BURNSW79	6	5.477	6.819	292.765	109.297	4140.000
CHILOQ79	6	4.780	5.503	153.450	40.260	4220.000
CRISVA79	6	4.962	5.991	210.082	85.137	4310.000
DAYVIL79	6	5.930	5.896	258.175	176.057	2230.000
DREWSE79	6	5.630	6.956	326.513	124.253	3516.000
FOSSIL79	6	5.367	5.469	226.194	207.162	2650.000
HAREFU79	6	4.904	5.724	266.609	37.960	5616.000
KLTFAL79	6	5.458	6.572	156.879	13.803	4098.000
KLTFAL79	6	5.285	6.292	158.594	11.503	4090.000
LAKVIE79	6	5.224	6.311	229.747	14.954	4778.000
MADRAS79	6	5.513	5.349	184.292	181.810	2230.000
MADRAS79	6	5.514	5.382	183.462	184.111	2440.000
MALFUG79	6	5.527	6.489	303.733	88.588	4109.000
MALINS79	6	5.263	6.348	180.883	.000	4627.000
MTOLUS79	6	5.376	5.210	181.801	178.358	2500.000
MITCHE79	6	5.543	5.467	232.440	177.207	2744.000
OCHOCO79	6	4.880	4.746	219.158	165.700	3975.000
OORANC79	6	5.482	6.422	279.266	88.588	4136.000
PAISLE79	6	5.431	6.579	221.174	48.312	4360.000
PAULIN79	6	5.364	6.353	242.402	147.289	3684.000
PLTNDA79	6	5.967	5.805	179.311	188.714	1410.000
PINEMT79	6	4.783	4.897	196.583	123.103	6240.000
P-RANC79	6	5.377	6.265	306.043	56.364	4195.000
REDMON79	6	5.390	5.305	180.141	156.495	3010.000
REDMDF79	6	5.404	5.330	183.462	156.495	3060.000
SISTER79	6	5.148	5.003	163.538	157.645	3180.000
SPRARI79	6	5.074	5.999	171.453	31.058	4360.000
SQABUT79	6	5.385	6.761	260.704	102.394	4665.000
SUNTEX79	6	5.244	6.462	263.235	110.447	4310.000
VALFAL79	6	5.407	6.575	235.747	31.058	4580.000
WAGONT79	6	5.374	6.754	250.580	86.287	4726.000
WITHOR79	6	5.497	7.034	339.476	23.006	4200.000
AUSTIN79	6	4.893	4.691	315.454	178.358	4213.000

STA	DATE	F	ET	X	Y	ALT
BAKERF	79 6	5.486	5.396	349.490	195.618	3368.000
BAKERK	79 6	5.561	5.510	351.981	191.016	3444.000
COVE	79 6	5.485	5.328	344.598	227.878	2920.000
ELGIN	79 6	5.602	5.446	338.882	246.293	2655.000
ENTPRI	79 6	5.166	5.016	370.729	237.085	3790.000
ENPRIS	79 6	5.301	5.131	376.445	255.500	3280.000
HALFWA	79 6	5.515	5.330	384.356	199.071	2670.000
HUNGTO	79 6	6.420	8.985	376.885	162.248	2130.000
JOHNDA	79 6	5.611	5.520	293.041	168.002	3063.000
LAGRAN	79 6	5.731	5.576	330.716	229.029	2755.000
LONCRE	79 6	5.099	4.914	285.569	187.564	3722.000
MSONDA	79 6	5.148	5.005	340.359	184.111	3900.000
MINAM7	79 6	4.914	4.641	354.397	254.349	3584.000
MOMENT	79 6	5.730	5.511	269.797	194.468	1995.000
RICHLA	79 6	6.009	5.916	381.866	191.016	2215.000
SENECA	79 6	4.906	4.766	292.210	148.440	4666.000
UKIAH	79 6	5.017	6.403	289.071	216.369	3355.000
UNIONX	79 6	5.455	5.26	340.515	222.124	2765.000
UNITY	79 6	5.300	7.394	328.737	168.002	4031.000
WALALA	79 6	5.590	7.207	326.322	276.265	2400.000
WALLOW	79 6	5.393	5.204	357.663	246.293	2923.000
BEULAH	79 6	5.853	8.246	337.481	132.307	3270.000
BURNJT	79 6	5.829	8.353	359.193	54.064	3930.000
DANNER	79 6	5.460	7.731	385.769	64.416	4225.000
IONSID	79 6	5.531	7.797	341.189	157.645	3915.000
JUTURA	79 6	6.060	8.518	349.293	124.253	2830.000
MHEURB	79 6	6.066	8.387	395.697	136.909	2240.000
MDRMIT	79 6	5.544	7.939	358.336	28.757	4464.000
NYSSA	79 6	6.116	8.460	396.541	128.855	2175.000
ONTARI	79 6	6.200	8.600	391.828	141.536	2145.000
OWYEDA	79 6	5.899	8.130	383.885	113.899	2400.000
RIVSID	79 6	5.735	8.046	337.481	106.996	3330.000
ROCVIL	79 6	5.462	7.619	390.635	94.340	3670.000
ROME2N	79 6	5.778	8.142	369.480	59.815	3410.000
SHEVIL	79 6	5.447	7.788	394.853	77.083	4620.000
VALE	79 6	6.178	8.585	383.885	136.909	2240.000

KRIGING ESTIMATES OF EVAPOTRANSPIRATION FOR OREGON, JUNE 1979

	0	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	128
290	3.07	3.07	3.11	3.13	3.16	3.22	3.27	3.32	3.37	3.45	3.69	3.97	4.19	4.38	4.53	4.63	4.87
282	3.08	3.05	3.09	3.11	3.14	3.19	3.25	3.34	3.44	3.55	3.83	4.14	4.37	4.55	4.67	4.74	5.09
274	3.06	3.06	3.03	3.08	3.11	3.17	3.25	3.41	3.57	3.82	4.11	4.38	4.61	4.75	4.89	4.94	5.04
266	3.04	3.04	3.04	3.06	3.08	3.15	3.26	3.45	3.70	4.02	4.38	4.60	4.80	4.91	4.97	4.99	5.04
258	3.03	3.02	3.02	3.02	3.02	3.11	3.23	3.46	3.79	4.12	4.59	4.76	4.81	4.94	5.00	5.01	4.97
250	3.09	3.05	2.98	2.97	2.99	3.03	3.15	3.43	3.81	4.23	4.77	4.89	4.88	4.91	5.01	5.01	4.93
242	3.08	3.08	3.03	3.02	2.99	2.99	3.04	3.38	3.70	4.07	4.74	4.74	4.70	4.76	4.82	4.78	4.73
234	3.07	3.07	2.97	2.98	3.01	3.04	3.08	3.29	3.61	3.86	4.20	4.44	4.49	4.56	4.60	4.46	4.45
226	3.06	3.06	2.98	3.00	2.99	3.10	3.18	3.31	3.48	3.89	4.21	4.33	4.39	4.40	4.36	4.22	4.30
218	3.06	2.92	2.93	2.96	3.02	3.11	3.21	3.32	3.56	4.01	4.37	4.39	4.46	4.46	4.32	4.22	4.37
210	2.93	2.93	2.93	2.96	3.01	3.11	3.20	3.27	3.50	4.21	4.58	4.58	4.56	4.53	4.26	4.21	4.37
202	2.96	2.95	2.95	2.95	2.99	3.07	3.15	3.24	3.38	4.37	4.73	4.60	4.59	4.50	4.21	4.24	4.36
194	3.10	2.95	2.94	2.95	2.95	3.03	3.20	3.45	3.82	4.44	4.72	4.76	4.78	4.75	4.53	4.43	4.44
186	3.00	2.98	2.96	2.95	2.94	3.01	3.29	3.68	4.15	4.66	4.83	4.89	5.02	5.17	4.88	4.65	4.55
178	3.02	3.00	2.99	2.99	3.00	3.10	3.40	3.86	4.40	4.92	4.93	5.00	5.12	5.23	4.96	4.75	4.57
170	3.06	3.06	3.05	3.03	3.08	3.20	3.48	4.02	4.60	5.00	5.03	5.04	5.08	5.07	4.85	4.69	4.59
162	3.06	3.05	3.07	3.11	3.19	3.36	3.68	4.18	4.68	4.98	5.07	5.08	5.12	5.07	4.94	4.80	4.72
154	3.02	3.05	3.09	3.15	3.29	3.49	3.84	4.31	4.77	5.11	5.18	5.15	5.22	5.25	5.13	5.05	4.90
146	2.90	3.08	3.22	3.30	3.42	3.62	3.92	4.36	4.89	5.21	5.19	5.20	5.27	5.40	5.34	5.21	5.09
138	3.06	3.00	3.30	3.37	3.47	3.66	3.97	4.39	4.86	5.25	5.28	5.16	5.23	5.38	5.40	5.33	5.22
130	3.11	3.17	3.20	3.33	3.55	3.73	4.03	4.41	4.83	5.35	5.43	5.14	5.23	5.39	5.45	5.42	5.43
122	3.16	3.17	3.26	3.40	3.63	3.80	4.00	4.29	4.76	5.55	5.79	5.33	5.34	5.43	5.51	5.53	5.55
114	3.34	3.18	3.27	3.39	3.64	3.82	3.95	4.11	4.44	5.56	6.03	5.69	5.60	5.53	5.61	5.64	5.70
106	3.30	3.27	3.22	3.37	3.64	3.82	3.98	4.23	4.68	5.49	5.90	5.80	5.69	5.68	5.69	5.75	5.81
98	3.26	3.18	3.13	3.32	3.63	3.89	4.13	4.48	4.94	5.63	5.96	5.86	5.80	5.77	5.82	5.84	5.90
90	3.20	3.10	3.06	3.22	3.62	3.93	4.30	4.66	5.16	5.87	6.13	5.98	5.92	5.86	5.94	5.95	5.98
82	3.20	3.06	2.95	3.06	3.64	3.93	4.35	4.86	5.26	5.94	6.17	6.08	5.96	6.05	6.05	6.04	5.99
74	3.22	3.08	3.01	3.18	3.60	3.96	4.42	4.89	5.30	5.78	6.05	6.04	6.01	6.09	6.08	6.08	6.02
66	3.37	3.21	3.13	3.33	3.68	4.00	4.41	4.79	5.16	5.51	5.80	5.90	5.98	6.05	6.15	6.14	6.04
58	3.55	3.35	3.25	3.46	3.81	4.10	4.46	4.77	5.06	5.33	5.64	5.84	5.99	6.14	6.20	6.24	6.05
50	3.66	3.51	3.45	3.60	3.95	4.26	4.51	4.87	5.06	5.23	5.57	5.87	6.04	6.24	6.35	6.24	6.00
42	3.64	3.57	3.54	3.69	3.97	4.38	4.74	5.04	5.24	5.40	5.71	6.01	6.22	6.37	6.37	6.19	5.95
34	3.63	3.57	3.51	3.66	4.02	4.48	4.93	5.34	5.63	5.96	6.29	6.30	6.41	6.52	6.36	6.13	5.89
26	3.56	3.51	3.51	3.66	4.04	4.57	5.07	5.59	5.97	6.24	6.44	6.43	6.49	6.52	6.33	6.06	5.82
18	3.56	3.52	3.50	3.68	4.05	4.61	5.18	5.78	6.18	6.33	6.40	6.39	6.39	6.42	6.30	5.96	5.70
10	3.57	3.53	3.51	3.64	3.99	4.57	5.19	5.82	6.19	6.27	6.37	6.37	6.37	6.31	6.19	5.96	5.85
2	3.61	3.56	3.56	3.65	3.99	4.55	5.13	5.66	5.97	6.13	6.33	6.34	6.33	6.21	6.18	5.99	5.98

KRIGING ESTIMATES OF EVAPOTRANSPIRATION FOR OREGON, JUNE 1979

	136	144	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264
290	5.23	5.38	5.65	6.00	6.09	6.37	6.26	6.30	6.45	6.47	6.52	6.68	6.42	6.37	6.35	6.61	6.54
282	5.17	5.33	5.72	6.00	6.13	6.41	6.31	6.34	6.43	6.45	6.65	6.65	6.43	6.40	6.46	6.44	6.48
274	5.20	5.42	5.66	5.98	6.17	6.46	6.36	6.41	6.37	6.40	6.57	6.58	6.44	6.46	6.51	6.48	6.42
266	5.12	5.29	5.56	5.93	6.21	6.42	6.42	6.38	6.31	6.43	6.46	6.47	6.42	6.51	6.59	6.57	6.43
258	5.03	5.11	5.43	5.84	6.23	6.56	6.47	6.28	6.20	6.26	6.33	6.34	6.45	6.57	6.64	6.67	6.62
250	4.86	4.93	5.31	5.80	6.20	6.61	6.28	6.04	5.95	6.04	6.18	6.28	6.41	6.58	6.70	6.81	6.85
242	4.71	4.73	5.03	5.65	5.89	5.90	5.66	5.69	5.64	5.83	6.05	6.17	6.30	6.55	6.80	6.97	7.05
234	4.49	4.41	4.50	5.14	5.55	5.61	5.48	5.52	5.59	5.75	5.87	5.92	6.10	6.43	6.83	7.18	7.23
226	4.41	4.30	4.34	4.96	5.45	5.61	5.54	5.51	5.62	5.68	5.71	5.65	5.86	6.27	6.67	7.10	7.16
218	4.59	4.52	4.66	5.10	5.61	5.71	5.53	5.59	5.58	5.61	5.59	5.55	5.74	6.05	6.41	6.73	6.76
210	4.53	4.64	4.77	5.20	5.61	5.73	5.64	5.58	5.54	5.52	5.54	5.47	5.62	5.87	6.12	6.36	6.33
202	4.53	4.71	4.89	5.23	5.55	5.75	5.65	5.53	5.47	5.46	5.40	5.43	5.52	5.78	5.97	6.06	5.95
194	4.49	4.67	4.90	5.19	5.47	5.72	5.64	5.48	5.34	5.31	5.33	5.38	5.50	5.70	5.88	5.88	5.69
186	4.49	4.48	4.69	5.01	5.27	5.54	5.38	5.30	5.23	5.19	5.20	5.30	5.45	5.65	5.76	5.77	5.65
178	4.49	4.36	4.46	4.79	5.10	5.22	5.23	5.18	5.10	5.06	5.06	5.13	5.44	5.74	5.88	5.89	5.78
170	4.42	4.17	4.24	4.65	5.02	5.23	5.25	5.17	5.06	4.95	4.81	5.02	5.42	5.80	5.96	6.00	5.82
162	4.55	4.38	4.44	4.78	5.05	5.23	5.31	5.21	5.04	4.94	4.85	5.07	5.47	5.91	6.07	5.99	5.81
154	4.79	4.65	4.69	4.92	5.11	5.23	5.29	5.18	5.04	4.94	4.94	5.15	5.55	6.07	6.23	6.11	5.94
146	5.00	5.00	5.03	5.16	5.20	5.20	5.20	5.12	5.02	4.94	4.95	5.11	5.42	6.01	6.28	6.12	5.86
138	5.24	5.22	5.26	5.35	5.32	5.26	5.18	5.05	4.99	4.92	4.93	4.98	5.13	5.68	6.09	6.03	5.93
130	5.40	5.44	5.50	5.54	5.46	5.28	5.14	5.02	4.90	4.90	4.89	5.02	5.21	5.65	6.04	6.04	6.06
122	5.58	5.62	5.73	5.78	5.51	5.27	5.08	4.94	4.93	4.98	5.03	5.18	5.38	5.72	6.06	6.29	6.24
114	5.70	5.77	5.81	5.77	5.45	5.13	4.96	4.95	4.96	5.11	5.26	5.40	5.59	5.90	6.19	6.39	6.43
106	5.83	5.79	5.73	5.56	5.27	4.88	4.72	4.84	5.04	5.28	5.48	5.65	5.90	6.15	6.39	6.61	6.67
98	5.89	5.78	5.62	5.37	5.03	4.69	4.57	4.85	5.16	5.55	5.73	5.90	6.07	6.34	6.56	6.71	6.72
90	5.87	5.72	5.54	5.22	4.87	4.53	4.41	4.94	5.43	5.83	6.03	6.23	6.30	6.58	6.71	6.74	6.59
82	5.86	5.69	5.43	5.13	4.93	4.69	4.71	5.29	5.91	6.34	6.46	6.54	6.49	6.64	6.71	6.69	6.53
74	5.86	5.64	5.32	5.21	5.07	5.05	5.21	5.79	6.43	7.00	7.00	6.83	6.70	6.68	6.71	6.60	6.47
66	5.86	5.61	5.38	5.26	5.23	5.40	5.57	6.14	6.78	7.50	7.23	6.98	6.73	6.69	6.65	6.50	6.34
58	5.86	5.77	5.44	5.35	5.37	5.52	5.78	6.27	6.73	7.10	7.01	6.80	6.68	6.62	6.51	6.35	6.16
50	5.83	5.71	5.47	5.42	5.55	5.67	5.85	6.23	6.52	6.78	6.68	6.60	6.60	6.52	6.41	6.25	6.00
42	5.82	5.69	5.54	5.66	5.73	5.82	6.19	6.26	6.38	6.46	6.46	6.46	6.52	6.52	6.38	6.19	5.86
34	5.82	5.79	5.79	5.87	5.95	6.04	6.08	6.08	6.07	6.14	6.22	6.36	6.50	6.55	6.46	6.30	6.00
26	5.84	5.94	6.06	6.14	6.13	6.09	6.02	5.94	5.87	5.96	6.10	6.27	6.44	6.56	6.59	6.50	6.30
18	5.87	6.06	6.31	6.38	6.26	6.20	6.11	6.01	5.92	5.98	6.08	6.22	6.38	6.59	6.74	6.75	6.49
10	5.95	6.14	6.30	6.30	6.31	6.29	6.21	6.09	6.03	6.07	6.16	6.31	6.43	6.62	6.79	6.81	6.60
2	6.06	6.18	6.27	6.32	6.34	6.35	6.32	6.22	6.13	6.17	6.24	6.38	6.49	6.62	6.74	6.74	6.72

KRIGING ESTIMATES OF EVAPOTRANSPIRATION FOR OREGON, JUNE 1979

	272	280	288	296	304	312	320	328	336	344	352	360	368	376	384	392	400
290	6.62	6.79	7.13	7.31	7.38	7.38	7.29	7.12	6.72	6.34	6.01	5.83	5.70	5.62	5.58	5.55	5.55
282	6.55	6.68	6.92	7.32	7.42	7.51	7.45	7.12	6.61	6.17	5.81	5.63	5.52	5.47	5.45	5.44	5.46
274	6.40	6.64	6.94	7.31	7.41	7.54	7.34	6.94	6.41	5.92	5.54	5.38	5.32	5.33	5.34	5.34	5.38
266	6.26	6.66	7.03	7.31	7.26	7.24	7.01	6.59	6.11	5.61	5.20	5.12	5.15	5.20	5.24	5.10	5.11
258	6.58	6.81	7.18	7.37	7.05	6.96	6.69	6.29	5.82	5.35	4.85	4.90	4.98	5.12	5.13	5.13	5.11
250	6.82	6.94	7.16	7.26	6.99	6.68	6.38	6.06	5.62	5.24	5.04	5.09	5.06	5.09	5.13	5.14	5.12
242	6.97	7.02	7.04	7.09	6.83	6.50	6.19	5.81	5.53	5.36	5.22	5.18	5.07	5.07	5.12	5.11	5.14
234	6.99	6.93	6.94	6.81	6.58	6.29	5.99	5.72	5.48	5.36	5.23	5.17	5.10	5.10	5.12	5.14	5.17
226	6.92	6.76	6.69	6.53	6.32	6.14	5.88	5.64	5.40	5.29	5.24	5.21	5.19	5.19	5.17	5.18	5.21
218	6.61	6.46	6.39	6.22	6.01	5.84	5.77	5.52	5.33	5.29	5.26	5.23	5.23	5.21	5.19	5.21	5.24
210	6.15	6.02	5.93	5.83	5.70	5.57	5.41	5.21	5.24	5.30	5.38	5.39	5.38	5.31	5.20	5.34	5.53
202	5.72	5.57	5.49	5.47	5.20	5.04	5.10	5.11	5.10	5.20	5.43	5.49	5.51	5.51	5.32	5.58	5.81
194	5.43	5.22	5.13	5.17	5.04	4.88	4.77	5.01	4.97	5.15	5.49	5.74	5.90	5.95	5.85	6.04	6.18
186	5.42	5.13	5.01	5.05	4.95	4.71	4.83	5.27	5.20	5.29	5.83	6.20	6.46	6.63	6.60	6.64	6.69
178	5.59	5.29	5.21	5.19	5.05	4.95	5.41	6.10	6.12	6.22	6.57	6.86	7.20	7.45	7.38	7.31	7.22
170	5.65	5.49	5.36	5.42	5.40	5.63	6.23	7.30	7.12	7.08	7.32	7.55	8.00	8.33	8.14	7.91	7.70
162	5.61	5.32	5.23	5.28	5.47	6.04	6.68	7.43	7.68	7.71	7.79	8.07	8.54	8.95	8.58	8.26	7.98
154	5.65	5.33	4.98	5.04	5.48	6.15	6.81	7.46	7.86	8.08	8.27	8.39	8.65	8.80	8.71	8.48	8.22
146	5.65	5.36	5.09	5.17	5.58	6.03	6.58	7.30	7.98	8.25	8.39	8.47	8.60	8.69	8.68	8.58	8.35
138	5.80	5.63	5.49	5.56	5.83	6.31	6.74	7.33	8.04	8.34	8.48	8.57	8.59	8.60	8.57	8.47	8.42
130	6.01	5.92	5.90	5.98	6.12	6.41	6.75	7.20	7.99	8.37	8.51	8.50	8.49	8.47	8.43	8.42	8.39
122	6.24	6.24	6.29	6.36	6.44	6.61	6.83	7.21	7.86	8.27	8.46	8.45	8.36	8.31	8.27	8.26	8.24
114	6.43	6.46	6.61	6.71	6.67	6.79	7.01	7.38	7.90	8.21	8.32	8.30	8.20	8.13	8.09	8.06	8.08
106	6.58	6.59	6.68	6.75	6.74	6.85	7.06	7.39	7.90	8.14	8.23	8.18	8.06	7.98	7.90	7.87	7.91
98	6.57	6.53	6.57	6.60	6.66	6.78	7.01	7.30	7.82	8.08	8.20	8.12	8.04	7.90	7.78	7.67	7.78
90	6.52	6.43	6.48	6.46	6.49	6.71	6.91	7.29	7.72	8.00	8.13	8.10	8.01	7.89	7.75	7.68	7.74
82	6.50	6.43	6.43	6.44	6.45	6.70	7.02	7.34	7.68	7.89	8.16	8.11	8.02	7.90	7.76	7.74	7.78
74	6.38	6.30	6.31	6.29	6.37	6.64	6.96	7.33	7.60	7.87	8.11	8.17	8.07	7.93	7.81	7.75	7.78
66	6.28	6.21	6.20	6.23	6.30	6.59	6.96	7.29	7.58	7.87	8.16	8.20	8.12	7.97	7.78	7.74	7.77
58	6.07	6.09	6.14	6.20	6.24	6.56	6.90	7.29	7.46	7.85	8.07	8.32	8.19	8.02	7.85	7.76	7.75
50	5.93	6.01	6.11	6.24	6.33	6.64	7.01	7.31	7.48	7.74	8.03	8.24	8.16	8.03	7.90	7.79	7.76
42	5.83	6.01	6.17	6.32	6.41	6.72	7.10	7.31	7.42	7.64	7.91	8.10	8.08	8.00	7.89	7.83	7.76
34	5.99	6.13	6.26	6.42	6.53	6.78	7.02	7.19	7.27	7.47	7.76	8.00	7.98	7.93	7.86	7.81	7.78
26	6.24	6.29	6.40	6.47	6.59	6.78	6.89	7.01	7.05	7.26	7.60	7.84	7.88	7.84	7.80	7.77	7.75
18	6.46	6.46	6.52	6.61	6.64	6.78	6.92	7.00	6.99	7.20	7.47	7.68	7.75	7.75	7.73	7.72	7.71
10	6.62	6.59	6.62	6.70	6.70	6.81	6.92	7.00	6.97	7.14	7.39	7.58	7.64	7.67	7.65	7.66	7.67
2	6.70	6.67	6.72	6.77	6.83	6.84	6.95	7.03	6.95	7.10	7.35	7.50	7.56	7.59	7.59	7.61	7.62

ESTIMATES OF KRIGING VARIANCE FOR OREGON, JUNE 1979

	0	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	128
290	1.20	1.00	.80	.59	.38	.17	.07	.20	.22	.13	.19	.31	.38	.46	.52	.60	.65
282	1.16	.96	.76	.55	.34	.15	.10	.19	.20	.10	.12	.22	.26	.32	.40	.48	.53
274	1.13	.93	.74	.54	.35	.16	.11	.22	.23	.16	.10	.15	.13	.18	.30	.37	.41
266	1.12	.92	.74	.55	.38	.25	.21	.25	.26	.19	.07	.13	.09	.13	.22	.27	.31
258	1.11	.92	.74	.56	.41	.29	.24	.27	.27	.23	.16	.15	.15	.14	.15	.18	.21
250	1.08	.92	.74	.56	.40	.26	.18	.23	.26	.20	.12	.09	.11	.10	.06	.05	.14
242	1.07	.89	.73	.55	.37	.19	.05	.19	.22	.15	.01	.07	.07	.09	.11	.10	.08
234	1.05	.87	.69	.52	.35	.19	.10	.19	.22	.14	.08	.14	.12	.08	.06	.11	.10
226	1.04	.86	.67	.50	.33	.15	.07	.19	.22	.17	.03	.14	.13	.07	.12	.08	.10
218	1.03	.87	.68	.49	.30	.14	.10	.18	.20	.17	.12	.15	.15	.13	.15	.15	.13
210	1.04	.85	.65	.47	.29	.11	.09	.15	.13	.12	.12	.12	.10	.07	.10	.13	.16
202	1.03	.83	.64	.45	.29	.18	.14	.08	.04	.09	.10	.07	.10	.09	.06	.13	.16
194	.98	.82	.62	.43	.26	.17	.16	.11	.13	.15	.13	.14	.15	.12	.12	.14	.09
186	.97	.78	.59	.40	.20	.06	.16	.17	.16	.14	.06	.14	.16	.08	.13	.15	.08
178	.96	.78	.59	.40	.22	.11	.14	.17	.12	.08	.11	.17	.18	.09	.12	.16	.16
170	.95	.77	.60	.43	.27	.14	.05	.17	.15	.13	.18	.22	.20	.10	.07	.09	.17
162	.92	.77	.60	.44	.30	.19	.14	.20	.20	.18	.19	.23	.22	.15	.12	.13	.16
154	.91	.74	.58	.43	.30	.23	.22	.22	.18	.13	.11	.18	.20	.14	.14	.18	.15
146	.86	.70	.54	.38	.25	.20	.22	.21	.11	.07	.05	.15	.18	.08	.11	.19	.18
138	.82	.66	.51	.33	.15	.10	.20	.22	.16	.14	.15	.16	.15	.07	.14	.19	.22
130	.80	.63	.46	.29	.15	.12	.21	.23	.20	.18	.16	.10	.09	.08	.14	.13	.20
122	.75	.59	.42	.27	.12	.10	.20	.20	.16	.13	.10	.05	.07	.16	.16	.03	.16
114	.66	.53	.38	.24	.13	.13	.20	.16	.04	.10	.10	.12	.15	.21	.21	.16	.19
106	.60	.47	.33	.18	.12	.18	.22	.19	.13	.16	.17	.17	.16	.22	.25	.22	.18
98	.54	.41	.27	.13	.07	.17	.22	.23	.20	.19	.18	.14	.06	.21	.26	.23	.12
90	.47	.35	.22	.13	.10	.13	.18	.23	.21	.13	.14	.16	.15	.25	.28	.25	.17
82	.40	.29	.15	.05	.04	.05	.14	.23	.21	.11	.14	.22	.24	.29	.31	.29	.26
74	.33	.25	.16	.13	.14	.12	.18	.25	.26	.21	.23	.27	.30	.31	.31	.29	.30
66	.23	.17	.13	.17	.15	.07	.19	.27	.28	.26	.27	.30	.31	.30	.26	.24	.28
58	.09	.11	.07	.17	.16	.09	.19	.26	.27	.24	.25	.29	.28	.23	.17	.13	.22
50	.09	.15	.17	.19	.17	.08	.18	.25	.24	.15	.16	.24	.25	.16	.05	.07	.20
42	.23	.22	.19	.19	.17	.08	.18	.24	.21	.10	.11	.20	.21	.16	.12	.17	.23
34	.33	.26	.15	.11	.18	.19	.23	.24	.21	.13	.07	.17	.16	.13	.17	.21	.23
26	.40	.30	.16	.10	.20	.24	.25	.22	.19	.16	.12	.14	.09	.06	.15	.18	.17
18	.47	.36	.24	.17	.20	.24	.23	.14	.13	.19	.19	.11	.07	.08	.08	.13	.04
10	.54	.41	.27	.15	.15	.22	.23	.13	.14	.24	.26	.21	.18	.18	.17	.19	.16
2	.62	.48	.32	.14	.12	.24	.28	.26	.28	.34	.36	.35	.33	.32	.32	.32	.32

ESTIMATES OF KRIGING VARIANCE FOR OREGON, JUNE 1979

	136	144	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264
290	.68	.69	.71	.76	.77	.74	.76	.77	.75	.73	.70	.65	.60	.58	.53	.51	.50
282	.55	.55	.59	.58	.59	.58	.61	.63	.62	.60	.55	.50	.45	.42	.37	.35	.35
274	.42	.43	.43	.41	.42	.43	.47	.50	.50	.47	.41	.35	.31	.28	.20	.19	.22
266	.29	.28	.28	.23	.25	.30	.34	.38	.38	.36	.29	.19	.19	.20	.09	.11	.14
258	.17	.13	.17	.08	.12	.16	.21	.27	.27	.26	.21	.08	.12	.20	.18	.18	.19
250	.11	.09	.14	.09	.12	.05	.12	.19	.16	.18	.16	.13	.18	.24	.25	.24	.24
242	.10	.15	.12	.05	.14	.10	.08	.15	.05	.12	.09	.10	.20	.25	.25	.23	.23
234	.13	.14	.08	.13	.17	.15	.14	.17	.13	.15	.14	.12	.17	.24	.23	.14	.15
226	.13	.14	.09	.15	.15	.17	.19	.18	.09	.13	.17	.09	.11	.22	.22	.11	.12
218	.02	.16	.19	.17	.05	.14	.20	.18	.11	.15	.18	.12	.14	.23	.25	.21	.20
210	.14	.20	.24	.22	.16	.17	.19	.14	.14	.19	.19	.06	.14	.24	.28	.25	.22
202	.19	.23	.27	.26	.21	.18	.16	.08	.12	.22	.22	.15	.18	.25	.28	.24	.17
194	.16	.20	.25	.27	.22	.11	.11	.15	.20	.25	.25	.21	.20	.25	.26	.22	.13
186	.12	.10	.20	.26	.22	.11	.01	.16	.24	.27	.25	.19	.14	.19	.21	.16	.15
178	.14	.07	.15	.21	.21	.14	.07	.19	.25	.25	.20	.14	.03	.16	.18	.06	.13
170	.15	.08	.10	.17	.18	.16	.14	.21	.26	.23	.10	.11	.15	.19	.20	.17	.20
162	.08	.09	.13	.10	.11	.11	.08	.20	.27	.24	.15	.15	.19	.19	.21	.24	.27
154	.03	.14	.19	.14	.12	.10	.09	.20	.27	.27	.23	.21	.19	.12	.16	.25	.30
146	.15	.21	.24	.20	.14	.04	.15	.22	.26	.27	.24	.21	.15	.08	.15	.26	.31
138	.23	.26	.26	.22	.18	.14	.19	.21	.22	.22	.20	.17	.06	.13	.21	.28	.31
130	.25	.27	.24	.20	.21	.21	.21	.14	.13	.14	.09	.16	.14	.19	.25	.27	.28
122	.24	.26	.19	.09	.19	.24	.22	.13	.11	.14	.11	.20	.23	.26	.26	.23	.19
114	.23	.25	.19	.10	.20	.25	.25	.22	.21	.21	.22	.27	.29	.29	.25	.16	.05
106	.19	.24	.24	.22	.25	.26	.26	.26	.25	.25	.26	.30	.31	.29	.22	.12	.07
98	.10	.24	.28	.28	.27	.23	.20	.23	.23	.20	.23	.29	.31	.26	.18	.13	.13
90	.17	.27	.31	.31	.27	.17	.08	.19	.19	.09	.16	.26	.29	.23	.08	.12	.18
82	.27	.32	.35	.34	.29	.19	.12	.20	.19	.11	.16	.25	.28	.22	.12	.16	.22
74	.32	.35	.36	.36	.33	.28	.24	.24	.19	.11	.18	.25	.26	.20	.10	.17	.25
66	.32	.34	.34	.35	.34	.32	.30	.28	.19	.04	.15	.22	.24	.19	.07	.18	.26
58	.29	.31	.28	.30	.32	.32	.32	.31	.24	.16	.15	.16	.22	.22	.19	.22	.25
50	.27	.24	.17	.21	.26	.29	.31	.31	.27	.21	.12	.07	.19	.22	.23	.23	.20
42	.25	.20	.04	.14	.17	.21	.28	.29	.26	.22	.18	.15	.16	.18	.22	.20	.09
34	.25	.22	.15	.15	.09	.12	.23	.25	.19	.19	.21	.18	.09	.11	.20	.19	.14
26	.22	.23	.18	.15	.14	.16	.22	.21	.09	.12	.20	.17	.12	.14	.18	.18	.21
18	.19	.21	.13	.08	.17	.20	.22	.22	.16	.18	.21	.14	.06	.16	.14	.10	.23
10	.23	.25	.16	.09	.17	.17	.17	.23	.25	.27	.27	.21	.17	.21	.17	.14	.28
2	.34	.34	.28	.23	.22	.12	.09	.24	.32	.36	.37	.34	.32	.33	.31	.32	.40

ESTIMATES OF KRIGING VARIANCE FOR OREGON, JUNE 1979

	272	280	288	296	304	312	320	328	336	344	352	360	368	376	384	392	400
290	.49	.51	.50	.47	.41	.34	.30	.30	.38	.47	.53	.59	.64	.68	.77	.90	1.05
282	.34	.37	.38	.35	.28	.18	.14	.11	.25	.36	.42	.46	.50	.52	.62	.76	.89
274	.19	.25	.28	.26	.19	.07	.10	.10	.21	.29	.31	.34	.36	.37	.47	.62	.78
266	.01	.17	.19	.17	.13	.14	.18	.19	.22	.23	.20	.22	.23	.20	.32	.50	.69
258	.15	.18	.12	.07	.02	.16	.22	.21	.18	.16	.07	.12	.15	.02	.21	.42	.63
250	.23	.21	.14	.10	.14	.21	.24	.20	.09	.11	.10	.07	.13	.12	.23	.41	.60
242	.24	.23	.15	.04	.18	.24	.24	.17	.12	.12	.14	.12	.09	.13	.27	.42	.59
234	.22	.23	.17	.15	.22	.26	.22	.10	.10	.08	.15	.18	.13	.17	.29	.42	.58
226	.21	.21	.14	.18	.26	.29	.24	.13	.09	.06	.17	.23	.23	.25	.30	.41	.55
218	.21	.18	.03	.17	.27	.31	.30	.22	.16	.14	.21	.26	.27	.27	.27	.37	.51
210	.20	.19	.15	.21	.29	.32	.31	.28	.22	.19	.20	.25	.26	.23	.19	.29	.46
202	.13	.17	.18	.24	.29	.30	.30	.28	.22	.15	.11	.21	.23	.17	.03	.22	.41
194	.08	.12	.11	.21	.26	.26	.26	.23	.17	.11	.02	.17	.22	.14	.05	.22	.40
186	.16	.13	.09	.18	.21	.15	.16	.18	.10	.08	.13	.20	.23	.17	.15	.26	.41
178	.21	.19	.14	.15	.18	.10	.10	.13	.14	.16	.20	.24	.24	.19	.21	.30	.42
170	.25	.22	.12	.08	.19	.18	.15	.02	.13	.17	.23	.25	.21	.12	.19	.29	.40
162	.29	.25	.16	.14	.22	.24	.21	.15	.11	.09	.21	.26	.20	.06	.16	.25	.36
154	.31	.25	.13	.12	.23	.27	.26	.21	.15	.13	.23	.27	.24	.17	.17	.19	.28
146	.32	.26	.15	.14	.25	.29	.27	.22	.17	.18	.23	.28	.26	.19	.11	.06	.18
138	.32	.29	.24	.23	.28	.29	.24	.17	.09	.14	.20	.26	.26	.17	.02	.07	.11
130	.30	.29	.26	.25	.28	.26	.17	.08	.09	.10	.11	.22	.25	.20	.13	.10	.10
122	.24	.25	.22	.21	.25	.25	.17	.10	.13	.12	.12	.23	.25	.19	.11	.14	.20
114	.18	.21	.13	.11	.21	.25	.22	.16	.10	.15	.21	.27	.27	.19	.04	.16	.25
106	.17	.18	.14	.13	.19	.25	.25	.20	.09	.17	.26	.32	.31	.24	.15	.15	.25
98	.16	.13	.16	.16	.14	.22	.27	.26	.23	.26	.31	.34	.33	.26	.15	.06	.22
90	.15	.03	.16	.15	.02	.19	.29	.32	.32	.34	.36	.36	.33	.28	.18	.11	.20
82	.22	.18	.22	.21	.16	.23	.31	.35	.36	.37	.37	.34	.30	.26	.19	.09	.16
74	.27	.26	.27	.25	.21	.25	.32	.36	.37	.36	.33	.27	.23	.20	.14	.10	.19
66	.30	.30	.30	.24	.16	.20	.28	.34	.35	.32	.26	.18	.11	.13	.05	.14	.28
58	.28	.30	.30	.22	.06	.14	.24	.29	.33	.28	.19	.05	.08	.15	.18	.25	.39
50	.23	.29	.31	.26	.18	.17	.18	.22	.27	.26	.19	.12	.18	.25	.30	.38	.51
42	.15	.28	.33	.33	.27	.21	.09	.13	.22	.23	.20	.16	.23	.32	.40	.50	.62
34	.19	.31	.38	.39	.34	.27	.16	.14	.16	.17	.15	.09	.23	.37	.48	.60	.73
26	.28	.37	.43	.45	.42	.36	.28	.21	.09	.11	.15	.13	.28	.44	.56	.69	.83
18	.34	.43	.50	.53	.50	.46	.38	.30	.20	.20	.26	.30	.41	.54	.67	.80	.94
10	.41	.51	.57	.61	.59	.56	.50	.43	.38	.37	.41	.46	.56	.67	.79	.92	1.05
2	.51	.60	.67	.70	.70	.67	.63	.58	.55	.55	.59	.64	.72	.82	.93	1.04	1.17

VALIDATION TEST FOR OREGON, JUNE 1979

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
ASTORI79	6	45.70	286.63	3.266	3.172	.242	.190	.094
BANDON79	6	21.94	79.38	2.894	3.439	.213	-1.182	-.545
BROKIN79	6	28.29	2.30	3.695	4.559	.491	-1.233	-.864
CAPBLC79	6	13.72	57.52	3.177	3.454	.243	-.562	-.277
CLODAL79	6	45.73	222.12	3.175	3.078	.170	.235	.097
COQUIL79	6	32.06	81.69	3.670	3.495	.144	.460	.175
DORA2W79	6	42.19	80.54	4.009	4.128	.203	-.264	-.119
ELKTON79	6	63.28	110.45	4.275	5.570	.277	-2.461	-1.295
GOLBEC79	6	21.43	27.61	3.549	3.648	.313	-.176	-.099
HONEPA79	6	37.12	133.46	3.565	3.768	.262	-.397	-.203
ILLAHE79	6	40.29	43.71	4.353	4.308	.246	.090	.045
LAURMT79	6	63.09	201.37	3.185	3.821	.134	-1.736	-.636
NEWPOR79	6	39.02	181.81	2.974	3.280	.302	-.557	-.306
NBENDF79	6	29.53	97.79	3.535	3.515	.227	.041	.020
OTIS2N79	6	44.10	209.46	3.189	3.093	.194	.219	.096
PORFOR79	6	22.96	51.76	3.677	3.152	.428	.803	.525
POWERS79	6	39.43	60.97	3.985	4.080	.207	-.209	-.095
REDSPO79	6	36.28	117.35	3.770	3.592	.212	.386	.178
SEASID79	6	44.91	275.07	3.210	3.239	.210	-.064	-.029
TIDWAT79	6	46.49	166.85	3.392	3.727	.270	-.644	-.335
TLAMOK79	6	47.36	238.24	2.991	3.324	.260	-.653	-.333
VALSET79	6	58.11	196.77	3.375	3.271	.148	.270	.104
BONDAM79	6	141.27	250.90	4.876	5.215	.266	-.656	-.339
CASDIA79	6	117.05	165.70	4.725	4.849	.193	-.283	-.124
COROSU79	6	81.35	181.81	4.878	5.025	.230	-.307	-.147
CORWSO79	6	68.90	173.76	4.912	4.327	.244	1.185	.585
COTGRO79	6	89.43	123.10	5.043	5.361	.081	-1.121	-.318
CGRODA79	6	90.28	118.50	5.366	5.324	.085	.143	.042
DOREDA79	6	94.50	123.10	5.265	5.206	.104	.183	.059
EUGENE79	6	80.52	146.14	5.181	5.273	.111	-.275	-.092
FERIDA79	6	76.37	146.14	5.302	5.222	.089	.266	.080
FDRGRO79	6	84.93	243.99	5.015	4.776	.094	.781	.239
LACOMB79	6	105.43	180.66	5.352	4.698	.188	1.506	.654
LEABUR79	6	107.09	144.99	5.425	5.190	.188	.543	.235
LOPODA79	6	104.62	132.31	5.395	5.354	.169	.101	.041
NOTI1N79	6	68.07	142.69	5.132	4.823	.194	.701	.309
SCREFA79	6	108.75	197.92	4.290	4.551	.135	-.710	-.261
BEVETO79	6	98.81	241.69	4.771	4.751	.138	.053	.020
CHYROV79	6	77.58	235.94	4.034	4.540	.108	-1.537	-.506
CKLANI79	6	74.57	283.17	3.480	3.956	.325	-.834	-.476
DALLAS79	6	75.54	202.52	4.798	3.991	.188	1.861	.807
ESCADA79	6	123.30	225.58	4.142	4.594	.188	-1.042	-.452
FOSTDA79	6	107.92	166.85	4.914	5.118	.151	-.526	-.204

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
HPTLDW79	6	131.47	238.24	4.690	4.606	.189	.194	.084
HILBOR79	6	90.64	242.84	4.764	4.888	.109	-.376	-.124
MMINVI79	6	80.84	223.28	4.221	4.394	.193	-.394	-.173
NLAMET79	6	102.07	226.73	4.372	4.581	.145	-.550	-.209
ORECIT79	6	109.42	231.33	4.613	4.502	.143	.293	.111
PTLDWS79	6	109.42	248.59	5.017	4.892	.157	.316	.125
SHELEN79	6	98.81	267.01	4.850	4.496	.289	.658	.354
SALEMW79	6	90.49	201.37	4.509	4.802	.194	-.664	-.293
SCODAM79	6	80.03	240.54	4.811	4.439	.080	1.320	.372
SCOMIL79	6	114.56	203.67	4.102	4.314	.160	-.529	-.212
SILVER79	6	101.26	207.16	4.640	4.316	.156	.821	.324
TRODAL79	6	119.22	246.29	5.002	4.820	.179	.431	.182
VNONIA79	6	80.84	267.01	4.319	4.335	.218	-.034	-.016
ASHLAN79	6	108.87	14.95	6.410	6.251	.192	.362	.159
CAVEJC79	6	60.01	11.50	6.181	5.225	.424	1.468	.956
DRAIN 79	6	76.78	115.05	6.252	4.909	.203	2.983	1.343
GRTPAS79	6	78.01	29.91	6.453	5.756	.196	1.573	.697
HOARDA79	6	126.88	14.95	5.669	6.421	.339	-1.291	-.752
IDLPAR79	6	94.50	94.34	5.810	5.946	.318	-.241	-.136
LEMLAK79	6	132.46	94.34	5.943	5.752	.424	.293	.191
LCREDA79	6	110.59	46.01	6.385	6.310	.198	.168	.075
MEDFOD79	6	101.16	20.71	6.461	6.539	.072	-.290	-.078
MEDFWS79	6	101.16	25.31	6.598	6.430	.089	.565	.168
PROSPC79	6	119.16	50.61	6.284	6.118	.239	.338	.166
ROSBUR79	6	75.09	82.84	6.272	5.413	.313	1.534	.859
RUCH 79	6	92.58	16.10	6.361	6.494	.210	-.290	-.133
SSUMIT79	6	75.44	42.56	5.258	6.218	.227	-2.016	-.960
BELKNA79	6	139.46	158.80	4.511	4.513	.140	-.006	-.002
DTRODA79	6	128.67	187.56	4.490	4.557	.248	-.134	-.067
GVTCAM79	6	151.07	227.88	4.110	5.281	.231	-2.437	-1.171
MARION79	6	143.62	179.51	4.477	4.296	.204	.402	.181
MKENZI79	6	135.31	150.74	4.842	4.767	.186	.175	.075
OKRIDG79	6	120.65	120.80	5.522	5.523	.318	-.003	-.001
SANTPA79	6	147.77	166.85	3.988	4.607	.170	-1.500	-.619
TRELYN79	6	135.55	215.22	4.615	4.289	.244	.660	.326
CHEMUL79	6	182.24	85.14	4.256	6.110	.441	-2.790	-1.854
RONCRO79	6	203.17	23.01	5.804	6.485	.379	-1.107	-.681
SUMLAK79	6	208.32	65.57	7.613	5.977	.259	3.212	1.636
WIKIDA79	6	159.46	116.20	5.877	5.094	.400	1.237	.783
ANTELO79	6	195.08	201.37	5.493	5.606	.268	-.218	-.113
ALINTO79	6	227.01	256.65	6.403	6.121	.312	.504	.282
BORDMA79	6	251.51	264.71	6.611	6.511	.355	.168	.100
CONDON79	6	227.83	223.28	5.622	5.983	.211	-.784	-.361
DUFUR 79	6	181.28	238.24	5.456	6.322	.186	-2.008	-.866
HEPPNE79	6	259.67	226.73	7.442	6.029	.382	2.286	1.413
HERMIS79	6	271.92	263.56	6.244	7.135	.342	-1.524	-.891
HODRIV79	6	162.50	254.35	5.905	6.137	.223	-.491	-.232

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
KENT	79 6	202.51	220.97	5.635	5.464	.231	.355	.171
MIKALO	79 6	219.66	239.39	6.141	5.906	.226	.494	.235
MILTON	79 6	314.39	272.76	7.597	7.169	.235	.883	.428
MORO	79 6	201.70	240.54	5.643	5.990	.235	-.715	-.347
PAKDAL	79 6	159.23	241.69	5.745	5.213	.179	1.257	.532
PDLTON	79 6	303.77	256.65	7.053	7.362	.205	-.681	-.309
PDLTON	79 6	293.15	254.35	7.474	6.913	.177	1.334	.561
PILOT1	79 6	294.79	240.54	7.146	6.980	.211	.362	.166
PINGRO	79 6	169.85	215.22	5.735	5.236	.305	.904	.499
THEDAL	79 6	178.02	248.59	6.767	5.700	.188	2.465	1.067
ADEL	79 6	253.75	12.65	6.909	6.028	.419	1.361	.881
ALKALA	79 6	248.61	66.72	6.694	6.532	.287	.302	.162
ADREMI	79 6	323.19	37.96	7.261	6.737	.344	.893	.524
BARNST	79	233.71	134.61	5.116	5.858	.254	-1.473	-.742
BEND	79 6	175.16	142.69	5.190	5.327	.234	-.284	-.137
BROTHE	79 6	214.30	124.25	4.903	5.025	.281	-.231	-.122
BURNSW	79 6	292.77	109.30	6.819	6.043	.305	1.404	.776
CHILOQ	79 6	153.45	40.26	5.503	6.204	.347	-1.191	-.701
CRISVA	79 6	210.08	85.14	5.991	6.392	.287	-.748	-.401
DAYVIL	79 6	258.18	176.06	5.896	5.704	.324	.338	.192
DREWSE	79 6	326.51	124.25	6.956	7.699	.261	-1.455	-.743
FOSSIL	79 6	226.19	207.16	5.469	5.598	.244	-.260	-.129
HAREFU	79 6	266.61	37.96	5.724	6.683	.411	-1.495	-.959
KLTFAL	79 6	156.88	13.80	6.572	6.187	.072	1.439	.385
KLTFAL	79 6	158.59	11.50	6.292	6.547	.074	-.937	-.255
LAKVIE	79 6	229.75	14.95	6.311	6.467	.293	-.289	-.156
MADRAS	79 6	184.29	181.81	5.349	5.309	.047	.186	.040
MADRAS	79 6	183.46	184.11	5.382	5.463	.046	-.376	-.081
MALFUG	79 6	303.73	88.59	6.489	6.726	.312	-.424	-.237
MALINS	79 6	180.88	.00	6.348	6.118	.452	.341	.230
MTOLUS	79 6	181.80	178.36	5.210	5.378	.092	-.551	-.168
MITCHE	79 6	232.44	177.21	5.467	5.357	.278	.209	.110
OCHOCO	79 6	219.16	165.70	4.746	5.454	.338	-1.218	-.708
OORANC	79 6	279.27	88.59	6.422	6.584	.331	-.282	-.162
PAISLE	79 6	221.17	48.31	6.579	6.928	.297	-.641	-.349
PAULIN	79 6	242.40	147.29	6.353	5.348	.277	1.910	1.005
PLTNDA	79 6	179.31	188.71	5.805	5.400	.133	1.112	.405
PINEMT	79 6	196.58	123.10	4.897	5.035	.319	-.245	-.138
P-RANC	79 6	306.04	56.36	6.265	6.676	.356	-.688	-.411
REDMON	79 6	180.14	156.50	5.305	5.334	.079	-.103	-.029
REDMDF	79 6	183.46	156.50	5.330	5.226	.088	.352	.104
SISTER	79 6	163.54	157.65	5.003	4.739	.250	.529	.264
SPRARI	79 6	171.45	31.06	5.999	6.085	.322	-.152	-.086
SQABUT	79 6	260.70	102.39	6.761	6.504	.150	.663	.257
SUNTEX	79 6	263.24	110.45	6.462	6.660	.176	-.470	-.198
VALFAL	79 6	235.75	31.06	6.575	6.394	.256	.358	.181
WAGONT	79 6	250.58	86.29	6.754	6.603	.245	.306	.151

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
WITHOR79	6	339.48	23.01	7.034	7.579	.350	-.921	-.545
AUSTIN79	6	315.45	178.36	4.691	6.090	.303	-2.541	-1.399
BAKERF79	6	349.49	195.62	5.396	5.341	.115	.161	.055
BAKERK79	6	351.98	191.02	5.510	5.453	.118	.166	.057
COVE 79	6	344.60	227.88	5.328	5.275	.144	.139	.053
ELGIN 79	6	338.88	246.29	5.446	5.560	.236	-.235	-.114
ENTPRI79	6	370.73	237.09	5.016	5.251	.261	-.459	-.235
ENPRIS79	6	376.45	255.50	5.131	5.046	.391	.136	.085
HALFWA79	6	384.36	199.07	5.330	5.763	.190	-.994	-.433
HUNGTO79	6	376.89	162.25	8.985	7.431	.326	2.724	1.554
JOHNDA79	6	293.04	168.00	5.520	4.757	.232	1.582	.763
LAGRAN79	6	330.72	229.03	5.576	5.710	.243	-.272	-.134
LONCRE79	6	285.57	187.56	4.914	5.459	.245	-1.101	-.545
MSONDA79	6	340.36	184.11	5.005	6.113	.210	-2.415	-1.108
MINAM779	6	354.40	254.35	4.641	5.441	.172	-1.931	-.800
MOMENT79	6	269.80	194.47	5.511	5.848	.275	-.642	-.337
RICHLA79	6	381.87	191.02	5.916	6.083	.163	-.414	-.167
SENECA79	6	292.21	148.44	4.766	6.084	.297	-2.417	-1.318
UKIAH 79	6	289.07	216.37	6.403	6.199	.307	.369	.204
UNIONX79	6	340.52	222.12	5.260	5.450	.139	-.508	-.190
UNITY 79	6	328.74	168.00	7.394	6.005	.233	2.880	1.389
WALALA79	6	326.32	276.27	7.207	6.777	.295	.792	.430
WALLOW79	6	357.66	246.29	5.204	4.781	.149	1.095	.423
BEULAH79	6	337.48	132.31	8.246	7.729	.195	1.170	.517
BURNJT79	6	359.19	54.06	8.353	7.959	.233	.817	.394
DANNER79	6	385.77	64.42	7.731	7.939	.249	-.417	-.208
IONSID79	6	341.19	157.65	7.797	7.640	.248	.315	.157
JUTURA79	6	349.29	124.25	8.518	8.236	.281	.532	.282
MHEURB79	6	395.70	136.91	8.387	8.523	.094	-.444	-.136
MDRMIT79	6	358.34	28.76	7.939	7.743	.336	.337	.196
NYSSA 79	6	396.54	128.86	8.460	8.258	.150	.521	.202
ONTARI79	6	391.83	141.54	8.600	8.448	.117	.445	.152
OWYEDA79	6	383.89	113.90	8.130	8.153	.243	-.046	-.023
RIVSID79	6	337.48	107.00	8.046	7.633	.328	.722	.413
ROCVIL79	6	390.64	94.34	7.619	7.971	.241	-.717	-.352
ROME2N79	6	369.48	59.82	8.142	8.121	.218	.045	.021
SHEVIL79	6	394.85	77.08	7.788	7.694	.247	.189	.094
VALE 79	6	383.89	136.91	8.585	8.580	.173	.011	.005

SILLX = 1.82 RANGX = 170.
SILLY = 1.3 RANGY = 170.
REDUCED ERRORS MEAN,MR IS -.009214656729092
REDUCED ERRORS VARIANCE,VR IS 1.0890179432
MEAN OF (ETR-ETK) IS -.008407238956385
VARIANCE OF (ETR-ETK) IS .2780269045168

APPENDIX C

Results of the "best" subregional semivariogram search for June 1979.

TESTING SEMIVAROGRAM MODELS FOR OREGON COAST, JUNE 1979

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
ASTORI79	6	45.70	286.63	3.266	3.249	.079	.059	.017
BANDON79	6	21.94	79.38	2.894	3.486	.060	-2.406	-.592
BROKIN79	6	28.29	2.30	3.695	3.632	.149	.163	.063
CAPBLC79	6	13.72	57.52	3.177	3.521	.071	-1.294	-.344
CLODAL79	6	45.73	222.12	3.175	3.148	.058	.113	.027
COQUIL79	6	32.06	81.69	3.670	3.455	.039	1.083	.215
DORA2W79	6	42.19	80.54	4.009	3.850	.062	.634	.159
GOLBEC79	6	21.43	27.61	3.549	3.912	.107	-1.112	-.363
HONEPA79	6	37.12	133.46	3.565	3.628	.096	-.203	-.063
ILLAHE79	6	40.29	43.71	4.353	3.771	.091	1.925	.582
NEWPOR79	6	39.02	181.81	2.974	3.363	.087	-1.322	-.389
NBENDF79	6	29.53	97.79	3.535	3.601	.074	-.243	-.066
OTIS2N79	6	44.10	209.46	3.189	3.200	.064	-.044	-.011
PORFOR79	6	22.96	51.76	3.677	3.295	.098	1.224	.382
POWERS79	6	39.43	60.97	3.985	3.989	.071	-.016	-.004
REDSPO79	6	36.28	117.35	3.770	3.618	.077	.550	.152
SEASID79	6	44.91	275.07	3.210	3.232	.075	-.080	-.022
TIDWAT79	6	46.49	166.85	3.392	3.137	.097	.819	.255
TLAMOK79	6	47.36	238.24	2.991	3.210	.097	-.702	-.219
VALSET79	6	58.11	196.77	3.375	3.214	.102	.504	.161

SILLX = .138 RANGX = 52.
SILLY = .138 RANGY = 52.
REDUCED ERRORS MEAN,MR IS -.01732609886332
REDUCED ERRORS VARIANCE,VR IS 1.005056648863
MEAN OF (ETR-ETK) IS -.003041962112506
VARIANCE OF (ETR-ETK) IS .07806539780511

TESTING SEMIVARIOGRAM MODELS FOR WILLAMETTE VALLEY, JUNE 1979

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
ELKTON79	6	63.28	110.45	4.275	5.730	.320	-2.571	-1.455
LAURMT79	6	63.09	201.37	3.185	4.730	.290	-2.868	-1.545
CASDIA79	6	117.05	165.70	4.725	4.867	.234	-.294	-.142
COROSU79	6	81.35	181.81	4.878	4.705	.304	.314	.173
CORWSO79	6	68.90	173.76	4.912	4.751	.314	.287	.161
COTGRO79	6	89.43	123.10	5.043	5.393	.105	-1.080	-.350
CGRODA79	6	90.28	118.50	5.366	5.338	.120	.082	.028
DOREDA79	6	94.50	123.10	5.265	5.138	.120	.367	.127
EUGENE79	6	80.52	146.14	5.181	5.286	.125	-.296	-.105
FERIDA79	6	76.37	146.14	5.302	5.179	.100	.389	.123
FDRGRO79	6	84.93	243.99	5.015	4.798	.108	.660	.217
LACOMB79	6	105.43	180.66	5.352	4.672	.287	1.270	.680
LEABUR79	6	107.09	144.99	5.425	5.168	.289	.478	.257
LOPODA79	6	104.62	132.31	5.395	5.426	.238	-.064	-.031
NOTI1N79	6	68.07	142.69	5.132	5.225	.235	-.193	-.093
SCREFA79	6	108.75	197.92	4.290	4.473	.185	-.426	-.183
BEVETO79	6	98.81	241.69	4.771	4.754	.165	.042	.017
CHYROV79	6	77.58	235.94	4.034	4.631	.135	-1.625	-.597
CKLANI79	6	74.57	283.17	3.480	4.576	.345	-1.866	-1.096
DALLAS79	6	75.54	202.52	4.798	3.938	.248	1.727	.860
ESCADA79	6	123.30	225.58	4.142	4.618	.258	-.938	-.476
FOSTDA79	6	107.92	166.85	4.914	4.949	.212	-.075	-.035
HPTLDW79	6	131.47	238.24	4.690	4.512	.281	.336	.178
HILBOR79	6	90.64	242.84	4.764	4.879	.119	-.335	-.115
MMINVI79	6	80.84	223.28	4.221	4.288	.290	-.124	-.067
NLAMET79	6	102.07	226.73	4.372	4.580	.211	-.454	-.208
ORECIT79	6	109.42	231.33	4.613	4.463	.187	.346	.150
PTLDWS79	6	109.42	248.59	5.017	4.905	.205	.248	.112
SHELEN79	6	98.81	267.01	4.850	4.536	.341	.537	.314
SALEMW79	6	90.49	201.37	4.509	4.811	.247	-.608	-.302
SCODAM79	6	80.03	240.54	4.811	4.496	.098	1.006	.315
SCOMIL79	6	114.56	203.67	4.102	4.368	.210	-.580	-.266
SILVER79	6	101.26	207.16	4.640	4.322	.220	.678	.318
TRODAL79	6	119.22	246.29	5.002	4.847	.217	.334	.155
VNONIA79	6	80.84	267.01	4.319	4.359	.317	-.071	-.040
DRAIN 79	6	76.78	115.05	6.252	4.871	.257	2.723	1.381
BELKNA79	6	139.46	158.80	4.511	4.951	.233	-.912	-.440
DTRODA79	6	128.67	187.56	4.490	4.635	.350	-.245	-.145
MKENZI79	6	135.31	150.74	4.842	4.757	.233	.177	.085
OKRIDG79	6	120.65	120.80	5.522	5.322	.360	.333	.200
TRELYN79	6	135.55	215.22	4.615	4.420	.329	.340	.195

SILLX = .3024 RANGX = 27.
SILLY = .3024 RANGY = 27.
REDUCED ERRORS MEAN,MR IS -.07203686867732
REDUCED ERRORS VARIANCE,VR IS 1.017549774722
MEAN OF (ETR-ETK) IS -.04015987491067
VARIANCE OF (ETR-ETK) IS .2661947258472

TESTING SEMIVARIOGRAM MODELS FOR SOUTH-WEST VALLEY, JUNE 1979

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
ASHLAN79	6	108.87	14.95	6.410	6.157	.154	.646	.253
CAVEJC79	6	60.01	11.50	6.181	6.168	.155	.033	.013
GRTPAS79	6	78.01	29.91	6.453	6.214	.156	.607	.239
HOARDA79	6	126.88	14.95	5.669	6.252	.156	-1.477	-.583
IDLPAR79	6	94.50	94.34	5.810	6.177	.155	-.933	-.367
LEMLAK79	6	132.46	94.34	5.943	6.051	.155	-.275	-.108
LCREDA79	6	110.59	46.01	6.385	6.161	.153	.573	.224
MEDFOD79	6	101.16	20.71	6.461	6.389	.111	.216	.072
MEDFWS79	6	101.16	25.31	6.598	6.281	.115	.936	.317
PROSPC79	6	119.16	50.61	6.284	6.112	.153	.439	.172
ROSBUR79	6	75.09	82.84	6.272	6.114	.155	.401	.158
RUCH 79	6	92.58	16.10	6.361	6.151	.154	.536	.210
SSUMIT79	6	75.44	42.56	5.258	6.379	.155	-2.843	-1.121

SILLX = .1365 RANGX = 12.
SILLY = .1365 RANGY = 12.
REDUCED ERRORS MEAN,MR IS -.08779763825982
REDUCED ERRORS VARIANCE,VR IS 1.149246263077
MEAN OF (ETR-ETK) IS -.04005621507209
VARIANCE OF (ETR-ETK) IS .1747733155082

TESTING SEMIVARIOGRAM MODELS FOR NORTH-CENTRAL OREGON, JUNE 1979

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
BONDAM79	6	141.27	250.90	4.876	5.169	.390	-.470	-.293
GVTCAM79	6	151.07	227.88	4.110	5.340	.275	-2.346	-1.230
MARION79	6	143.62	179.51	4.477	5.136	.678	-.801	-.659
ANTELO79	6	195.08	201.37	5.493	5.631	.267	-.268	-.138
ALINTO79	6	227.01	256.65	6.403	6.350	.313	.094	.053
BORDMA79	6	251.51	264.71	6.611	6.361	.320	.442	.250
CONDON79	6	227.83	223.28	5.622	6.049	.224	-.902	-.427
DUFUR 79	6	181.28	238.24	5.456	6.247	.184	-1.844	-.791
HEPPNE79	6	259.67	226.73	7.442	6.059	.401	2.185	1.383
HERMIS79	6	271.92	263.56	6.244	7.118	.303	-1.586	-.874
HODRIV79	6	162.50	254.35	5.905	6.099	.220	-.414	-.194
KENT 79	6	202.51	220.97	5.635	5.441	.249	.389	.194
MIKALO79	6	219.66	239.39	6.141	5.909	.210	.506	.232
MILTON79	6	314.39	272.76	7.597	7.160	.214	.944	.437
MORO 79	6	201.70	240.54	5.643	5.991	.234	-.718	-.348
PAKDAL79	6	159.23	241.69	5.745	5.212	.179	1.260	.533
PDLTON79	6	303.77	256.65	7.053	7.370	.185	-.736	-.317
PDLTON79	6	293.15	254.35	7.474	6.940	.169	1.298	.534
PILOT179	6	294.79	240.54	7.146	6.930	.233	.447	.216
PINGRO79	6	169.85	215.22	5.735	4.989	.300	1.362	.746
THEDAL79	6	178.02	248.59	6.767	5.706	.184	2.473	1.061
DAYVIL79	6	258.18	176.06	5.896	5.305	.347	1.004	.591
FOSSIL79	6	226.19	207.16	5.469	5.610	.272	-.271	-.141
MADRAS79	6	184.29	181.81	5.349	5.316	.045	.155	.033
MADRAS79	6	183.46	184.11	5.382	5.475	.047	-.427	-.093
MTOLUS79	6	181.80	178.36	5.210	5.325	.105	-.356	-.115
MITCHE79	6	232.44	177.21	5.467	5.654	.421	-.288	-.187
PLTNDA79	6	179.31	188.71	5.805	5.393	.132	1.135	.412
AUSTIN79	6	315.45	178.36	4.691	4.993	.408	-.473	-.302
BAKERF79	6	349.49	195.62	5.396	5.407	.116	-.033	-.011
BAKERK79	6	351.98	191.02	5.510	5.384	.112	.378	.126
COVE 79	6	344.60	227.88	5.328	5.311	.136	.046	.017
ELGIN 79	6	338.88	246.29	5.446	5.552	.231	-.220	-.106
ENTPRI79	6	370.73	237.09	5.016	5.249	.265	-.454	-.233
ENPRIS79	6	376.45	255.50	5.131	5.080	.369	.084	.051
HALFWA79	6	384.36	199.07	5.330	5.776	.196	-1.009	-.446
LAGRAN79	6	330.72	229.03	5.576	5.662	.213	-.187	-.086
LONCRE79	6	285.57	187.56	4.914	5.370	.285	-.854	-.456
MSONDA79	6	340.36	184.11	5.005	5.247	.240	-.494	-.242
MINAM779	6	354.40	254.35	4.641	5.447	.170	-1.955	-.806

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
MOMENT	79 6	269.80	194.47	5.511	5.862	.260	-.688	-.351
RICHLA	79 6	381.87	191.02	5.916	5.359	.196	1.259	.557
UKIAH	79 6	289.07	216.37	6.403	6.215	.338	.324	.188
UNIONX	79 6	340.52	222.12	5.260	5.417	.133	-.431	-.157
WALALA	79 6	326.32	276.27	7.207	6.865	.268	.660	.342
WALLOW	79 6	357.66	246.29	5.204	4.787	.144	1.101	.417

SILLX = .65 RANGX = 73.
SILLY = .65 RANGY = 73.
REDUCED ERRORS MEAN,MR IS -.01480317970347
REDUCED ERRORS VARIANCE,VR IS 1.008167072492
MEAN OF (ETR-ETK) IS -.01370052302745
VARIANCE OF (ETR-ETK) IS .2469337216274

TESTING SEMIVARIOGRAM MODELS FOR SOUTH-EAST OREGON, JUNE 1979

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
SANTPA79	6	147.77	166.85	3.988	5.118	.548	-1.527	-1.130
CHEMUL79	6	182.24	85.14	4.256	6.158	.471	-2.770	-1.902
RONGRO79	6	203.17	23.01	5.804	6.312	.396	-.807	-.508
SUMLAK79	6	208.32	65.57	7.613	5.992	.317	2.878	1.621
WIKIDA79	6	159.46	116.20	5.877	4.589	.579	1.694	1.288
ADEL 79	6	253.75	12.65	6.909	6.084	.462	1.215	.825
ALKALA79	6	248.61	66.72	6.694	6.483	.354	.355	.211
ADREMI79	6	323.19	37.96	7.261	6.774	.364	.806	.487
BARNST79		233.71	134.61	5.116	5.806	.280	-1.304	-.690
BEND 79	6	175.16	142.69	5.190	5.331	.268	-.272	-.141
BROTHE79	6	214.30	124.25	4.903	5.047	.304	-.261	-.144
BURNSW79	6	292.77	109.30	6.819	6.229	.361	.982	.590
CHILOQ79	6	153.45	40.26	5.503	5.839	.469	-.491	-.336
CRISVA79	6	210.08	85.14	5.991	6.255	.358	-.440	-.264
DREWSE79	6	326.51	124.25	6.956	7.686	.270	-1.405	-.730
HAREFU79	6	266.61	37.96	5.724	6.683	.448	-1.434	-.959
KLTFAL79	6	156.88	13.80	6.572	6.215	.082	1.247	.357
KLTFAL79	6	158.59	11.50	6.292	6.551	.082	-.908	-.259
LAKVIE79	6	229.75	14.95	6.311	6.474	.326	-.285	-.163
MALFUG79	6	303.73	88.59	6.489	6.788	.366	-.495	-.299
MALINS79	6	180.88	.00	6.348	6.126	.502	.313	.222
OCHOCO79	6	219.16	165.70	4.746	5.801	.571	-1.396	-1.055
OORANC79	6	279.27	88.59	6.422	6.631	.342	-.358	-.209
PAISLE79	6	221.17	48.31	6.579	6.940	.319	-.640	-.361
PAULIN79	6	242.40	147.29	6.353	5.096	.333	2.180	1.257
PINEMT79	6	196.58	123.10	4.897	5.062	.330	-.288	-.165
P-RANC79	6	306.04	56.36	6.265	6.725	.419	-.711	-.460
REDMON79	6	180.14	156.50	5.305	5.269	.084	.124	.036
REDMDF79	6	183.46	156.50	5.330	5.244	.094	.279	.086
SISTER79	6	163.54	157.65	5.003	4.771	.254	.460	.232
SPRARI79	6	171.45	31.06	5.999	5.966	.338	.057	.033
SQABUT79	6	260.70	102.39	6.761	6.492	.177	.639	.269
SUNTEX79	6	263.24	110.45	6.462	6.632	.209	-.372	-.170
VALFAL79	6	235.75	31.06	6.575	6.355	.286	.412	.220
WAGONT79	6	250.58	86.29	6.754	6.606	.296	.272	.148
WITHOR79	6	339.48	23.01	7.034	7.591	.366	-.921	-.557
HUNGTO79	6	376.89	162.25	8.985	8.283	.518	.975	.702
JOHNDA79	6	293.04	168.00	5.520	5.583	.456	-.094	-.063
SENECA79	6	292.21	148.44	4.766	6.081	.389	-2.108	-1.315
UNITY 79	6	328.74	168.00	7.394	7.079	.367	.520	.315

STA	DATE	X	Y	ETR	ETK	ERK	RER	DIFF
BEULAH	79 6	337.48	132.31	8.246	7.689	.219	1.189	.557
BURNJT	79 6	359.19	54.06	8.353	7.945	.260	.801	.408
DANNER	79 6	385.77	64.42	7.731	7.959	.267	-.442	-.228
IONSID	79 6	341.19	157.65	7.797	8.036	.305	-.432	-.239
JUTURA	79 6	349.29	124.25	8.518	8.259	.277	.492	.259
MHEURB	79 6	395.70	136.91	8.387	8.548	.113	-.479	-.161
MDRMIT	79 6	358.34	28.76	7.939	7.601	.395	.537	.338
NYSSA	79 6	396.54	128.86	8.460	8.273	.186	.434	.187
ONTARI	79 6	391.83	141.54	8.600	8.533	.128	.187	.067
OWYEDA	79 6	383.89	113.90	8.130	8.145	.299	-.028	-.015
RIVSID	79 6	337.48	107.00	8.046	7.475	.369	.940	.571
ROCVIL	79 6	390.64	94.34	7.619	7.961	.300	-.624	-.342
ROME2N	79 6	369.48	59.82	8.142	8.117	.219	.054	.025
SHEVIL	79 6	394.85	77.08	7.788	7.663	.284	.234	.125
VALE	79 6	383.89	136.91	8.585	8.571	.200	.032	.014

SILLX = 1.57 RANGX = 150.
SILLY = 1.57 RANGY = 150.
REDUCED ERRORS MEAN,MR IS -.01789152603548
REDUCED ERRORS VARIANCE,VR IS 1.005888708054
MEAN OF (ETR-ETK) IS -.02575321886145
VARIANCE OF (ETR-ETK) IS .3795143219616