COMPARISON OF METHODS TO ESTIMATE EVAPOTRANSPIRATION

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COMPARISON OF METHODS TO ESTIMATE EVAPOTRANSPIRATION

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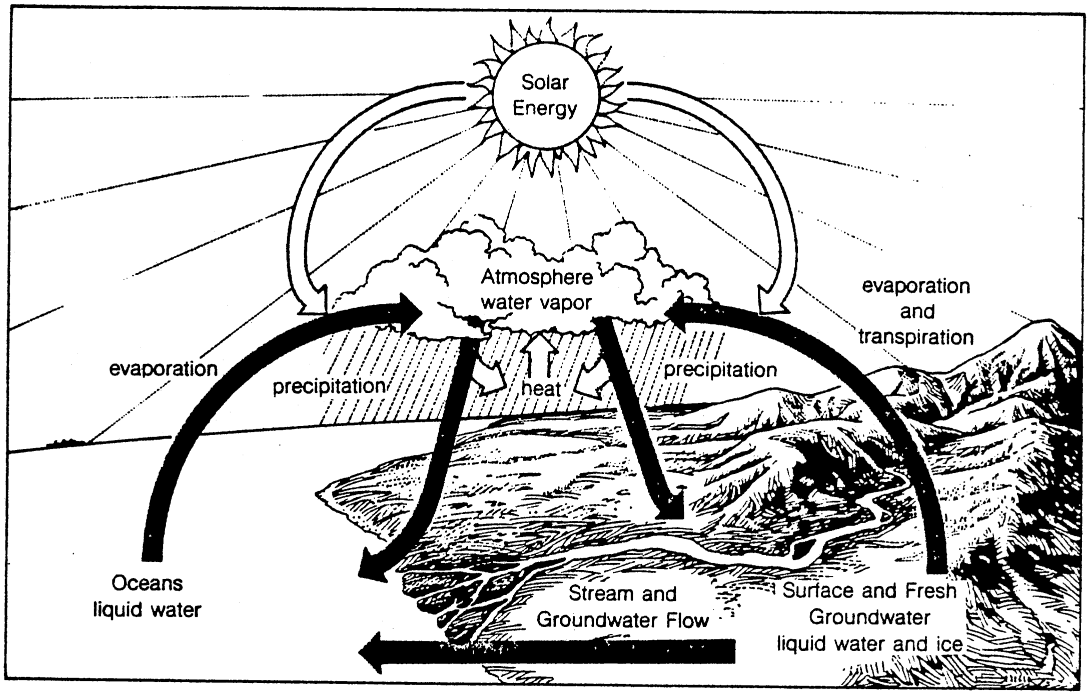
CHAPTER I

INTRODUCTION

Evapotranspiration (ET) is an intergral component of the hydrologic cycle (Figure 1). Potential ET has been defined as the water loss from an extensive, closed homogeneous cover of vegetation that never suffers from a lack of water (Mather, 1974). Actual ET is the measured amount of water lost to the atmosphere by plants when soil moisture is limiting the full amount of water that a plant could use if it were available. Accurate estimates are useful for planning purposes, while accurate measurements establish the amounts of ET that can be expected in a certain area. Equipment such as weighing lysimeters, heat flux plates, and radiometers are employed to accurately measure ET (Rosenberg, 1969; and Brun et al., 1972). ET measurement equipment is expensive, and gathering data for a large area is time-consuming (Blaney and Criddle, 1950).

For this reason alternative methods of assessing ET are being sought. This research will determine if reflectance values from Landsat digital data can be input into a remote sensing form of the Blaney-Criddle equation and can provide an estimate of ET. ET or consumptive use is defined as:

> The sum of volumes of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation



Source: Miller, <u>Living in the Environment</u> (1979).

Figure 1. Hydrologic Cycle

> on the area in any specified time, divided by the given area. (Blaney and Criddle, 1950, p.3).

ET estimates are necessary to plan system layouts for farm irrigation and to improve irrigation practices. When determining the amount of irrigation necessary, a farmer requires some knowledge of ET so that a balance between amount of water applied and amount of water evaporated can be reached. Irrigation and consumptive use information are widely used by water superintendents as well as Federal, State, and local agencies responsible for the planning, construction, operation, and maintenance of multiple-purpose projects (Blaney and Criddle, 1962). Water requirements can be established if the amount of ET can be estimated.

Related Studies

Estimating ET values can be time consuming and expensive. In an attempt to provide estimates of ET without requiring the necessary equipment and time, empirical equations have been derived (Blaney and Criddle, 1950). In their 1950 paper Blaney and Criddle outlined a method to estimate water requirements for irrigated lands, where only climatological data were available.

Blaney and Criddle (1962) reported results of experimental studies in the U.S. and foreign countries in which the Blaney-Criddle empirical equation was utilized. The empirical equation was developed so that ET from crops, natural vegetation, and irrigation water could be estimated for any area where basic climatological data were available. The factors that were used in developing the empirical formula included temperature, length of growing season, and monthly percentage of annual daytime hours. Also used in the empirical formula was the crop coefficient (K-coefficient). The crop coefficient was determined by correlating data for ET use with other climatological data. Thus, a coefficient for each crop was determined. They found that consumptive use of each crop could be calculated if the monthly temperature, latitude, computed monthly percentage of annual daytime hours, and growing period of the crop were available. Blaney and Criddle (1962) discussed the various methods used in measuring the amount of water consumed by crops or natural vegetation. They also discussed the influences of precipitation, temperature, humidity, wind movement, growing season, latitude and sunlight, quality and water supply, soil fertility, and plant pests and diseases, on water use. The study found that the method developed to estimate consumptive use of water by irrigated crops from climatological data was satisfactory for computing seasonal use where measured data were not available.

The Blaney-Criddle equation has been identified in the literature as a potential estimate of evapotranspiration. Cruff and Thompson (1967) reported on the computational formulas of six empirical equations, including the Blaney-Criddle method. Comparisons were made to estimates of evaporation from a lake surface that were calculated from open pan evaporation data. Models from Thornthwaite, U.S. Weather Bureau, Lowry-Johnson, Lane, and the Harmon methods were part of the analysis. A wide range of conditions were tested including areas such as highly arid, arid being irrigated, and subhumid. The Blaney-Criddle method gave the best estimates in arid environments being irrigated and in subhumid environments. Accuracy was within plus or minus twenty-two percent of the adjusted pan evaporation. The percentage range plus or minus twenty-two percent was considered to be the range of reliability for estimating lake evaporation from evaporation pans (Cruff and Thompson, 1967).

Taylor and Ashcroft (1972) found that the Blaney-Criddle equation had been correlated with field experiments. Crop coefficients that were determined by experiment or field experience, should be used for localities similar to the one from which they were derived. Blaney and Criddle (1950) have made provisions for cases in which sufficient basic data are not available. This allows the results of a study in one area to be applied to some other area. Garton and Criddle (1955) based their research on Oklahoma crops on other studies in other areas of the West, because of the limited measurements on consumptive use of water by crops in the state. The crop coefficient has been derived for various localities throughout the U.S. Taylor and Ashcroft (1972) assumed that the Blaney-Criddle estimated actual ET instead of potential, because it was based on correlations with existing irrigation practices. The conditions for potential ET are not realized because plants are not always supplied with ample water. In terms of this research the data employed by Taylor and Ashcroft (1972) are estimates from empirical equations and not estimates based on actual measurements. The dispute in the literature has no bearing on the outcome of this research. It will be shown later that the Blaney-Criddle estimate assumes a full supply of water based on the assumptions of the equation.

Bordne and McGuinness (1973) found the potential ET values derived by lysimeters compared favorably to six of the fourteen or more methods available to compute potential ET, including the Blaney-Criddle method. Their study illustrated the computational details of determining daily potential ET by the Jensen-Haise, Blaney-Criddle, Christiansen, Penman, vanBavel, and the U.S. Weather Bureau pan evoporation methods. They found that the Blaney-Criddle equation could be used to estimate ET for a variety of crops. Although the Blaney-Criddle method was originally derived for estimated seasonal consumptive use, it could be used for shorter time periods.

Remote Sensing

Remote sensing implies that data were collected by some device without being in direct contact with the object. Some remote sensing techniques utilize hand-held radiometers to collect data, while others utilize aerial photographs, satellite imagery, or some other medium. This research utilizes Landsat digital data. Landsat digital data are computer compatible, cover large expanses of land (185-by-185 km), and have data sensed and recorded in different parts of the electromagnetic spectrum. Landsat data are advantageous to utilize because of the minimal amount of ground work required and the time savings in gathering the data. Additional discussion on Landsat will appear in Chapter II.

The Blaney-Criddle Equation in Remote Sensing

The equation that was derived by Blaney and Criddle (1950) was designed to give estimates of ET for a particular crop. Although other empirical equations exist that can be used to estimate ET, the Blaney-Criddle equation is the only one that also has a remote sensing counterpart. The remote sensing form of the Blaney-Criddle equation will be stated later. The feasibility of using color-infrared (CIR) aerial photography to estimate ET from large parcels of land has been studied by the U.S. Geological Survey at the Gila River Phreatophyte Project since 1967. Culler and Turner (1970) used CIR aerial photography to measure vegetative cover and volume. Culler, Jones, and Turner (1972) used CIR aerial photography to compare adjusted densitometric measurements and estimates of ET and of transpiration.

Jones (1977) used CIR aerial photography much in the same way as Culler and Turner (1970) and Culler, Jones, and Turner (1972). The use of the k-coefficient as defined by near infrared irradiance was tested on two sites of the Gila River Phreatophyte Project (Jones, 1977). Optical density data were obtained from the positive transparencies using a transmittance densitometer and Wratten filters. The filters transmitted the entire visible light spectrum (.4 to .7 microns). The data from the filters were expressed by the optical density of the multilayered film in the blue (.4 - .5 microns), green (.5 - .6 microns), and red (.6 - .7 microns) wavelength range. Each dye layer of the film was viewed as a radiometer, which was sensitive to a particular wavelength range, and then related to the irradiance sensed by the three layers. Brightness values for 3.67 acre cells were obtained from the CIR film through use of a transmittance densitometer. Monthly ET values were computed by the water budget and compared to the ET estimates made by the brightness values. The mean deviation of 32 percent occurred between ET computed as a residual of the water budget and estimated from photography. More accuracy could be obtained by greater geometric fidelity and consistent CIR or multiband photography (Jones, 1977).

Remote sensing can be used in estimating ET by detecting and monitoring surface types or conditions which are related to ET. Remote sensing, utilizing black and white and CIR aerial photography, have been applied to the widely used equation developed by Blaney and Criddle. An assumption that has been accepted is that the k-coefficient in the Blaney-Criddle equation can be defined by remote sensing (ASP, 1975).

Study Area

The study area, located in southwestern Oklahoma, covers an area of approximately 11,637 square kilometers (Figure 2). The major landcover types in the area are tall grass prairie, postoak-blackjack forest, mixed grass eroded plains, and bottomland type (Duck and Fletcher, 1943). The rainfall amounts vary between 63.5 cm (25 inches) in the extreme western portion of the area to approximately 81 cm (32 inches) in the eastern portion. In general the soils include Rolling Red Plains and Granitic Soils in the western half to Reddish Prairies and Cross Timbers in the eastern half. The major geomorphic provinces include the Central Redbed Plains, Granite Mountain Region, Mangum Gypsium Hills, Western Sandstone Hills, Western Redbed Plains, Weatherford Gypsum Hills , and the Boston Mountains (Johnson, 1979). Topography in the area varies from gently rolling hills and broad flat plains to gently rolling hills cut by steep-walled canyons.

The chief economic enterprise in this area is agriculture. Although portions of seven counties comprise the study area, the agricultural products are much the same. The principal crop in the area is wheat. Cotton, grain sorghum, alfalfa, and livestock production also contribute to the economy.

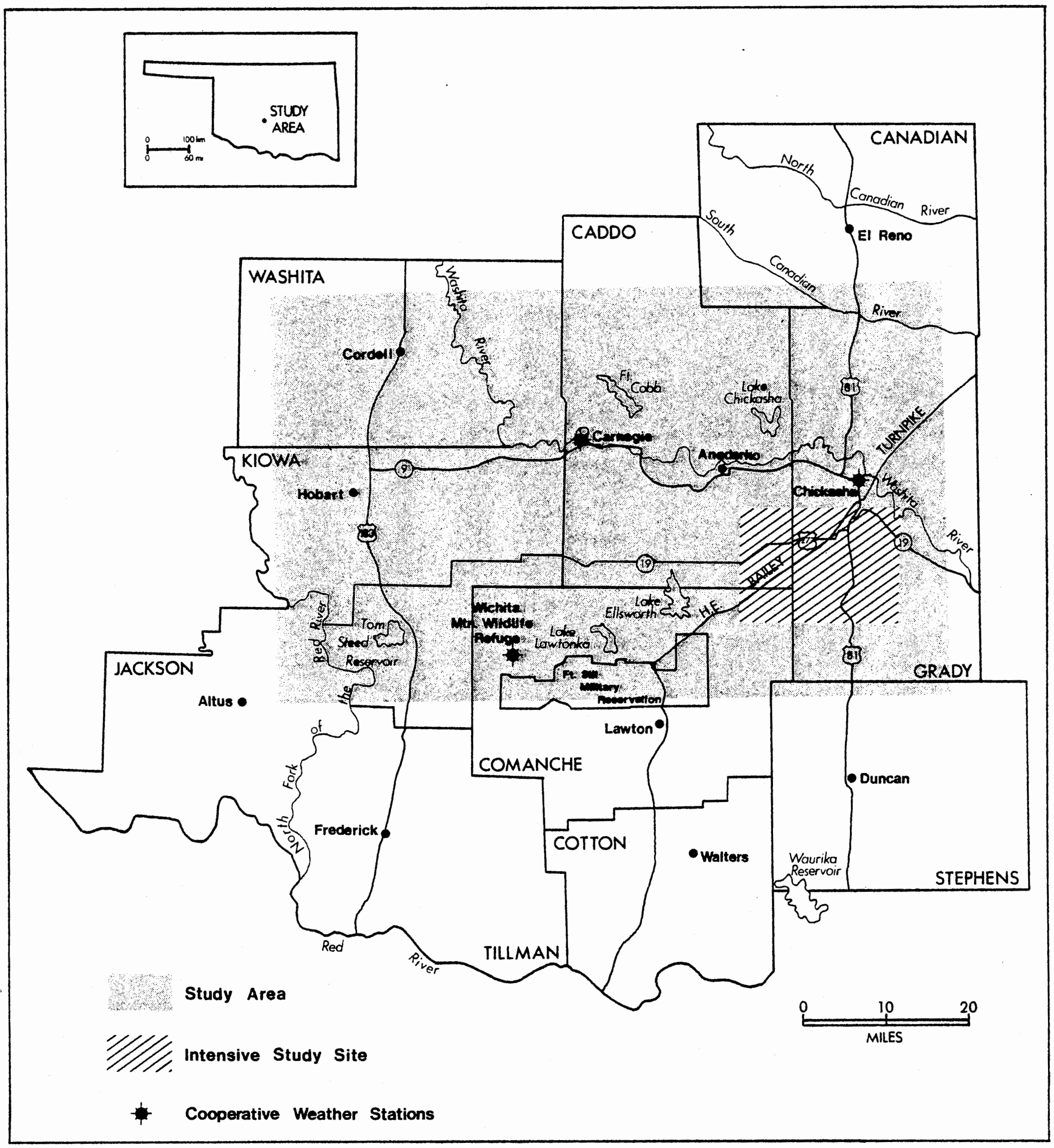


Figure 2. Study Area

Summary

This research will utilize Landsat digital data and the remote sensing form of the Blaney-Criddle equation in an attempt to estimate ET. This remote sensing derived ET estimate will then be tested against the original form of the Blaney-Criddle equation to determine if there is a significant difference between the means of each estimate. Future investigations would have to compare this study to actual ET measures to determine which estimate most closely represents on site conditions. Chapter II will describe the methodology and procedure that were followed; Chapter III will contain the analysis and results obtained from Chapter II; and Chapter IV will present the summary and conclusions of the research.

CHAPTER II

METHODOLOGY AND PROCEDURE

The equations that will be used for this research, and the underlying assumptions of the Blaney-Criddle equation are presented in this chapter. Basic information about Landsat and digital processing; the procedures followed in processing the Landsat digital tape; and the data inputs into the equations are also discussed.

The Conventional Blaney-Criddle Equation

Estimated seasonal consumptive use (evapotranspiration) in inches can be computed from the following formula:

$$U = K * F \qquad (2.0)$$

where:

U = seasonal consumptive use in inches;

K = empirical seasonal coefficient;

F = sum of the monthly factors (f) for the season (sum of the products of mean monthly temperature (t) in degrees Fahrenheit and monthly percentage of annual daytime hours (p)).

The equation for monthly or short-period consumptive use in inches is:

$$u = k * f \qquad (2.1)$$

where:

u = Monthly consumptive use, in inches;

k = Monthly consumptive use coefficient;

f = t x p/100 = Monthly consumptive use factor;

t = Mean monthly temperature, in degrees Fahrenheit;

p = Monthly percentage of daytime hours of the year (Blaney and Criddle, 1962).

Assumptions

In order to apply the consumptive use formula between regions, the following assumptions, as stated by Blaney and Criddle (1962), must be made:

> 1. Seasonal consumptive use (U) of water varies directly with the consumptive use factor (F).
>
> 2. Crop growth and yields are not limited by inadequate water at any time during the growing season.
>
> 3. The fertility and productivity of the soils at the various locations are similar.
>
> 4. Growing periods for alfalfa, pasture, orchard crops, and "natural" vegetation, although usually extending beyond the frost-free periods, are usually indicated by such periods. Yields of crops dependent upon vegetative growth only vary with the length of the growing season (p. 19).

The conditions for these assumptions may not always be met. For example, this research tried to comply with assumption number 2, by checking the precipitation and runoff records for the study area, to make certain that the seasonal conditions were not unseasonably dry or extremely warm. The records indicated that the average amount of precipitation was normal to wet, while the temperatures were slightly warmer than average. Complying with assumptions can be difficult, but they must be made so that data from one regional area can also be used in other regional areas where basic data are not available. Because this research used K-coefficients derived from other areas, these assumptions were made.

The Remote Sensing Blaney-Criddle

The general remote sensing form of the Blaney-Criddle equation is:

$$ET = (f(R))(f(f)), \qquad (2.2)$$

where:

ET = evapotranspiration, calculated by relative visible to near-infrared irradiance;

$f(R) = 0.37 + 8.25(\Sigma(R/100)^{2}/n)^{2.45}$ (this equation is to be equivalent to k, which was defined in equation 2.1);

n = number of samples;

R = relative visible to near-infrared irradiance; and

$f(f) = (10^{3}/12)$, the f term is equivalent to the f defined in equation 2.1 (Jones, 1977).

Equation 2.1 is the standard that will be used for purposes of this study. Equation 2.2 will be computed using Landsat reflectance values as the irradiance value input. The details of utilizing equations 2.1 and 2.2 will be discussed later in this chapter.

Landsat and Digital Processing

On July 23, 1972, the first Earth Resources Technology Satellite (ERTS) was launched. This was the first unmanned satellite specifically designed to acquire data about earth resources on a systematic, medium resolution, repetitive, and multispectral basis. The purpose of the launch was to test the feasibility of collecting earth resource data from unmanned satellites. On January 22, 1975, just prior to the launch of ERTS-B, the National Aeronautics and Space Administration (NASA), renamed the ERTS program to the "Landsat" program. ERTS-1 was re-named Landsat 1 and ERTS-B became Landsat 2 at launch. Landsat-3 was launched on March 5, 1978 (Lillesand and Kiefer, 1979). Landsat-4 was launched on July 16, 1982.

Orbital Characteristics

The Landsat satellite is in a sun-synchronous and near polar orbit at an altitude of 918 kilometers (570 miles) above the earth. The sun-synchronous orbit means that the satellites' orbital planes circle the earth at the same angular rate that the earth moves around the sun (NASA, 1979). Landsat's orbital velocity is constant, and all points in its orbit are passed at relatively constant local sun time, slightly after mid-morning in the northern hemisphere, or slight before in the southern hemisphere . Each 24 hour day the orbit progresses slightly westward, but every 18 days the satellite passes over the same geographic center.

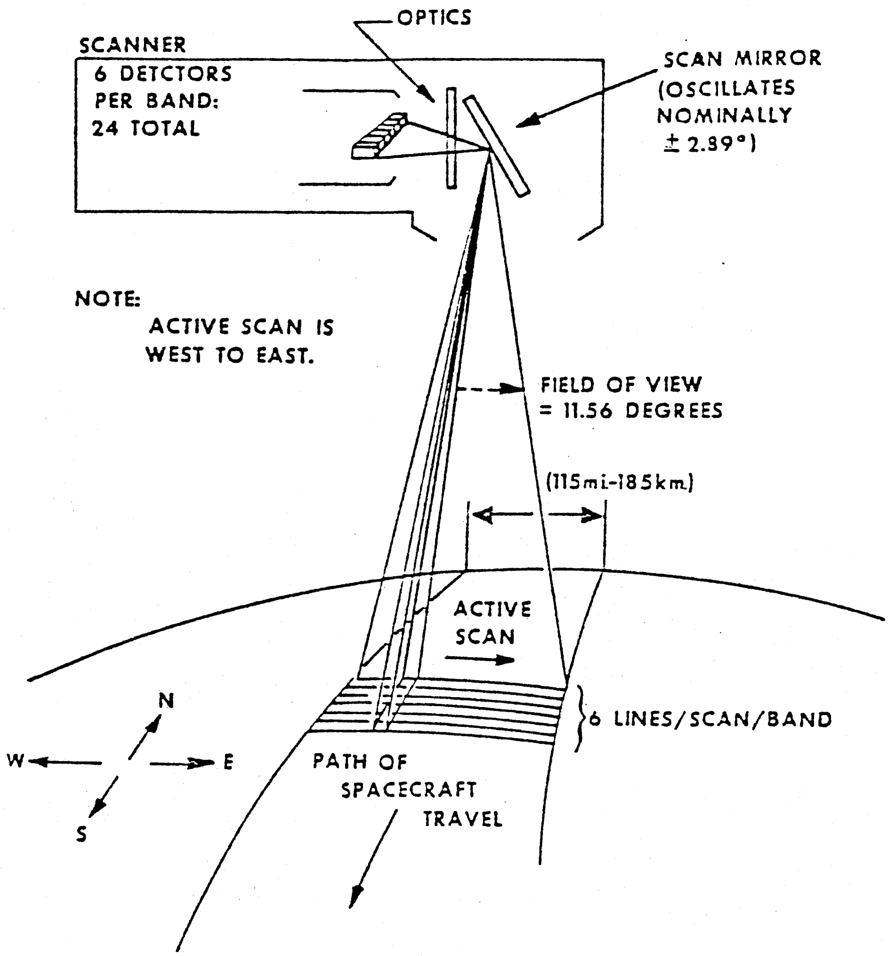
Scanner Systems

The Landsat satellites have on-board two remote sensing systems; a three channel return beam vidicon (RBV) system and a four channel multispectral scanner (MSS). This research has only utilized MSS data, and therefore the discussion involves only the MSS.

The MSS mirror oscillates through a scan angle of 11.56 degrees and scans a swath 185 kilometers (115 miles) wide (Figure 3). Each mirror oscillation scans six contiguous lines simultaneously. The data are arranged in four arrays (one for each band) of six detectors each (one for each line). Active scanning takes place only during the eastbound mirror sweep, upon completion of the sweep, the mirror retraces the scan (Sabins, 1978).

The underlying assumption of the multispectral system of data collection is that a distinct amount of solar radiation is reflected by each ground object (Walsh, 1977). The MSS utilizes four bands of the electromagnetic spectrum (Table I). A unique amount of radiation is reflected by objects on the earth's surface. The MSS records this amount of reflectivity in each of the four bands. Differences in reflectivity (or "spectral signature") allows one to differentiate between an object and those surrounding it, by the reflectivity differences (Mynar, 1982).

The ground resolution of each Landsat picture element (pixel) is 79-by-79 meters with a 23 meter overlap (Figure 4). The digital number for each pixel is based on the 79-by-79 meter ground resolution cell. The 56-by-79 meter



Source: NASA. Earth Resources Orientation and Training Course in Remote Sensing Technology, Landsat Series. (1979).

Figure 3. Landsat Scanning System

TABLE I

LANDSAT SPECTRAL BANDS

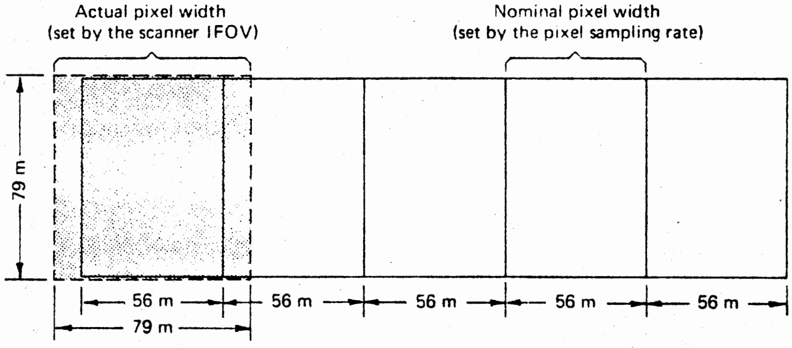
Band	Wavelength	Type of Radiation
4	0.5-0.6 um	Visible green
5	0.6-0.7 um	Visible red
6	0.7-0.8 um	Reflected near IR
7	0.8-1.1 um	Reflected near IR

Adapted from NASA (1979).

cell is referred to as the "nominal" pixel dimension while the 79-by-79 meter pixel is the actual area over which each MSS measurement is made (Lillesand and Kiefer, 1979).

Study Area Selection

Site selection of the study area was based on several criteria. The site needed to be located in an east to west transition zone between forest and cropland. This was needed because of the limited information on K-coefficients. Since K-coefficients have been developed for only certain landcover types, this study sought to encompass as many landcover types as possible. Climatic conditions of the proposed area also were considered. As indicated, precipitation, runoff, and temperature records were examined to make certain that current and recent climatic conditions did not introduce undue vegetation stress. Available ground control data were also an important element in study site



Source: Lillesand and Kiefer, Remote Sensing and Image Interpretation (1979).

Figure 4. Actual Versus Nominal MSS Pixel Sizes

location. The Landsat scene centered near Lawton, OK (Path 30, Row 36) met this criteria. The U.S.D.A. Agricultural Research Service (ARS) has collected climatic, hydrologic, and some landcover data for portions of the Little Washita Watershed, located 80 km northeast of Lawton, for approximately 20 years. Because each Landsat MSS data tape is quite expensive, tape selection was limited to data tapes maintained by the Center for Applications of Remote Sensing (CARS). All MSS digital tapes centered at Lawton were evaluated. Factors including climatic conditions, time of year, data quality, and ground conditions were assessed for each available tape. An April 8, 1981 tape (I.D. 82226816272XO) was chosen for this analysis.

The April 8, 1981 tape was processed and displayed at CARS. Analysis equipment included a Perkin-Elmer 8/32 mini-computer, Comtal image processing system, Altek graphic digitizer, and a Versatec raster processor and printer/plotter. The NASA Earth Laboratory Applications Software Package (ELAS) was utilized in conjunction with the mini-computer. ELAS, a geobased information system, is designed for analyzing and processing digital data such as that collected by multispectral scanners or digitized from maps (Graham, 1980). It is designed for ease of user operation and includes a FORTRAN operating subsystem and an expandable set of application modules which are FORTRAN overlays.

Digital Processing

Landsat MSS computer-compatible tapes (CCT's) must be preprocessed prior to actual computer-aided analysis. Reformatting, an initial preprocessing step, allows the user to read and manipulate the data in a computer compatible format detailed to resident software. The module NCCT was utilized to reformat the April 8, 1981 data for this research.

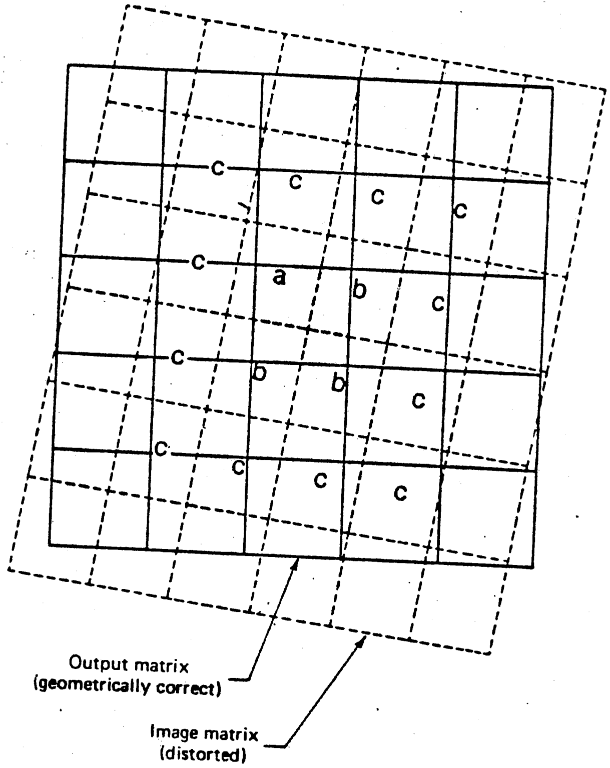
Preprocessing also corrects inherent geometric distortions. These distortions result from variation in spacecraft attitude, altitude, and velocity (Sabins, 1978). There are two groups of distortions, systematic and random. Systematic and random distortions are corrected by applying formulas derived by mathematical modeling. The eastward rotation of the earth beneath the satellite is an example, and data are offset or skewed because of this. To straighten the data to a north-south direction it must be geometrically referenced.

Systematic and random distortions are corrected by analyzing ground control points (GCP's) identifiable both on Landsat data and referenced maps. Numerous GCP's are located in terms of their image coordinates (scanline and element) and ground coordinates (Universal Transverse Mercator coordinates). The GCPs are then submitted to a least squares regression analysis to determine coefficients for two transformation equations that interrelate the geographic and image coordinates. Once an acceptable "fit" is achieved between the location of GCP's identified on the

Landsat data tape and those identified on the maps, the data are then resampled to apply the geometric transformations to the original data (Figure 5). The CCT utilized in this study was resampled using 35 GCPs and an output cell size of 100 meters (level of data aggregation). The output cell should not be smaller than the actual resolution of the satellite. The PMGC module is used to compute mapping coefficients for Landsat data (Graham, 1980). Once the mapping coefficients are computed the data are mapped into the desired coordinate system by utilizing the PMGE module.

The root mean square (RMS) obtained upon completing the mapping module (PMGE) was 35 meters. A RMS error means that from a specific geographic point, the RMS is within the given meter radius of that point (Blanchard, 1983). A 100 meter RMS error is considered a good fit for a georeferenced Landsat product (NASA, 1979).

Once the georeferencing was completed, the next step was to use the search (SRCH) module to collect classes of spectral homogeneity. The search module operates by moving a 3-by-3 window through the entire data set. The window is evaluating pixel groups according to preset statistical criteria. A pixel group with a standard deviation in each channel falling between 0.1 (standard deviation lower bound) and 1.0 (standard deviation upper bound) and a coefficient of variation of 5 is considered homogeneous (Graham, 1980). Each pixel group is collected and merged into clusters of pixels depending upon the degree of homogeneity and the number of bins. When the SRCH is completed a final



Source: Lillesand and Kiefer, _Remote Sensing and Image Interpretation_ (1979).

Figure 5. Geometrically Corrected Image

preparation (FP) merges all similar classes and produces the final statistics (Graham, 1980). The SRCH module defined 33 statistical clusters from the Landsat tape.

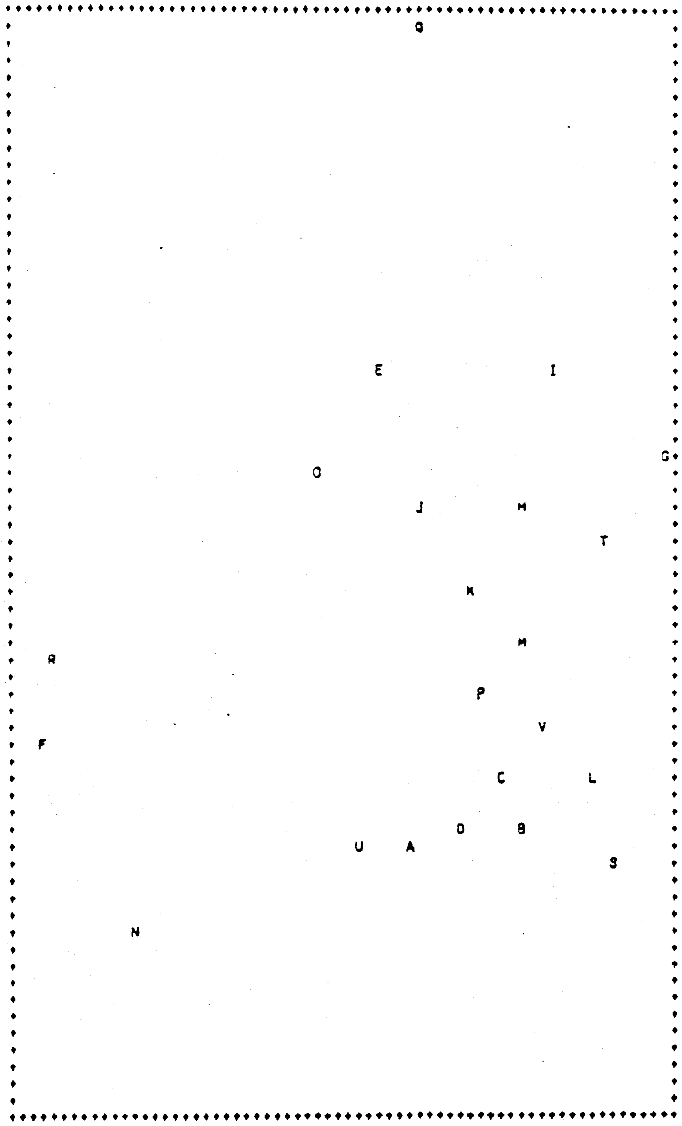
Upon completion of the search module, a classification module is utilized. The maximum likelihood classifier (MAXL) uses statistical output from the SRCH module as a method of classifying individual pixels based on the means and covariances. MAXL quantitatively evaluates the variance and correlation of the spectral response patterns when classifying an unknown pixel. Based on the mean vector and covariance matrix the statistical probability is computed for a given pixel being a member of a particular statistical cluster.

Once the data are classified one must determine what landcover types are represented by the classification and which classes should be combined. This is done by utilizing statistical output from the SRCH routine. The module, statistical print (STPR) is used to list statistics produced from SRCH. The final statistics reflect the signatures produced when similar clusters have been merged (Graham, 1980).

Statistical means and covariance and correlation matrices, can all be used in determining the land cover types that are represented and the classes to be grouped. For example, a bare soil class would have a high reflectance value in all four bands of the electromagnetic spectrum and water would have a relatively low reflectance value due to band absorption. Therefore, the mean reflectance values can be used to determine general landcover types. Identification of landcover types can also be achieved through use of a two-space plot (Figure 6). The two-space plot can be used as a guide for naming and describing classes (NASA, 1979). This is done by plotting one band against another. Band 5 and band 7 are generally the bands used because of the interrelationships that exist between their respective radiation bands. Water, for example, reflects infrared energy (band 7) at right angles to incident energy or absorbs the incident energy, and therefore an extremely low level of reflectance is recorded by Landsat in that part of the spectrum. Aquatic vegetation, for example, reflects at a significant level in the visible and non-visible spectral region. By observing spatial relationships of classes on the plots, inferences can be made as to landcover type identification.

The divergence and scaled distance matrices also provide insight as to the degree the statistical classes are related to one another(NASA, 1981). A high value between two classes indicates that they are not related, whereas a lower number (generally below 10) means that those classes are related.

Classes are identified based on the information provided by the mean reflectance values, two-space plot, and divergence and scaled distance matrices. It is then necessary to prepare for field checking. Field checking is done to determine if the classes have been properly identified and to identify classes with specific landcover types.



Source: NASA. <u>Earth Resources Orientation and Training Course in Remote Sensing Technology</u>, <u>Landsat Series</u>. (1979).

Figure 6. Two-Space Plot

An electrostatic plot of the study area is produced for field work. The plot shows the spectral classes that are in the study area represented by different plot symbols. The purpose of the field work is to determine what landcover types are represented by the symbols. The electrostatic plot is convenient to use because landmark locations (i.e. highways, roads, towns, etc.) may be located on the plot, facilitating identification. Upon completion of landcover identification, a decision was made as to which cover types would be used for this study. Wheat, alfalfa, and forest were used, because of the K-coefficients that exist.

Each landcover type identified through the classification was randomly sampled in order to obtain raw reflectance values per Landsat band for input in equation 2.2. This was accomplished by utilizing the classified data as a guide and displaying the classes on the Comtal image processing system. The first sites sampled were located near the Little Washita watershed (intensive sample sites). If the desired cover type was not located within the watershed, then the region outside of the watershed was sampled (Figure 2). A 5-by-5 pixel area of a homogeneous landcover type (wheat, alfalfa, or forest) was determined using the build polygon (BLDP) module (Graham, 1980). The midpoint of each 5-by-5 pixel area was recorded by scanline and element. Any pixel that was not one of the three cover types described above were recorded for editing purposes. Pixels within a "homogeneous" 5-by-5 pixel area may require editing because of poor vegetative cover; the edge effect of a transition zone between landcover types; or a bare area in the field because of disease. These factors influence the reflectance values (among other factors), and cause spectral class differences. The print matrix module (PMAT) was used to print off each sample midpoint and corresponding reflectance values for the four bands of Landsat data. All of the sample sites and the reflectance values for each band of data were written out to a magnetic tape. The data were taken to the Oklahoma State University Computer Center (UCC) so that the reflectance values for the landcover types could be written into a time sharing option (TSO) file for ease of data entry and manipulation. At this point the pixels identified for editing could be deleted, and programs could be written to compute ET using the reflectance values as the irradiance value input. The Statistical Analysis System (SAS) could also be utilized, once the data were in a TSO file.

The k-coefficient in the Blaney-Criddle equation can be defined by remote sensing (ASP, 1975). This study, unlike other research, inputs reflectances values from Landsat into the remote sensing form of the Blaney-Criddle equation to compute ET. In this study, the Blaney-Criddle equation for calculating a monthly ET estimate utilizes one date of Landsat data. Although the other inputs such as the percentage of daytime hours in the year and the temperature input are monthly estimates, the Landsat values are a daily reflectance value produced in part through an accumulation of recent environmental conditions. For purposes of this research, it was assumed the mean reflectance value throughout the 30 day period was represented by the values from the one day. This assumption could be a source of error because of the slight changes in sun angle throughout the thirty day period. Factors such as the time of day, season, and sun angle influence the reflectance values. The different reflectance values from each of the four bands of Landsat data were used as the irradiance value (R) input into equation 2.2. In addition, band averages of 4 and 5, 5 and 6, 6 and 7, 4 and 6, 4 and 7, and 5 and 7 were also input as R values to determine if a particular band average gave a more comparable ET estimate to equation 2.1.

Two vegetation indices, the transformed vegetation index (TVI) and the green vegetation index (GVI) were also input as irradiance values in equation 2.2. These two indices are calculated by inputting Landsat reflectance values into the two equations stated below:

$$TVI = ((MSS7-MSS5)/(MSS7+MSS5)+0.5) \qquad (2.4)$$

$$GVI = -0.290(MSS4)-0.562(MSS5)+0.600(MSS6)+0.49(MSS7) \qquad (2.5)$$

The TVI is useful because the difference in the numerator increases as vegetation density increases. GVI contains the maximum amount of information about green or living vegetation (Wiegand, 1979). Although Landsat individual bands and band averages give some indication of the amount of biomass or vegetation cover, it was hypothesized that a more quantifiable biomass indicator, such as TVI or GVI should be tested.

The K-coefficients for equation 2.1 were derived by taking the range of values cited in the literature (USDA, 1967 ; Blaney and Criddle, 1950) for each landcover type, and computing ET for each K-coefficient. The coefficients cited in the literature are seasonal coefficients, which could influence the monthly ET estimate because of greater variation between monthly and seasonal estimates. The range of seasonal coefficients were used because lower values were used for more humid areas and higher values were used for more arid climates (Appendix A). The characteristic climate in the study area is classified as Dry Subhumid (Thornthwaite, 1941). The range of the K-coefficients used, are more representative than if just one value were used, since the study area was not exclusively classified as humid nor arid as were the K-coefficients.

Temperature Data

The temperature data for this research came from the Oklahoma Cooperative weather stations, published by the National Oceanic and Atmospheric Administration (NOAA). The cooperative weather stations that recorded daily temperature and were included in the study area were Carnegie 4 ENE, Chickasha Experiment Station, and the Wichita Mountain Wildlife Refuge (Figure 2). Because the date of the Landsat tape was April 8, thirty days prior to and including April 8 were used to compute the mean monthly temperature in degrees Fahreheit (F). The mean temperature of the three stations were used as the monthly temperature.

Monthly Percentage of Daytime Hours Data

The monthly percentage of daytime hours in the year was a tabled value (Appendix B). The latitude of the study area varied between 34 degrees 45 minutes north latitude to 35 degrees north latitude. For the monthly p value, a weighted average was taken between two tabled values since seventy-three percent of the days which made up the monthly period occurred in March and twenty-seven percent occurred in April. The 35 degree north latitude values were used because the variation between 34 degrees and 35 degrees as shown in Appendix B are negligible. Also a 15 minute difference in terms of latitude was not considered to be enough of a significant difference to warrant using a different value.

Data Arrangement

It was stated earlier in this chapter that each of the remote sensing derived landcover types were randomly sampled in order to obtain reflectance values for each Landsat band. This was accomplished by utilizing the classified data as a guide in locating the desired landcover types. Once the desired cover type was located, the reflectance values were obtained. This procedure, repeated thirty times for each landcover type (wheat, alfalfa, forest), generated a representative sample for each cover type. Once the reflectance values were obtained, ET was computed using equation 2.2 for the twelve remote sensing variables (bands 4,5,6,7; band averages of 4 and 5, 5 and 6, 6 and 7, 4 and

6, 4 and 7,and 5 and 7; TVI; and GVI) for each of the 30 samples. Only 11 ET estimates were calculated from equation 2.1 for each landcover type. As shown in Appendix A, the range of K-coefficients for alfalfa, for example, are between .80 and .90. ET was calculated for every one-one hundredth increment of those values, thus resulting in eleven estimates. This was also done for the wheat and forest cover types. The eleven estimates were then incremented by one-one hundredth , so that the entire range of ET values for each cover type would be represented. The monthly ET range for wheat was 3.54 to 4.01 inches; alfalfa was 3.78 to 4.25 inches; and forest was 2.83 to 3.31 inches. By incrementing the ranges by one-one hundredth, 48 estimates were computed for wheat and alfalfa and 49 for forest. The range of ET values for each cover type were then sequentially numbered 1 thru 48 for the wheat and alfalfa and 1 thru 49 for the forest, to facilitate randomly sampling of the values. The data were randomly sampled because each remote sensing estimate had to have a corresponding estimate from equation 2.1. Pairing the data allowed for the relationship between the two ET estimates to be calculated. The goal was not to establish the dependence of one estimate on the other (as regression analysis does), but rather determine the relationship between the two estimates from equation 2.1 and 2.2. A random numbers table was used in selecting the 30 ET values for each cover type and in pairing the ET estimates from equation 2.1 with the remote sensing estimates. The 30 selected estimates from equation 2.1 were randomly paired with remote sensing values 10 times for each landcover type, in order for a sufficient number of replications to be analyzed. Once the data were paired, the two statistical analyses were repeatedly performed.

Summary

This chapter included the equations utilized for this research; the fundamentals of Landsat; digital processing; and the procedure followed. Reflectance values from Landsat have never been been input into the remote sensing form of the Blaney-Criddle equation. Chapter III describes the statistical analyses used to test for differences between equations 2.1 and 2.2. The results of the tests allow for conclusions to be drawn about the data and techniques employed.

CHAPTER III

RESULTS

Two statistical analysis techniques analyzed the data collected for this research. A t-test evaluates if significant differences exist between the means of the ET values computed from equation 2.1 ($u = k * f$) and 2.2 ($ET = (f(R))(f(f))$. The t-test procedure computes a t-statistic for testing the null hypothesis that the means of the two groups of data are not significantly different from one another. If the computed value of t exceeds the tabled t value at a specified significance level, the null hypothesis is rejected. The 95% confidence level was used for this analysis, because this has been the standard level of comparision (Taylor, 1977).

Another statistical test, correlation analysis, was used to measure the strength of the relationship between the two ET estimates. The correlation coefficients (r) range from -1 to 1. A correlation coefficient close to 1 indicates that the two variables are strongly and positively correlated; a correlation coefficient near zero means little correlation; and a correlation coefficient close to -1 means that the variables are strongly and negatively correlated (Helwig, 1978). The correlation procedure calculates a correlation coefficient between two variables, testing the null hypothesis that r = 0, or no significant relationship exists between the two variables. The 95% confidence level was once again used for the correlation analysis. If the computed value of r should exceed the tabled value of r at the specified significance level, the null hypothesis is rejected, which indicates a significant relationship between the variables that are being compared (Snedecor and Cochran, 1980).

The monthly ET estimates computed for equations 2.1 and 2.2 are shown in Appendix C. One set of estimates are shown for each cover type. The only column of data that changed throughout the replication process was the BCC column (estimate from equation 2.1). It would be redundant to list all of the randomized estimates from equation 2.1, therefore, only one is shown. The ET estimates computed by the different irradiance value input into equation 2.2 are designated by the following variable names. RSR1 is band 4, RSR2 is band 5, RSR3 is band 6, RSR4 is band 7, RSTVI is TVI, RSGVI is GVI, RSAVG45 is the band average of 4 and 5, RSAVG56 is the band average of 5 and 6, RSAVG67 is the band average of 6 and 7, RSAVG46 is the band average of 4 and 6, RSAVG47 is the band average of 4 and 7, and RSAVG57 is the band average of 5 and 7.

T-Test Results

The null hypothesis, no significant difference between the mean ET estimates computed from equation 2.1 and the mean ET estimates computed from equation 2.2, was tested.

The summary of the t-test results are shown in Table II. Table II shows the percentage of times the null hypothesis was rejected for each landcover type. The null hypothesis was rejected in every sample for the forest and wheat landcover types. These results support the alternative hypothesis (the mean ET estimates from equation 2.1 and equation 2.2 are significantly different). The results for the alfalfa landcover type, however, did not reject the null hypothesis every time. As indicated in Table II, it was rejected 90% of the time. No significant difference existed when band 7 was used as the irradiance value input into equation 2.2 for every replication. Also in the first replication, band 6 and the band average of 6 and 7 did not differ significantly from the mean ET estimate calculated by equation 2.1. Summarizing the information in Table II, the null hypothesis was rejected in every test for the wheat and forest cover types; and it was rejected in 90% of the tests for the alfalfa cover type. The mean ET estimates from equation 2.1 and 2.2 are significantly different at the 95% confidence level.

Correlation Results

Correlation analysis was implemented to test for a relationship between the ET estimates. The correlation procedure tested the null hypothesis that no significant relationship existed between the ET estimates computed from equation 2.1 and the other remote sensing estimates computed from equation 2.2. The computed correlation coefficient (r)

TABLE II

RESULTS OF THE T-TEST PROCEDURE
N = 120, FOR EACH COVER TYPE

Landcover	Null Rejected
Forest	100%
Wheat	100%
Alfalfa	90%

must exceed the tabled value of r at the specified confidence level (95%) in order to reject the null hypothesis. Table III shows the percentage of times that the null hypothesis was accepted for each landcover type. The forest cover type showed no significant relationship between the ET estimate from equation 2.1 and the remote sensing estimates from equation 2.2. The null hypothesis was accepted every time for the forest landcover type; 98% of the time for the wheat cover type; and 97% of the time for the alfalfa cover type. Acceptance of the null hypothesis indicates that no significant relationship existed between the ET estimates from equation 2.1 and 2.2 (for the various irradiance value inputs), at the 95% confidence level.

TABLE III

RESULTS OF THE CORRELATION PROCEDURE
N = 120, FOR EACH COVER TYPE

Landcover	Null Hypothesis Accepted
Forest	100%
Wheat	98%
Alfalfa	97%

Summary

This research has found that the ET estimates from equations 2.1 and 2.2 are significantly different. Chapter IV discusses possible reasons why the two estimates are different, and draws conclusions based on the research performed for this study.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

The objective of this research was to determine if significant differences existed between the mean ET values computed from equations 2.1 and 2.2. The statistical tests support the conclusion that the two estimates are indeed different. This discussion, therefore, focuses on the various factors that could account for the significant differences in the two ET estimates.

The first of these factors is the use of a seasonal consumptive use coefficient to estimate a monthly ET value in equation 2.1. The seasonal coefficients were originally derived for most crops in the western U.S. They were computed by taking measured consumptive use values (U) and correlating them with temperature and growing season information. Crop consumptive use coefficients (K) were then computed by the formula $K = U/F$. These variables were defined in equation 2.0. The coefficients varied because of the different conditions under which they were calculated. Differences in soil type, water supply, and methodology produced coefficients which were believed to be suitable for use only under "normal" conditions (USDA, 1967). Studies in the humid, eastern U.S. failed to indicate differences between the seasonal coefficients used there and those used in the western states. The seasonal coefficients may not fall within the exact range of values that have been published, and seasonal consumptive use may be either higher or lower (USDA, 1967), but the literature does not suggest expected orders of magnitude. In addition, the seasonal coefficient does not show the variation that a monthly coefficient should indicate. The monthly coefficients are influenced by the temperature and the growth stage of the crop. These two factors account for most of the variation (USDA, 1967). This research used the published seasonal coefficients because the monthly coefficients were not available. The decision to use certain coefficients was governed by the availability or lack there of in the literature. More accurate ET estimates could be derived from equation 2.1 if monthly coefficients were available.

The results of this study suggest that the cultivated crop coefficients are not representative of a "natural" cover type. The forest cover type in the study area was assigned the most appropriate crop coefficients , but none were specifically designed for "natural" vegetation. Such coefficients for "natural" vegetation are not available in the literature.

The ET estimates from the two equations were also estimates of ET for two different geographic levels: one level being regional and the other being point specific. The K-coefficients used to calculate ET for equation 2.1 were experimentally derived in the western U.S. (USDA, 1967). The coefficients are transferred from one region to another when ET estimates are made for the various crops. The K-coefficients that were defineable by remote sensing (ASP, 1975), however, were derived at one point specific location. The reflectance values that were obtained at sample locations in the study area would not be transferable to another region with the same landcover type because the sample was for one day, April 8, at one certain time. The reflectance values would vary from one location to the next outside of that particular Landsat scene.

The ET estimates from equation 2.1 were gross estimates for a regional perspective. Cruff and Thompson (1967) found that the Blaney-Criddle equation provided a good estimate of potential ET when compared with other empirical estimates such as Thornthwaite, Lowry-Johnson, Hamon, Lane, and the Weather Bureau. In this research however, two empirical estimates were compared, and it was not known which represented actual ET. Therefore, suggesting that empirical estimates should be used only if it is known which estimate more closely represents reality.

Limitations and Recommendations

The primary limitation of this study was the lack of measured ET values with which to compare the computed values of ET from equations 2.1 and 2.2. It cannot be determined which ET estimate derived from the equations is more accurate. This study only evaluated the relationship of the two equations. On site measures or reliable estimates of ET are required for the particular landcover types. Moreover, the ET estimates computed from the remote sensing form of the Blaney-Criddle equation should be compared against another ET estimate that is based on "measured" data and not empirical data. Even though the Blaney-Criddle estimate is considered to a good empirical estimate of ET, an estimate utilizing "measured" data may be more comparable. An energy balance approach that measures the soil heat flux may be one possible consideration.

The final recommendation would be to test the remote sensing form of the Blaney-Criddle equation to determine how well remote sensing techniques estimate the k-coefficient. The k value is assumed to be defineable by remote sensing (ASP, 1975), however the correlations between measured and estimated k-coefficients should be analyzed. This could be completed by utilizing the satellite data from Landsat 4. Landsat 4 has two sensors on board: the MSS and Thematic Mapper (TM). The TM operates in seven spectral bands which were chosen primarily for vegetation monitoring (U.S.G.S., 1982). Utilization of Landsat 4 data would provide higher resolution data with possibly different results than those obtained in this study. It may also be possible to incorporate other parameters into the remote sensing equation (i.e. water holding capacity) to facilitate estimating ET. It may be that the remote sensing estimate needs to be multiplied or manipulated in some way, in order to provide an accurate ET estimate.

This study had been a geographic study in which the spatial distribution of ET has been estimated for the given study area. Although at this point, it is not known which of the two estimates are closer to actual ET, a future study could determine this. A future study could also utilize the results obtained in this study to determine if there is a way that the ET estimate from equation 2.2 could be manipulated in such a way to provide accurate ET estimates. If a future study found that one of the two estimates in this study closely represented actual ET, then such information could be used by planners. People who plan irrigation layouts must know how much water is lost to the atmosphere through ET. If the amount of ET could be estimated, planners could provide estimates on the amount of irrigation water that would be needed to satisfy the water requirements of the crop. Jensen (1983) suggested that Landsat data should be utilized not only for providing landcover information, but also for providing insight on biophysical variables such as vegetation biomass, vegetation moisture content, and soil moisture content. This research has utilized the Landsat data for more than landcover mapping, and concurs that the data should be utilized in such a way to provide maximum and meaningful information.

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APPENDIX A

CROP COEFFICIENTS (K) FOR SEASONAL CONSUMPTIVE USE FOR IRRIGATED CROPS

TABLE IV

SEASONAL CONSUMPTIVE USE CROP COEFFICIENTS (K)

Crop	Length of Normal Growing Season or Period 1/	Consumptive-use coefficient (K) 2/
Alfalfa	Between frosts	0.80 to 0.90
Bananas	Full year	.80 to 1.00
Beans	3 months	.60 to .70
Cocoa	Full year	.70 to .80
Coffee	Full year	.70 to .80
Corn (Maize)	4 months	.75 to .85
Cotton	7 months	.60 to .70
Dates	Full year	.65 to .80
Flax	7 to 8 months	.70 to .80
Grains, small	3 months	.75 to .85
Grain, sorghums	4 to 5 months	.70 to .80
Oilseeds	3 to 5 months	.65 to .75
Orchard crops:		
Avocado	Full year	.50 to .55
Grapefruit	Full year	.55 to .65
Orange and lemon	Full year	.45 to .55
Walnuts	Between frosts	.60 to .70
Deciduous	Between frosts	.60 to .70
Pasture crops:		
Grass	Between frosts	.75 to .85
Ladino whiteclover	Between frosts	.80 to .85
Potatoes	3 to 5 months	.65 to .75
Rice	3 to 5 months	1.00 to 1.10
Soybeans	140 days	.65 to .70
Sugar beet	6 months	.65 to .75
Sugarcane	Full year	.80 to .90
Tobacco	4 months	.70 to .80
Tomatoes	4 months	.65 to .70
Truck crops, small	2 to 4 months	.60 to .70
Vineyard	5 to 7 months	.50 to .60

1/ Length of season depends largely on variety and time of year when the crop is grown. Annual crops grown during the winter period may take much longer than if grown in the summertime.

2/ The lower values of (K) for use in the Blaney-Criddle formula, U = KF, are for the more humid areas, and the higher values are for the more arid climates.

Source: U.S. Dept. of Agriculture. *Irrigation Water Requirements* (1967).

APPENDIX B

MONTHLY PERCENTAGE OF DAYTIME HOURS (P) OF THE YEAR FOR LATITUDES 18 TO 65 DEGREES NORTH OF THE EQUATOR

TABLE V

MONTHLY PERCENTAGE OF DAYTIME HOURS (P)

Latitude North	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
65°	3.52	5.13	7.56	9.97	12.72	14.15	13.59	11.18	8.55	6.53	4.08	2.62
64°	3.81	5.27	8.00	9.92	12.50	13.63	13.26	11.08	8.56	6.63	4.32	3.02
63°	4.07	5.39	8.04	9.86	12.29	13.24	12.97	10.97	8.56	6.73	4.52	3.36
62°	4.31	5.49	8.07	9.80	12.11	12.92	12.73	10.87	8.55	6.80	4.70	3.65
61°	4.51	5.58	8.09	9.74	11.94	12.66	12.51	10.77	8.55	6.88	4.86	3.91
60°	4.70	5.67	8.11	9.69	11.78	12.41	12.31	10.68	8.54	6.95	5.02	4.14
59°	4.86	5.76	8.13	9.64	11.64	12.19	12.13	10.60	8.53	7.00	5.17	4.35
58°	5.02	5.84	8.14	9.59	11.50	12.00	11.96	10.52	8.53	7.06	5.30	4.54
57°	5.17	5.91	8.15	9.53	11.38	11.83	11.81	10.44	8.52	7.13	5.42	4.71
56°	5.31	5.98	8.17	9.48	11.26	11.68	11.67	10.36	8.52	7.18	5.52	4.87
55°	5.44	6.04	8.18	9.44	11.15	11.53	11.54	10.29	8.51	7.23	5.63	5.02
54°	5.56	6.10	8.19	9.40	11.04	11.39	11.42	10.22	8.50	7.28	5.74	5.16
53°	5.68	6.16	8.20	9.36	10.94	11.26	11.30	10.16	8.49	7.32	5.83	5.30
52°	5.79	6.22	8.21	9.32	10.85	11.14	11.19	10.10	8.48	7.36	5.92	5.42
51°	5.89	6.27	8.23	9.28	10.76	11.02	11.09	10.05	8.47	7.40	6.00	5.54
50°	5.99	6.32	8.24	9.24	10.68	10.92	10.99	9.99	8.46	7.44	6.08	5.65
49°	6.08	6.36	8.25	9.20	10.60	10.82	10.90	9.94	8.46	7.48	6.16	5.75
48°	6.17	6.41	8.26	9.17	10.52	10.72	10.81	9.89	8.45	7.51	6.24	5.85
47°	6.25	6.45	8.27	9.14	10.45	10.63	10.73	9.84	8.44	7.54	6.31	5.95
46°	6.33	6.50	8.28	9.11	10.38	10.53	10.65	9.79	8.43	7.58	6.37	6.05
45°	6.40	6.54	8.29	9.08	10.31	10.46	10.57	9.75	8.42	7.61	6.43	6.14
44°	6.48	6.57	8.29	9.05	10.25	10.39	10.49	9.71	8.41	7.64	6.50	6.22
43°	6.55	6.61	8.30	9.02	10.19	10.31	10.42	9.66	8.40	7.67	6.56	6.31
42°	6.61	6.65	8.30	8.99	10.13	10.24	10.35	9.62	8.40	7.70	6.62	6.39
41°	6.68	6.68	8.31	8.96	10.07	10.16	10.29	9.59	8.39	7.72	6.68	6.47
40°	6.75	6.72	8.32	8.93	10.01	10.09	10.22	9.55	8.39	7.75	6.73	6.54
39°	6.81	6.75	8.33	8.91	9.95	10.03	10.16	9.51	8.38	7.78	6.78	6.61
38°	6.87	6.79	8.33	8.89	9.90	9.96	10.11	9.47	8.37	7.80	6.83	6.68
37°	6.92	6.82	8.34	8.87	9.85	9.89	10.05	9.44	8.37	7.83	6.88	6.74
36°	6.98	6.85	8.35	8.85	9.80	9.82	9.99	9.41	8.36	7.85	6.93	6.81
35°	7.04	6.88	8.35	8.82	9.76	9.76	9.93	9.37	8.36	7.88	6.98	6.87
34°	7.10	6.91	8.35	8.80	9.71	9.71	9.88	9.34	8.35	7.90	7.02	6.93
33°	7.15	6.94	8.36	8.77	9.67	9.65	9.83	9.31	8.35	7.92	7.06	6.99
32°	7.20	6.97	8.36	8.75	9.62	9.60	9.77	9.28	8.34	7.95	7.11	7.05
31°	7.25	6.99	8.36	8.73	9.58	9.55	9.72	9.24	8.34	7.97	7.16	7.11
30°	7.31	7.02	8.37	8.71	9.54	9.49	9.67	9.21	8.33	7.99	7.20	7.16
29°	7.35	7.05	8.37	8.69	9.50	9.44	9.62	9.19	8.33	8.00	7.24	7.22
28°	7.40	7.07	8.37	8.67	9.46	9.39	9.58	9.17	8.32	8.02	7.28	7.27
27°	7.44	7.10	8.38	8.66	9.41	9.34	9.53	9.14	8.32	8.04	7.32	7.32
26°	7.49	7.12	8.38	8.64	9.37	9.29	9.49	9.11	8.32	8.06	7.36	7.37
25°	7.54	7.14	8.39	8.62	9.33	9.24	9.45	9.08	8.31	8.08	7.40	7.42
24°	7.58	7.16	8.39	8.60	9.30	9.19	9.40	9.06	8.31	8.10	7.44	7.47
23°	7.62	7.19	8.40	8.58	9.26	9.15	9.36	9.04	8.30	8.12	7.47	7.51
22°	7.67	7.21	8.40	8.56	9.22	9.11	9.32	9.01	8.30	8.13	7.51	7.56
21°	7.71	7.24	8.41	8.55	9.18	9.06	9.28	8.98	8.29	8.15	7.55	7.60
20°	7.75	7.26	8.41	8.53	9.15	9.02	9.24	8.95	8.29	8.17	7.58	7.65
19°	7.79	7.28	8.41	8.51	9.12	8.97	9.20	8.93	8.29	8.19	7.61	7.70
18°	7.83	7.31	8.41	8.50	9.08	8.93	9.25	8.90	8.29	8.20	7.65	7.74

Source: U.S. Dept. of Agriculture. _Irrigation_ _Water_ _Requirements_ (1967).

APPENDIX C

MONTHLY ET ESTIMATES

TABLE VI

MONTHLY ET ESTIMATES FOR WHEAT

RSR1	RSR2	RSR3	RSR4	RSTVI	RSGVI	RSAVG45	RSAVG56	RSAVG67	RSAVG46	RSAVG47	RSAVG57	BCC
1.46	1.46	6.75	12.11	1.46	5.53	1.46	2.00	9.06	2.00	2.42	2.41	3.57
1.46	1.46	5.04	9.09	1.46	4.08	1.46	1.85	6.76	1.85	2.18	2.18	3.70
1.46	1.46	6.07	12.76	1.46	5.91	1.46	1.87	8.82	1.92	2.41	2.32	3.86
1.46	1.46	5.65	10.65	1.46	5.02	1.46	1.86	7.76	1.89	2.28	2.22	3.94
1.46	1.46	5.20	10.58	1.46	5.01	1.46	1.79	7.42	1.84	2.24	2.16	3.57
1.47	1.47	5.50	7.61	1.46	3.53	1.47	1.98	6.47	1.93	2.11	2.18	3.84
1.46	1.46	5.08	9.13	1.46	4.29	1.46	1.83	6.81	1.85	2.18	2.13	3.70
1.46	1.46	4.11	7.98	1.46	3.58	1.46	1.74	5.70	1.76	2.08	2.05	3.77
1.47	1.47	4.32	6.78	1.46	3.13	1.47	1.81	5.40	1.82	2.04	2.03	3.90
1.46	1.46	5.23	9.95	1.46	4.68	1.46	1.81	7.22	1.87	2.24	2.15	3.69
1.47	1.47	4.70	7.30	1.46	3.46	1.47	1.84	5.85	1.84	2.06	2.06	3.57
1.46	1.46	7.26	15.68	1.46	7.45	1.46	1.94	10.73	2.01	2.61	2.48	3.74
1.47	1.47	4.59	7.20	1.46	3.32	1.47	1.84	5.74	1.83	2.06	2.08	3.80
1.47	1.46	5.55	10.02	1.46	4.47	1.46	1.90	7.46	1.91	2.27	2.26	3.80
1.47	1.47	5.79	9.86	1.46	4.43	1.47	1.94	7.56	1.94	2.28	2.27	3.87
1.46	1.46	5.49	9.13	1.46	4.63	1.46	1.84	7.08	1.88	2.16	2.10	3.75
1.47	1.46	5.69	9.63	1.46	4.50	1.46	1.90	7.40	1.93	2.25	2.20	3.56
1.46	1.46	5.44	9.82	1.46	4.70	1.46	1.84	7.31	1.88	2.22	2.16	3.94
1.46	1.46	5.42	9.36	1.46	4.63	1.46	1.84	7.12	1.87	2.17	2.13	3.59
1.47	1.46	9.58	15.26	1.46	7.76	1.46	2.20	12.12	2.25	2.67	2.60	3.57
1.46	1.46	5.06	9.33	1.46	4.39	1.46	1.82	6.87	1.84	2.18	2.13	3.69
1.46	1.46	4.61	7.63	1.46	3.91	1.46	1.76	5.92	1.80	2.04	1.98	3.77
1.46	1.46	6.37	11.90	1.46	5.89	1.46	1.89	8.73	1.94	2.36	2.26	3.69
1.47	1.46	6.79	11.57	1.46	5.48	1.46	1.99	8.88	2.02	2.39	2.35	3.58
1.47	1.48	5.21	7.31	1.46	3.19	1.47	1.99	6.17	1.94	2.13	2.20	3.77
1.46	1.46	6.73	12.98	1.46	5.78	1.46	1.99	9.38	2.00	2.48	2.45	3.62
1.47	1.47	5.76	10.04	1.46	4.51	1.47	1.93	7.61	1.93	2.27	2.28	3.93
1.47	1.46	12.06	17.63	1.46	9.33	1.47	2.41	14.61	2.48	2.89	2.80	3.54
1.47	1.47	6.64	9.31	1.46	4.69	1.47	2.00	7.87	2.02	2.24	2.22	3.56
1.47	1.46	8.97	13.63	1.46	7.09	1.46	2.14	11.08	2.20	2.55	2.48	3.93

TABLE VII

MONTHLY ET ESTIMATES FOR ALFALFA

RSR1	RSR2	RSR3	RSR4	RSTVI	RSGVI	RSAVG45	RSAVG56	RSAVG67	RSAVG46	RSAVG47	RSAVG57	BCC
1.47	1.49	3.22	4.02	1.46	1.96	1.48	1.81	3.59	1.74	1.83	1.91	3.80
1.48	1.52	3.18	3.64	1.46	1.79	1.49	1.89	3.40	1.75	1.81	1.96	4.13
1.47	1.47	3.52	5.70	1.46	2.47	1.47	1.78	4.45	1.74	1.95	2.00	4.18
1.47	1.51	3.13	4.05	1.46	1.86	1.49	1.86	3.55	1.74	1.84	1.99	4.11
1.47	1.49	2.82	3.60	1.46	1.85	1.48	1.74	3.18	1.67	1.76	1.84	3.89
1.47	1.50	3.36	4.32	1.46	2.00	1.48	1.85	3.80	1.75	1.86	1.98	3.91
1.47	1.50	3.35	4.23	1.46	1.96	1.48	1.86	3.76	1.76	1.86	1.99	3.95
1.47	1.49	3.32	4.54	1.46	2.10	1.48	1.81	3.87	1.73	1.86	1.96	4.20
1.47	1.47	3.13	5.00	1.46	2.24	1.47	1.73	3.92	1.70	1.88	1.93	4.09
1.47	1.48	3.65	4.71	1.46	2.29	1.47	1.80	4.14	1.78	1.89	1.92	4.00
1.47	1.48	3.02	3.39	1.46	1.87	1.48	1.75	3.20	1.72	1.76	1.80	3.80
1.48	1.50	2.90	3.26	1.46	1.75	1.49	1.79	3.07	1.73	1.77	1.85	3.96
1.47	1.48	3.66	4.51	1.46	2.22	1.47	1.83	4.06	1.77	1.86	1.93	4.23
1.48	1.49	3.33	3.94	1.46	1.97	1.48	1.81	3.62	1.78	1.85	1.89	3.81
1.47	1.49	2.65	3.23	1.46	1.77	1.48	1.72	2.92	1.65	1.72	1.80	3.78
1.47	1.48	3.44	4.98	1.46	2.24	1.47	1.81	4.12	1.73	1.89	1.99	4.00
1.47	1.49	3.08	3.95	1.46	1.95	1.48	1.78	3.48	1.71	1.80	1.89	3.89
1.47	1.49	3.13	3.80	1.46	1.93	1.48	1.79	3.44	1.72	1.79	1.88	3.79
1.47	1.48	3.14	4.36	1.46	2.08	1.47	1.76	3.69	1.71	1.84	1.90	3.95
1.47	1.49	2.99	3.12	1.46	1.80	1.48	1.76	3.05	1.72	1.73	1.78	4.19
1.47	1.48	3.19	4.03	1.46	2.06	1.47	1.76	3.58	1.71	1.80	1.86	3.82
1.48	1.50	3.77	4.88	1.46	2.14	1.48	1.92	4.28	1.82	1.94	2.06	3.90
1.47	1.49	3.33	4.18	1.46	2.02	1.48	1.81	3.73	1.76	1.85	1.92	3.88
1.47	1.47	3.00	3.69	1.46	2.03	1.47	1.71	3.32	1.68	1.75	1.78	4.06
1.47	1.48	3.26	4.26	1.46	2.13	1.47	1.76	3.71	1.71	1.81	1.88	4.06
1.47	1.50	3.63	4.24	1.46	2.02	1.48	1.92	3.93	1.77	1.84	2.00	3.93
1.47	1.49	2.79	3.04	1.46	1.76	1.48	1.74	2.91	1.68	1.71	1.77	4.16
1.47	1.48	2.86	3.43	1.46	1.88	1.47	1.72	3.12	1.67	1.74	1.79	3.79
1.47	1.49	3.84	4.34	1.46	2.13	1.48	1.90	4.08	1.82	1.87	1.96	4.25
1.47	1.48	3.07	3.55	1.46	1.93	1.47	1.76	3.30	1.70	1.75	1.82	4.16

TABLE VIII

MONTHLY ET ESTIMATES FOR FOREST

RSR1	RSR2	RSR3	RSR4	RSTVI	RSGVI	RSAVG45	RSAVG56	RSAVG67	RSAVG46	RSAVG47	RSAVG57	BCC
1.47	1.49	1.69	1.62	1.46	1.47	1.48	1.55	1.65	1.52	1.51	1.53	3.17
1.47	1.50	1.73	1.63	1.46	1.47	1.49	1.58	1.67	1.54	1.52	1.55	2.85
1.47	1.52	1.71	1.63	1.46	1.46	1.49	1.59	1.67	1.54	1.52	1.56	2.89
1.48	1.50	1.70	1.61	1.46	1.46	1.49	1.57	1.65	1.54	1.52	1.55	3.30
1.47	1.51	1.75	1.72	1.46	1.47	1.49	1.59	1.73	1.54	1.54	1.58	2.85
1.47	1.51	1.78	1.68	1.46	1.47	1.48	1.59	1.73	1.54	1.52	1.57	2.90
1.47	1.48	1.98	2.06	1.46	1.53	1.48	1.60	2.02	1.57	1.58	1.62	3.15
1.48	1.50	1.68	1.59	1.46	1.46	1.49	1.56	1.63	1.53	1.51	1.53	2.92
1.47	1.50	1.77	1.74	1.46	1.47	1.48	1.59	1.75	1.54	1.53	1.58	2.90
1.47	1.48	1.85	1.90	1.46	1.51	1.47	1.57	1.87	1.54	1.55	1.58	3.17
1.47	1.51	1.74	1.68	1.46	1.47	1.49	1.59	1.70	1.54	1.53	1.57	3.18
1.47	1.49	1.64	1.57	1.46	1.46	1.48	1.54	1.60	1.51	1.50	1.52	2.85
1.48	1.52	1.76	1.68	1.46	1.47	1.49	1.60	1.72	1.55	1.53	1.58	2.85
1.47	1.49	1.62	1.56	1.46	1.46	1.48	1.54	1.59	1.51	1.50	1.52	3.30
1.47	1.48	1.62	1.58	1.46	1.46	1.47	1.53	1.60	1.51	1.50	1.52	2.92
1.47	1.52	1.76	1.71	1.46	1.47	1.49	1.60	1.73	1.55	1.54	1.59	3.17
1.47	1.49	1.86	1.82	1.46	1.49	1.48	1.59	1.84	1.55	1.55	1.58	3.17
1.47	1.51	1.77	1.66	1.46	1.47	1.49	1.60	1.71	1.54	1.52	1.57	3.05
1.47	1.49	1.78	1.75	1.46	1.48	1.47	1.57	1.76	1.53	1.53	1.56	3.30
1.47	1.48	1.65	1.62	1.46	1.47	1.47	1.53	1.64	1.51	1.50	1.52	3.05
1.47	1.48	1.67	1.64	1.46	1.47	1.47	1.53	1.65	1.51	1.51	1.53	2.84
1.47	1.48	1.63	1.58	1.46	1.46	1.47	1.53	1.60	1.51	1.50	1.51	2.94
1.47	1.52	1.71	1.67	1.46	1.47	1.49	1.58	1.69	1.53	1.52	1.58	3.17
1.47	1.50	1.72	1.65	1.46	1.47	1.48	1.57	1.69	1.53	1.52	1.55	3.12
1.47	1.52	1.82	1.75	1.46	1.47	1.49	1.62	1.79	1.56	1.54	1.60	2.92
1.47	1.51	1.89	1.78	1.46	1.48	1.49	1.62	1.83	1.57	1.55	1.60	3.23
1.48	1.54	1.95	1.86	1.46	1.48	1.50	1.68	1.90	1.58	1.57	1.66	2.92
1.47	1.50	1.78	1.71	1.46	1.47	1.48	1.59	1.75	1.54	1.53	1.57	2.98
1.47	1.49	1.66	1.62	1.46	1.47	1.48	1.55	1.64	1.51	1.51	1.54	2.84
1.47	1.50	1.72	1.67	1.46	1.47	1.48	1.57	1.69	1.53	1.52	1.56	3.16

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