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Title: Identification of Irrigation Practices using Photographic and Optical-Mechanical Scanning Remote Sensing Techniques

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Irrigation is essential for profitable agriculture in the western United States. It is the largest consumer of water and power in Oregon. Conflicting uses of water and power and their scarcity demands judicious planning for allocation of these resources. Creditable baseline data are not only needed for irrigated crop acreages, but also for irrigation methods as an indicator of amount of water and power used. A data-gathering system is needed which is quick, reliable and comparatively inexpensive.

The primary objective of this research was to develop a methodology to use remotely sensed data for irrigation method identification. The main tasks were to: (1) analyze multidate images for different emulsions and scales to identify irrigation methods:

(2) develop mission parameters; (3) develop an image interpretation key; (4) investigate the feasibility of using a quantitative approach to irrigation method identification.

The North Unit Deschutes Irrigation District of central Oregon was selected to develop and test the methodology. Field layout of different irrigation methods, their association with crops, soils, and slopes were noted for the area imaged by three CIR aerial flights during the 1979 growing season. A detailed crop calendar showing different phenological stages that affect the spectral properties of crops was developed.

Images used for analysis included: Landsat MSS color transparencies at 1:1,000,000 for June 4, June 22, July 18, 1979; Landsat MSS color prints at 1:250,000 for May 17, and June 22, 1979; Landsat RBV images at 1:125,000 for June 8, 1978 and July 28, 1979; U-2 CIR photographs at 1:30,000 for June 28, 1973 and at 1:130,000 for August 2, 1978; CIR aerial photographs for May 12, July 9, and August 5, 1979 at 1:30,000 and 1:23,000.

Two methods of analysis were used. Manual interpretation of the images employed light tables, magnifiers and stereomicroscope. Each test field along the flight line was carefully studied for detection of irrigation patterns using associated tones, colors, textures, and their temporal variations, in addition to crop calendar data, soil, and slope maps, ground information gathered, and black and white images at 1:8,000. Digital analysis of the data for discrimination of irrigated and non-irrigated crop types was discouraging as the data were for the late growing season (July 28, 1979), when most crops were either harvested or in the senescing stage and their spectral signatures overlapped.

Conclusions drawn from this study are that: image-oriented analysis rather than quantitative analysis is best suited for irrigation method discrimination; CIR images provide better discrimination than black and white images; while irrigated and non-irrigated crops can be discriminated using multidate 1:1,000,000 images, for satisfactory discrimination of all irrigation methods, 1:30,000 or larger imagery is needed; and the best time for differentiating irrigation methods is the early growing season.

As a result of this research, optimum mission parameters for flying photographic missions were developed and an image interpretation key useful for irrigation methods discrimination was developed.

Identification of Irrigation Practices Using Photographic and Optical-Mechanical Scanning Remote Sensing Techniques

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CHAPTER I

INTRODUCTION

Introduction to the Problem

Increasing pressures on our natural resources demand an efficient use of these resources. The growing need for agricultural products in the western United States is met in most cases by increasing the irrigation water supply, especially in the arid marginal water resource areas. Agricultural irrigation is the largest user of water and power in Oregon. Consumptive use of water by irrigation not only reduces hydroelectric power production, but also uses large amounts of energy to operate some irrigation systems. The amount of water and power used varies with different irrigation methods. Gravity or surface irrigation methods use more water than is needed by the crops but consume very little power. On the other hand, sprinkler irrigation systems use comparatively little water, but require more energy to operate. Conflicting uses of these resources demand judicious allocation of these resources between users. For this reason, water resource managers need to have an accurate and reliable data base for irrigation water use. The problems with manual data collection are:

1. Lack of reliability - Most data are collected by questionnaires, census reports, personal interviews, on-ground estimations, or office estimations, which suffer from the subjectivity and biases of data collectors, and are sometimes based on incomplete samples.
2. Cost of data - The time and manpower required for planning, data acquisition and data reduction are very expensive.
3. Timeliness of data - By the time data are collected, they are outdated.

In view of these problems, a data acquisition technique is needed to identify irrigated acreages under various irrigation methods during the growing season to establish a creditable baseline on irrigation water use which is quick, reliable, and comparatively inexpensive.

Problem Statement

Remote sensing is a possible data-gathering system to supplement manual data-gathering efforts. This research is an attempt to evaluate the comparative advantages of different remote sensing techniques in differentiating between irrigation methods, by using different scales, emulsions, and multidate imagery. The advantages of remote sensing in irrigation method differentiation are:

1. It provides a near-instantaneous coverage of a large area. This is very important as the irrigation season is short.

2. It provides a vertical perspective which is similar to a map and can be used to produce an irrigation method map.
3. Repetitive coverage of an area over the irrigation season is possible showing relative usage of various methods over the growing season.
4. It may be cheaper than manual data collection methods. It should provide a check of accuracy of reported acreages.

Research Objectives

The primary objective of this research was to develop image interpretation aids, and determine the practicality of using image-oriented and quantitative approaches of remote sensing to irrigation method discrimination. To achieve this objective the main tasks were to:

1. analyze multidate images on different emulsions and scales to recognize what method of irrigation was being used;
2. develop guidelines as to which sensor, emulsion, scale, and time of the year/cropping season was needed to obtain the imagery for optimum use of remote sensing technology in irrigation water management;
3. develop an image interpretation key and other photo interpretation aids to be used with the key;
4. investigate the feasibility of using a quantitative approach to irrigation method identification.

Relevance of the Research

For profitable agriculture in arid and semi-arid regions, irrigation is absolutely necessary. It is also important for profitable farming and quality control of certain crops in humid and sub-humid environments. An ever-increasing population has put heavy pressure on agricultural lands and the demands cannot be met without irrigation. Expansion of irrigation in marginal lands has given rise to two issues: proper maintenance of irrigation systems to avoid water-logging and salinity; and maintenance of a balanced use of water supply between conflicting users. Failure to maintain either of these would result in abandonment of the marginal irrigated lands and the bread baskets of today would revert to the dust bowls of tomorrow. Thus, a careful monitoring is needed to evaluate the consumptive use of water and power in agriculture. It is not sufficient to know how much land is under irrigation. The irrigation method must be known, as each method consumes a different amount of water and power. Although most surface irrigation systems waste water and result in water-logging and salinity, if properly managed they conserve water by applying water to the root zone and preventing excessive evaporation. Their application efficiency may be as good as sprinkler systems if properly managed. Sprinkler systems are noted for conserving water and soil conditions, but the highly sophisticated systems consume much power, and in the face of energy crisis the question arises as to what is going to be the system for the future. The answer will not come out of the laboratories; it has to come out of the fields where irrigation systems and their effects on soils, their application efficiency, and their water and power consumption can be assessed. Any attempt to look into these problems starts with the identification of irrigation practices.

Literature Review

All the literature pertinent to this research can be classified under three categories:

1. studies concerned with the design of irrigation methods, field layout, spatial dimensions, water distribution, and wetting patterns;
2. studies concerned with the reflectance properties of vegetation and soils, since these are two important factors that help distinguish irrigated and non-irrigated crops and irrigation methods;
3. studies concerned with research in remote sensing for identification of irrigated and non-irrigated crops.

Design of Irrigation Methods

A detailed description of surface irrigation methods is available in Design and Evaluation of Irrigation Methods by A. M. Michael, Sri Mohan, and K. R. Swaminathan (1972). Irrigation by J. D. Zimmerman

(1966) and Irrigation Principles and Practices by O. W. Israelson (1932) deal with different aspects of field layout and design of surface irrigation methods under different soil and slope conditions.

C. H. Pair (1975) in Sprinkler Irrigation gives an extensive treatment to all kinds of sprinkler irrigation methods. He also describes the wetting patterns of sprinklers as affected by pressure, wind, and spacing. In another article, Mechanized Sprinkler Systems, Their Applications and Limitations--What Next? (1970), he discusses the future of mechanized systems in the face of the energy crisis. W. K. Bilanski and E. H. Kidder (1958), describe water distribution pattern of sprinklers in Factors that Affect the Distribution of Water from a Medium-Sprinkler Rotary Irrigation Sprinkler. Solid set irrigation systems are described by J. Keller (1970) in Design, Use and Management of Solid Set Systems, and a good treatment of traveller irrigation systems is given by J. D. Pinchot (1970), in Technology and Management of Travelling Sprinklers.

Sub-surface irrigation is described by J. B. McNamara (1970) in Sub-irrigation--the Basis of Tomorrow's Agriculture, and by E. G. Hansen, et al., in Influence of Subsurface Irrigation on Crop Yield and Water Use.

Reflectance Properties of Vegetation and Soils

Properties and mechanisms of reflectance from healthy leaves, and their change in reflectance when under stress, are described by R. N. Colwell (1978) in Some Basic Considerations in Remote Sensing. The results of his experiments in the 1950's showed that the collapse of spongy mesophyll in a leaf under stress results in less reflectance in the near-infrared, and the first previsual symptoms are recorded on the color infrared (CIR) film much before they can be seen on panchromatic films. Edward B. Knipling (1969), on the other hand, maintains that the decreased reflectance registered on a CIR film is not because of decreased reflectance in the near-infrared but because of increased visible reflectance. Both authors agree on the superiority of color infrared film as the detector of stress conditions over the panchromatic film. Fundamentals of leaf reflectance effects of pigmentation and moisture content, and effects of moisture content on soil reflectance are discussed by R. M. Hoffer and C. J. Johannsen (1969) in Ecological Potentials in Spectral Signature Analysis. They agree with Knipling that changes in the red tone of vegetation on CIR film is due to increased reflectance in the visible portion of the spectrum.

> We have observed striking examples of this type of situation in which yellowing vegetation and healthy green vegetation reflected similarly on black and white infrared film (sensitive only to 0.7 - 0.9 micrometer wavelengths), but marked differences were seen on the CIR film due to spectral changes in the visible rather than the infrared wavelengths. This was also substantiated by spectrophotometric measurements of plant leaves.

They also noted a large decrease in reflectance with an increase in moisture. Hoffer discusses the fundamentals of energy-matter interactions in greater details in Biological and Physical Considerations in Applying Computer-Aided Analysis Techniques to Remote Sensor Data (1978). He discusses the temporal and spatial effects on the spectral characteristics of vegetation, soil, water and snow. Regarding soil reflectance, he states:

> One of the most outstanding reflectance characteristics of dry soils is a generally increasing level of reflectance with increasing wavelength, particularly in the visible and near-infrared portion of the spectrum . . . as the moisture content increases, the reflectance decreases.

Identification of Irrigated and Non-Irrigated Crops

Although much work has been done on crop discrimination, little attention has been given to the irrigation aspect of the agricultural scene. Only a few studies dealing with identification of irrigated lands were done in the last six years. B. H. Künecke of the University of Oregon (1974) produced a map of irrigated agricultural lands of Eastern Oregon. He describes the methodology in Distribution of Irrigation in Eastern Oregon. The irrigated lands were delineated using multidate ERTS imagery and were field-checked. The information regarding crop types and irrigation methods were gathered and incorporated in the map as a result of field-checking.

Michael A. Evans and R. W. Marrs (1974) in Identification of

Irrigated Crop Types from ERTS-1 Density Contour Maps and Color Infrared Photography describe the use of Landsat band 5 imagery and CIR photography for irrigated crop identification. Multidate CIR images were photo-interpreted and color, texture, and growth patterns were used to identify crops. ERTS band 5 images for three different dates were density-sliced and isodensity contour maps were prepared. They were superimposed on a crop-type map prepared by photo-interpreting CIR images and field-checking. The results showed that large evenly vegetated fields were quite distinct but as the fields became smaller in size and the contrast decreased, the irrigated crops became very difficult to identify.

Murland R. Packer in Developing Operational Techniques for the Use of Landsat Data in Identifying Irrigated Agriculture in Idaho discussed the use of photo interpretation of Landsat photographic products and computer-aided analysis for identification of irrigated crop land and crop types. He considered photo interpretation of Landsat photographic products impractical due to the small field size of many of the irrigated fields of Idaho. Individual fields and associated crop types could not be accurately identified on the imagery. However, irrigated crop land was readily identified, although detailed discrimination of crop types was not possible by digital classification. This was attributed to high variability between individual fields of the same crop due to different farming practices and physical conditions.

Use of Landsat imagery for quickly and cheaply estimating irrigated land area is described by William C. Draeger (1976), in a study conducted in the Klamath River Basin of Oregon. He describes the procedure in Monitoring Irrigated Land Acreage, Using Landsat Imagery: An Application Example. Landsat color composites at a 1:250,000 scale from two different dates (July 21 and September 4) during the 1975 growing season were interpreted. In July, all irrigated fields were red, but some non-irrigated fields were also red. On the September image, all dry farmed fields appeared tan in color, while the vast majority of irrigated fields were still red.

R. N. Colwell, et al. (1978) described a methodology used in estimating the irrigated acreage in the Sacramento Valley in the annual report Determining the Usefulness of Remote Sensing for Estimating Agricultural Water Demand in California. Both manual interpretation and computer-aided analysis was done. Manual interpretation was on 1:150,000 Landsat images for three different dates in May, August and October. The same multidate concept was used for computer-assisted analysis. Landsat tapes for three dates in the growing season were registered to a common base and then classified.

K. W. Webster, et al., in Selected Irrigation Acreage Estimates in Northern Florida from Landsat (1978), explained a method adapted to identify irrigated rye and corn in Suwanee County of Florida.

They used standard Landsat images at the scale of 1:250,000, but the images lacked color contrast and it was not possible to identify the two crops. Then they used custom-printed enhanced images at the 1:125,000 scale which had good color saturation and contrast, and it was possible to delineate irrigated rye. Irrigated corn could not be separated as a suitable time for its delineation could not be determined. They found that it was easier to identify irrigated corn by using an interactive system to obtain a satisfactory digital classification.

T. H. L. Williams and J. Poracsky (1979) used multidate Landsat band 5 imagery, crop calendars, and irrigation practices to identify and map wheat, corn and sorghum in western Kansas. The methodology is explained in their paper Mapping Irrigated Lands in Western Kansas from Landsat. Visual estimates of gray tones on a relative basis was used for delineation of the three crop types.

Currently, delineation of irrigated lands in river basins of Oregon is being done as part of the Statewide Land Use Inventory Program of the Oregon Water Resources Department, by the Environmental Remote Sensing Application Laboratory (ERSAL) at Oregon State University, under the direction of Dr. Barry Schrumpf. The program is using multidate Landsat color composites and U-2 high-altitude photographs to delineate irrigated lands from non-irrigated lands. None of the above studies attempted to differentiate between different irrigation methods.

Research Design

The literature cited above provided a significant amount of background material for this study, which used the physical characteristics of different irrigation methods, related them to the multispectral reflectance of irrigated and non-irrigated crops and soils, and tried to develop a methodology to identify irrigation methods based on actual field observations in the North Unit Deschutes Irrigation District (N.U.D.I. District) of central Oregon. Besides the literature cited, this study has drawn on various other sources of information. They include publications of the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, United States Department of Agriculture, United States Department of Interior, Department of the Army, Navy and the Air Force, Oregon State Water Resources Board, OSU Agricultural Experiment Station and OSU Extension Service. The OSU Environmental Remote Sensing Application Laboratory (ERSAL) and OSU Library provided much helpful information in the form of images and remote sensing-related literature.

Field Observations

The N.U.D.I. District was selected as the intensive study area. Background information about its physiographic conditions, climate, vegetation, soil, nature and history of agriculture, and irrigation was collected. Fields with different crop-irrigation combinations were selected and located on 7.5 minute U.S.G.S. topographic maps. The fields that were selected for study of irrigation methods were covered by three infrared flight missions that were to be flown over the area for research on water management in the N.U.D.I. District by Duane M. Nellis. The fields were carefully studied during early, mid-, and late-growing season, which coincided with the dates of CIR photographic flights, and oblique ground photographs were taken. Characteristics of irrigation practices, irrigation scheduling, different stages of crop growth and possible associations of different irrigation methods with crops, soils, and slopes were noted during the field observations and in discussions with the extension agent, irrigation water master, and farmers in the North Unit. This helped in developing a comprehensive crop and irrigation calendar. The observations made in the fields included:

1. field layout of different irrigation methods, i.e., orientation of furrows or sprinkler laterals with respect to crop rows;
2. distance between furrows and depth of furrows;
3. distance between laterals and sprinkler spacing;
4. irrigation methods association with crops, soils and slopes.

Image Acquisition

Three different kinds of images were analyzed; Landsat MSS color composite images and Landsat RBV images; CIR aerial photographs; black and white panchromatic photographs.

ERSAL provided all of the Landsat images and computer compatible tapes. Coverage for the 1979 growing season was available in the form of Landsat MSS color composite transparencies at the 1:1,000,000 scale. June 4, June 22, and July 18, 1979, images were selected. A Landsat RBV image at a 1:125,000 scale for June 8, 1978 was also available. ERSAL director, Dr. Barry Schrumpf, procured May 17 and June 22, 1979 color composite prints at 1:250,000 and a July 28, 1979 RBV image at 1:125,000.

U-2 CIR aerial photographs for August 2, 1978 and June 28, 1973 were also available at ERSAL. Their scales were 1:130,000 and 1:30,000, respectively. CIR photography for the 1979 growing season was flown on May 12, July 9, and August 5, 1979 by James W. Rinker. He used a Hasselbad 500 EL camera on a light aircraft and a 70 mm CIR film. The first two sets of photographs were developed by Rapid Color in Glendale, California and the third set was developed by Precision Photo Laboratory, Inc., Dayton, Ohio. Since these photographs were being used at the same time by Duane M. Nellis and were not available most of the time, it was decided to reproduce them by using color films. Dr. J. F. Lahey and William Hamilton reproduced the three sets of CIR photographs by using Kodak Ektachrome color film (ASA 64), and filters appropriate to the fluorescent light source. The product matched closely with the original set, the image scale was enlarged and some of the details were accentuated which helped in the interpretation. The original CIR transparencies at scales ranging from 1:30,000 to 1:33,200 were used for image analysis initially, but subsequently were replaced by color reproductions at 1:23,000.

The Oregon Army National Guard, 1042nd MI Company, was requested to fly black and white photography for the same flight line. This was flown on June 7 and June 18, 1979. These photographs at 1:8,000 were used to provide additional ground truth and helped in location and delineation of field outlines on 7.5 minute U.S.G.S. topographic sheets. The spatial dimensions of fields were also calculated from these photographs.

Methods of Interpretation and Analysis

Two methods of analysis were used:

1. Subjective appraisal - manual photo interpretation of Landsat MSS color composite images, RBV images and CIR aerial photographs, using light tables, magnifiers, and stereomicroscopes. The fields which were specifically observed during field surveys were located on each set of imagery. CIR photographs at 1:23,000 for May 12, July 9, and August 5, 1979 were used as the base. Each field was carefully studied on these images to note irrigation patterns, associated tone and texture, and the change in reflectance over time.

Ancillary material such as crop calendars, slope maps and physical characteristics of irrigation methods which were summarized in a tabular form were used in image analysis. The spectral temporal variations and spatial measurements were noted in a tabular form for each set of imagery. The same procedure was repeated for each type of imagery.

2. Digital classification was used for discrimination of irrigated and non-irrigated crop types, but the results were discouraging as the data were for the late growing season (July 28, 1979) when most crops were either harvested or were in the senescing stage, and discrimination was not possible.

Results

The results of this study are in the form of:

1. optimum mission parameters for irrigation method separation, i.e., what kind of image (emulsion), at what scale and time (approximate growing season) was required for irrigation method identification;
2. an image interpretation key for irrigation method identification developed for 1:23,000 imagery for the N.U.D.I. District, but usable for other smaller and larger scales and for other arid and semi-arid areas;
3. an evaluation of the key to determine its utility as affected

by photo interpretation experience, familiarity with farming and irrigation and the general background of the interpreter, as well as to test the usefulness of the hierarchical arrangement of the key in delineating confusing classes;

4. a suggestion for future research in quantitative analysis of remote sensing data for irrigation method recognition.

Report Format

The organization of this dissertation is intended to familiarize the reader with different irrigation methods, then with the fundamentals of remote sensing, and finally with image interpretation, analysis, and development of the methodology for irrigation method discrimination. Within this framework, Chapter II provides information about three main kinds of irrigation methods--surface, sprinkler, and sub-surface irrigation--and summarizes their diagnostic physical characteristics in a tabular form. Chapter III discusses photographic and optical-mechanical scanning systems and their image characteristics in relation to irrigation method discrimination. Chapter IV provides information about the geographic setting of the N.U.D.I District: its physiography, climate, vegetation, soil and agriculture and irrigation.

Image interpretation and analysis is presented in Chapter V. Three different kinds of images are analyzed and the results of the analysis--optimum mission parameters, an image interpretation key, and an evaluation of the utility of the key is presented. Possibilities of a quantitative analysis of remotely sensed data are examined in Chapter VI. Chapter VII provides a summary of and conclusions derived from this research.

CHAPTER II

IRRIGATION METHODS

Irrigation is as old as cultivation. Ancient irrigation works, most of them located next to rivers, can be found in Egypt, India, Iran, Iraq, Turkey, Peru and Mexico. Variations in irrigation methods are found throughout the world. They range from the most primitive basin flooding to highly sophisticated sprinkler and drip irrigation systems. Irrigation methods can be placed under three main categories:

1. Surface Irrigation Methods - Irrigation water applied on the ground surface. Within surface irrigation methods there are variations related to slope.
2. Sprinkler Irrigation Methods - Irrigation water applied above the ground surface. These systems are capable of handling all slopes from 0 to 15 percent.
3. Subsurface Irrigation Method - Application of water under the ground or in the root zone. This system is applied only to level surfaces.

Surface Irrigation Methods

Introduction

Surface irrigation or gravity irrigation refers to the application of water at the ground level. Water flows onto the field by gravity. In most cases the soil is the reservoir for storing water as well as the conveyor and distributor in the form of ditches. Although there are many variations in the form of the system according to slope, soil, surface roughness, source of water, and crop types, most systems are comprised of a supply of water, a field supply line which supplies water from the source to the field, a head ditch or pipeline extending from one end of the field to the other, a measuring device (weir or meter) to monitor the amount of water supplied, and in some cases a reuse reservoir to recycle water. As compared to other methods they are cheapest to install. Surface irrigation methods fall under two categories: level systems and graded systems. Graded systems operate the same way as level systems with modification to accommodate the slope factor:

Level Systems		Graded Systems
1a. Wild flooding		1b. Terraces
2a. Controlled flooding (border strip)		2b. Graded and contour border
3a. Furrow	3b. Corrugation	3c. Contour furrow and contour ditch

Wild Flooding

1a. Basin Irrigation

In this method water is applied onto unprepared land and allowed to follow natural slopes without much guidance or obstruction. It is the earliest and the crudest method of water application and has been in use throughout Asia, Africa, and Southern Europe through centuries. This primitive method of flooding large tracts of comparatively low land is still in use for irrigating some pasture lands. As is seen in Figure 1, it requires little field preparation and results in excessive water loss through seepage and evaporation. The shape and size of the field varies with surface roughness and with amount of water available. Basin irrigation is used for paddy, pastures, small grains, and orchard irrigation.

1b. Terraces

In steeper lands basin irrigation is replaced by a series of terraces. Terraces are suitable for slopes with deep soils of medium to heavy texture. Where labor costs are low, terraces can be made by hand and used for most crops. Where labor is expensive and terraces are formed by machines, they are used for high value crops such as orchards and vegetables. Figure 2 shows terraces with orchard crops.

Controlled Surface Flooding

2a. Border Strip

Border strip irrigation is a controlled surface flooding method of water application. The field is divided into a number of parallel strips called borders, separated by low ridges or levees as can be seen in Figures 3 and 4. Water is turned into the border from a

Figure 1. Wild flooding of pastures.

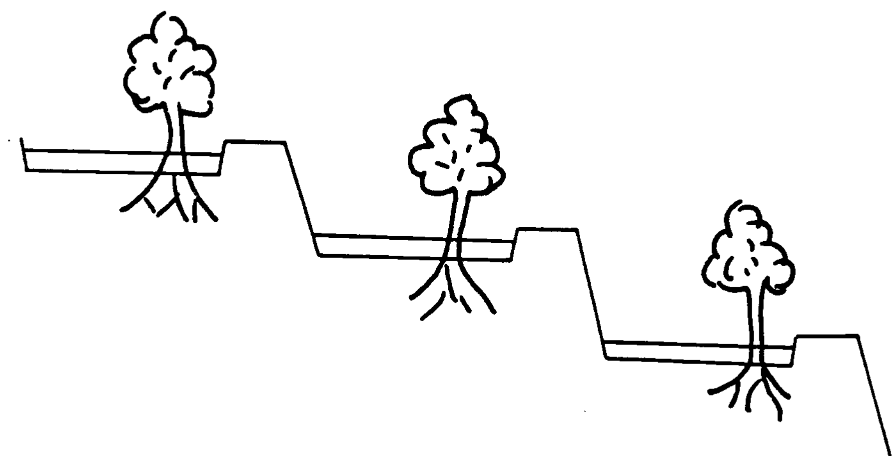


Figure 2. Terraces with orchard crops.

Figure 3. Border strip irrigation.

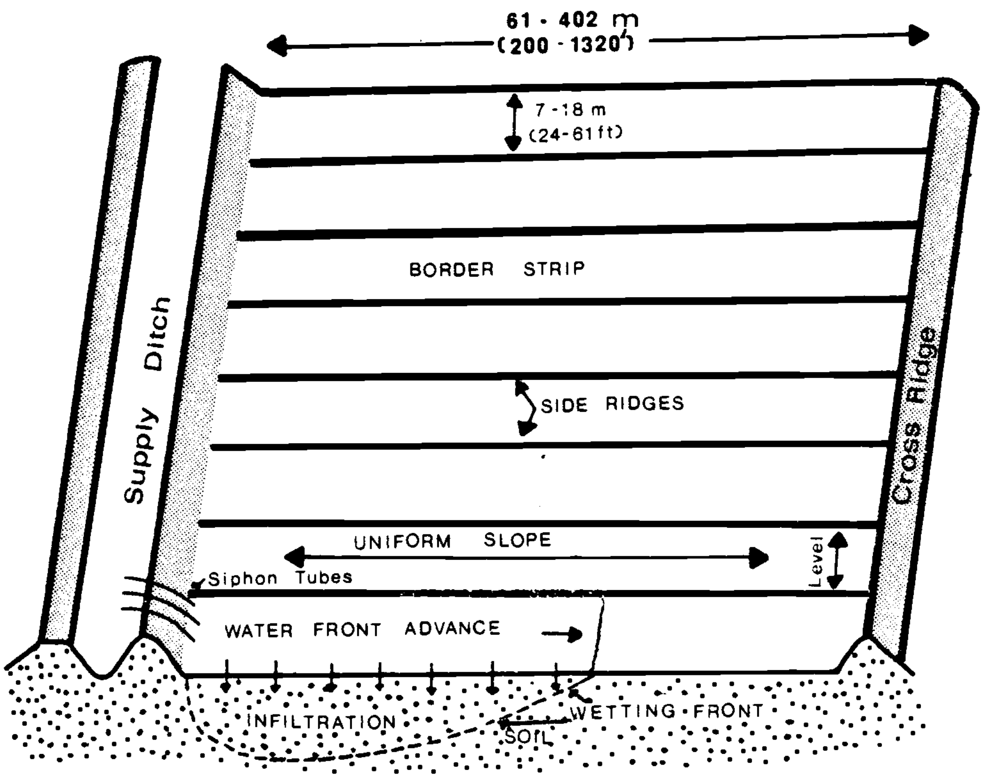


Figure 4. Border strip irrigation field layout, showing advancing water front and infiltration. After Michael, et al., 1972.

permanent ditch along the upper end of the field either by breaking the ridge and using check dams to control the flow or by using siphon tubes, and is allowed to flow down the strip. Water advances down the slope and infiltrates into the soil, moving vertically and laterally as a wetting front. As water moves down the border it is absorbed by the soil, and when infiltration has accounted for the whole discharge the advancing front terminates.

To achieve a uniform distribution of water, the rate of water supply should be twice as fast as the soil intake rate. This helps to spread water over the entire area as fast as desirable and results in an even distribution. A slight uniform grade helps the flow of water and prevents puddling in the low spots. Normally the direction of the border strip is in the direction of the greatest slope. The borders are usually level crosswise.

The size of the border strip on a particular farm varies with soil condition, ground slope and the amount of available water. In general, the width of the strip is smaller on steep slopes. The width length ratio varies from 1:6 to 1:15. The width varies from 7 to 18 meters (24 to 60 ft), and the length from 61 to 402 meters (200 to 1320 ft). Many forty-acre fields are divided into three or four lengths of 134 meters (440 ft) or 100 meters (330 ft). Shorter lengths provide better distribution of water.

The border method is applicable to most soils. It is best suited to soils which take water readily so that the desired amount per irrigation may be absorbed from the water as it flows over the land. On heavy soils, waste from the lower end will occur before the desired depth is obtained. On medium to light textured soils longer time deliveries would result in excessive percolation at the upper end of the run. Table I gives desirable slopes for border strip irrigation with different soils.

TABLE I. DESIRABLE SLOPES WITH DIFFERENT SOILS FOR BORDER STRIP IRRIGATION

Soil Type	Desirable Slope
Heavy texture soil	1 to 3 percent
Medium texture soil	2 to 5 percent
Light texture soil	3 to 7 percent

Border strip irrigation is best suited to close growing crops such as wheat, barley, and forage crops. It is possible to grow paddies by dividing the borders into basins by putting in cross-checks.

2b. Graded and Contour Borders

Graded and contour borders are similar to border strips except that they are on slopes greater than 3 percent. When a field can be levelled to a desirable slope economically and without affecting its productivity, borders are laid along the general slope of the field and are called graded borders. When land slope exceeds safe limits, and the field is undulating and levelling is not feasible, borders are laid across the slope and are called contour borders or contour levees. The strips are usually narrow to avoid excessive accumulation of water at the downstream end. The field is divided into a series of terraces around the slope. The drop from one terrace to another ranges from 10 to 61 cm (4 to 24 in). The height of the ridge should be sufficient to contain irrigation water and storm runoff. A head ditch is laid down on the upstream side of the contour border, and water is allowed to run down the slope from one terrace to another by means of spillways. At the downstream end water is collected in a channel to drain away.

Furrow, Corrugation, Contour Furrow, and Contour Ditch Irrigation

3a. Furrow Irrigation

Furrow irrigation is commonly used for row crops such as corn, potatos, sugarbeets, beans and other vegetable crops. It is the most suitable method of surface irrigation when crops are sensitive to ponded soil condition, or are susceptible to fungal root injury. Compared to other surface methods, there is less open water surface and therefore less evaporative loss in furrow irrigation. Additionally, cultivation and other field operations are possible soon after irrigation. Usually furrows are aligned down the main slope of the land and water is supplied from a head ditch, either by breaking canal banks to supply water to the ditch or by using plastic or aluminum siphon tubes (see Figures 5 and 6).

Figure 7 shows the field layout for furrow irrigation. The length of the furrows depends on the slope and nature of the soil. On some soils, furrows are used on a surface with 10 to 15 percent slope by employing very small streams of water to prevent erosion. However, slopes of 1 to 3 percent are preferable. Furrow length varies from 30 meters (100 ft) or less for gardens to as much as 402 meters (1320 ft) for field crops, but lengths of 91 to 201 meters (300 to 660 ft) are more common. In the case of light soils, excessive percolation losses near the supply ditch may result from the use of very long furrows. Movement of water in a furrow is shown in Figure 8. If the slopes are steeper than 3 percent and the irrigating head is large, erosion may become a serious problem and the length may be limited to 30 meters (100 ft). On soils of heavy texture furrows may be from 91 to 201 meters (300 to 660 ft) long, depending on slope and irrigating heads. The steeper slopes require a smaller head and shorter lengths (see Table II).

Spacing and depth of furrows is determined by crop spacing, since one furrow provides water for each row. When salinity is not a problem, water may be distributed in furrows between each row of crop. However, under saline conditions, alternate furrows may be irrigated

Figure 5. Furrow irrigation with check dam.

Figure 6. Furrow irrigation with siphon tubes.

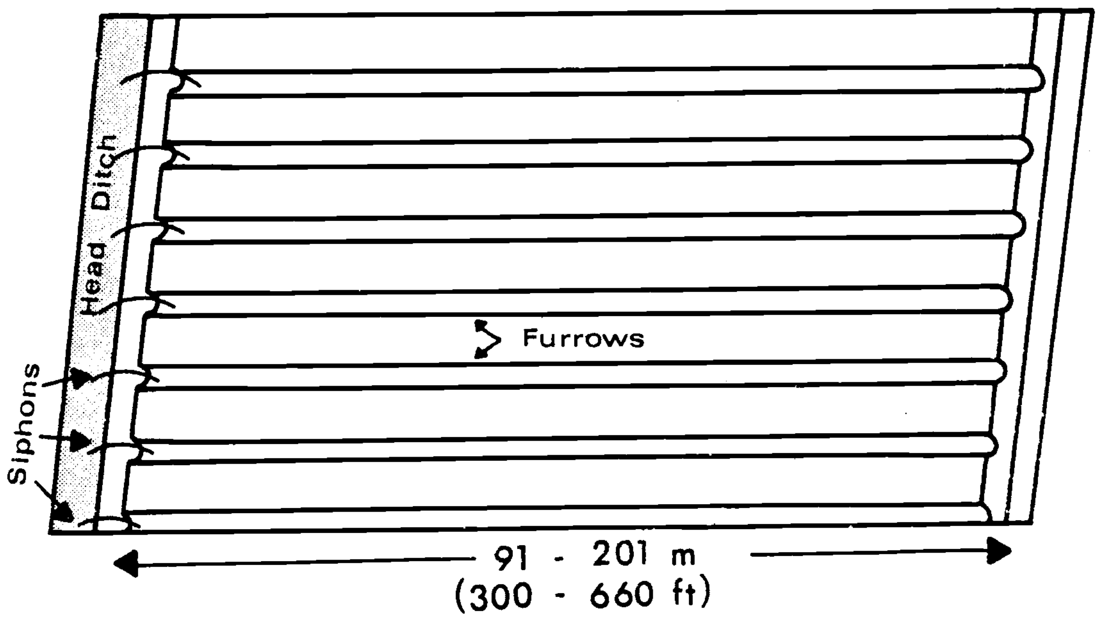


Figure 7. Furrow irrigation field layout. After Withers and Vipond, 1974.

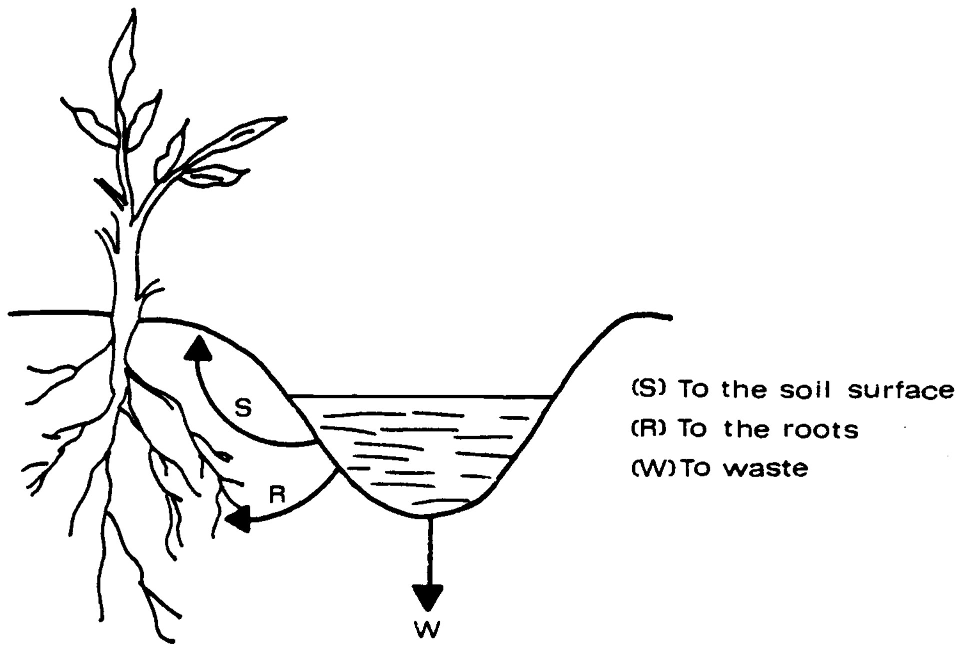


Figure 8. Movement of water into the soil in furrow irrigation may result in excessive waste in light soils. After Withers and Vipond, 1974.

to avoid salt accumulation near the plant. Water is allowed to flow in alternate furrows, keeping every other furrow dry. In subsequent irrigation the pattern is usually alternated. For most vegetable crops--chilies, onions, garlic, carrots, cabbages, etc.--two rows of crops are planted on either side of the ridge and irrigation furrows are laid between each ridge.

TABLE II. GENERAL LENGTH OF FURROWS IN DIFFERENT SOILS AND SLOPES (length in meters)

Slope (%)	Soil Texture		
	Heavy	Medium	Light
0 - 5	110 - 183	85 - 128	55 - 91
5 - 8	73 - 146	55 - 73	30 - 55

The spacing of row crops varies. Sugar beets are planted 45 to 61 cm (18 to 24 in) apart, potatoes and corn usually 83 to 122 cm (33 to 48 in) apart. In orchards furrows may be 1 to 2 meters (3 to 6 ft) apart along the rows of trees.

The depth of the furrows also varies with crop type. Row crops like sugar beets, carrots, onions and garlic are best irrigated with furrows 7 to 15 cm (3 to 6 in) deep. For others 15 to 25 cm (6 to 10 in) furrows provide better control of water distribution.

3b. Corrugations

Corrugations are a modified form of furrow irrigation. They are usually small, shallow, broadly spaced and are mostly used to irrigate uncultivated crops, such as forage and grains. The spacing of corrugations varies from 45 to 91 cm (1.5 to 3 ft). They are especially advantageous when available irrigation streams are small and the land has an uneven surface that would require extensive levelling if irrigated by furrows. Corrugations can be used on land with down slopes of 0.4 to 8 percent and cross slopes of 12 percent. Usually the field is divided into narrow strips of about 61 meters (200 ft) by cross ditches that run across the corrugations and are usually obliterated every time a field operation is carried on, having to be rebuilt again. A typical field layout of corrugations is shown in Figure 9.

3c. Contour Furrows and Contour Ditches

Where land slope exceeds the safe limit of soil erosion, furrows can be made perpendicular to the slope (following the contour). As seen in Figure 10, furrows are curved to fit the topography of the land and have a gentle slope along their length. Field supply channels run down the land slope to feed individual furrows. Furrow lengths vary from 30 to 201 meters (100 to 660 ft). Contour furrows are used to irrigate orchards and vegetables that are generally planted along the contours. Contour ditches run parallel to contours. Water is

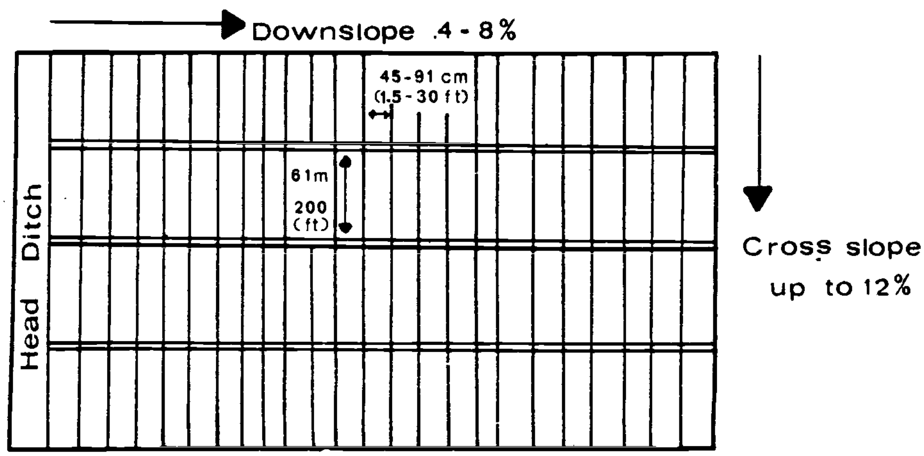


Figure 9. Corrugation field layout.

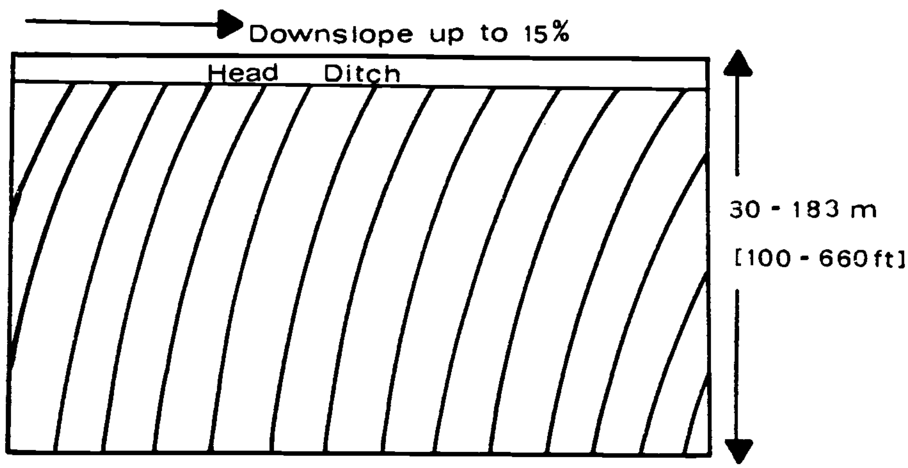


Figure 10. Contour furrow irrigation field layout.

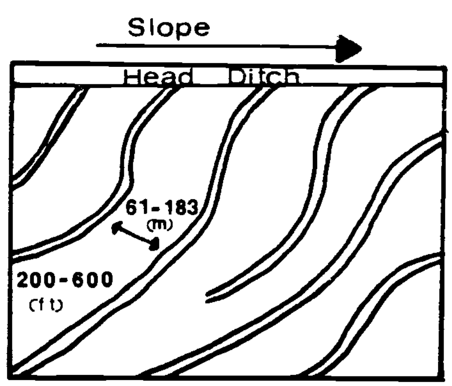


Figure 11. Contour ditch irrigation field layout.

delivered from the head ditch that runs down the slope (Figure 11). Spacing between ditches varies from 61 to 183 meters (200 to 600 ft). They are used to irrigate grains and other close growing crops (see Figure 12).

Sprinkler Irrigation Methods

Introduction

In sprinkler irrigation water is sprayed into the air through a sprinkler nozzle and allowed to fall on the ground like rain. It is sometimes referred to as overhead irrigation. Sprinkler irrigation was first used in the early 1900's to sprinkle water on lawns in the cities. By 1946 it was being used for agricultural purposes. During the 1962 to 1964 drought years, farmers in the northeastern United States suffered tremendously and realized the importance of irrigation during the critical growing period. This resulted in the doubling of sprinkler-irrigated acreage during that period. Thus, while irrigation is essential for dry lands, it is becoming increasingly important in humid areas. The farmer needs not to worry now about drought-resistant varieties and adverse effects of application of fertilizers in case the rain fails. For some crops quality control is more important than yield per acre. Sprinkler irrigation provides a boon to this type of farmer due to its diversity of application. The system can be used not only for watering plants, but also for frost protection, crop

Figure 12. Contour ditch irrigation.

cooling, and application of pesticides, herbicides and fertilizers.

From the soil conservation point of view, sprinkler irrigation is very important. It has reduced the problems of eutrophication of streams and lakes by irrigation water runoff. It improves soil condition by preventing salinity, which is so common with surface irrigation methods. It is more beneficial for plants since water falls like rainfall and does not injure the root system by flooding. It has reduced the problems of soil erosion since there is no runoff when properly applied. It has made it possible to extend the agricultural operations on marginal lands which could not be used previously because of their irregular surface or coarse soil texture. It minimizes water loss associated with surface irrigation as water is conveyed in pipes and is used more efficiently, minimizing evaporative losses. Perhaps the most important aspect is that it cuts down heavily on labor requirements until the equipment breaks. For this reason alone most farmers convert from gravity to sprinkler methods.

Main Components of Sprinkler Systems

All sprinkler systems have several features in common: a pumping unit, a mainline pipe unit, a lateral pipe unit, and sprinklers.

1. The Pumping Unit

The pumping unit takes water from the source and makes it available to the system under pressure. It is powered either by an electric motor or an internal combustion engine which uses gasoline, diesel, or natural gas for fuel.

2. The Mainline Pipe Unit

This pipeline unit delivers water from the pumping unit to the laterals. They are of three main types:

a. Flexible and portable pipelines made of lightweight durable rubber compounds and synthetic material;

b. Rigid and portable pipelines made of lightweight aluminum pipes equipped with quick couplers for easy handling;

c. Permanent pipelines installed either above or below the ground. Those installed above the ground are of galvanized steel and below the ground installations are usually made of plastic, asbestos cement or galvanized steel.

3. The Lateral Pipe Unit

The lateral pipes deliver water from the main pipe unit, but usually are of a smaller size. They are usually spaced at regular intervals along the mainline. In semi-permanent and portable systems, they are continuously moved laterally along the mainline to various connection points. They may be either hand-moved, intermittent mechanical-moved, solid set, or permanent systems.

4. Sprinklers

Sprinklers are of two main types:

a. Perforated pipe system: In this system lateral pipes are perforated to serve as sprinklers. It is usually used for low operating pressure. The sprays are directed on both sides of pipe and can cover a strip of land from 10 to 15 meters (32 to 50 ft) wide. It is suitable for soils with moderate infiltration rates and is used for lawns, gardens and small vegetable fields.

b. Rotating head sprinklers: The most commonly used sprinklers are of a rotating head type. They are of three kinds: rapidly whirling type, slowly rotating type, and boom type.

(1) The rapidly whirling type is used to irrigate turf and orchards. The operating pressure is between 15 and 30 psi and water discharge per sprinkler is from 0.5 to 10 gpm.

(2) Slowly rotating type sprinklers are available in different sizes and kinds ranging from small single-nozzle sprinklers which operate at very low pressures to large multiple nozzle high-pressure sprinklers with large area coverage and high precipitation rates. Small single nozzle sprinklers operate at 20 to 60 psi and the discharge rate for each sprinkler varies from 0.5 to 5 gpm. Irrigation capacity is 0.03 to 0.2 acres per sprinkler and the wetted diameter is up to 18

meters (60 ft).

High-pressure, large-volume sprinklers operate with pressure of 80 to 130 psi and the discharge rate varies from 80 to 1000 gpm. Irrigation capacity is from 1 to 6 acres and the wetted diameter is 36 to 70 meters (120 to 320 ft). These sprinklers are used for canneries, agricultural and industrial disposal, or for tall crops in humid areas.

Between single nozzle and large-volume sprinklers is a group of one or two nozzle, intermediate-pressure sprinklers used mostly for agricultural crops. They operate within a 30 to 80 psi pressure range, their discharge rate is from 3 to 100 gpm, and they are capable of irrigating about 0.2 to 1 acre with an 18 to 36 meters (60 to 120 ft) wetted diameter.

(3) The boom-type sprinkler consists of a long pipe arm or boom supported from a central tower. The pipe is covered with large nozzles and rotates about the central point of the sprinkler. The wetted diameter is from 91 to 152 meters (300 to 500 ft) and the operating pressure ranges from 50 to 80 psi. Water discharge capacity varies from 135 to 900 gpm and is capable of irrigating from 2 to 5 acres per setting. Table III gives the classification of sprinklers with

TABLE III. SPRINKLER CLASSIFICATION

Type of Sprinkler	Pressure Range (psi)	Wetted Diameter (meter)	Discharge Rate (gpm)	Irrigation Capacity (acre)
Rapidly whirring type	15 - 30	9 - 18	0.5 - 5	0.02 - 0.15
Low pressure rotating head type	20 - 60	9 - 24	0.5 - 10	0.03 - 0.2
Medium pressure rotating head type	30 - 80	18 - 36	3 - 100	0.2 - 1
High pressure rotating head type	80 - 130	36 - 70	80 - 1000	1 - 6
Boom type	50 - 80	91 - 152	135 - 900	2 - 5

their specific features.

5. Wetting Pattern of the Sprinklers

The wetting pattern of rotating head sprinklers is affected by pressure, spacing and wind. Bilanski and Kidder (1958) tested the effect of pressure and found that the higher the pressure the more desirable the distribution. A high pressure caused a greater breakup of the jet as it left the nozzle. As the pressure was increased, an increase occurred in the trajectory distance, resulting in greater dispersion and breakup of the jet. But since the travel distance of a drop of water is proportional to its size, further increase in pressure may result in a decrease of total trajectory distance, because air resistance is much greater in the case of very small drops exposing a much larger surface area. Air resistance does not allow the small drop to travel far. This loss of distance results in excessive water deposition near the sprinkler. Whereas with lower pressure the drops are larger and the water falls away from the sprinkler in a ring shape resulting in a doughnut-shaped pattern of water distribution. Effect of pressure is shown in Figure 13.

Spacing influences the water application pattern, since sprinkler fallout follows a conical pattern with maximum water falling near the sprinkler and gradually tapering to zero at a maximum trajectory distance. To achieve a uniform application rate, the sprinkler must overlap the wetted circular pattern of another sprinkler along the

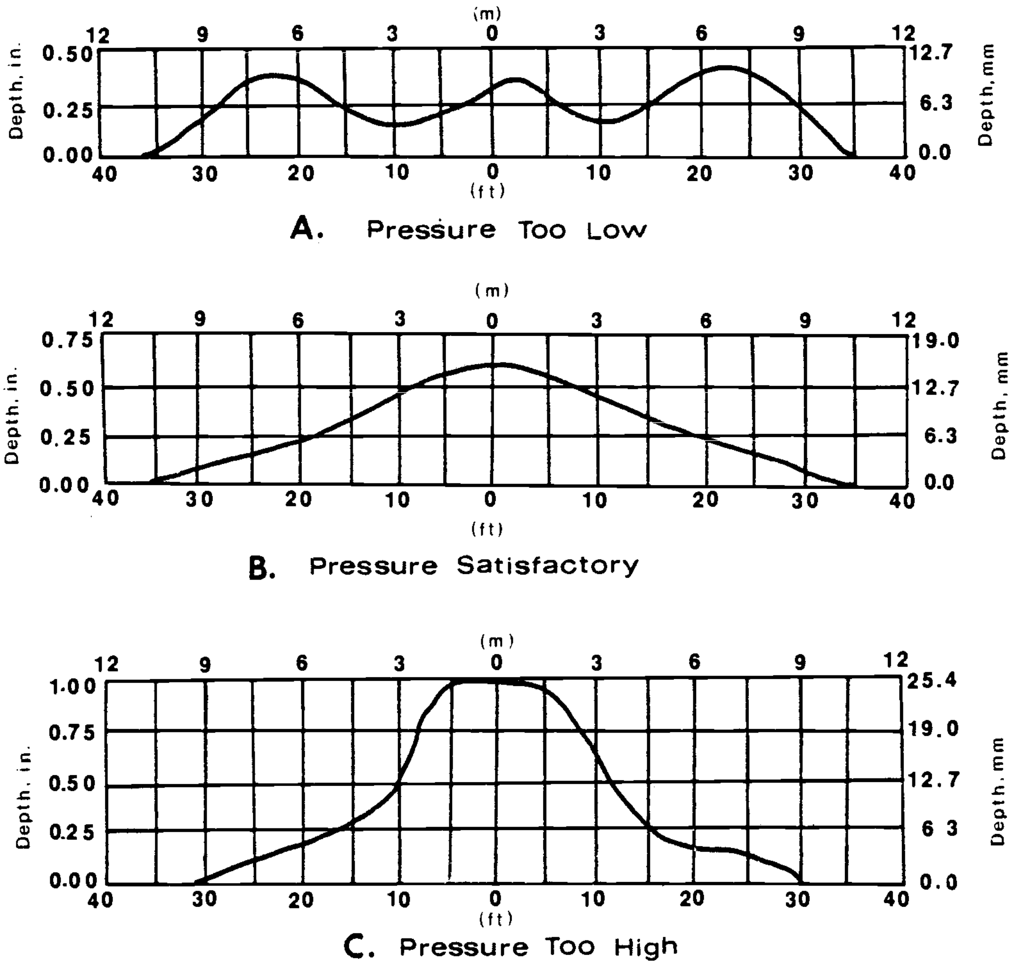


Figure 13. Sprinkler pattern as affected by pressure.

A. Too low pressure results in doughnut shaped wetting pattern.

B. Satisfactory pressure results in an even water distribution.

C. Too high pressure decreases total trajectory distance resulting in excessive water deposit near the sprinkler.

After Pair, 1975.

lateral line and the lateral line pattern must overlap (see Figure 14). Spacing pattern of the sprinkler is governed by wind, pressure and discharge rate. Wind distorts the sprinkler wetting pattern. The higher the wind speed the closer the sprinkler spacing must be. Increased pressure increases the diameter of wetted area and results in a more uniform distribution pattern. Discharge rate is a built-in characteristic of the nozzle and is specified by the manufacturer.

The effect of wind on the sprinkler pattern is shown in Figure 15. Wind distorts the water distribution pattern. The amount of distortion depends on wind speed and the size of the droplets. The higher the wind speed and the smaller the drop size, the more distorted the water distribution pattern. Wind distortion can be counteracted by closer spacing of the sprinklers. Wind produces variable effects on distribution uniformity. There is a tendency for higher concentration of water depth near the sprinkler. Higher wind causes the water application rate to be greater than normal and results in runoff. Sprinkler irrigation systems are of two main types: stationary type and continuously moving type.

Stationary Type

This type of system applies water at a relatively constant rate and is comprised of four different kinds:

1. Hand Move Type

Hand move portable systems consist of a mainline and one or more

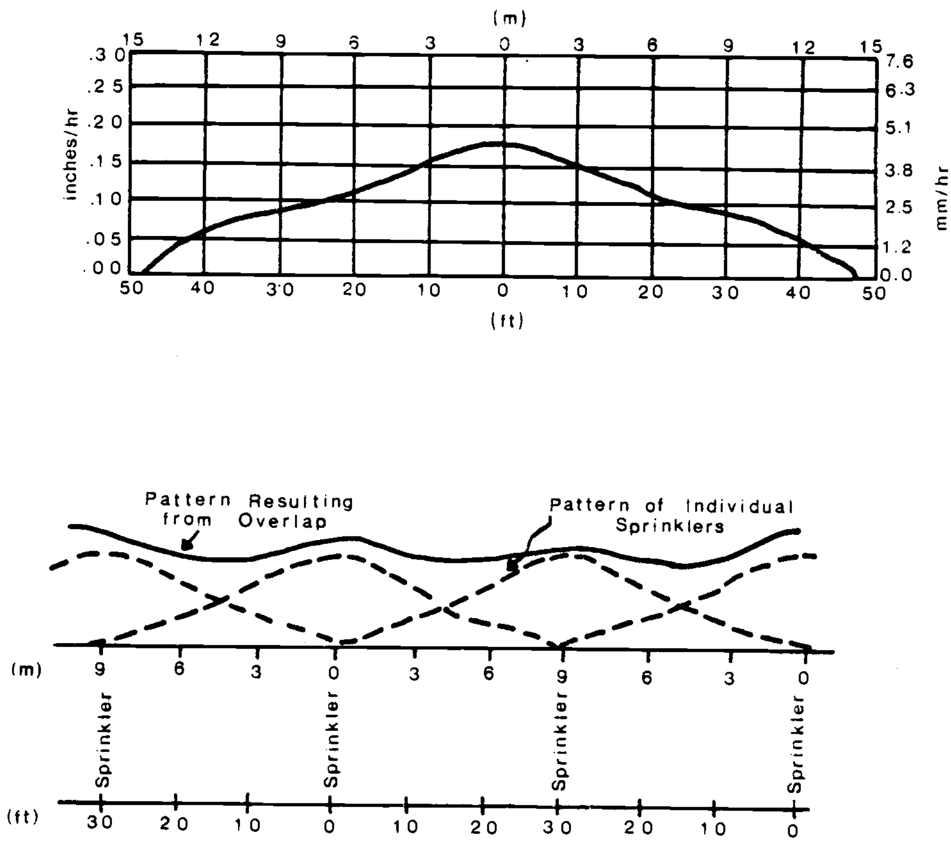


Figure 14. Sprinkler pattern as affected by spacing. Distribution pattern from single sprinkler and from overlapping sprinklers. After Pair, 1975.

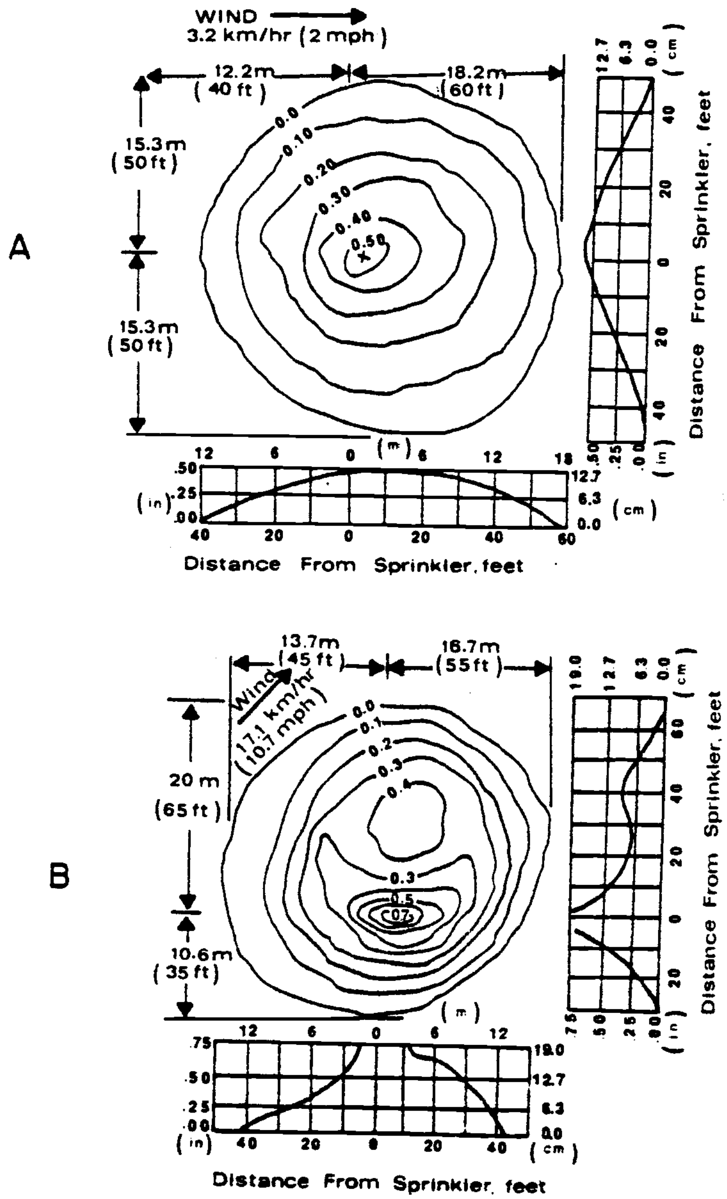


Figure 15. Sprinkler pattern as affected by wind.
A. Under favourable conditions.
B. Under windy conditions.
After Pair, 1975.

laterals of light aluminum pipe with quick-attaching couplers. The distance between laterals ranges from 12 to 27 meters (40 to 90 ft), but 15 to 18 meters (50 to 60 ft) are more common. Laterals may be perforated to serve as sprinklers or else use medium-size rotating sprinklers. Once the desired amount of water is applied, the water is shut off and the laterals are moved to the next position (see Figures 16 and 17).

2. Side-roll or Side-move Type

Side-roll systems have a lateral made either of aluminum or galvanized steel pipe which acts as an axle for wheels. The wheels are usually spaced 18 to 30 meters (60 to 100 ft) apart along the lateral which may be 804 meters (0.5 mi) long on level land. Small or medium-size sprinklers are used, and the lateral remains stationary when irrigating. After the desired amount of water has been applied, the lateral is moved to a new location by means of an air-cooled gasoline, hand, hydraulic or electric engine which is located in the center of the lateral line.

The side-move type is similar to the side-roll system except that the lateral is mounted on "A" frame wheels or towers. The advantages of this system over the side-roll type are that the sprinkler remains in an upright position all the time and the lateral is high enough to move over tall crops. Some side-move systems have sublaterals of small pipes trailing from the main lateral with sprinklers attached to them.

Figure 16. Hand move sprinkler system.

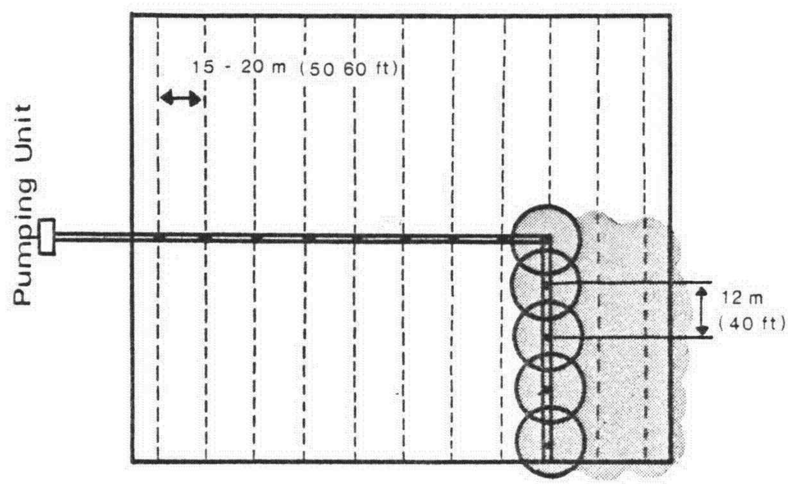


Figure 17. Field layout for hand move sprinkler system.

Thus, more area can be irrigated at one setting. Figures 18, 19 and 20 show side-roll and side-move systems and their field layouts.

3. Big Gun or Boom Sprinkler System

This system has either a big gun or a long sublateral with several nozzles spaced on the boom to provide an even distribution of water. The gun rotates due to the back pressure of water coming through the lateral and irrigates an area of approximately 2 to 5 acres. The wetted diameter ranges from 36 to 152 meters (120 to 500 ft). Figure 21 shows a big gun irrigating a corn field.

4. Solid Set

It is called solid set because the system is permanently set in the field or at least is installed for one season and is not moved until the crop is harvested. The laterals are generally installed underground, but sometimes overhead or on the ground depending upon the crop. In most systems only part of the system works at a time. This is accomplished by opening and closing control valves located at the sprinklers or in the lateral lines. Valves may be controlled manually or remotely controlled from centrally located stations. Completely automatic systems require no labor. The moisture-sensing instruments start the system when water is needed and shut it off when the entire field is irrigated. Since the installation of the system is very costly, it is used for high-value crops such as potatoes, strawberries, and citrus or other orchards. Field layout resembles the hand move system; small to

Figure 18. Side-roll irrigation system.

Figure 19. Side-move irrigation system.

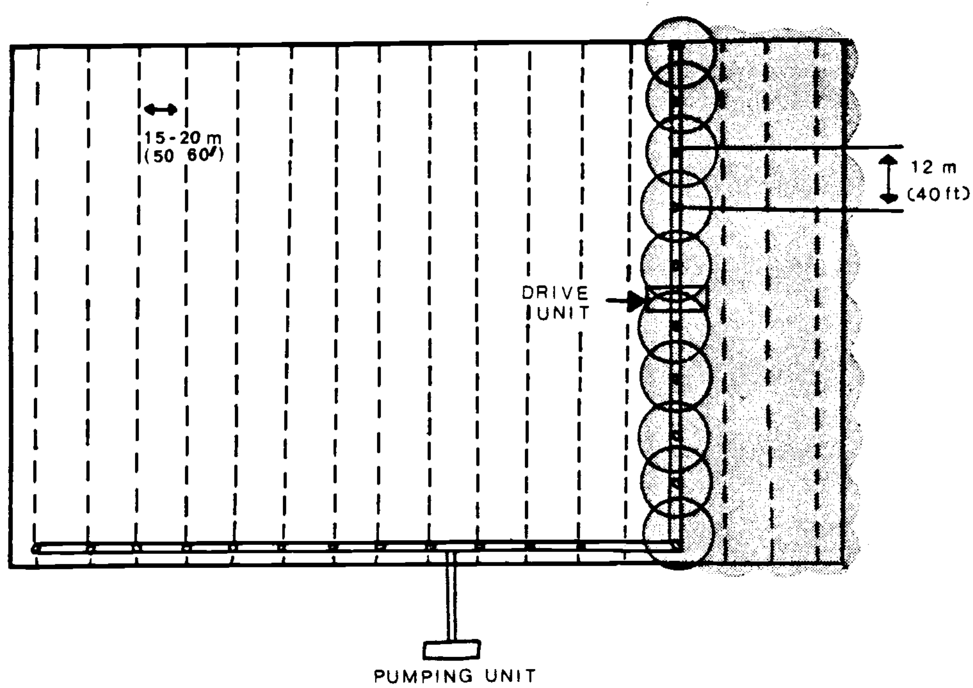


Figure 20. Field layout for side-roll sprinkler system.

Figure 21. Big gun sprinkler.

medium-size sprinklers are used at a spacing of 9 meters (30 ft). Distance between laterals is approximately 12 meters (40 ft). Figure 22 shows solid set system for potatoes.

Continuously Moving Sprinkler System

With continuously moving sprinkler systems the application of water starts at zero, increases to a maximum and then decreases to zero again as the system passes over a location. They are of three kinds:

1. Center Pivot

The center pivot system was invented by the Colorado rancher, Frank Zybach, in 1952. It consists of a single sprinkler lateral that has one end anchored to a fixed center and the other end rotates in a circle around the center pivot. The lateral is supported by towers, cables, or trusses which move on wheels, tracks, or skid support units located 24 to 76 meters (80 to 250 ft) apart along its length. Lateral length varies from 201 to 804 meters (660 to 2640 ft). The lateral is kept in a straight line as it moves around the center pivot by an alignment system that speeds up or reduces the speed of support units as required to maintain alignment. A safety device automatically shuts down the entire system in case the alignment system fails and support unit gets too far out of alignment.

The lateral is driven by a series of power units, one at each tower. This allows different rates of speed to each supporting unit

Figure 22. Solid set irrigation system for potatoes.

(tower). Because of the circular area covered each succeeding tower away from the center must travel at a faster rate if the lateral is to rotate uniformly in a straight line.

The water application rate along a center pivot lateral is a function of nozzle size, pressure, sprinkler spacing, length of lateral, and sprinkler type. Thus, the rate of water application is not affected by the change in speed. It only affects the depth and duration of water application. The water application rate varies along the lateral length from a low near the pivot to higher values at the outer end (see Figure 23). In a 402 meters (1320 ft) lateral, beginning at the center pivot water is applied along the 201 meters (660 ft), half of the lateral length to irrigate the inside one-fourth of the area. The outside one-fourth of the area must have the same volume of water applied through 54 meters (177 ft) of the lateral. Water application rate varies along a center pivot because the time the water is applied per unit length of the lateral decreases from center pivot to outer end.

The center pivot system requires fields free of any obstructions and is best adapted to soils with high intake rates, i.e., where the infiltration rate exceeds the application rate of the center pivot system. Although center pivot systems are used on rugged topography, operations are easier on level and uniformly sloping lands.

The center pivot system irrigates a circular area and thus corners of the field are not irrigated. This problem can be overcome by using

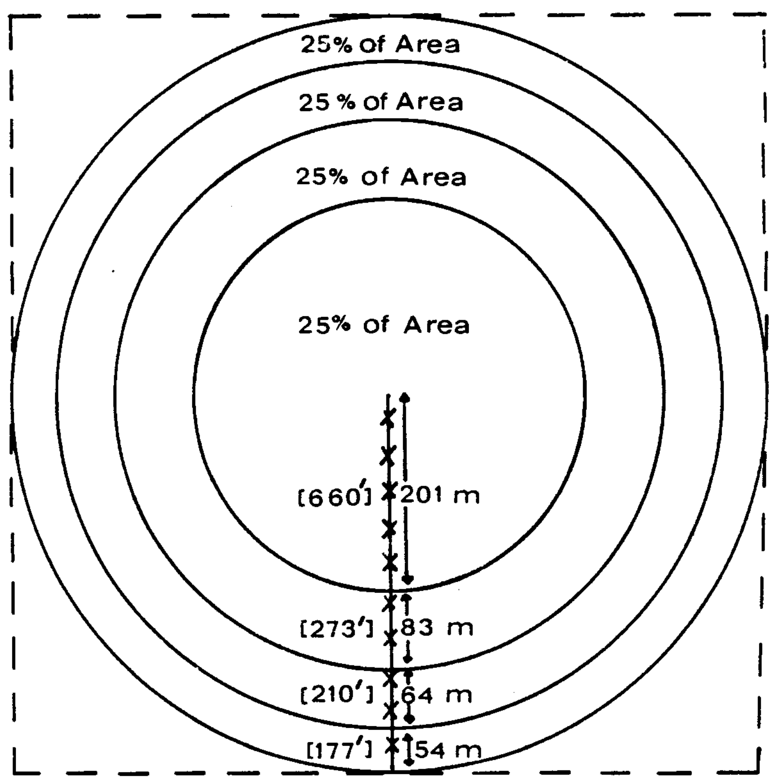


Figure 23. Water application in center pivot irrigation system. From Pair, 1975.

large sprinklers at the outer end of the lateral that start operating when the lateral travels past the corner, or by installing furrow irrigation, hand move or solid set systems on the corners. Figure 24 shows a center pivot in operation.

2. Continuously Moving Straight Lateral System

This system irrigates a rectangular field usually 160 acres in size. The lateral is supported by two-wheeled carriages at 12 to 24 meter (40 to 80 ft) intervals along the lateral. The place of the center pivot is taken by a self-propelled cable towed water-driven winch, which is equipped with a water motor. The motor drives the winch that winds up a steel cable towing the power unit. The speed of the winch unit controls the speed of the towers, and each tower propels itself. When the system reaches the end of the field, it is stopped automatically by a trigger mechanism on the cable that closes the water valve or the winch unit and the sprinklers. Then the system is disconnected and towed to the starting position. The lateral pipeline is 2.1 meters (7 ft) or more in height to provide crop clearance and the rate of lateral travel varies from 15 to 61 cm (0.5 to 2 ft) per minute. The water application efficiency varies from 75 to 80 percent. Figure 25 shows a continuously moving system installed in a field.

3. Traveller Sprinkler System

Originally designed as a means to reduce labor requirements associated with conventional irrigation systems in tall-growing crops,

Figure 24. Center pivot irrigation.

Figure 25. Continuously moving straight lateral.

traveller sprinklers are now used in a wide variety of applications. The sprinkler is typically of a large volume or boom type, covering a wetted diameter of 61 to 152 meters (200 to 500 ft). A long (up to 200 meters or 660 ft) flexible hose connects the sprinkler to the main pipeline. This extremely wear-resistant hose is dragged across the field by the same power that propels the sprinklers. A steel cable which is anchored at the opposite end of the field guides the sprinkler as it moves. When the water is turned on, the sprinkler moves under its own power across the field, sprinkling as it goes. Provisions are made for the adjustment of speed, since speed controls the amount of water applied. As the sprinkler moves the cable is wound around the drum. At the end of the run the sprinkler stops automatically. Then it can be moved to the next position. Figure 26 shows the traveller sprinkler in operation.

As seen in Figure 27, the traveller system irrigates rectangular strips and is also adaptable to a wide range of field sizes and shapes. Initial cost per acre is low. It can be used on topography ranging from level to rolling and irregular, and on fields having obstacles such as power lines, trees and buildings.

Sub-surface and Trickle Irrigation Methods

Sub-surface irrigation as described by Davis (1970) is:

> the application of water under the soil so that it moves by capillarity into the root zone of the crop. Applying water at the surface in a similar manner

Figure 26. Traveller sprinkler system.

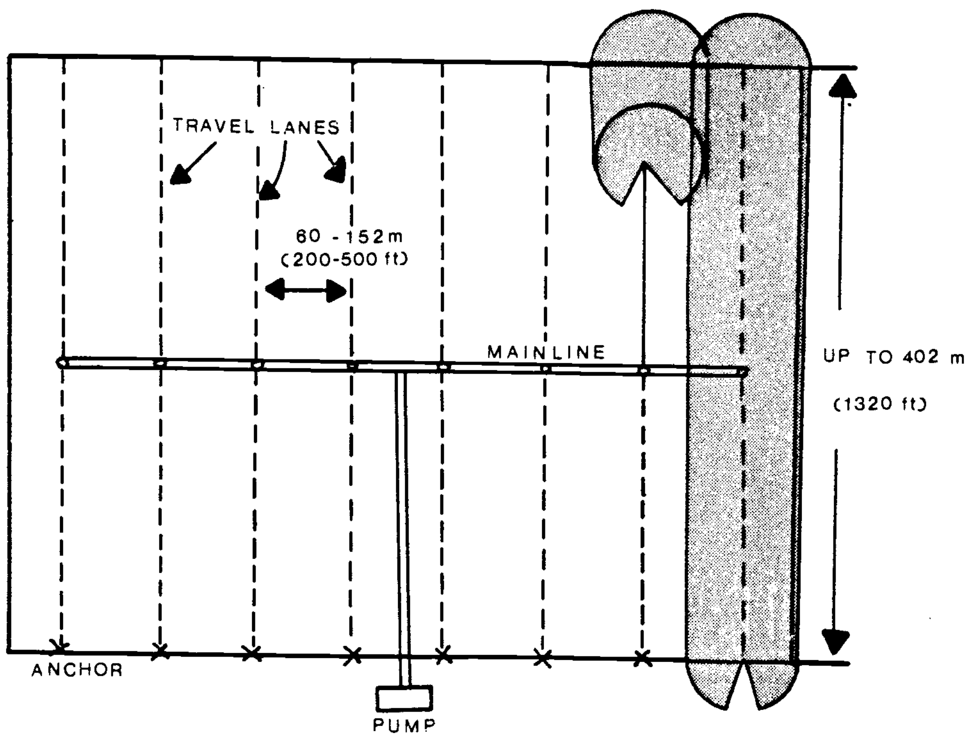


Figure 27. Field layout for traveller sprinkler system. From Pair, 1975.

> is called trickle irrigation. Sub-irrigation is another method of irrigation below the soil surface but it requires using the ground water table to wet the root zone. Sub-irrigation is limited because of the special soil profile required. Sub-surface and trickle irrigation are applicable to all types of soils.

Trickle or drip irrigation with surface mulches is one of the most recent developments in irrigation practices. It was developed in Israel by the water engineer, Simca Blass, in 1959, and has been used since then because of its considerable potential for reducing water losses. In the United States it represents a negligible portion of irrigated land. Most of the progress in the United States has been made in the last two decades, after inexpensive plastic pipes became available. Sub-irrigation by means of underground tile lines or seepage ditches has been employed in Florida and some western and mid-western states for many years for irrigation and drainage in areas where the soil profile produces perched water tables. Trickle irrigation is the application of water on the surface under low pressure and covered by some kind of mulch. It is more widely used than sub-surface irrigation. The same kind of equipment is used for both sub-surface and trickle irrigation. The main components of sub-surface irrigation systems are water supply, pump, water meter, constant head control, filter, main pipeline, laterals, and emitters or perforations. Figure 28 shows the field layout for trickle

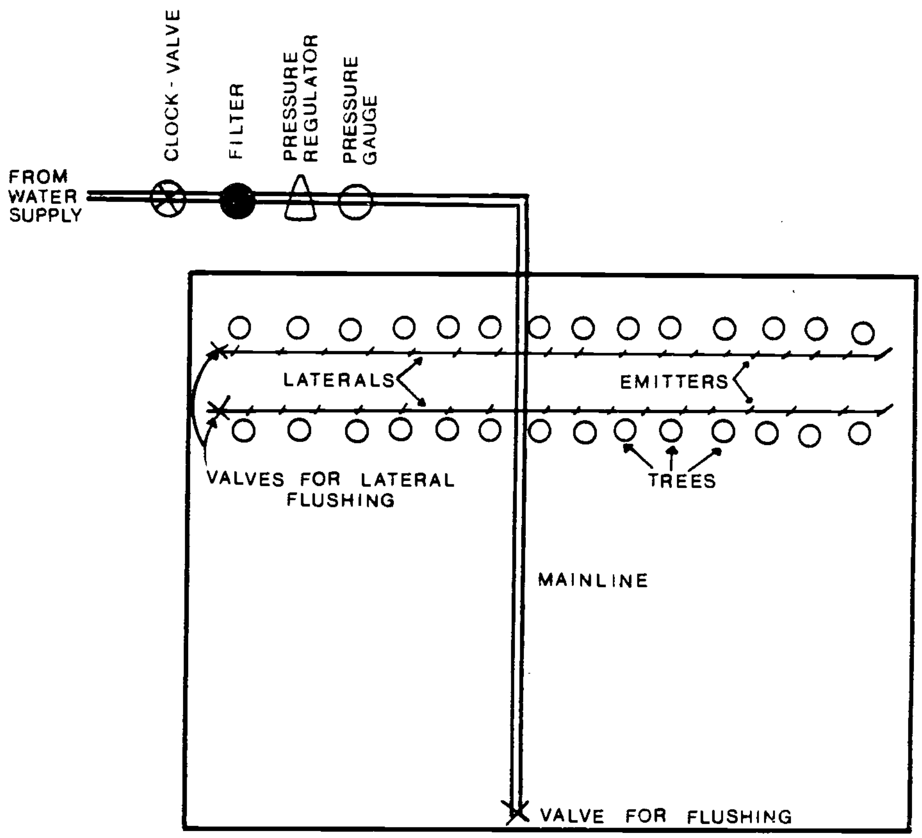


Figure 28. Field layout for trickle irrigation system. From Pair, 1975.

irrigation and Figure 29 shows the head of the system which includes a clock valve, filter, pressure regulator and pressure gauge. The water supply is usually a well. The main line is a plastic pipe that runs along the field and supplies water to the laterals. Laterals are usually double-walled plastic pipes with perforations to emit water. They are laid either on the surface covered by mulch or are buried underground to a depth of 5 to 10 cm (2 to 4 in), as can be seen in Figure 30. The spacing between laterals is governed by the type of the crops to be grown. In close-growing crops laterals may be spaced as close as 50 cm (1.6 ft) or as wide as 6 meters (20 ft) in orchard crops. The perforated pipe allows water to escape to the soil under very low pressure, so that the soil remains in an unsaturated condition. Precise amounts of water can be applied to replenish the depleted soil moisture at frequent intervals. The system is designed for daily water application and can be used as often as desired to apply water and fertilizers. Evaporation and deep percolation are minimized. There is a continuous balance of water, fertilizer and air in the entire life cycle of the plant, resulting in optimum growth, better fruiting and early maturity of the crop. The main advantages of sub-surface irrigation are: (1) Decreased tillage by properly managed irrigation as it improves soil aeration and reduces weeds; (2) decreased water usage by eliminating

Figure 29. Head of trickle irrigation system.

Figure 30. Trickle irrigation system, laterals are buried underground. Usually no sign of irrigation is present.

evaporation and percolation; (3) increased yield by increasing plant density; (4) plant protection from insects and diseases by avoiding wetting the leaves and restricting the weed growth, thus limiting the population of potential host for pests; (5) higher quality of crop by applying water and fertilizers at required times; (6) increased fertilizer efficiency is achieved by applying soluble fertilizers in the root zone, thus eliminating the fertilizer loss to the atmosphere and preventing eutrophication of streams and lakes; (7) minimum water consumption allows use of small wells; (8) irrigation labor is reduced to a minimum; (9) field operations can be carried on at the time of irrigation; (10) growing season is reduced by two to three weeks, because of negligible evaporative cooling so the soil temperatures are 2 to 7 degrees higher, thus favouring early maturity; (11) saline water can be used with minimum hazards as compared to other methods.

There are problems associated with drip irrigation too, such as clogging of laterals, poor soil moisture distribution and relatively high cost of installation. The water has to be carefully filtered. As distribution of water is not visible, several probes have to be made to insure adequate water distribution. Salinity usually builds up on the fringes of wetted area which can be washed down to the root zone during a rain. To minimize this hazard, sub-surface irrigation should be continued through the rain to help the salt to leach down through the soil profile.

Chapter Summary

Irrigation methods have their own characteristic diagnostic field shapes, sizes and wetting patterns, which provide the basis for their identification. Nature of surface, slope, soil texture, and crop association provide additional aids. Summarized in Tables IV and V, these characteristics provide basic physical data needed for determining the spatial, spectral, and temporal characteristics of irrigated scene. There are no diagnostic clues for identification of subsurface irrigation except for crop health.

Remote sensing systems suited to irrigation methods identification and their image characteristics will be described in the next chapter.

TABLE IV. SUMMARY OF SURFACE IRRIGATION SYSTEMS

Method	Soil texture	Surface/slope	Shape	Size	Distance	Crops	Identification features
Wild flooding	medium to heavy	level/0-3%	varies	varies, usually small	-	paddy, small grains, pastures orchards	1. small fields (paddy may be large), flooded 2. uneven water distribution 3. crop damage near head ditch
Terraces	medium to heavy	level/3-15%	varies	very small	-	paddy, orchards, vegetables	1. small fields 2. irregular shape 3. fields across the slope
Border strip	moderately heavy to moderately light	level/0-3%	varies with length of strips	varies, usually up to 40 acres	strips 7-18m (24-60') wide	wheat, forage, barley, hay	1. level land 2. broad rectangular strip 3. more water near head ditch affecting crop health 4. presence of canals or head ditch 5. presence of check dams or siphon tubes
Graded/ contour border	moderately heavy to medium	level within strips/ 3-15%	varies with slope	usually small	varies, drop from one terrace to the other 10-61 cm	paddy, vegetable, orchard, wheat, hay	1. fields follow grade 2. narrow strips 3. check dams close to levees may be seen 4. more water may collect on the up-stream side of the levell
Furrow	all soil texture except very coarse	level/0-3%	varies, usually recti-linear	varies, usually up to 40 acres	varies, with crops 45-122 cm (18-48 in)	all row crops, grains, vegetables	1. rows on slightly sloping or level lands 2. more water near the head ditch affecting crop health 3. canals, check dams, or siphon tubes may be seen
Corru-gation	moderately heavy to heavy	level to un-even/0.4-8% downslope, and up to 12% cross-slope	varies	varies	between cor-rugations: 45-91 cm (1.5-3 ft) cross-ditch 61 m (200 ft)	forage, small grains	1. closely spaced channels 2. absence of big ridges 3. uneven surface appearance with pattern aligned in certain rows
Contour furrow/ ditch	all except very coarse	level to un-even/3-15%	irregu-lar	small	varies with crops: for contour fur-row 45-122 cm (18-48 in); for contour ditch 61-183 m(200-600 ft)	contour fur-row; row crops, vege-tables, con-tour ditch; grain, close growing crops	1. furrows and ditches follow the grade, run at right angle to slope 2. gentle slope along the length

TABLE V. SUMMARY OF SPRINKLER IRRIGATION SYSTEM

Method	Soil texture	Slope, Shape	Size	Lateral distance	Sprinkler distance	Wetted diameter	Crops	Identification features
Hand move	all irrigable soils	0-15%, varies	any size, usually under 40 acres	12-27 m (40-90 ft) lateral length: usually up to 201 m (660 ft)	12 m (40 ft)	24 m (80 ft)	all crops	1. rectilinear or irregular shape 2. length of wet strip up to 201 m (660 ft), but in irregular shape could be up to 305 m (1000 ft) 3. sprinkler wetted diameter 24 m (80 ft) 4. obstacles may divide the field
Side-roll	all irrigable soils	0-15%, usually rectilinear	usually 40+ acres	15-18 m (50-60 ft) length of lateral: 305+ m (1000+ ft)	12 m (40 ft)	24 m (80 ft)	all except tall crops and orchard	1. rectilinear fields usually 2. length of wet strip 305+ m (1000+ ft), covers full length of field 3. sprinkler wetted diameter 24 m (80 ft) 4. no obstacles in the field 5. laterals and wheels can be seen
Solid set	all irrigable soils	0-15%, varies	varies, usually small	21 m (40 ft)	9 m (30 ft)	18 m (60 ft)	high value cash crops potatoes, blueberries orchards	1. sprinkler lateral fixed 2. only part of the field irrigated at a time 3. sprinkler wetted diameter 18 m (60 ft)
Center pivot	well-drained soils preferred	0-15%, circle partial circles	40-640 acres	lateral length: 201-804 m (660-2640 ft)	5+m (15+ft)	-	all except tall crops & orchards	1. circular or partial circular shapes 2. 201-804 m (660-2640 ft) radius
Continuously moving straight lateral	well-drained lighter soils preferred	0-15%, rectilinear	160 acres	lateral length: 805 m (2640 ft)	-	-	all except tall crops & orchards	1. rectilinear fields 2. length of wet strip 804 m (2640 ft)
Gun/traveler	well-drained	0-15%, varies	up to 60 acres	-	-	36-152 m (120-500 ft)	all crops	1. 1-5 acres irrigated in one setting 2. irregular field shape 3. uneven surface 4. obstructions in the field

CHAPTER III

PHOTOGRAPHIC AND OPTICAL MECHANICAL SCANNING SYSTEMS USEFUL IN IRRIGATION METHOD DISCRIMINATION

The applicability of photographic and optical mechanical scanning systems in the detection of irrigation practices will be discussed in this chapter. The image of an irrigated area recorded by a sensor in a given portion of electromagnetic spectrum is the result of the interaction of energy with the object and the environment, which gives an irrigated area a characteristic tone, color, or spectral reflectance. There are two approaches to the analysis of remotely sensed data, approaches which divide remote sensing into two branches.

Image-oriented analysis utilizes the pictorial aspects of the data and uses photographic sensors. This approach is older and more fully developed. It provides a wide variety of film/filter combinations, can have a high resolution, allows stereoscopic viewing, is of relatively low cost, and the image resembles the physical environment and can hence be used with minimum corrections.

Numerically oriented analysis emphasizes the quantitative aspects of the data, treating the data as a collection of measurements. Typically used aboard an aircraft or satellite is a multispectral scanner (MSS) which can operate over a larger portion of the electromagnetic spectrum than is available to a photographic system. When placed on an orbiting satellite MSS provides repetitive coverage at a very low cost. However, it has the limitation of comparatively poor resolution, image distortion, and an expensive, complicated digital data processing system requiring skilled personnel for processing. This branch of remote sensing has the flexibility of being used as an image-oriented system as well. Thus the analysis can be done in two manners:

1. False color composites of multispectral scanner (MSS) and Return Beam Vidicon (RBV) images can be optically enhanced at larger scales and can be manually interpreted;
2. Computer assisted analysis of the digital data can be used in the detection and identification of objects.

Since the interaction of the electromagnetic radiation (EMR) with matter provides all remote sensing data, a discussion of the electromagnetic spectrum is herein followed by the description of photographic systems, optical mechanical scanning systems, and image characteristics with respect to the identification of irrigation methods.

The Electromagnetic Spectrum

The electromagnetic spectrum is the continuum of electromagnetic energy ranging from long, very low-frequency radio waves to very short and extremely high-frequency gamma and cosmic waves. The spectrum is broken down by wavelength or frequency into various bands or spectral regions such as gamma rays, x-rays, ultraviolet (UV), visible, infrared (IR), microwave, radio, and radar. Division into these bands is purely arbitrary.

The wavelengths of interest in this study are the reflective or photographic wavelengths, which extend from 0.38 to 1.3 micrometers. They are further divided into two regions. The visible wavelengths extend from 0.38 to 0.72 micrometers. This is the region of the spectrum to which human eyes respond and is generally used for conventional photography, and occasionally by aircraft-based MSS, for imaging. The region between 0.72 to 1.3 micrometers is called the reflective infrared or near-infrared (NIR), and is used for imaging by infrared films and optical mechanical scanners.

The chief source of energy for these reflective wavelengths in solar energy, which, like all electromagnetic radiation (EMR), travels at the speed of light in a vacuum. Solar energy peaks in the visible portion of the spectrum at about 0.5 micrometers (see Figure 31). When this energy comes in contact with matter, it may be reflected, absorbed, or transmitted by the matter. The energy that is reflected passes back through the atmosphere and is recorded by the sensor. What happens to this solar radiation when it passes through the atmosphere and the way it interacts with matter has important effects on the quality of the image.

Light that falls on a surface is called incident energy or irradiance and is a combination of direct sunlight and skylight, the

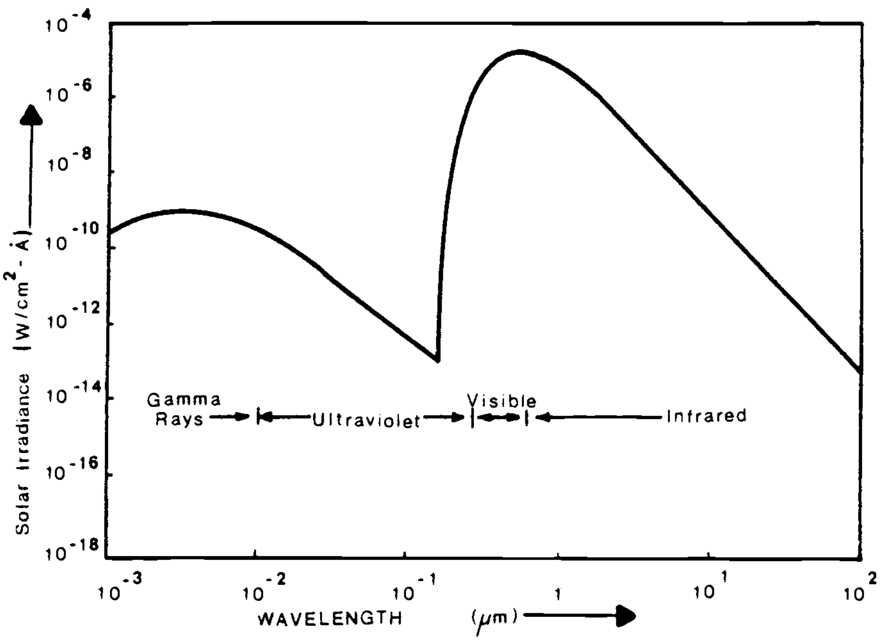


Figure 31. Spectral distribution of solar energy. From Estes and Senger, 1974.

latter resulting from atmospheric scattering and reflectance. Irradiance is not constant, differing from place to place, time to time, and with changes in sun angle. The amount and spectral quality of the reflected energy affects the contrast ratio and hence the quality of the image. These qualities are described by the product of irradiance and the reflective properties of the surface, which is called radiant flux. On a clear day almost 80 percent of the solar energy reaches the target, but normally the sky is not clear and the irradiance and radiant flux undergo many changes.

The atmosphere affects the light mostly by absorption, transmission, scattering and reflection.

Absorption and Transmission

Some of the solar energy is absorbed by atmospheric gases, dust particles and water vapor, and helps to heat the atmosphere. Absorption is wavelength dependent and is more effective in the IR region and the visible part of the spectrum. Figure 32 shows absorption bands created by water, carbon dioxide, oxygen and ozone gases. Where absorption is least, energy is transmitted. These regions are called atmospheric windows, which are used by remote sensors for imaging. The spectral region between 0.3 to 1.3 micrometers is one of these windows which is used by the photographic sensors and optical mechanical scanners.

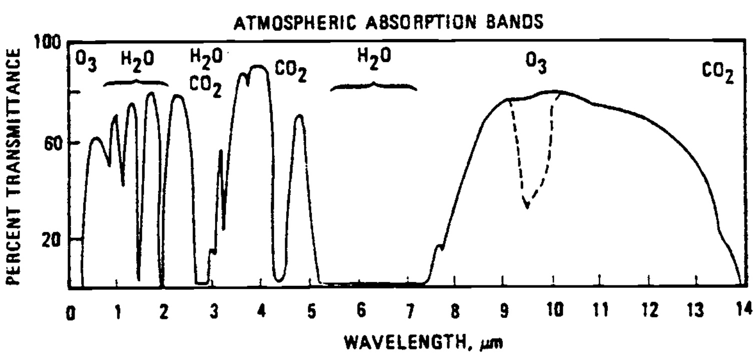


Figure 32. Atmospheric absorption and transmission.
From Sabins, 1978.

Scattering

Scattering, like absorption, is also wavelength dependent, being more pronounced in the shorter wavelengths. With scattering there is no loss of energy, but the energy is reflected or refracted by the particles in unpredictable directions, causing some of the energy to be directed outside the field of view of the sensor. If the field of view is large, some of the energy reaches the sensor, otherwise it is lost. In both cases deterioration of the image results. There are two major kinds of scattering, selective and non-selective.

1. Selective Scattering

Selective scattering is of two kinds, Rayleigh and Mie. With Rayleigh scattering, the molecules responsible for scattering are much smaller than the wavelength of the energy being scattered. In a clear atmosphere (in the absence of water vapor and dust particles), the major scattering agents are oxygen and nitrogen molecules which are shorter than the visible wavelengths. Rayleigh scattering is inversely proportional to the fourth power of the wavelength, hence the blue is scattered sixteen times more than the red. Scattering of the ultraviolet and blue presents the problem of haze and strong skylight which is added to the scene equally, thus reducing the contrast between the object and the background and reducing the image quality. For this reason a yellow filter is used in black and white photography to reduce the effect of skylight.

In Mie scattering, the scattering particles are equal to the scattered wavelengths of energy. Dust, smoke and water cause Mie scattering. Consequently all visible wavelengths are equally scattered.

2. Nonselective Scattering

Nonselective scattering is caused by dust, fog, cloud and aerosol with particle size more than ten times the wavelength of energy. Scattering is nonselective with respect to wavelength and all energy is equally scattered.

The scattering that occurs in the atmosphere is a combination of all the three kinds. The atmosphere rarely approximates a Rayleigh atmosphere even at its clearest. In a semi-arid climate, with dry summer and strong wind conditions, such as the intensive study area for this study, some dust is always present which is enhanced by the tilling operations. Thus, the dust particles which are equal in diameter to the wavelength of light are the most important scattering agents, causing Mie scattering. The atmosphere here is virtually free of fog and clouds and relative humidity is very low in the growing season, except very close to the irrigated fields where water is constantly being evaporated as sprinkling continues. Because of strong winds, it seldom accumulates in considerable quantities to cause any significant damage to the image quality.

Reflection

Reflection of energy takes place when the energy that is not absorbed or scattered reaches the target; some of it is scattered or reflected. The rest is either absorbed or, if the target is transparent to the energy, transmitted through the target. It is the reflected energy which is so important in photographic remote sensing. Reflected solar energy is the source of remote sensing data in the photographic region of the electromagnetic spectrum. Reflection is the ratio of the reflected energy to the total incident energy and depends on the reflective property of an object. Reflective property or reflectivity of an object is dependent on the nature of reflecting surface. If the surface is smooth it causes specular or "mirror" reflection. In this kind of reflection, average surface roughness is many times smaller than the wavelength of energy incident upon it. When the surface is rough, as is the case in agricultural scene due to differing crop heights, orientation, the presence of furrows and ditches, it results in diffuse reflection which is non-directional. Few surfaces reflect incident energy equally in all directions. Such surfaces are called Lambertian surfaces and freshly fallen snow is an example. In most cases, the reflection is of a mixed type. Figure 33 shows different types of reflections. Aerial and space images record this reflected solar energy which is dependent on wavelength, angle of incidence, viewing angle, and the physical and electrical properties of surfaces.

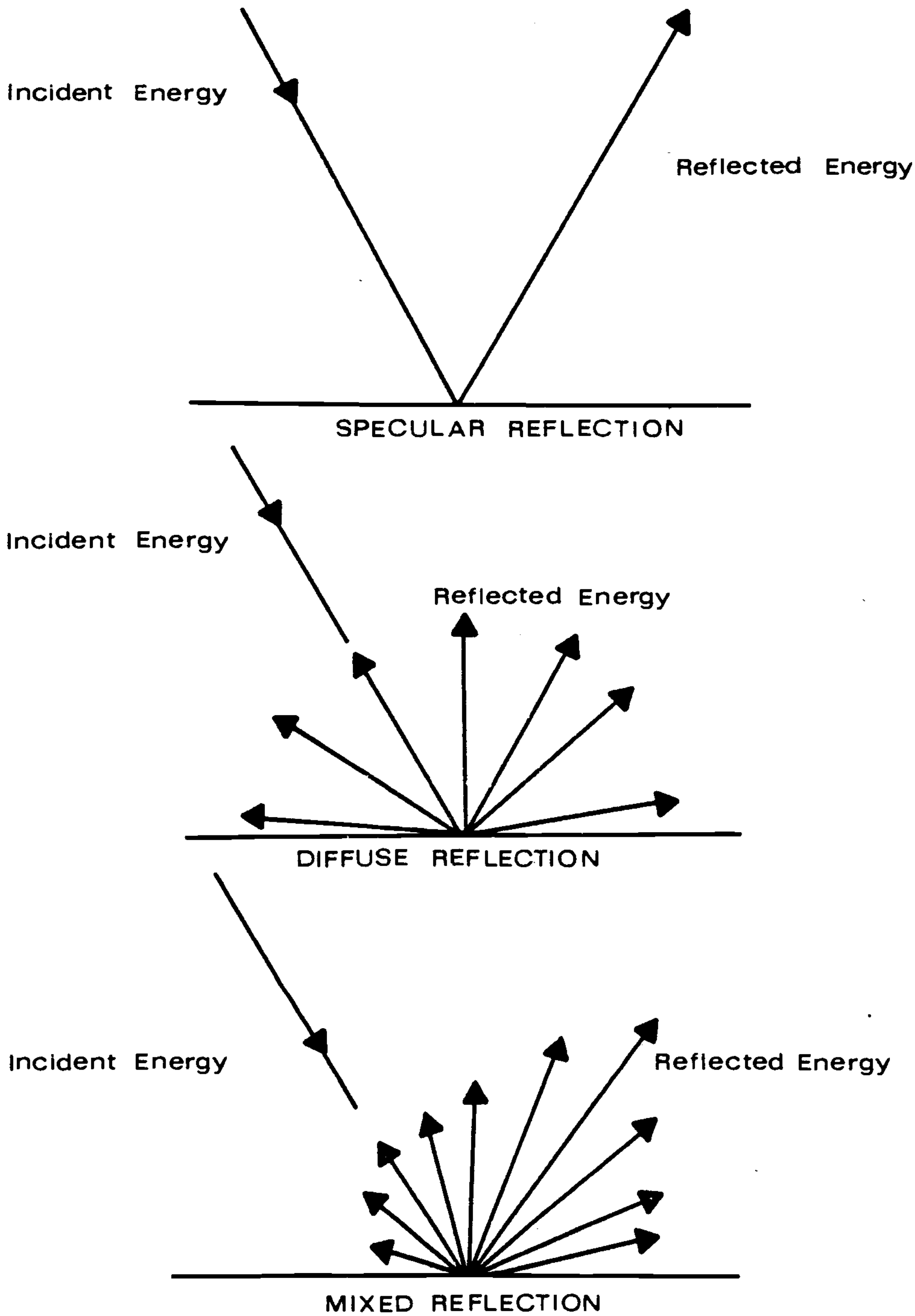


Figure 33. Various types of reflections.

Photographic Systems

In photographic systems a variety of cameras are used for acquiring the image, using a lens as the optical system and the film as the detector.

Cameras

An aerial camera consists of a light-free box which has a lens, aperture, shutter, and filter at one end and a light-sensitive film at the other end. The film is inside a magazine which has a supply spool, a take-up spool, and a drive mechanism that drives the film from the supply to take-up spool. A mapping or cartographic camera is a framing camera in which the film is advanced frame by frame. Its chief feature is its high resolution and distortion correction. A continuous strip camera has a narrow field of view, approximately 75 degrees as compared to the 90 degrees of a mapping camera. It operates on the principle of moving the film behind a slit in the focal plane of the camera at exactly the same speed as the image moves past the slit. The slit admits light continuously, permitting sharp, clear images at low altitudes.

The optical components of the camera consist of the lens, aperture, shutter and filter.

1. Lens

The spectral transmission of a lens is a critical point in photography. A modern high-performance lens uses a high lead content glass which reduces the spectral transmission in the short wavelength region. The lens normally has a 50 to 60 degree field of view (FOV) but a wide-angle lens may have a FOV of 90 degrees or more. In many cases, the FOV of a photographic system is considerably larger than that of a line scanner.

The focal length is the dimension along the optical axis from the rear nodal point of the lens to the focal plane, when the lens is focused at infinity. The focal length of the camera determines the scale of the image. The scale is given by:

$$S = f/H$$

where, S is the scale of vertical imagery,

f is the focal length, and

H is the flying height of the aircraft.

At any given altitude image size changes in direct proportion to the changes in focal length, and for a given focal length image size changes with the changes in altitude. Effect of focal length and altitude is shown in Figures 34 and 35.

The resolving power of the lens is its ability to separate adjacent objects from each other. It is determined by the number of lines/mm that the lens will reproduce. A 3-line resolution test consists of three black bars, five times as long as they are wide.

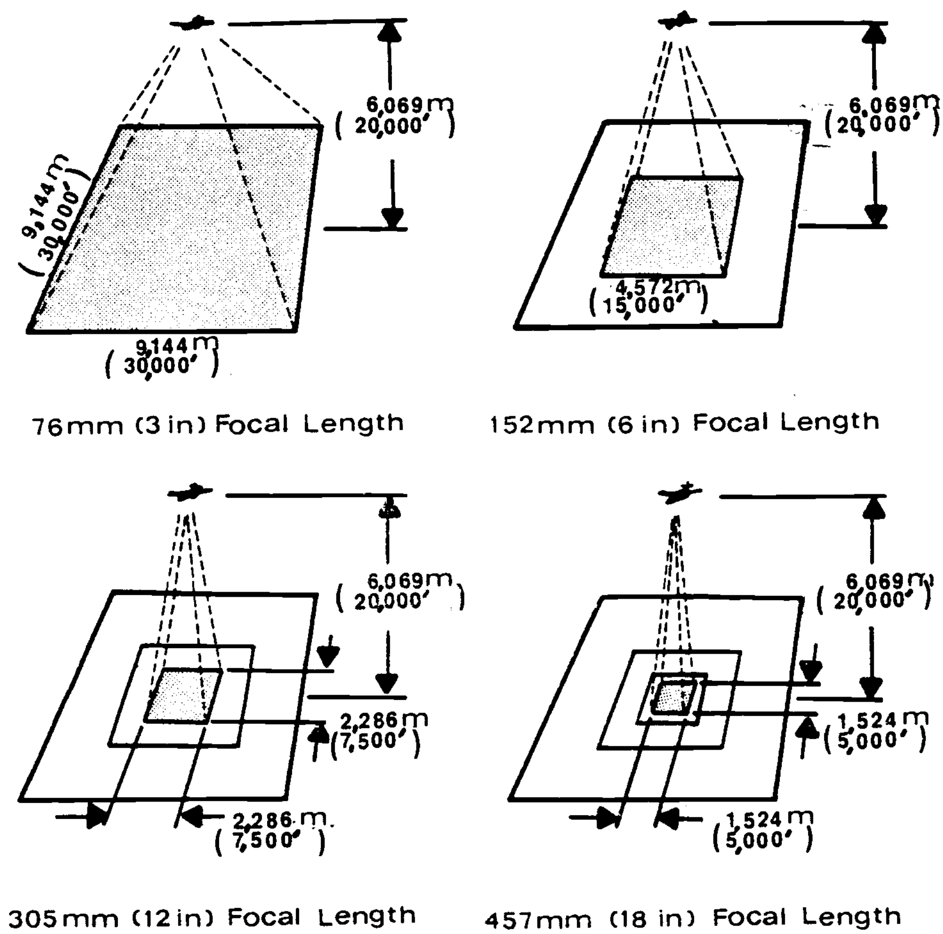


Figure 34. Effect of focal length on scale and ground coverage. From Naval Reconnaissance and Technical Support Center - Image Interpretation Handbook, 1967.

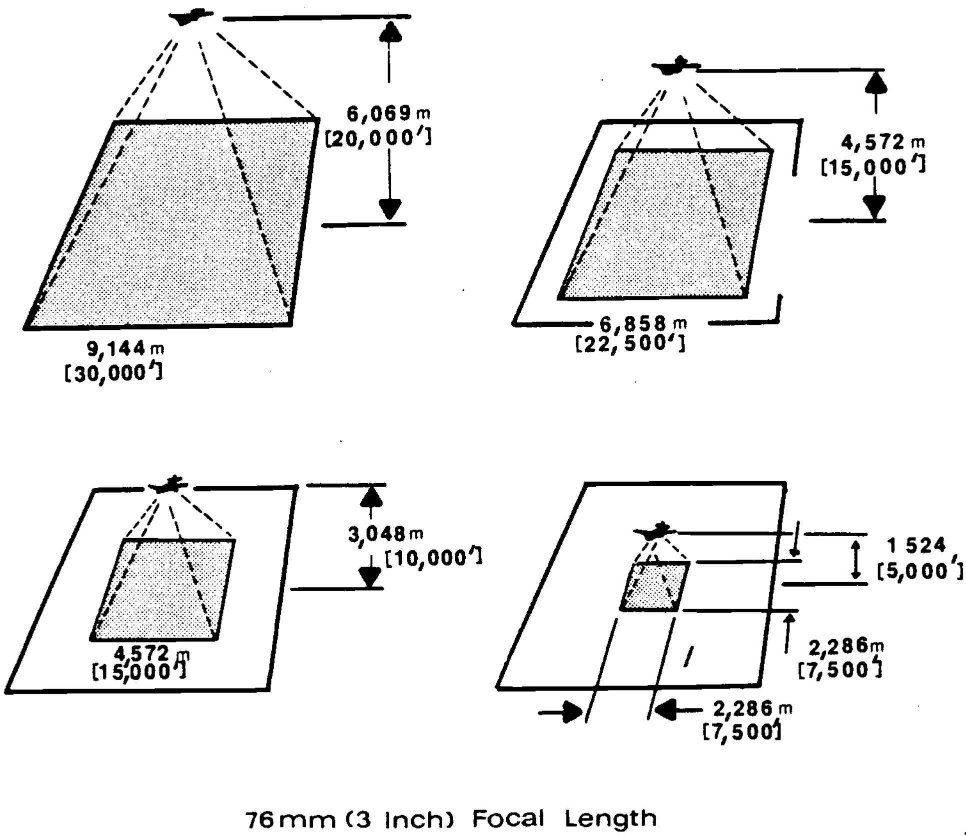


Figure 35. Effect of altitude on scale and ground coverage. From Naval Reconnaissance and Technical Support Center - Image Interpretation Handbook, 1967.

A resolution target has numerous line groups of various sizes as can be seen in Figure 36. A lens is tested by determining the smallest line group in which the bars can be distinguished from the spaces. It is not the size but the ability to separate a furrow from an adjacent furrow, or two siphon tubes from each other, or wheels of a side-roll system, which enables us to identify the irrigation practices.

2. Aperture

The aperture or the speed of a lens is determined by its f/stop. The f/stop is the ratio of the camera focal length to the diameter of the lens. Given two lenses of the same focal length, but of two different diameters, the larger lens will pass more light than the smaller one and is said to be faster.

3. Shutter

The shutter admits light to the film at the time of exposure. While the lens aperture controls the intensity of light admitted, the shutter controls the length of time the light strikes the film. The combination of aperture and shutter speed determines the exposure.

4. Filter

Under certain conditions use of corrective filters becomes necessary to obtain a good image. Most commonly used filters are antivignetting filters and UV filters. An antivignetting filter is used for uniform exposure. Vignetting, or image intensity fall-off,

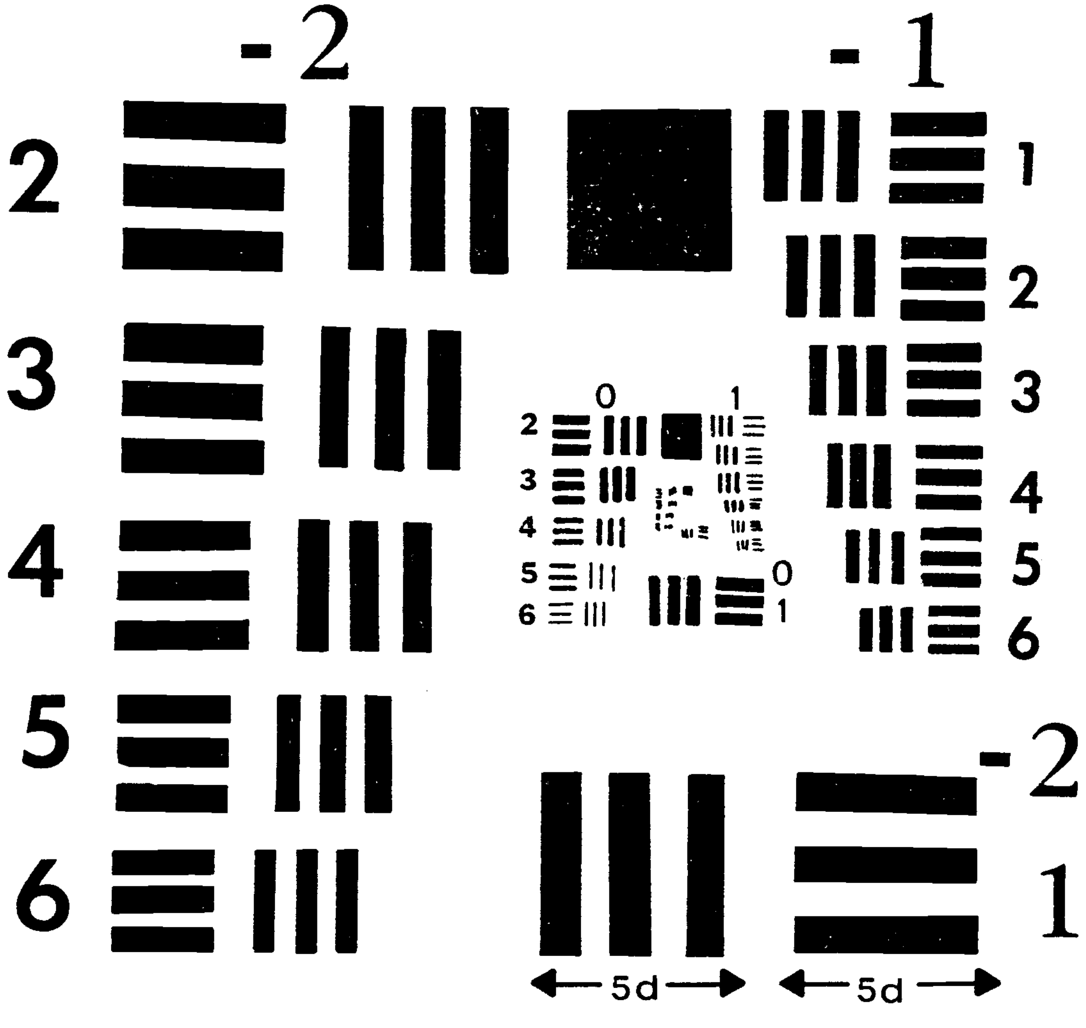


Figure 36. Resolution power test targets. From Manual of Remote Sensing, 1975.

takes place when a wide-angle lens is used. The edges of the image are considerably darker than the center. To compensate for this, antivignetting filters are used. Atmospheric haze also creates problems that can be eliminated by using haze compensation filters.

Camera Film

In a photographic system the film serves as the radiation detector. It consists of an emulsion layer, an antihalation layer and a plastic base. The light passes through the film and is registered on the emulsion. The antihalation layer prevents the reflection of light from the base back into the emulsion layer. There are four types of emulsions in use for aerial photography: black and white, black and white infrared, color, and color infrared.

1. Black and White Emulsion

Most black and white films are sensitive to all wavelengths in the visible portion of the spectrum (0.38 to 0.72 micrometers). They are known as panchromatic films. The emulsion is a suspension of silver halide grains in a gelatin base. When the film is exposed to light, the impinging photons disassociate a small amount of silver from the silver halide and turn it into a silver atom. When the film is developed, the silver atom turns into metallic silver and the film is said to contain a latent image. On further processing, the unexposed silver grains are removed, leaving clear areas on the emulsion. At this stage the film is known as a film negative. When printed on a photographic paper, the situation is reversed. This process is explained in Figure 37.

The granularity of the film defines the film speed. A high resolution film has large silver halide grains so that only a few photons are needed to expose the film. But when the film is developed it lacks the fine detail that is achieved on a slow film which has smaller silver halide crystals, meaning that a relatively large number of photons are needed to form an image. But the disadvantage of a slow film is that, because of the longer exposure time needed, the film may suffer blur when mounted on a very unstable platform.

The resolving power of the film is determined by a number of factors. The most important is the granularity of the film which is determined by the grain size of silver halide and the processing of the film. Faster film with large silver halide grains has poor resolution. One way of determining the resolving power of the film is to determine the maximum number of line-pairs/mm that can be distinguished on a developed film. Targets with high-contrast ratios produce better film resolution than targets with low-contrast ratios. Depending on the contrast ratio of the target, the film resolution may range from 300 line-pairs/mm to 80 line-pairs/mm. The combined resolution of the lens and the film is called the system resolution,

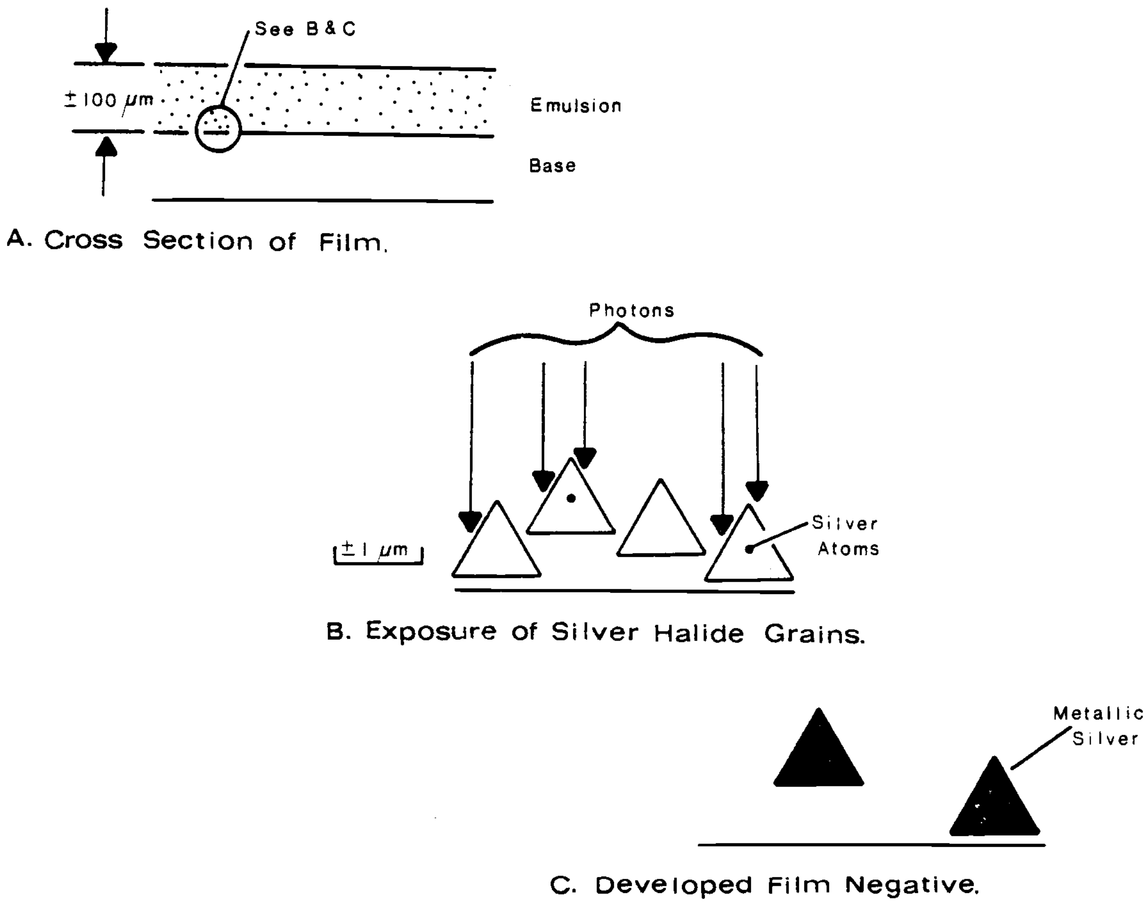


Figure 37. Film technology. From Sabins, 1978.

and usually ranges from about 25 to 100 line-pairs/mm. Ground resolution, which expresses the ability to resolve ground features on aerial photographs, is given by:

$$Rg = (Rs*f)/H$$

where, Rg = ground resolution in line-pairs/mm,

Rs = system resolution in line-pairs/mm,

f = camera focal length in mm, and

H = absolute flying height in m.

Ground resolution when divided by two (Rg/2) gives minimum ground separation which is the minimum distance between two targets that can be resolved on a photograph. Figure 38 illustrates ground resolution calculation for an idealized furrow irrigation system on an aerial photograph. Distance between furrows ranges from 45 to 120 cm. Most row crops (except corn and potato) are sown 50 cm apart. Thus, minimum ground separation (Rg/2) of 50 cm, or ground resolution (Rg) of 1 line-pair/m is desired for interpretation of irrigation practices. Given a focal length of 152 mm and system resolution of 30 line-pairs/mm, the flying height which would produce the Rg of 1 line-pair/m can be calculated by transposing the above equation:

$$H = (Rs*f)/Rg;$$

$$H = (30 \text{ line-pairs/mm}* 152\text{mm})/1 \text{ line-pair/m};$$

$$H = 4560 \text{ m}.$$

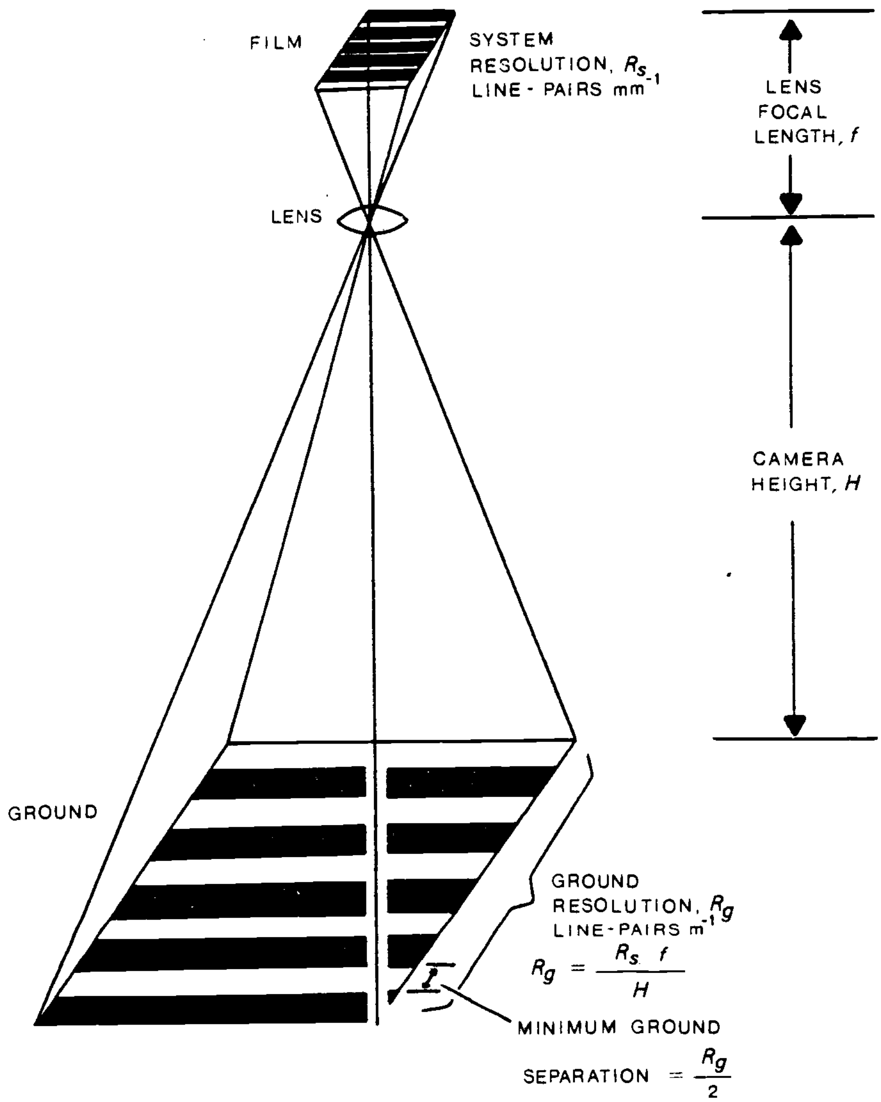


Figure 38. Ground resolution and minimum ground separation for irrigation method identification on aerial photographs. From Sabins, 1978.

2. Black and White Infrared Emulsion

Special sensitizing procedures can make a black and white film sensitive to infrared wavelengths of approximately 0.9 micrometers. Infrared photography has certain advantages over panchromatic black and white photographs. It provides a better haze penetration because the yellow filter eliminates the severe scattering effect of shorter wavelengths. By eliminating the effect of skylight better contrast is achieved. Maximum reflectance variation from vegetation occurs in IR region. IR radiation is absorbed by water, hence water appears very dark and it is easy to distinguish the boundary between irrigated and dry land if surface waters are present.

3. Color Emulsion

Color film frequently has an advantage over black and white film. An average observer discriminates many more colors than shades of gray. The capability of visual perception of color associated with a feature when combined with spatial characteristics such as shape, size and texture, permits discrimination of irrigated fields from their unirrigated counterparts.

The visible region of the spectrum extends from approximately 0.38 to 0.72 micrometers, which is subdivided into many components, as shown in Figure 39. Most people can perceive these colors. All the colors that we perceive do not exist in the spectrum. The

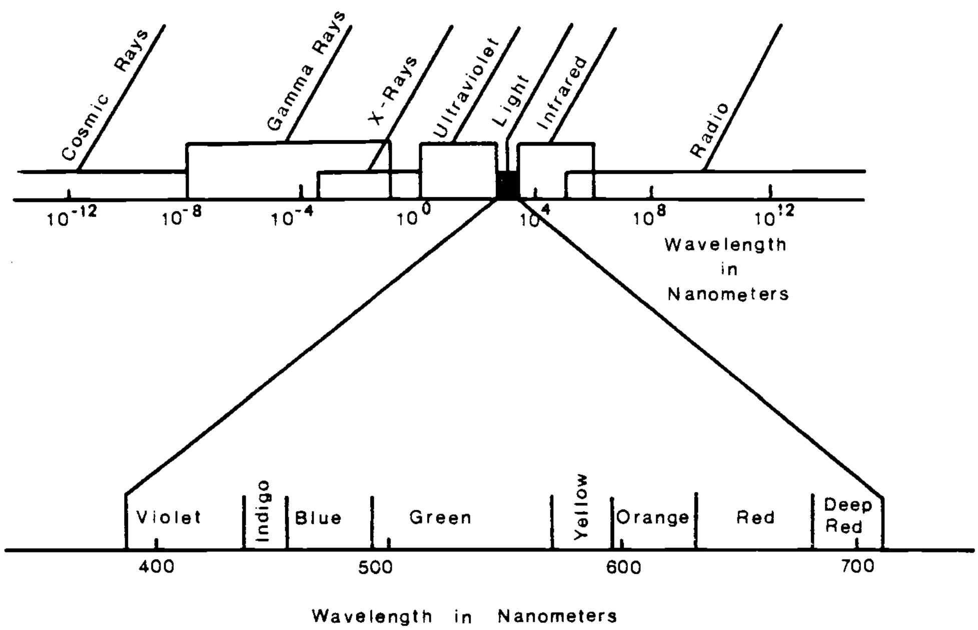


Figure 39. Visible spectrum and spectrum colors. From Wenderoth, 1972.

spectrum colors are violet, indigo, blue, green, yellow, orange, and red. Others are mixtures of these colors and are called non-spectrum colors. The color we see is the brain's code for EMR of these wavelengths. When the EMR in specific wavelengths interacts with matter, some of the energy is reflected and reaches the eyes. As this reflected light impinges on the retina, a signal is sent to the brain and a specific object is perceived as being of a specific color. This sensation of color differs from individual to individual and should not be confused with the spectrophotometrically measured color of an object, which depends on its reflectance characteristics and the make-up of light impinging upon it. The lens-film-filter combination attempts to capture this reflectance from an object.

There are a number of ways in which energy interacts with matter to produce color. Green leaves absorb blue and red light and reflect most of the green light so that vegetation appears green. When a substance reflects all light in equal proportions it appears white. If it reflects only part of the incident energy, it appears gray and black when it absorbs all of the incident energy. Thus, the reflected light waves return to the observer to create the perceptual impression of color.

There are three perceptual dimensions of color: hue, chroma and value. Hue describes a color as red, yellow, blue or green, etc. Chroma refers to the amount of white contained in a color. It is a measure of pureness of the color and expresses the amount of hue contained in the color. Value is the measure of amount of black contained in the color. As a hue takes on a progressively lower value, it approaches pure black. The purpose of color photographic processes is to reproduce these color dimensions as closely as possible. There are two main approaches to this: additive color photography and subtractive color photography. Subtractive color photography is widely used in remote sensing.

Subtractive color photography uses three primary color filters: yellow, magenta and cyan. Ideally, each subtractive primary filter absorbs one-third of the visible spectrum and transmits two-thirds. Subtractive color filters thus allow non-absorbed light to be transmitted. A yellow subtractive filter subtracts blue and transmits green and red light, a magenta subtractive filter subtracts green and transmits blue and red light, and a cyan subtractive filter subtracts red and transmits green and blue light. When the three are placed together the combination appears black as no light is allowed to pass.

A color film is based on the same silver halide chemistry as the black and white film. It consists of a transparent base coated with emulsion layers, each layer sensitive to one of the additive primary colors: blue, green and red. There are two types of aerial color films: reversal and negative. The reversal film when processed produces a positive transparency in which the images appear similar to the original scene. A negative film yields a negative transparency in which the images appear in the complementary colors of the original scene.

Figure 40 shows the spectral sensitivity and image formation on a reversal film. The top layer is sensitive to blue, the middle layer is sensitive to green and the bottom layer is sensitive to red light. As both green and red layers are also sensitive to blue, a metallic silver yellow filter is placed after the first layer to prevent the blue light from exposing the green and red layers. After the film is exposed, it is processed and bleached. When viewed by a white light the resulting transparency portrays the original scene in true colors.

The process of image formation in a color negative film is shown in Figure 41. The emulsion layers are in the same order as for reversal film. After exposure the film is developed in a color developer and bleached. The final result is a color negative transparency in the complementary colors.

4. Infrared Color Film (IR)

Infrared color film is sometimes referred to as false color or camouflage detection film as it was used in World War II to differentiate between normal vegetation and camouflage. With this film certain objects are purposely imaged with different colors than they exhibit in nature, hence it is called a false color film. The spectral sensitivity is changed to correspond to the

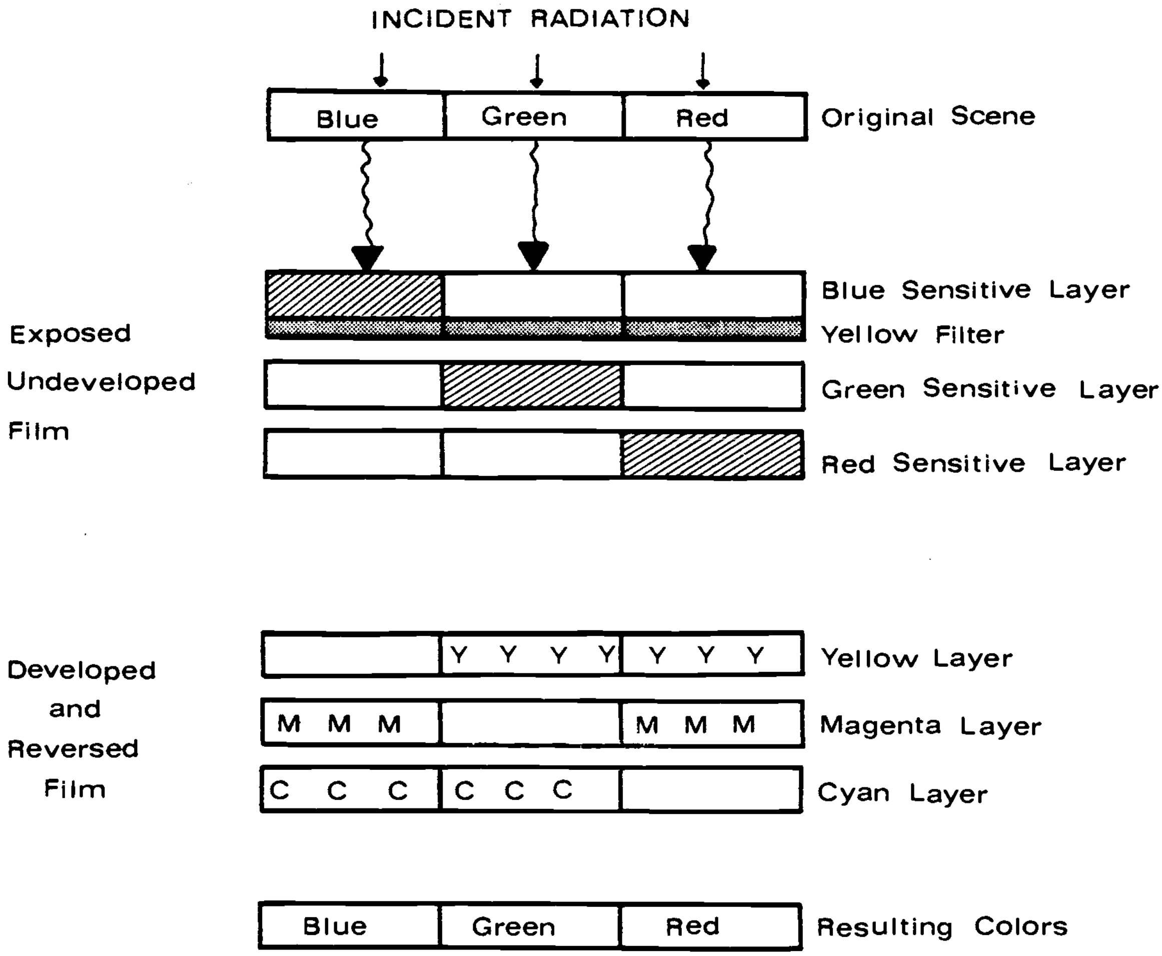


Figure 40. Spectral sensitivity and image formation in a color reversal film.

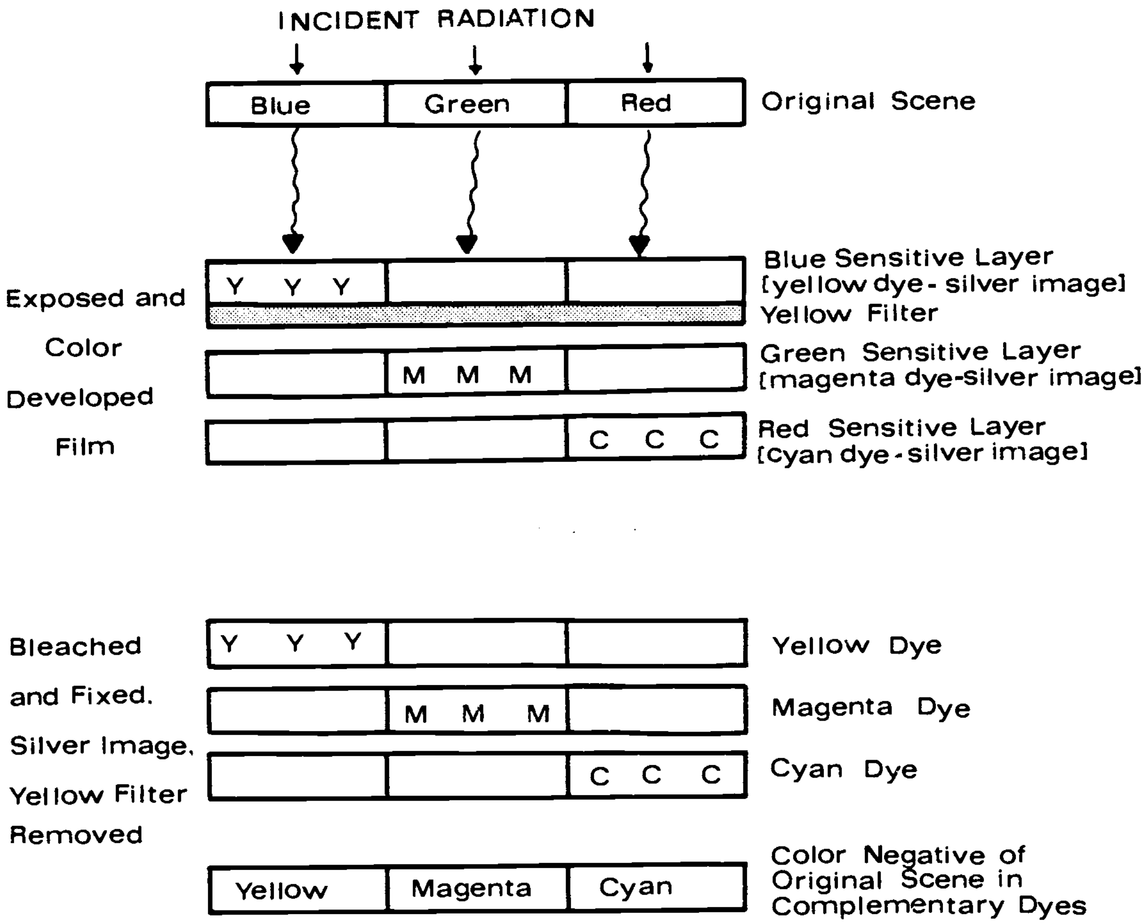


Figure 41. Color negative film processing.

photographic IR region. In a color film three layers are sensitive to blue, green and red light. In an IR film, the blue light is eliminated by using a yellow filter over the lens. This elimination of blue wavelengths improves the haze penetration capacity of the IR film, and changes the spectral sensitivity of each layer as is shown in Figure 42. The three layers are sensitive to IR, red and green wavelengths and the spectral sensitivity of the film ranges from 0.5 to 0.9 micrometers. With the elimination of blue, the three dye layers (cyan, magenta and yellow) now respond to IR, red, and green wavelengths, respectively. After the film is exposed, it is developed by a reversal process and dyes are formed in each layer. Figure 43 shows how the image is formed on an IR film. The areas that were struck by green light appear blue, those struck by red appear green and those struck by IR appear red.

Optical-Mechanical Scanning Systems

In a scanning system, data are acquired sequentially as opposed to simultaneous image acquisition in a photographic system. Data may be converted into an image format for interpretation or can be used for computer-aided analysis. The digital nature of the data is very convenient for machine handling. Landsat has provided the data for this study, so the mechanism of Landsat data acquisition system and its inherent weaknesses in irrigation method discrimination are described in detail.

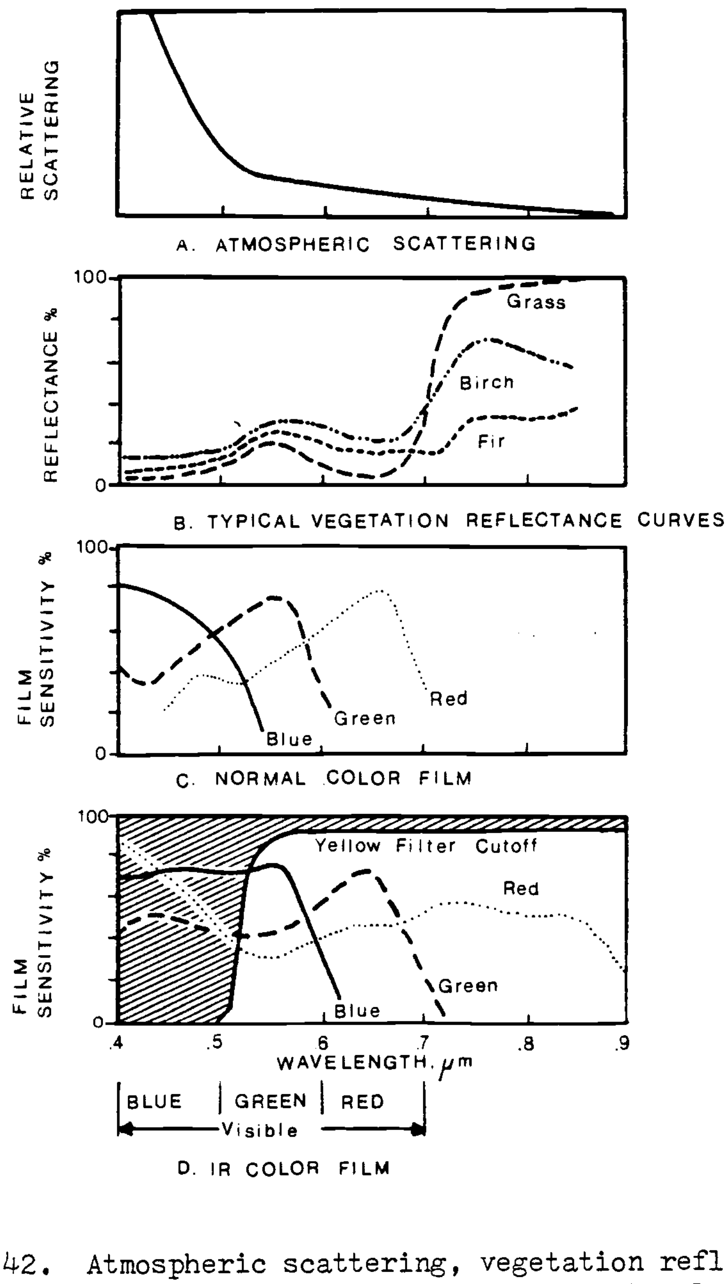


Figure 42. Atmospheric scattering, vegetation reflectance, and spectral sensitivity of normal color and infrared films. From Sabins, 1978.

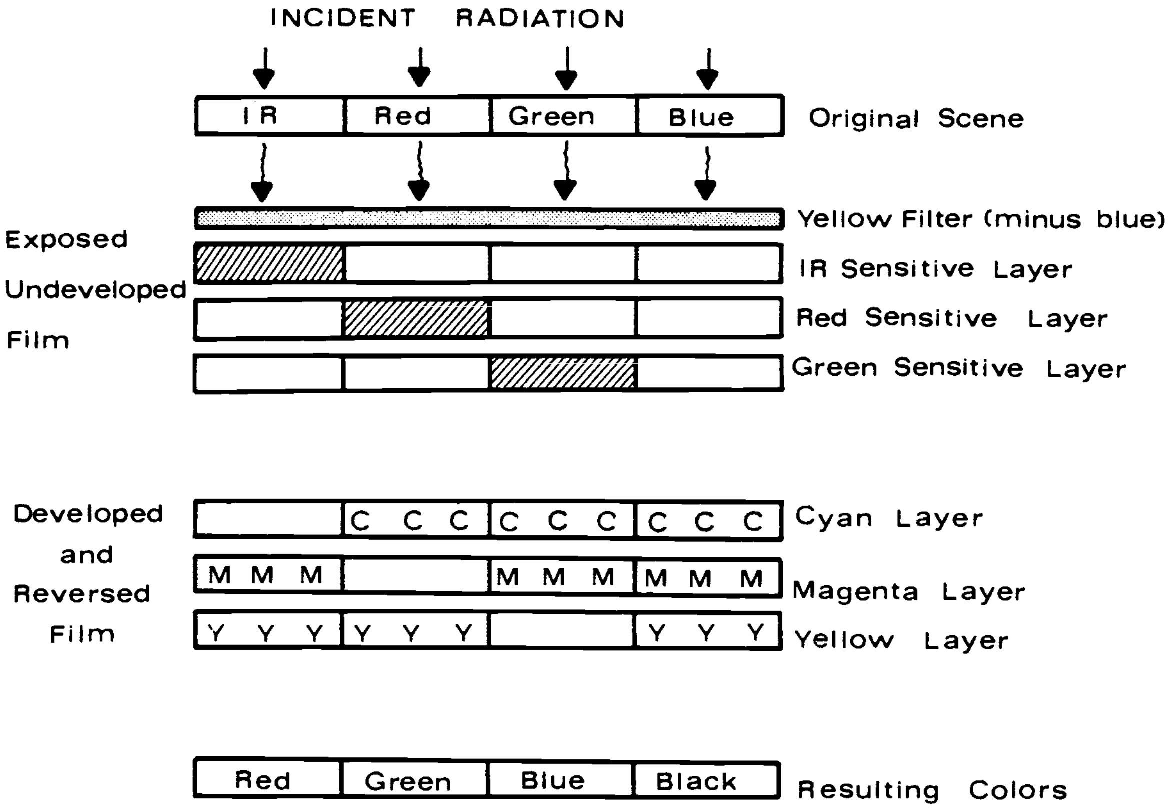


Figure 43. False color infrared film response.

Landsat Satellites

On July 23, 1972, NASA launched the first Earth Resources Technology Satellite (ERTS 1). It was followed by an identical second satellite on January 22, 1975. At this point the satellites were renamed as Landsat 1 and Landsat 2. On March 5, 1978, Landsat 3 was launched with some modifications and additional features. Landsat 1 ceased to operate on July 6, 1978, hence all further discussions refer to Landsat 2 and 3, for MSS, and Landsat 3 for RBV.

Landsat Orbital Parameters

The satellites operate in a circular, sun synchronous orbit at a nominal altitude of 920 km (570 mi), crossing the equator at 9:30 a.m. during the descending node. One orbit takes 103 minutes to complete, resulting in 14 orbits per day and complete coverage of the earth every 18 days. The two satellites are so placed in space that Landsat 2 followed the orbital track of Landsat 3 (initially occupied by Landsat 1) after 9 days. Each satellite passes over adjacent points at the same latitude at the same local time as on the previous day, and repetitive image centers do not vary by more than 37 km (23 mi). This feature facilitates comparison of Landsat images of a given area collected during repetitive coverage. Table VI gives orbital parameters for Landsat 2 and 3 as provided by USGS (1979).

TABLE VI. LANDSAT ORBITAL PARAMETERS

Orbital Parameter	Landsat 2	Landsat 3
Semi-major Axis (km)	7285.989	7285.776
Inclination (deg)	99.210	99.117
Period (minute)	103.210	103.150
Eccentricity	0.001019	0.001330
Time of Descending Node Equatorial Crossing (location)	9:08 a.m.	9:31 a.m.
Coverage Cycle Duration	18 days (251 rev)	18 days (251 rev)
Distance Between Adjacent Ground Track at Equator (km)	159.38	159.38

Source: Landsat Data Users Handbook, USGS (1979).

Landsat Scanner

The satellites carry two types of scanners: a return beam vidicon (RBV) and a multispectral scanner (MSS).

1. Return Beam Vidicon (RBV)

The RBV system on Landsat 3 has two panchromatic cameras, operating in the range of 0.51 to 0.75 micrometers. They produce two side-by-side images in the same spectral region. Each image portrays 99 by 99 km (66 by 66 mi) areas and four RBV images constitute one MSS scene.

2. Multispectral Scanner (MSS)

Each Landsat carries a MSS which produces a continuous strip image of the earth's surface. The spectral sensitivity of MSS spectral bands is given in Table VII. The thermal infrared band on Landsat 3 failed to operate, hence all further discussions are pertinent to bands 4 through 7 which are identical on all these satellites.

The MSS continuously scans 185 km swaths in raster fashion, with each scan line perpendicular to the Landsat orbital track, as is seen in Figure 44. The photoelectric sensor consists of an oscillating mirror with a scan angle of 11 ± 2.89 degrees and four spectral bands. With each across track mirror oscillation, six scan lines for each of the four detectors are scanned simultaneously.

TABLE VII. MSS SPECTRAL BAND SENSITIVITY

Band	Spectral Region	Wavelength Range (in micrometers)
4	Green	0.5 - 0.6
5	Red	0.6 - 0.7
6	IR	0.7 - 0.8
7	IR	0.8 - 1.1
8	TIR	10.4 - 12.6 (Landsat 3 only)

Source: Landsat Data Users Handbook, USGS (1979).

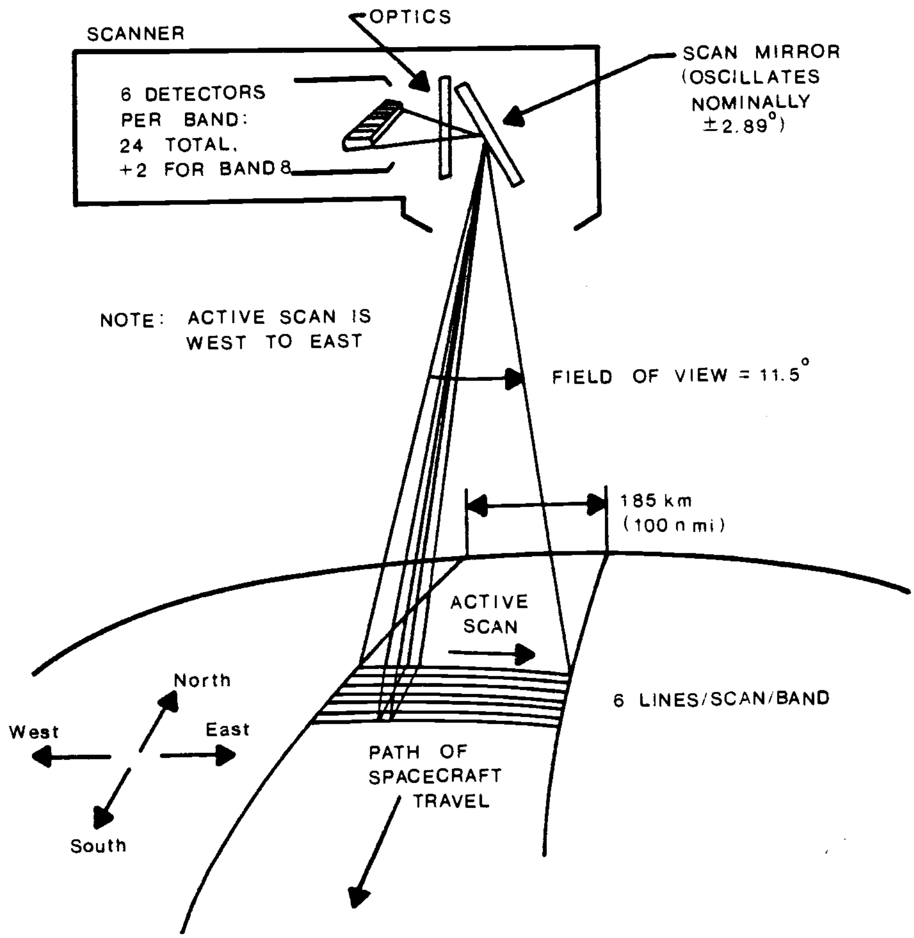


Figure 44. Landsat MSS scanning pattern. From USGS, 1979.

The forward motion of the satellite provides the along-track progression. The scanning pattern for a single MSS detector is shown in Figure 45. The instantaneous field of view (IFOV) of each detector is 0.086 by 0.086 mrad, which produces a 79 by 79 meter ground resolution cell, usually referred to as a picture element or a pixel. The data in various spectral bands are acquired sequentially and the effective dimensions of a pixel are 56 by 79 meter. A Landsat scene covers 185 by 185 km on the ground and is scanned in 28 seconds. It includes 2340 scan lines and 3000 to 3450 pixels per line. Variations in the number of pixels are due to variations in the satellite's altitude, which, along with IFOV, determines the size of the pixel. Each scene contains approximately 7.5 million pixels.

Landsat MSS data are transmitted to ground receiving stations and processed. Data are available in two formats: image format and computer-compatible tapes (CCT).

a) Image Format - Digital data received from Landsat are played back on an electron beam film recorder and black and white images are produced for each spectral band. Color composites, known as false color composites, are produced from black-and-white transparencies of bands 4, 5, and 7 to simulate CIR images. They are available both in color print or color transparency form.

Spatial resolution of Landsat images is a function of the

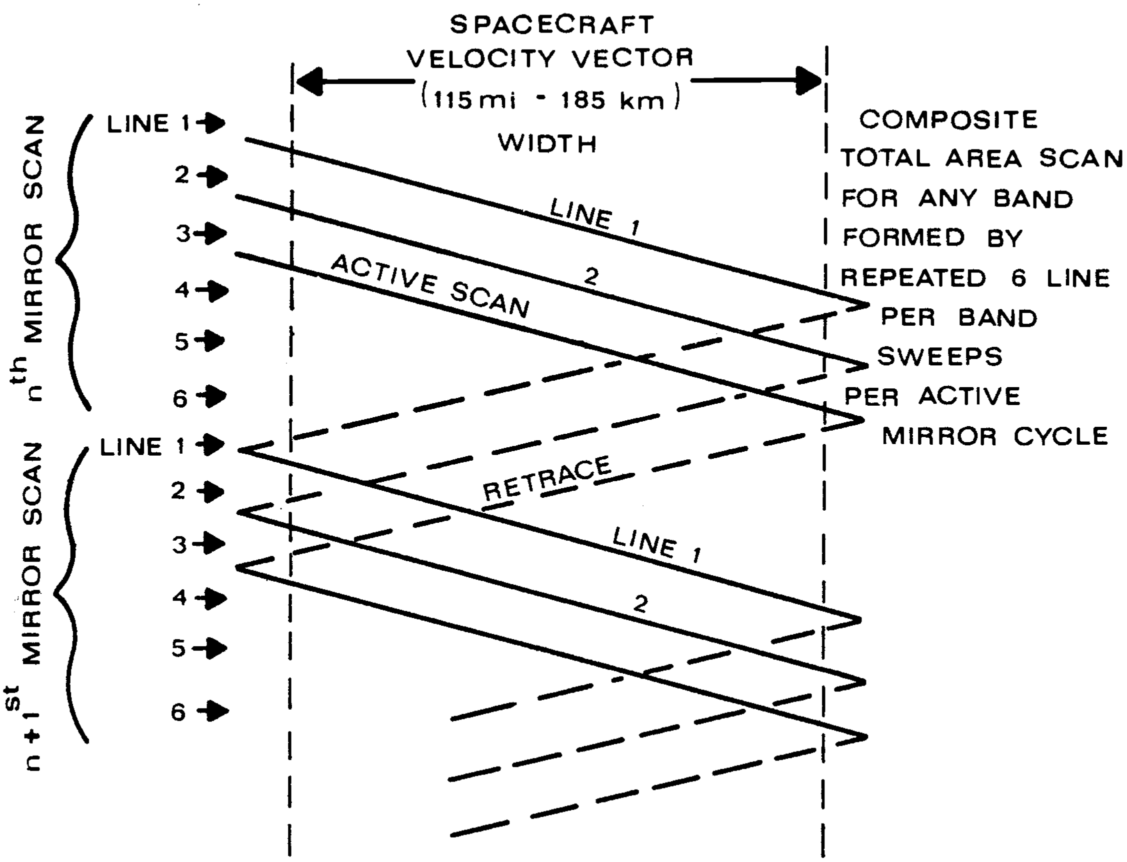


Figure 45. Scan pattern for a single MSS detector.
From USGS, 1979.

IFOV and the height of the sensor, and is also affected by atmospheric conditions, contrast ratio of the scene, and the play-back and reproduction of the image. Images are usually produced at a scale of 1:1,000,000 but can be enlarged to 1:500,000 or 1:250,000.

b) Computer-Compatible Tape (CCT) - The analog value of the scene (which is directly proportional to the surface reflectance) is converted into digital form by sequential sampling of the surface reflectance. These data are recorded onboard, then transmitted directly to earth receiving stations, where they are recorded on computer-compatible tapes. Each tape has information for one Landsat scene and is divided into four data files. Each file contains the brightness value for each band for a 46 km wide (in east-west direction) and 185 km long (in north-south direction) strip. The brightness values for bands 4, 5, and 6 are recorded using a seven-bit scale (0-127) and for band 7 on a six-bit scale (0-63). Prior to processing, bands 4, 5, and 6 values are multiplied by two and band 7 values are multiplied by four to produce a uniform eight-bit (0-255) format.

Limitations of Landsat Data

The photoelectric sensor of MSS looks at a small area (a pixel) on the ground at any one instant, outputting a voltage proportional to the radiation reaching it at that given instant. Then the sensor rotates and surveys another small area. As can be seen in Figure 46, the output voltage changes as the field of view passes over a boundary, but it does not change instantaneously. The radiation reaching to the sensor at one given instant is the composite reflectance of the pixel area being looked at. If the area is composed of a homogeneous surface, the output voltage is proportional to the true reflectance value. But if the area concerned is a boundary between more than one kind of surface, the output voltage produced is the integrated value of the entire pixel area. This mixed pixel or boundary pixel is thus regarded as containing spurious data. The pixel size of Landsat MSS is so large (79 x 79 m or about 1.125 acres) that in many instances the pixel is larger than the feature of interest on the ground. In irrigation method identification the most important clues are provided by the presence of furrows, wetted diameter of sprinklers, and the width and length of wetted strips. Normally all of these are smaller than the pixel size. Thus, with regard to irrigation, most Landsat pixels can be regarded as mixed class pixels. These factors severely limit the use of Landsat digital data for irrigation method identification.

The quality of the MSS image is affected by scattering. Scattering is more prominent in shorter wavelengths, therefore

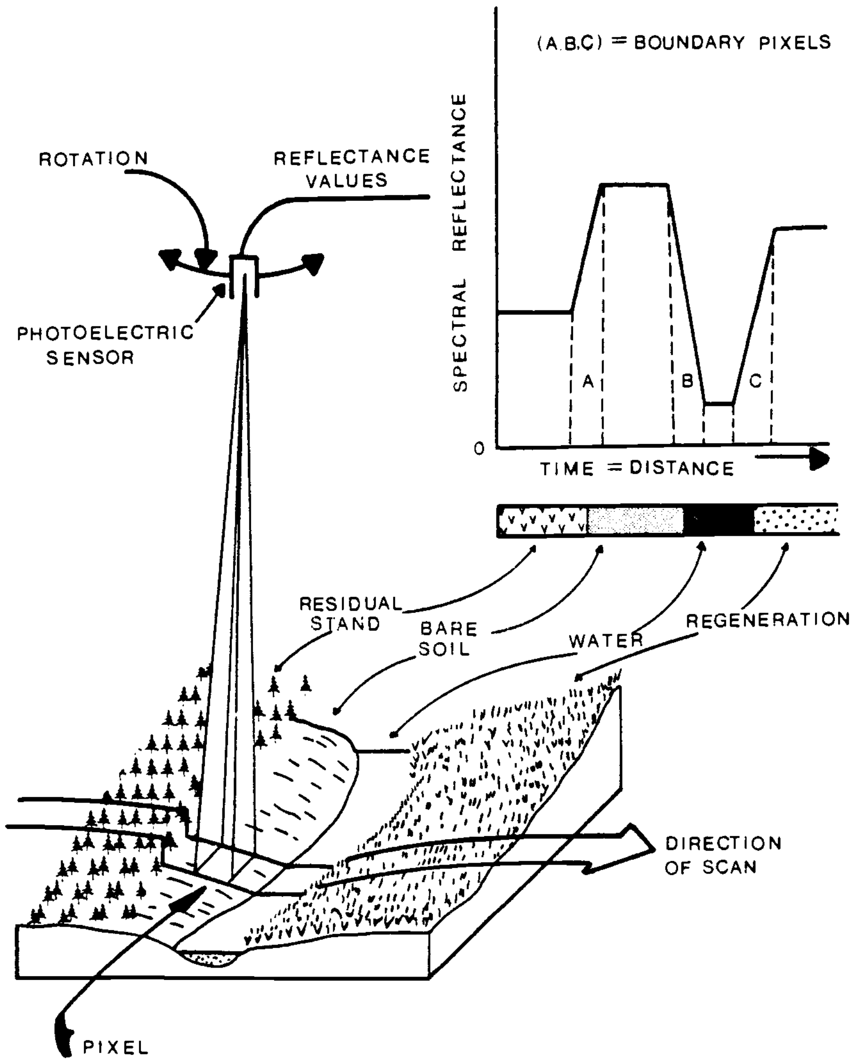


Figure 46. Boundary pixel problem in scanner data. From Grabau, 1976.

Landsat MSS data acquired in band 4 are subject to most atmospheric attenuation, whereas band 7 is relatively free of atmospheric effects. Atmospheric corrections are useful before analysis is done.

Image Charactersitics

All images have certain characteristics which can be used for interpretation purposes. We can classify them under three categories: spatial, spectral and temporal.

Spatial Characteristics

Spatial features of an image are vitally important for proper identification of an object. The most important spatial characteristics are size, shape, texture, pattern and site.

1. Size

The size of an object is one of the most important characteristics in identification of the object. By measuring the size of the fields, one can get some feel for the identity of irrigation practices. For example, small fields are associated with gravity systems or hand move sprinklers and larger fields are associated with side-roll or continuously moving systems. On a large scale photograph, the wetted diameter of a sprinkler in operation, or the distance between two laterals, may be helpful in deciding if it is a hand move or side-roll system.

2. Shape

The shape of the field alone can be a useful identification tool. Circular fields are associated with center pivot, rectilinear with most sprinklers, border strip, and furrows and irregular with furrows, contour furrow, hand move, gun and traveller systems.

3. Texture

Texture in an image is created by tonal repetition in groups of objects which are too small to be discerned as an individual object. It is the textural difference, the visual impression of roughness or smoothness on an aerial photograph, which can be used to identify agricultural crops and cultivation practices, thus providing a clue for irrigation methods. Unfortunately, texture is not as important on a MSS image because of its poor spatial resolution.

4. Pattern

Pattern is the perceptual impression provided by a repetitive arrangement of ground features. Repetition of certain features associated with agricultural practices, such as orchard crops, row crops, ditches, or furrows can be helpful identification aids.

5. Site and Situation

Site refers to the location of the object, whereas situation defines the manner in which it is located with respect to its surroundings. The location of a field with respect to terrain and water sources provides information about the kind of irrigation practice that would be followed. Irregular terrain surfaces with more than 3 percent slope and very light and very heavy soils rule out the possibility of surface irrigation. If the main supply ditch or canal is situated upslope and water runs downslope, it may be furrow irrigation. But if the wetting pattern is progressing across the slope it may be a hand move sprinkler system.

Spectral Charactersitics

Spectral characteristics of various objects are responsible for variations in spectral reflectance that are responsible for perceived color (hue, value, chroma), image contrast, and resolution. These are not only important for image interpretation, but for quantitative or computer-aided analysis of MSS data as well.

1. Color

Value variations on black and white images, hue-chroma-value variations on color and CIR images, or digital brightness values on MSS digital images help to identify ground features. These variations are in large part a function of the ability of the object to reflect incident energy. With an understanding of factors governing color or brightness, one can identify the object of interest. It is the contrast of the spectral response between the object and its surroundings which is used to determine the spatial characteristics of the object. In this study the main concern is spectral characteristics of soil moisture and vegetation which provide clues for identificaton of irrigated crops and irrigation practices.

a) Spectral Response of Vegetation - The spectral reflectance of green vegetation varies with wavelength. Figure 47 shows a typical spectral reflectance curve for a green leaf. In the visible wavelength region plant pigments, especially chlorophyll, dominate the spectral response. This region has two prominent absorption bands centered at approximately 0.45 micrometers (blue) and 0.65 micrometers (red). Plant leaves either absorb, transmit, or reflect incident energy. In the blue and red portion of the spectrum, most of the incident energy is absorbed by the chlorophyll present in the green leaf and very little is transmitted. Between these two chlorophyll absorption bands, centered at approximately 0.54 micrometers (green band), a reflectance peak is noted which causes the normal healthy vegetation to appear green to the eyes. If the plant is under stress because of some pathogen, or water stress, or because of excessive water application near the supply ditch, chlorophyll production is decreased and less energy is absorbed in blue and red bands. This

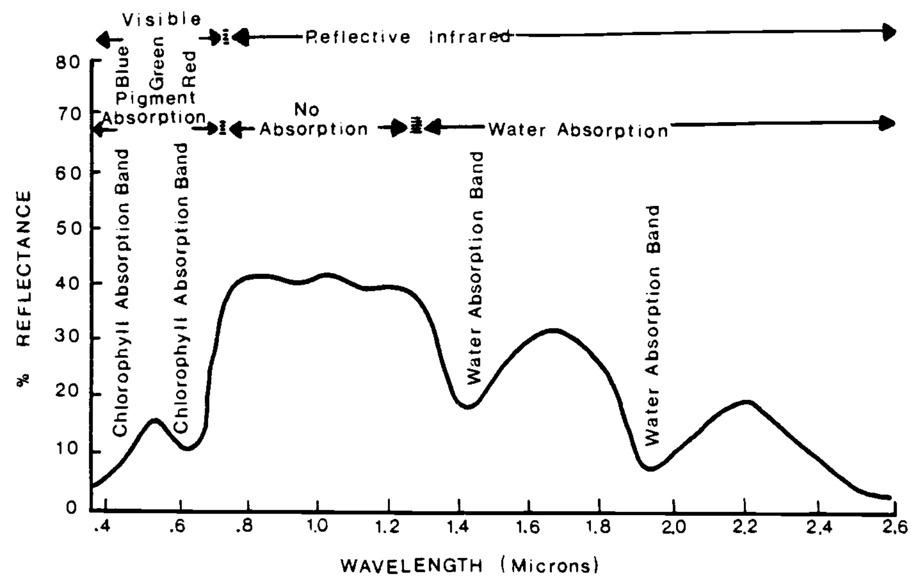


Figure 47. Spectral reflectance curve of a green leaf. From Hoffer and Johannsen, 1969.

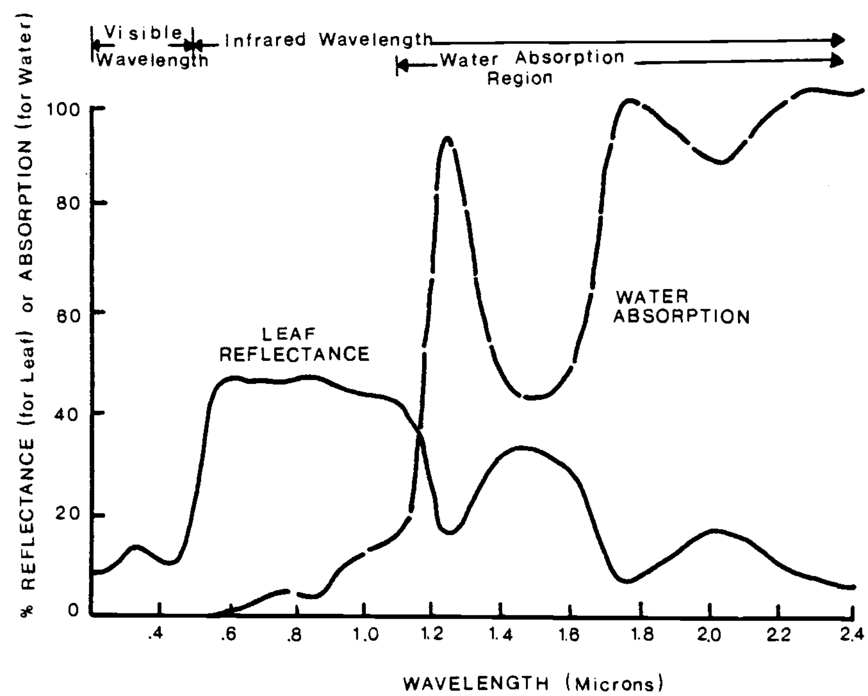


Figure 48. Relationship between leaf reflectance and water absorption. From Hoffer and Johannsen, 1969.

results in higher reflectance, especially in the red portion of the spectrum, which gives the yellow color to the leaf.

In the IR region chlorophyll plays an insignificant role in reflectance. Here, reflectance is governed by the internal structure of the leaf. Water absorbs most energy in this region. Figure 48 shows the relationship between leaf reflectance and water absorption. The minor water absorption band at 0.96 micrometer causes a slight decrease in reflectance. However, this effect is insignificant. On IR images healthy plant foliage appears as bright red or magenta and stress conditions are indicated by various degrees of deviation from the red color.

b) Spectral Reflectance of Wet Soil - The soil moisture content has a significant influence on the reflectance characteristics of soil. The moisture-holding capacity of a soil is inversely proportional to its particle size. The smaller the particle size the more water present in the soil. This tendency is found both in the visible and IR region. Figure 49 shows typical reflectance curves for a sandy soil at three different levels of moisture content. In an air-dried soil, most of the moisture content is removed from the sandy soil and there is no significant decrease in reflectance in the water absorption bands. Whereas sandy soils with

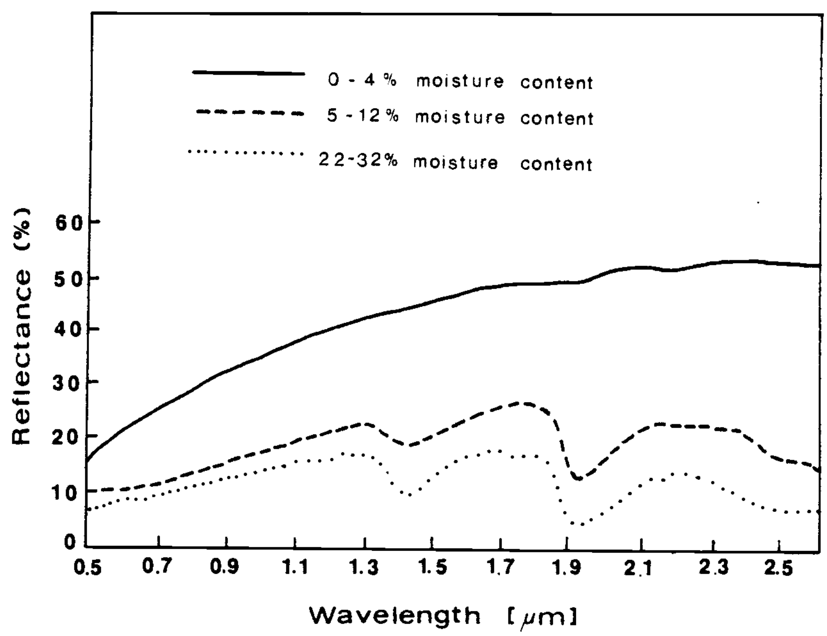


Figure 49. Reflectance curve of a sandy soil.
From Hoffer and Johannsen, 1969.

significant amounts of moisture show distinct decrease in reflectance both in visible and IR bands, Figures 50 and 51 show the same relationship in silt and clay soils. But here the air-dried soil curve in both cases shows decreased reflectance in water absorption bands because the soil still holds some moisture.

Although large moisture content decreases reflectance, there are other factors, for instance, the presence of organic matter in the soil, which have the same effect. Therefore, temporally changing moisture content should be considered before making any decisions.

2. Image Contrast

Contrast is the ratio between the brightest and the darkest parts of the image and is very important in determining the ability to discriminate between objects. It can be expressed as:

$$CR = B_{max}/B_{min}$$

where, Cr = contrast ratio,

B_{max} = maximum brightness,

B_{min} = minimum brighteness.

Figure 52 represents high, medium and low contrast on a brightness scale of 0 to 10. Images with low contrast appear monotonous and washed out and it is very difficult to discriminate between wet and dry land or the presence of siphon tubes or wheels from the background.

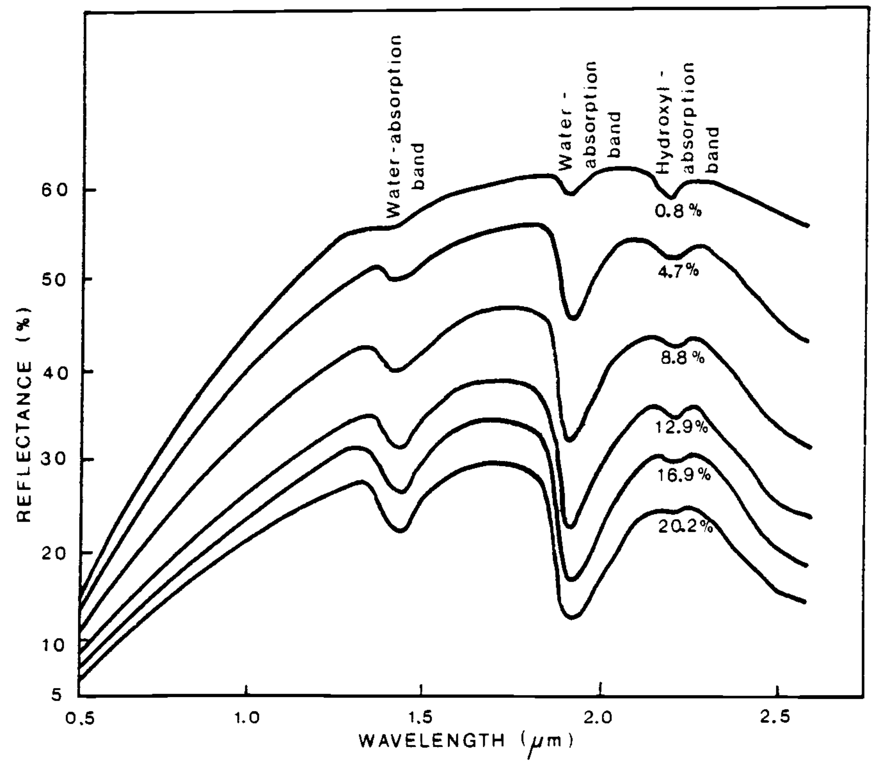


Figure 50. Reflectance curve of a silt soil with various moisture contents. From Hoffer, 1978.

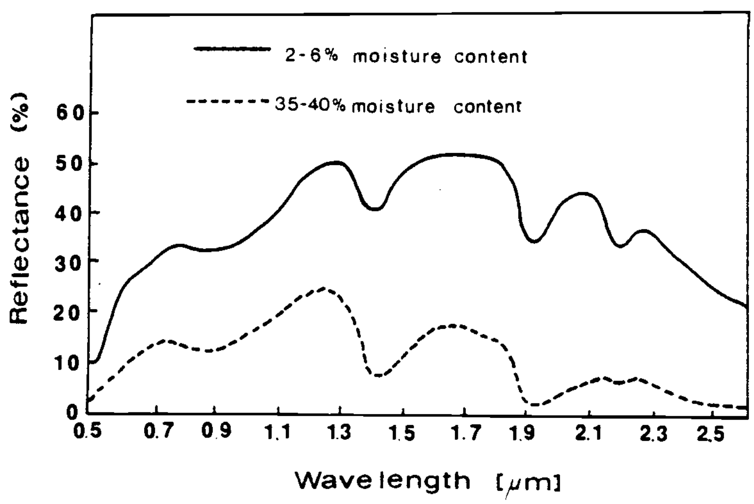


Figure 51. Reflectance curve of clay soil.
From Hoffer and Johannsen, 1969.

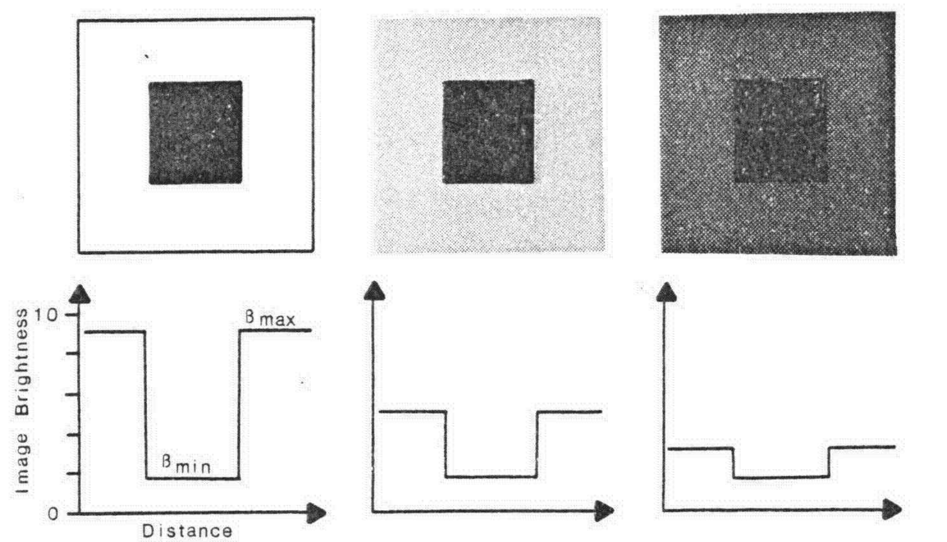


Figure 52. Images of different contrast ratio with corresponding brightness profile. From Sabins, 1978.

3. Image Resolution

The ability of an imaging system to record fine details so that the object can be distinguished is called image resolution. Image resolution is defined as the minimum distance between two objects at which the objects appear separately on the image. Image resolution is affected by shape, size and arrangement of the objects, and their contrast ratio. On a photograph it is related to the scale of the photograph, which, as previously discussed, is a function of flight height and the camera focal length, quality of lens, and the grain size of the film emulsion. In a scanning system resolution is the function of IFOV, the flying height of the sensor, and the image geometry of the scanning system. Resolution is related to the edge gradient. If the difference in density across an edge is great enough to be detectable it will be resolved even though the size may not be big enough. This is the reason that a three-inch-wide irrigation pipe on a photograph, or highways passing through forests on a MSS image, can be seen so clearly. The tone of the background also affects the resolution of small objects. Photographic emulsions have a tendency to scatter some of the energy from highly reflective objects which cause them to appear bigger than they actually are. For example, siphon tubes in furrow irrigation are resolved despite their small size.

Temporal Characteristics

Variation in spectral responses of vegetation and soil do not remain static, but change over time. Seasonal changes and temporal variability of agricultural scenes must be taken into account. Spectral responses of objects vary with the change in the amplitude and wavelength of EMR from 0.36 to 1.3 micrometers. Ground objects reflect varying amounts of solar radiation which is constantly changing with the changes in solar angle and atmospheric conditions. Variation in intensity and spectral distribution of solar radiation can be seen in Figure 53. The graph shows a large increase in IR radiation at 0.75 micrometers in the afternoon. This is probably due to the absorption of visible light by dust particles that are present in the atmosphere during daytime. CIR films appear more red in the afternoon compared to the morning. The amount of skylight also varies with time and the variation is greater at shorter wavelengths than at longer wavelengths.

When a vertical photograph is taken the time of the day determines the amount of shadow on the image. Shadows are enhanced if the photographs are taken in the morning or in the evening. Shadows sometimes help to identify objects which are otherwise unresolvable.

Temporal variability in agricultural scenes, agricultural operations, and irrigation scheduling are important factors and should be given due consideration along with spatial and spectral characteristics for successful interpretation.

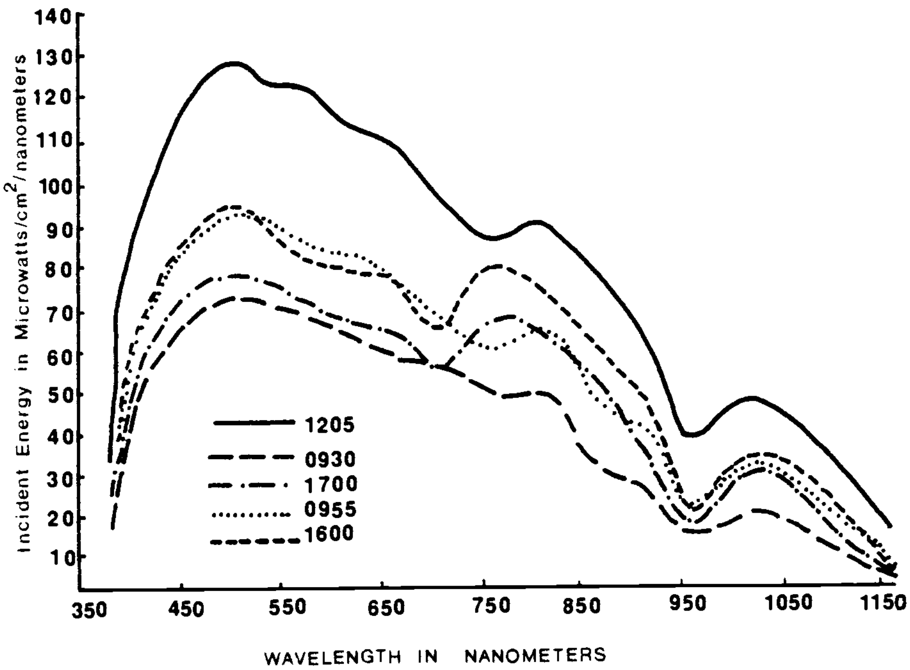


Figure 53. Spectral distribution of incident solar radiation. From Yost, 1969.

Chapter Summary

Photographic and optical mechanical scanning systems and their image characteristics have been discussed in relation to irrigation method identification in the sequence listed below:

1. Discussion of the electromagnetic spectrum emphasizing the characteristics that affect image quality.
2. Photographic systems were examined with special emphasis on lens, filter and film technology.
3. Landsat satellites were described emphasizing their orbital characteristics, sensors, data format and limitations of data in discrimination of irrigation practices.
4. Image characteristics were examined, especially those concerned with spatial, spectral and temporal aspects.

In the next chapter, the physical charactersitics of an intensive study area will be discussed, with emphasis on features which affect the reflectance characteristics and/or provide ancillary information for interpretation.

CHAPTER IV

THE NORTH UNIT DESCHUTES IRRIGATION DISTRICT

Introduction

This chapter provides information about North Unit Deschutes Irrigation District (N.U.D.I.D.) which has been chosen to test the identification methodology. It discusses the geographic setting of the district which provides the base for its most important economic activity--farming. It looks into the cultural practices and irrigation methods without which it is impossible to carry on a profitable farming operation. There are several reasons for choosing this district to develop the photointerpretation key:

1. The district lies in the semiarid intermontane region and typifies the arid central Oregon where cultivation of most crops is not possible without irrigation. Water is the limiting factor to growth in summer and irrigation represents the largest consumptive use of water.
2. Water conservation is an important issue in semiarid regions, and it is desirable to keep track of consumptive use and associated wastage. This district provides a good example of water wastage which results from the nature of repayment contracts, where the farmer has to pay a minimum two acre-feet per acre whether he uses the water on that acre or not and the water cannot be used

on other land. Thus the farmer is least concerned with conservation. If the law is modified several thousands of acres of irrigable land can be brought under irrigation with the same amount of water. The agencies involved in such development need to know and monitor potential uses.

3. The natural vegetation of the district is mostly sagebrush with some scattered junipers. The main land uses are farming and range. This reduces the diversity and simplifies the identification methodology. It is easy to distinguish between irrigated agriculture and dry farming and range land under the semiarid climatic conditions.

4. A wide variety of crops are grown in the district and this diversity in crop helps to delineate field outlines. Their spatial extent is easily measurable, than would be the case in monocultural environment.

5. The district since its first irrigation in 1946 has seen many changes in irrigation practices. Originally employed furrow and corrugation methods were replaced by sprinkler systems and the transition continues as the stationary-type systems are being replaced by continuously moving systems.

6. U-2 photographic coverage of the area during growing season is available.

7. Good Landsat coverage of the area is available in the form of MSS images, RBV images, and computer compatible tapes.

8. Dry climate and clear visibility conditions are ideal to fly photographic missions at different growth stages to determine the ideal time for photography.

Geographic Location

The N.U.D.I. District lies to the east of the Cascade Mountains in the Deschutes River drainage basin, in Jefferson County of central Oregon. It occupies the broad intermountain lava plateau between the deep canyons of the Deschutes and Crooked Rivers in the west and the Ochoco Mountains in the east. Willow Creek divides it roughly into two halves. The city of Madras is centrally located in the district (Figure 54), which extends 45 km (28 mi) in the north-south and 19.3 km (12 mi) in the east-west direction.

Geology and Physiography

Geology

Underlying geologic formations in an area control the topography which, in turn, affects the mode of economic activity of the area. They determine the field layout, the location of irrigation components with respect to slope, the amount of energy required to pump water, and other associated activities. Much of the North Units' southern and eastern parts are underlain by waterlaid rocks of the Dalles formation, composed mainly of fluviatile and lacustrine deposits.

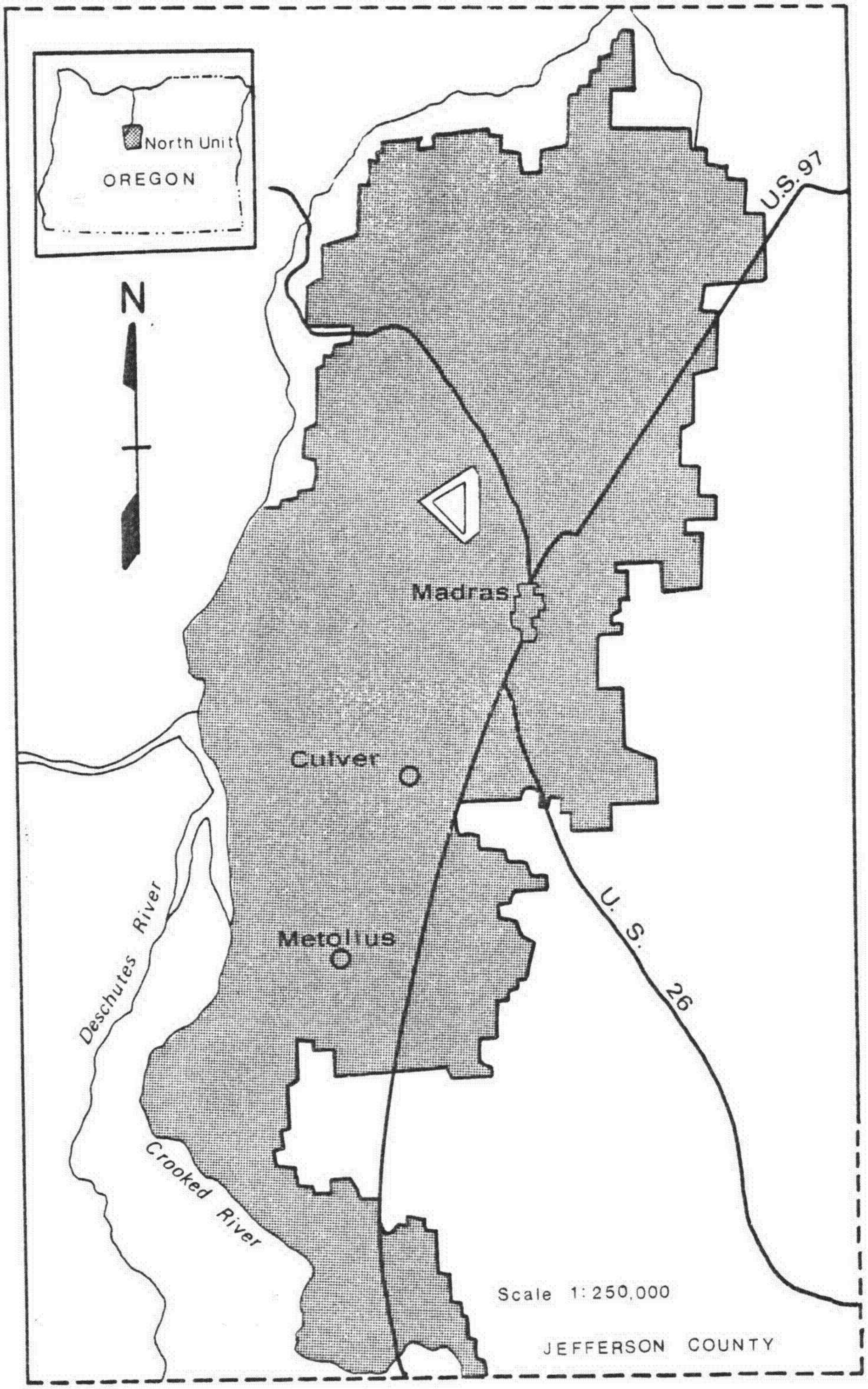


Figure 54. Location of N.U.D.I. District.

These semiconsolidated sandstones, sandy shales, conglomerates, tuft, and mudflows are deposited in thin to medium beds, intercalated by nearly horizontal flows of gray, open-textured olivine basalt, which cover the north and western part of the North Unit. Fluvial deposits of the eastern part are easily eroded and where the streams have exposed interbedded lava, a rolling topography with prominent benches and buttes has formed. In the northern and western part the more resistant basalt has protected and preserved the level Agency Plains against stream erosion.

Physiography

The resulting physiography of N.U.D.I. District is well-suited to agricultural operations and the farms are irrigable by surface or sprinkler methods. The elevation ranges from nearly 610 to 808 m (2000 to 2650 ft) above sea level. It has a general slope down toward the north. The city of Culver has an elevation of 803 m (2636 ft). Metolius, 771 m (2530 ft), and Madras, 696 m (2236 ft). The district can be divided into three subregions (Figure 55). The Agency Plains occupying the north, northwest part is a smooth level plain approximately 701 to 762 m (2300 to 2500 ft), with 0 to 3 percent slope. Separated from the Agency Plains by the Mud Spring Creek, the Mud Spring Creek area lies east of the Agency Plains and extends southeastward. This is the lowest area in the district, but has level to steeply sloping land with 3 to 12 percent slopes and elevation

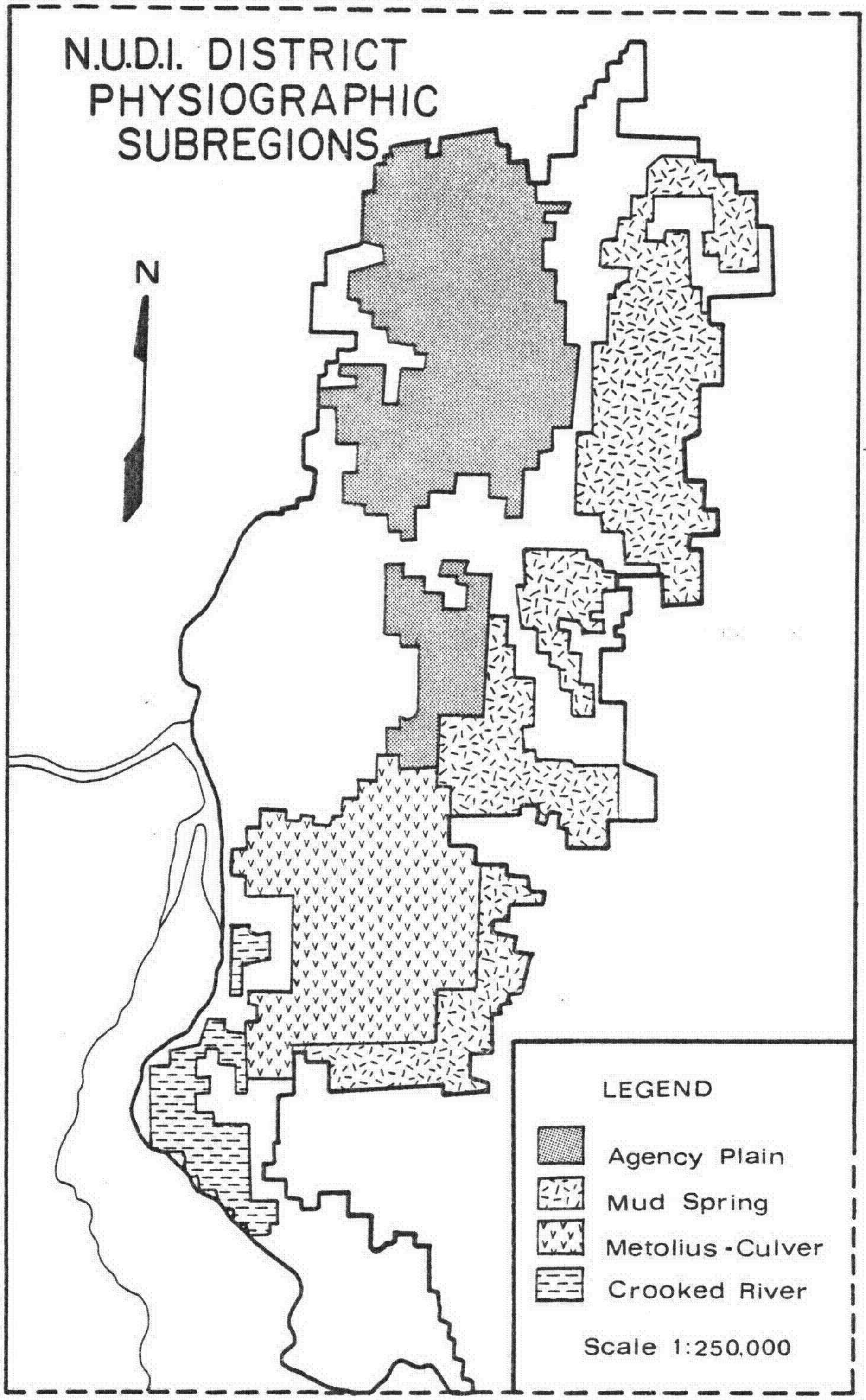


Figure 55. From Kimbal and Castle, 1962.

ranging from approximately 610 to 670 m (2000 to 2200 ft), which breaks into rougher topography along the eastern boundary of the district. Most of the southern part comes under Metolius-Culver area with level to gently rolling topography and 0 to 3 percent slope. Its elevation ranges from 762 to 808 m (2500 to 2650 ft). Adjacent to this subregion in the southwest is the Crooked River area, approximately 46 m (150 ft) higher with steeper slopes ranging from 0 to 12 percent, which originally was not a part of the district but was later incorporated into it.

The district is drained by the tributaries of the Deschutes River. The main tributaries are the Crooked River, Willow Creek and Mud Spring Creek.

Climate and Vegetation

Climate

Climate limits the farmer's choice of crops and cultivar either by imposing limitations on growing days or available moisture for growth. While the latter is overcome by irrigation, the former can be only slightly modified by irrigation.

The semiarid climate of the district has a Koeppen Cs climatic precipitation structure in its dry summers and slightly moister winters. Scant vegetation cover results in extreme summer heating and winter cooling of the ground. Absolute maximum temperature during summer ranges from 37.7°C to 40.5°C (100° to 105°F), with the absolute minimum temperature during winter varying from -17.8°C to -3.3°C (0 to -26°F). Extremes of 44.4°C (112°F) and -42.7°C (-45°F) have been reported for Madras. The mean monthly temperature for five months exceeds 10°C (50°F), the minimum limit for growth for most crops. The average growing season is 101 days long with frost occurring from September 16 to June 7. Long, cloudless summer days from May through September, together with five months of growing season, are suited to a wide variety of crops.

Average annual precipitation is 259 mm (10.19 in) at Madras, and is highly variable. Approximately 34 percent of the precipitation occurs in winter (mostly in the form of snow), 22 percent in spring, 17.5 percent in summer, and 26.5 percent in fall. Relative humidity ranges from 75 to 85 percent in winter and 10 to 25 percent in summer. July, August and September are the driest months (Table VIII). The dry growing season makes irrigation necessary for successful farming.

Winds are variable, although northwesterly winds dominate in summer and southwesterly winds prevail in winter. Average wind speed during the growing season is 4 km per hour (2.5 mph), so the lodging of irrigated crops and distortion of sprinkler patterns are minimal.

Vegetation

Natural vegetation of the region is mostly big sage brush, cheatgrass, bluebunch wheatgrass, weeds, herbs, and a few junipers

TABLE VIII. COMPARATIVE LONG TERM AND 1979

MONTHLY TEMPERATURE AND PRECIPITATION AT MADRAS, OREGON

Month	Average Temperature C (F)		Average Precipitation mm (in)	
	1979	1941-1970	1979	1941-1970
January	-8.9 (16.0)	-0.5 (31.1)	49.5 (1.95)	33.8 (1.33)
February	3.2 (37.8)	2.7 (36.9)	20.8 (0.82)	21.1 (0.83)
March	6.7 (44.1)	4.3 (39.8)	27.9 (1.10)	17.5 (0.69)
April	8.7 (47.6)	7.5 (45.5)	17.0 (0.67)	13.5 (0.53)
May	13.1 (55.6)	11.5 (52.7)	6.9 (0.27)	26.4 (1.04)
June	16.3 (61.3)	15.1 (59.2)	5.1 (0.20)	27.9 (1.10)
July	19.4 (67.0)	18.6 (65.5)	0.00 (0.00)	8.4 (0.33)
August	19.0 (66.2)	17.8 (64.0)	41.6 (1.64)	8.6 (0.34)
September	16.2 (61.2)	14.3 (57.8)	7.4 (0.29)	12.2 (0.48)
October	11.5 (52.8)	8.8 (47.9)	5.3 (2.21)	20.3 (0.80)
November	2.9 (37.2)	3.9 (39.1)	46.2 (1.82)	35.8 (1.41)
December	3.5 (38.4)	1.2 (34.1)	8.9 (0.35)	33.3 (1.31)

Source: Climatological Data for the U.S. by Sections, NOAA.

found in moister places near streams. Bunchgrasses are still abundant on ranges that have not been overgrazed. In early 1900's homesteading started and most of the area was converted to dryland farming. During the Depression years, most farms were unable to operate and were either abandoned or sold out. In 1934, most of the marginal area was planted with crested wheatgrass under the Central Oregon Land Utilization Project. When irrigation water was provided some of the land reverted to farming, but some of that land is still occupied by these improved ranges. They are easily recognized on all kinds of imagery from irrigated crop land.

Soil

The influence of soil properties on irrigation practices is of great importance. Soils act as a storage reservoir in which water is held between irrigations for plant use. The size of soil particles, their compactness, the depth of soil, and the amount of organic matter it contains influences the amount of water that can be stored and thus influences irrigation practices.

Soil Characteristics

The soils of this district are generally similar to other soils of arid regions in central Oregon. Due to lack of precipitation, soils are not highly leached and contain a moderate to large amount of nutrients. Most soils are sandy loam, ranging in texture from coarse sand to clay (Figure 56). The depth of most soils is between 41 and 66

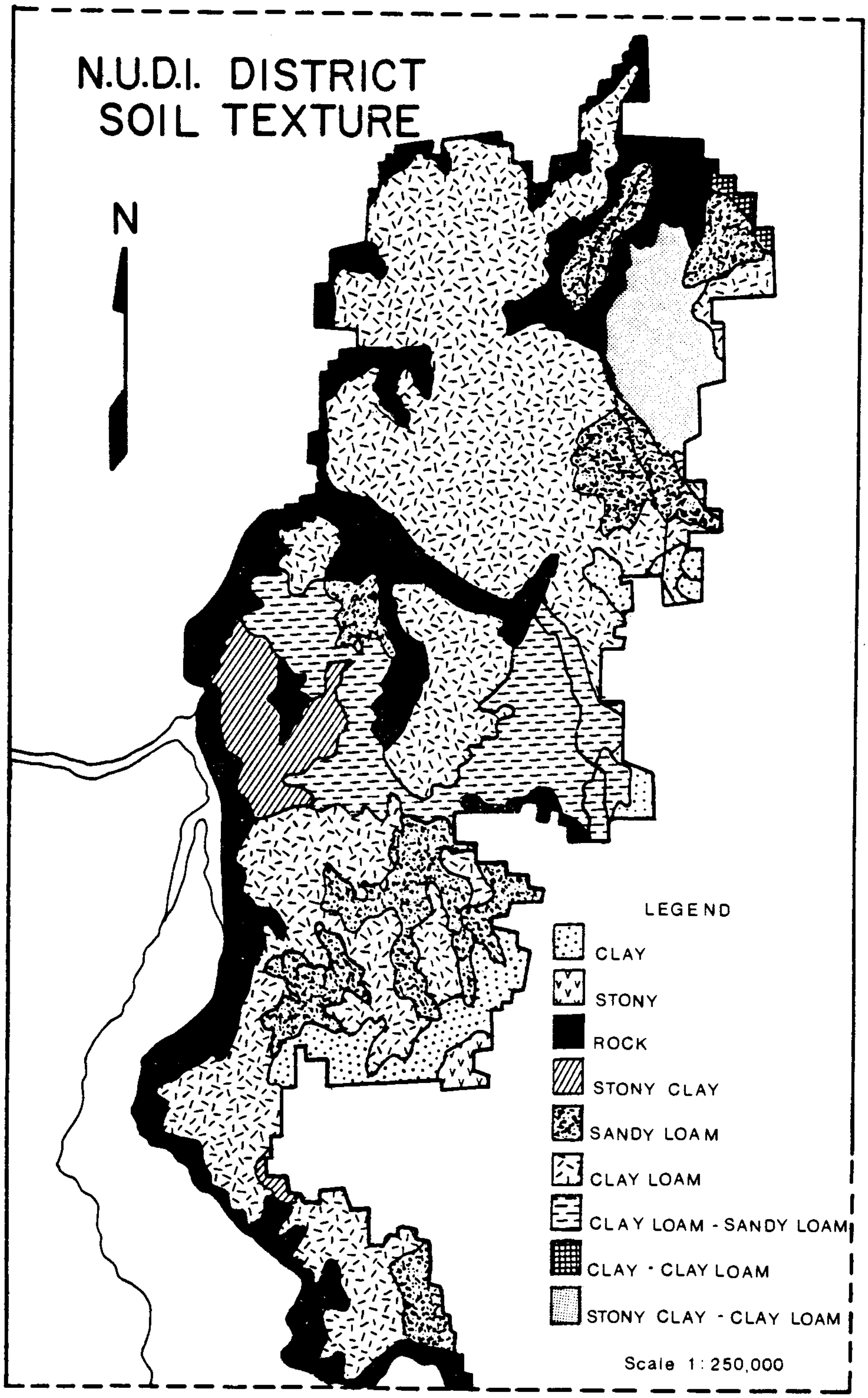


Figure 56. From OSU Ag. Exp. St. Soil Map Report, 1969.

cm (16 to 26 in). Soils overlie basalt, hardpan, semi-consolidated volcanic material, and pumiceous sandy loam deposits.

Soil Series

Most soils belong to Agency, Madras, or Metolius series:

1. Agency Soils

Agency soils are moderately deep, well-drained clay loam derived from medium-textured deposits of volcanic ash and pumice on basalt or other lava bedrock. They are low in organic matter but are moderately fertile.

2. Madras Soils

Madras soils are moderately deep, well-drained clay loam derived from waterlaid materials of the Dalles formation on nearly level land. Bedrock consists of caliche hardpan and basalt conglomerates which impeded internal drainage.

3. Metolius Soils

Metolius soils consist of deep, excessively drained sandy loams derived from pumice alluvium. Underlying bedrock consists of sandy loam deposits that are found in swales and drainage ways.

Soil Suitability

Most of the soils have from 0 to 7 percent slope with increasing slopes on the margins of the district (Figure 57). They are suited

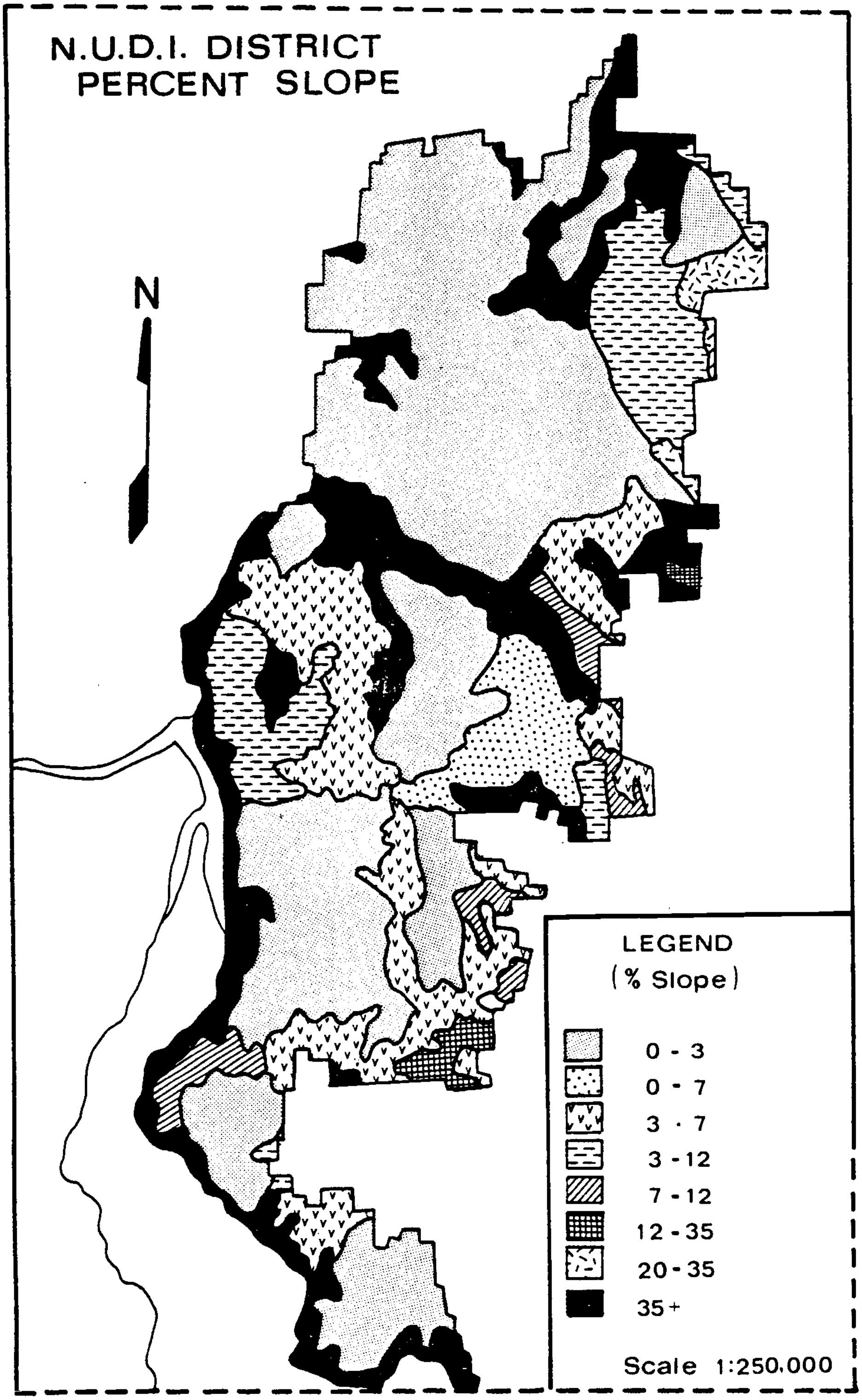


Figure 57. From OSU Ag. Exp. St. Soil Map Report, 1969.

for both surface and overhead irrigation; their capability is mainly limited by short growing season and aridity. On some steeper slopes, light-textured soils suffer from water and wind erosion and have to be carefully managed.

Irrigation

History

The North Unit Deschutes Irrigation District was organized on March 20, 1916, containing 130,000 acres of land initially, but was later reduced to 80,000 acres in 1922. Because of disagreement between the Director of the Reclamation Service and the landowners on the issue of acreage limitations, the development plan could not be implemented until November 1, 1937, when the Bureau of Land Reclamation was authorized the construction of the district. The first water was delivered during the 1946 crop year, and by 1949 water was available for all of the project's 50,000 acres. At that time the objective was to provide for the maximum number of settlers on the land and to protect family farms as a desirable way of life. During the Depression years, 77-acre parcels were regarded as subsistence units. By 1949, technology and economic conditions had changed so that small farms were no longer economic units. The farmers responded by increasing the farm size. By 1958, the average farm size had increased to 152 acres and by 1974 it was 173 acres.

Source of Water

Most of the district's water supply is diverted from the Deschutes River near Bend, Oregon. It is stored in the Wickiup Reservoir and is diverted to the North Unit Main Canal. Since it takes five days for the water released at the reservoir to reach the district, Haystack Reservoir was authorized for construction in 1954 so that water can be stored for immediate supply. In the late 1960's a pumping plant was constructed on the Crooked River and an additional 8,820 acres have been annexed by the district and are referred to as the Crooked River Water Rights Land. In normal years water is supplied by Wickiup Reservoir, but in scanty rainfall years it is pumped from the Crooked River. Figure 58 shows the water supply system for N.U.D.I. District.

Irrigation Practices

Irrigation is vital for profitable farming in the North Unit. The irrigation season generally starts on the first of April and continues to the middle of October, with peak requirements in June and July. Originally furrow irrigation was the only method used in the district on smooth surfaces and gently sloping lands with some contour furrows found on the peripheral areas with slopes greater than 3 percent. Today, sprinkler irrigation is replacing surface irrigation. In 1974 approximately 43 percent of all farms were irrigated by surface irrigation method and 57 percent by sprinklers.

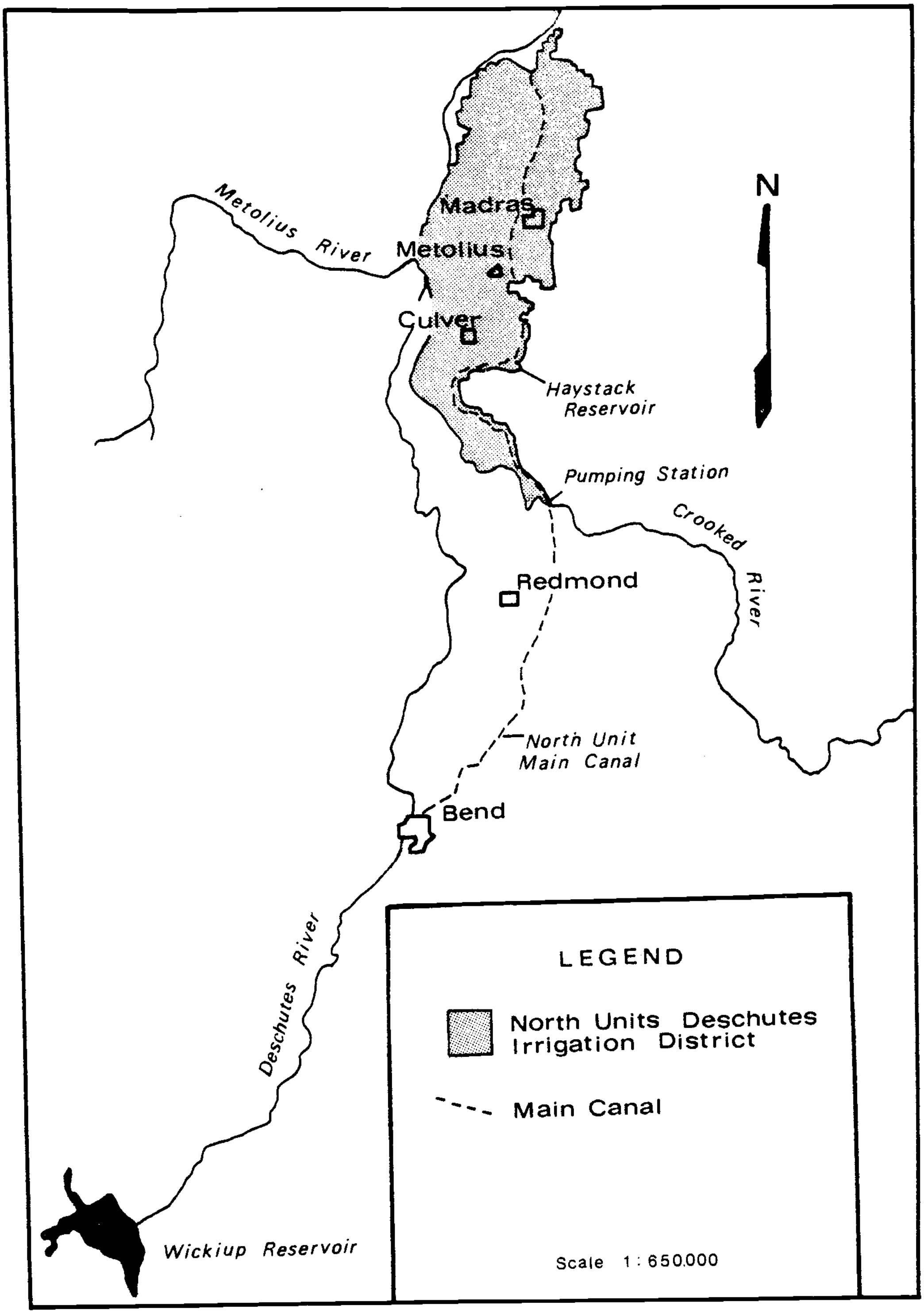


Figure 58. Water supply system for N.U.D.I. District.

In 1978, approximately 75 percent of the irrigation was by sprinklers and only 25 percent by surface irrigation methods. Four kinds of sprinkler systems are used in the district: side-roll, hand move, solid set, and center pivot.

1. Side-roll sprinkler systems are used on approximately 50 percent of the irrigated land. They are used on all kinds of soils with rather smooth surface. The fields are usually rectangular in shape and 40 to 80 acres in size. Main irrigated crops are mint, grains, row crops and grass seed.
2. Hand move systems are employed on irregular-shape and uneven topography or on fields which are divided by obstructions like canals or roads. Approximately 10 percent of all irrigated lands use this method, especially for hay, alfalfa and corn. Field size ranges from approximately 20 acres for rectilinear to nearly 40 acres for irregular shapes.
3. Solid set systems are used on smooth surfaces on smaller fields, usually 20 to 30 acres in size and semi-irregular in shape. They are associated with potato fields in the district and account for only one percent of the irrigated area.
4. Center pivot irrigation is gaining importance and reflects the farmer's response to advanced technology and rising labor costs. They are adaptable to a wide range of crop type and field conditions and are found on the peripheral areas of rough surfaces as well as on smooth Agency Plains. About 6 percent of all

irrigated area uses this method.

5. Furrow irrigation accounts for 25 percent of all irrigated lands. Average field size is approximately 20 acres in rectilinear shapes, with some fields of 40 acres irrigated by this method. In irregular fields size can vary from very small to more than 40 acres. It is used for row crops and some grains.

Besides these five kinds, farmers sometimes use two or three of these methods on the same field. Approximately 8 percent of total irrigated area is irrigated by more than one method. The practice of using furrow irrigation with hand-move or hand-move with side-roll or sometimes side-roll with center pivot creates confusion. The reasons for using mixed practices are: shape and surface roughness of the field; availability/scarcity of sprinkler systems; extreme water stress conditions for a specific crop; and small sections of a field (corners of center pivot system) may be irrigated by different sprinkler methods.

Agriculture

Prior to creation of the North Unit Deschutes Irrigation District, dry farming of wheat prevailed and some livestock was raised on ranges. With the introduction of irrigation the agricultural scene changed rapidly. Winter wheat acreage dropped and spring wheat became more important. Peppermint, barley, potatoes, alfalfa and grass seed which were previously not planted in the region were now widely planted. Today irrigated agriculture dominates the economy of the district, with approximately 92 percent of all irrigable land under irrigation. Table IX gives the land-use acreage summary for the district.

Irrigated Crops

The most important land-use in the North Unit is irrigated agriculture. In central Oregon the major irrigated crops are peppermint, grass seed, wheat, alfalfa, irrigated pastures and potatoes. Other minor crops are barley, garlic, corn, carrot seed, oats, peas, ryegrass, and sunflower. Table X gives the irrigated land acreage summary for the district.

Peppermint is a perennial crop that is usually planted either in early March or in early November. It takes about three weeks to emerge and is harvested in the second to third week of August. Once planted it can be left in the field for five years and is cultivated either once a year or once in two years. Cultivation controls the weeds but results in spreading Verticillium wilt which usually affects the crop after four to five years. Irrigation starts in the first week of April and continues through the second week of October at two-week intervals.

Blue grass is a perennial crop like mint and, once planted, it is left in the field for five years. It is planted, ordinarily in early September, in rows six inches apart and emerges in two to three weeks.

TABLE IX. LAND USE ACREAGE SUMMARY (1978)

Land Use	Acres
Total area in irrigation	46,278
Dry crop land	124
Idle, fallow or grazed (non-irrigated)	1,532
Other uses (urban, suburban, residential, commercial, industrial, etc.)	2,066
Total irrigable area	50,000

Source: Bureau of Land Reclamation, Report on Crop Production of North Unit Irrigation District.

TABLE X. IRRIGATED LAND ACREAGE (1978)

Crop	Acres
Peppermint	20,113
Grass seed	9,426
Wheat	5,320
Alfalfa	4,348
Irrigated pasture	1,919
Potato	1,627
Barley	678
Garlic	482
Others	2,365
Total	46,278

Source: Bureau of Land Reclamation, Report on Crop Production of North Unit Deschutes Irrigation District.

It starts heading in the first week of June and is harvested in the first week of July. The fields are usually burned after harvest. Irrigation starts in the first week of May and continues through the second week of June. Water is applied every two weeks. Like mint, it is irrigated once or twice before the irrigation season ends in fall to insure vigorous growth.

Wheat is sown in rows six inches apart, either in late March (spring wheat) or in late October (winter wheat). It emerges in two to three weeks and starts heading in the second week of June. Harvesting starts in the last week of August and continues through the second week of September. Irrigation starts on May 1, and continues until July 20, at ten-day intervals.

Alfalfa is another perennial crop planted in early April. It takes two weeks to emerge. It is the largest consumer of water and is irrigated throughout the season at two-week intervals. The first cutting is obtained around June 15, followed by second and third cuttings in early August and mid-September.

Irrigated pastures are also perennial crops, usually planted in May. Blue grass, clover and other mixed grasses are planted on shallow, stony soils and strongly sloping lands. They are grazed or harvested throughout the season and require irrigation from April through October.

Potatoes are planted in the third week of May and emerge in two to three weeks. They start flowering in the end of July and are harvested in the second week of October. They are planted in rows 34 inches apart and are cultivated twice, once before and once after emergence. Irrigation starts in June and continues until September 15, at an interval of two weeks.

Barley is sown in rows six inches apart. It is planted in early March and emerges in two to three weeks. It starts heading in the first week of June and is harvested in mid-August. Irrigation starts in the third week of May and continues until July at two-week intervals.

Garlic is a newcomer to the district being introduced in the last five years. It is planted in early October in rows 24 inches apart. It emerges in two weeks and matures in the last week of July. Then the tops are cut and the bulbs are left to dry. It is harvested by August 20. Irrigation starts on the first of May and continues until July 15, at an interval of ten days.

Figure 59 gives the crop and irrigation calendar for the district. It shows different stages of crop growth and irrigation seasons. Since alfalfa is harvested at least three times and irrigated pastures are grazed or harvested throughout the season and are allowed to re-grow, it is very hard to formulate a general schedule for their phenological state.

Dry Farming and Range

The amount of dry crop land in the area is nearly insignificant;

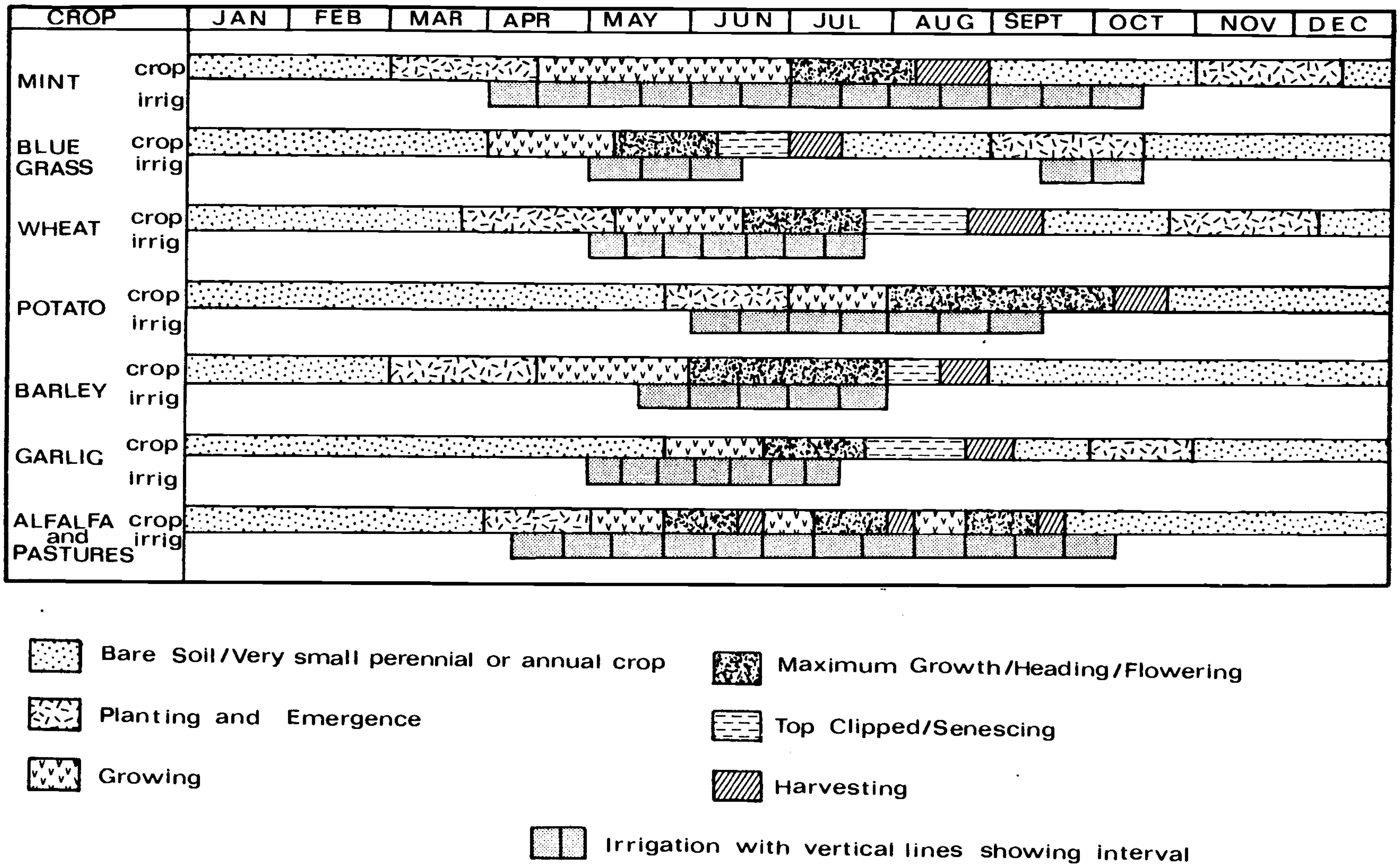


Figure 59. Crop and irrigation calender for N.U.D.I. District.

winter wheat and rye account for all of it. Non-irrigated range has a very low carrying capacity, occupying scabland, shallow, or stony soils and strongly sloping lands. Natural vegetation on the range includes bunchgrasses, big sage brush, and some herbs. A large area of formerly dry farm land has been seeded to crested wheatgrass and used for grazing.

Chapter Summary

The physical characteristics of North Unit Deschutes Irrigation District are suitable to a diversity of crop and irrigation situations. It further demonstrates the farmer's attitude towards changing economic and technological situations. The agronomic conditions of North Unit can be applied to semiarid western United States. The mission parameters required for irrigation method identificaton and the photo-interpretation key discussed in Chapter V, are based on these conditions and can be applied to other similar situations, with slight modifications required by local cultural practices.

CHAPTER V

IMAGE ANALYSIS, DEVELOPMENT OF MISSION PARAMETERS AND IMAGE INTERPRETATION KEY

Introduction

This chapter describes the analysis of different kinds of images to determine their usefulness in irrigation methods identification, development of mission parameters for image acquisition, and an image interpretation key for irrigation methods.

Three important criteria that affect image characteristics in relation to irrigated scenes are: variations in the multispectral reflectance from irrigated crops and soils; growing season and time of the photography; and the scale of imagery. Spectral reflectance of irrigated crops and soils varies with wavelength. In the visible portion of the spectrum, chlorophyll absorbs EMR in the blue and red centered at 0.45 and 0.65 micrometers, respectively, and reflects it in the green band centered at 0.54 micrometers. Irrigated soils absorb energy in every part of the visible spectrum. Maximum contrast is lacking in this portion, and is further reduced by scattering at shorter wavelengths. The near-infrared portion of the electromagnetic spectrum is best suited to crop discrimination and to separation of wet soils from dry soils and vegetation. In the near-infrared vegetation is highly reflective. Healthy plant foliage characteristically appears a bright red or magenta color with different species often distinguishable by varying hues, whereas unhealthy, damaged vegetation or dying vegetation tends to deviate from the red color (Knipling, 1969). Thus, a healthy crop can be easily distinguished from a crop under stress. Damaged crops near supply ditches for surface irrigation will not show up on black and white and color photographs but are easily seen on CIR photographs. A CIR film is specially designed to show variations in vegetation reflectance. It is sensitive to wavelengths between 0.50 and 0.90 micrometers. Vegetation reflectance is a function of amount of chlorophyll present, internal structure of the leaf, and its water content. Chlorophyll absorbs energy in the visible band, but not in the near-infrared. Reflectance in the near-infrared is controlled by the internal structure of the leaf. Water content affects the reflectance and hence the color formed on the film. Hoffer (1978) has shown that the reflectance of dry soils generally increases with wavelength, particularly in the visible and near-infrared portions of the spectrum, and increased moisture causes decreased reflectance throughout the reflective portion of the spectrum. Thus, maximum contrast is found for dry and wet soil reflectance. Both black and white and CIR images were acquired to determine their utility in irrigation method discrimination.

Temporal changes in the spectral response of irrigated soils and crops affect the image characteristics. The phenological state of crops changes over the growing season. The crop calendar developed in Chapter IV provides the information about planting, growing, heading and flowering, senescing and harvesting stages, along with the time of irrigation. The images used for analysis covered the whole growing season and were taken on different dates in May, June, July and August.

The trade-off between scale and cost of interpretation is an important factor. If the scale is enlarged, for example, from 1:20,000 to 1:10,000, the image interpreter's analysis area is increased four times. To minimize the cost, it is essential to determine the smallest usable scale for different kinds of images to be interpreted. The images used in this study ranged in scale from 1:23,000 to 1:1,000,000.

Image Analysis

Three different kinds of images were analyzed. They include:

1. Landsat MSS Color Composite Images

Date	Scale	Scene ID
June 4, 1979	1:1,000,000	3045618154
June 22, 1979	1:1,000,000	3047418152
July 18, 1979	1:1,000,000	2163818032
May 17, 1979	1:250,000	3043818160
June 22, 1979	1:250,000	3047418152

2. Landsat RBV Images

Date	Scale	Scene ID
June 8, 1978	1:125,000	3009518093 - A
July 28, 1979	1:125,000	3051018151 - B

3. CIR Aerial Photographs

Date	Scale	Scene ID
May 12, 1979	1:30,000	Provided by Rinker Enterprises
July 9, 1979	1:23,000	"
August 5, 1979	1:23,000	"
August 2, 1978	1:130,000	U-2 78-107 B
June 28, 1973	1:30,000	U-2 73-106

Besides these three commercially available types, black-and-white aerial photographs at 1:8,000 were used to provide additional ground truth. The black-and-white photographs were provided by the Oregon Army National Guard, 1042 MI Company.

Each image was interpreted for three different levels of detail:

1. Differentiate between irrigated and non-irrigated crops, using temporal spectral differences of irrigated and non-irrigated crops and soils;
2. Discriminate irrigation methods that can be differentiated by using spatial characteristics such as shape and size and, if needed and possible, use crop associations with shape and size.

Three different shapes--circular, rectilinear and other shapes were used for interpretation. Fields were divided into two broad categories: up to 40 acres and 40+ acres in size;

3. Discriminate irrigation methods based on such fine details as wetting patterns of sprinklers and surface irrigation, presence of furrows, corrugations, borders, laterals, wheel lines, and driving units, in addition to spatial (shape and size) and locational and relational (site and situation) features.

Landsat Color Composite Images

Landsat color composite transparencies at 1:1,000,000 were found useful in differentiating between irrigated and non-irrigated crops. Each image covers an 185 by 185 km (115 by 115 mi) area. Non-irrigated crops usually have poor growth and appeared slightly pink on the June 4, 1979 image. Bare soil signatures predominated. On the June 22, 1979 image, non-irrigated crops appeared slightly red, whereas all the irrigated crops appeared bright red. This date would prove satisfactory, except that alfalfa and pastures are often harvested in late June. Hence, another time window is needed. On the July 18, 1979 image, all non-irrigated crops are very dry and appeared bluish-tan in color, whereas all irrigated crops appeared red, and those harvested or clipped appeared whitish or yellowish. Late season irrigated pastures which were missed on two earlier dates were included in irrigated crop-land, as they appeared red on this date.

Discrimination of irrigation methods was attempted. Center pivots were easily recognized on the June 22 and July 18 images, but were hard to see on the June 4 image. All rectilinear fields larger than 40 acres were recognized as using the side-roll system, if the fields could be distinguished from each other. Field separation was difficult to see if adjacent fields had similar crops. Table XI gives a summary of the Landsat 1:1,000,000 image analysis.

Enlarged Landsat color composite prints for May 17, 1979 and June 22, 1979 at a 1:250,000 scale were analyzed. The printing was done using standard procedures at the EROS Data Center. It was noted that the prints lacked color contrast and it was very hard to delineate separate field boundaries, especially if the field size was less than 40 acres. Similar problems have been reported by Kirk B. Webster and associates in their study, "Selected Irrigation Acreage Estimates in Northern Florida from Landsat Data" (1978). They used custom printed, enhanced images at a 1:125,000 scale with satisfactory results. This was not possible in this study because of lack of funds, and it was decided to use the standard product and extract as much information as possible.

Wetting strips associated with side-roll sprinkler systems on field larger than 40 acres were visible on the May 17 image (Figure 60), if the crops were not high enough and the bare soil signature

Figure 60. Landsat MSS color composite print for southern part of North Unit Deschutes Irrigation District for May 17, 1979. Reproduction resulted in enlargement of the scale. Approximate image scale is 1:210,000.

TABLE XI. SUMMARY OF LANDSAT COLOR COMPOSITE TRANSPARENCIES ANALYSIS

Object of Interest	June 4, 1979 (1:1,000,000)	June 22, 1979 (1:1,000,000)	July 18, 1979 (1:1,000,000)
I. IRRIGATED VS. NON-IRRIGATED			
Irrigated crops.	Crops in different stages of growth appear in different shades of red.	Bright red hue.	Except for harvested blue grass and clipped garlic, everything else is red. Blue grass and garlic appear whitish and yellowish. Late season irrigated pastures are irrigated at this time.
Non-irrigated crops.	Slightly pink.	Slightly red.	Crops are dry, appear bluish tan.
II. INDIVIDUAL IRRIGATED CROPS -- Identification not feasible.			
III. IRRIGATION SYSTEMS			
Center pivot.	Hard to see unless planted to blue grass.	Circular outline only seen.	Circular outline only seen.
Rectilinear fields 40+ acres in size (only side-roll system).	Hard to delineate.	Easily seen if adjacent fields have different crops, which helps to delineate field boundary.	Easily seen if adjacent fields have different crops, which helps to delineate field boundary.

predominated. But on the June 22 image (Figure 61), vegetation has subdued the wetting pattern and it was impossible to identify any method. Moreover, field boundaries were hard to delineate because of lack of contrast, and shapes and sizes could not be used effectively as an element of recognition. Consequently, the author decided to incorporate crop association with irrigation methods for this type. Although there is no definite relationship between irrigation methods and crops in general, it was noted during field observations that some crop associations could be used as a supportive element if the image had good color contrast and resolution to differentiate between crop types and delineate field outlines. While all kinds of crop-irrigation combinations exist, it was noted that in the North Unit Deschutes Irrigation District side-roll systems were used for mint, grains, row crops, and grass seed. They were used on fields with rather smooth surfaces of lengths exceeding 305 m (1,000 ft). Ninety-one percent of all 40-acre fields which were square in shape used this method, as did all other fields more than 40 acres in size and rectilinear in shape. Hand move systems were used to irrigate alfalfa, pasture, and corn. They were used on uneven topography, or when obstacles such as canals or roads divided the field. If rectilinear in shape, the field sizes were from 20 to 25 acres. For all other shapes hand move systems were used if the length of the field was up to 305 m (1,000 ft). Solid set systems were used for irrigating potatoes and were installed on

Figure 61. Landsat MSS color composite print for southern part of North Unit Deschutes Irrigation District for June 22, 1979. Reproduction resulted in enlargement of scale. Approximate image scale is 1:210,000.

on smooth surface fields of 20 to 30 acres extent. Center pivots were used for all except corn and pasture. Furrow irrigation was employed for all row crops, grain and mint. This irrigation method was used on smooth surfaces and fields up to 40 acres, although 20-acre sizes were more common. All rectilinear fields that were 805 by 201 meters (2640 by 660 ft) in size used furrow irrigation.

Using these crop associations and a topographic map at a 1:250,000 scale, discrimination of irrigation methods was attempted. Center pivots which were so easily seen on the June 22 and July 18 transparencies were not clear on these enlarged prints. Crop associations did not prove helpful as farmers usually grow more than one crop under the same system. Where the fields could be delineated, side-roll systems were easily identified, but furrow, hand move, and solid set systems were confused. Table XII gives the summary of image analysis of these enhanced color composites.

Landsat RBV Images

Enlarged prints of RBV images at the scale of 1:125,000 were analyzed for June 8, 1978 and July 28, 1979. For the June 8, 1978 image (Figure 62) ground information was not available. It was used to reinforce the decisions made by using the July 28, 1979 image (Figure 63), on the presumption that irrigation methods remained unchanged in most cases. Each RBV image covers an area 99 by 99 km

TABLE XII. SUMMARY OF LANDSAT COLOR COMPOSITE PRINTS ANALYSIS

Object of Interest	May 17, 1979 (1:250,000)	June 22, 1979 (1:250,000)
I. IRRIGATED VS. NON-IRRIGATED		
Irrigated crops.	Different stages of growth, from green bare soil signature to pink to red, with lateral wetting pattern seen in some cases.	High reflectance, red to dark red, lateral pattern seen in some harvested fields.
Non-irrigated crops.	Cropped land appears slightly pink, fallow land appears pale green.	Cropped land appears from pink to slight red, fallow appears pale green.
II. INDIVIDUAL IRRIGATED CROPS		
Mint	Pink.	Bright red.
Wheat.	Spring wheat--greenish. Winter wheat--red.	Both spring and winter wheat appear dark red (darker than mint).
Potato.	Bare soil, greenish.	Greenish to slight pink.
Blue grass.	Red.	Red (less bright than mint).
Alfalfa.	Pink to slightly red.	Greenish to slightly red.
III. IRRIGATION SYSTEMS		
Center pivot.	Contrast lacking, difficult to identify, only big fields (640 acres) can be seen.	Difficult to identify as contrast is lacking if corners are well irrigated.

(Cont.)

TABLE XII (Continued)

III. IRRIGATION SYSTEMS (continued)

Rectilinear fields 40+ acres in size (only side-roll system).	If crops are not dense fields can be easily seen, wetting pattern of laterals can be seen in some cases.	Easily seen if adjacent fields have different crops, laterals are usually not seen as crops subdue wetting pattern.
Rectilinear fields up to 40 acres in size (overhead and surface delivery.	Field shapes and sizes can be used to identify furrow irrigation from sprinkler systems as 402 * 402 m (1320 * 1320 ft) fields are usually irrigated by sprinklers and 201 * 805 m (660 * 2640 ft) fields are irrigated by furrows in 40-acre fields.	Shapes and sizes can be used to identify furrow irrigation from other systems, if fields can be delineated and are 40 acres in size as usually 402 * 402 m (1320 * 1320 ft) fields are irrigated by sprinklers and 201 * 805 m (660 * 2640 ft) fields are irrigated by furrows. Not possible to identify fields less than 20 acres.
Other field shapes.	Side-rolls are identified by wetting pattern, if they are visible.	Not possible to identify any method as vegetation subdued pattern.

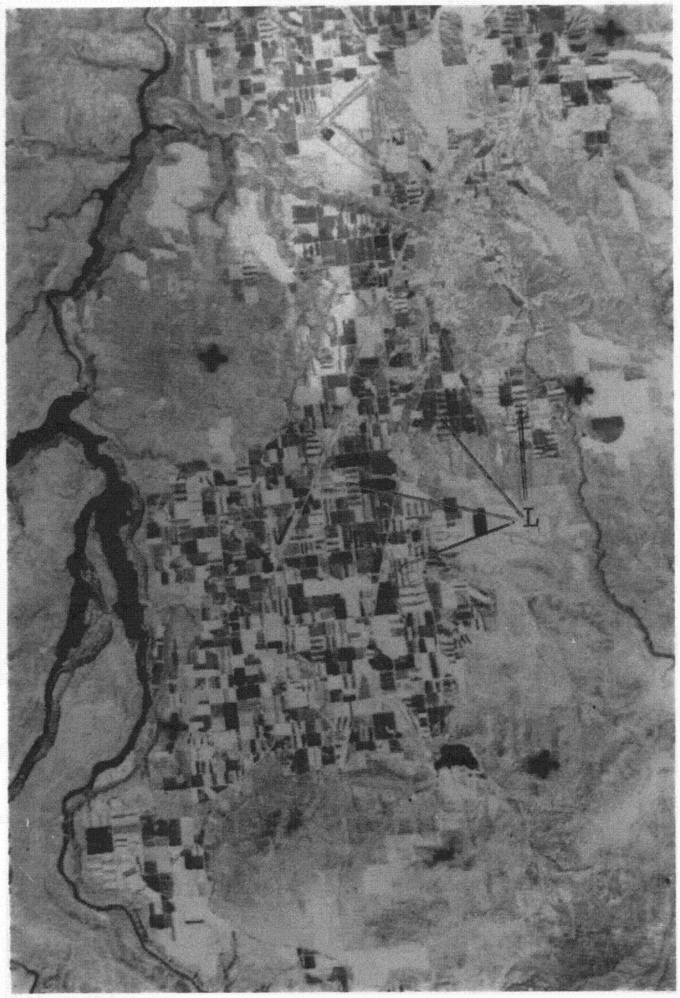


Figure 62. Landsat RBV image for southern part of North Unit Deschutes Irrigation District for June 8, 1978. Thin, dark gray strips marked by letter L show the wet strips of sprinkler systems. Reproduction resulted in reduction of the scale. Image scale is approximately 1:230,000.

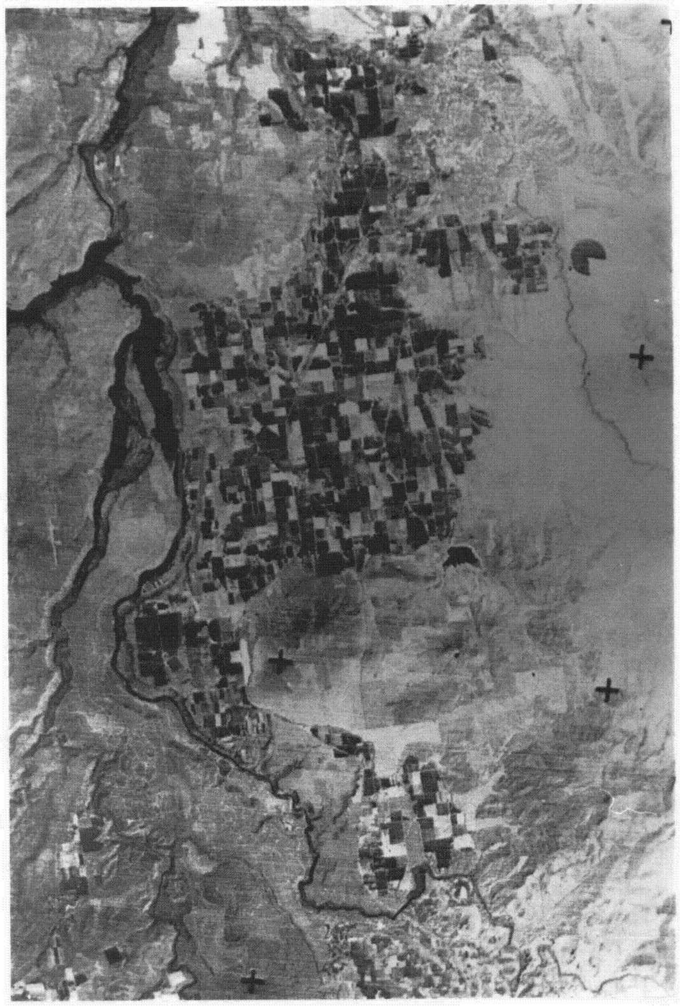


Figure 63. Landsat RBV image for southern part of North Unit Deschutes Irrigation District for July 28, 1979. Reproduction resulted in reduction of the scale and darkening of the image. Approximate scale is 1:230,000.

(66 by 66 mi) in one frame. They have much better resolution than standard MSS images, but slight gray tone variations are hard to perceive. It is difficult to quantify them and analysis may vary from interpreter to interpreter. Moreover, variations are found from image to image. Some images look washed out and lack contrast; others may have better contrast. Ranging from white to black, the gray tones printed on RBV images were interpreted as white, grayish white, very light gray, slightly light gray, gray, slightly dark gray, dark gray, very dark gray, and black.

On the July 28, 1979 image, any cropped field with a light gray to dark gray tone was irrigated. But many fields are harvested at this time and appear white. All non-irrigated cropped fields appeared very light gray, and, if harvested, they appeared white. On some harvested fields (alfalfa and pasture), the wetting pattern of sprinkler laterals can be seen. Apart from these, there was no other clue in terms of wetting pattern. It was very difficult to discriminate crop types because of little variation in gray tone between some crops; mint was easily confused with potatoes, wheat with barley, and garlic with blue grass. It was easier to discriminate the field boundaries if the fields were rectilinear and 40 acres or more in area. Then shape and size could be used for identification. But for fields that were smaller in size and other than rectilinear or circular in shape, it was very difficult to identify the irrigation methods. The June 8, 1978 image was used to decide the best time for identification.

This earlier date showed many more details. When crop cover was absent or growth was barely visible, irrigated wet strips could be seen. Irrigated fields were in different shades of gray, ranging from very light gray to light gray in tone. Fallow lands appeared white on this date and could be easily separated from cropped land. It was easy to identify sprinkler irrigation by its characteristic wet strips which appeared dark gray in tone. As both images were for different growing seasons, they were not used to discriminate between crop types. It would be easier to identify irrigation methods by using an early season and a late season image for the same growing season, and using crop associations with shape and size as diagnostic elements. Table XIII gives a summary of the RBV image analysis.

Color Infrared Aerial Photographs

CIR photographs for the area were acquired for three different dates during the 1979 growing season: May 12, July 9, and August 5. In addition to these, U-2 CIR photographs for June 28, 1973 and August 2, 1978 were also analyzed. The scale of these images was 1:23,000, 1:30,000, and 1:130,000. On a U-2 CIR photograph for August 2, 1978 at a scale of 1:130,000 (Figure 64), irrigated lands were easily separated from non-irrigated. Wetting patterns were visible in harvested fields, but for other fields vegetation has subdued the wetting pattern and shapes and sizes alone had to be used for identification. Crop associations could not be used as

TABLE XIII. SUMMARY OF LANDSAT RBV IMAGE ANALYSIS

Object of Interest	June 8, 1978 (1:125,000)	July 28, 1978 (1:125,000)
I. IRRIGATED VS. NON-IRRIGATED		
Irrigated crops.	Where crop cover is absent or there is only small growth, wet strip can be seen. Fields are in different shades of gray, from very light gray to gray.	Any field from light gray to dark gray is irrigated, but many fields are harvested and show no sign of irrigation. In some blue grass (harvested) fields and late season pastures, wetting patterns of sprinkler laterals can be seen.
Non-irrigated crops.	Cropped land--from very light gray to light gray, fallow land appears white.	Very light gray, if harvested appears white.
II. INDIVIDUAL IRRIGATED CROPS -- Identification not feasible.		
III. IRRIGATION SYSTEMS		
Center pivot.	Easily identified by circular outlines.	Easily identified by circular outlines.
Rectilinear fields 40+ acres in size, (only side-roll system).	Sprinkler wetting patterns can be seen, where crops subdue the wetting pattern, and contrast is lacking it is hard to delineate field outlines.	Shape and size can be determined as a result of better contrast.

(Cont.)

TABLE XIII (Continued)

III. IRRIGATION SYSTEMS (continued)

Rectilinear fields up to 40 acres in size (overhead and surface delivery).	If wetting strips are visible then field size can be determined, but smaller fields tend to merge together due to lack of contrast and irrigation methods can not be determined.	Wetting pattern not seen, but contrast of the image helps to delineate field outline. Only shape and size can be used to differentiate between irrigation methods if not less than 40 acres in size.
Other field shapes.	Irregular narrow fields merge together and cannot be identified. Larger fields with wet strips visible can be separated as to sprinkler systems by dark gray toned wet strips. Furrow irrigation hard to identify.	Only where dark gray toned strips can be seen, sprinkler methods could be identified. Otherwise not possible since the crop subdues the wetting pattern.

Figure 64. U-2 CIR photograph for cnetral part of North Unit Deschutes Irrigation District for August 2, 1978. Reproduction resulted in reduction of the scale. Approximate image scale is 1:268,000.

ground data were not available. The scale proved to be too small to provide all the details necessary for identification of different methods if the fields were smaller than 20 acres. A U-2 photograph for June 28, 1973 at a 1:30,000 scale, and a May 12, 1979 photograph at the same scale proved to be sufficient to provide all the details necessary for identification of irrigation types. July 9 and August 5 (1979) photographs were used to determine the optimum conditions for flying the mission. A summary of the analysis of these photographs is given in Table XIV.

The following conclusions were drawn from the foregoing analysis:

1. CIR images provide better discrimination of irrigation practices, as wet soils and vegetation are distinctly different on these images. Wet soils appear more blue than dry soils. Wetting patterns are readily seen and easily distinguished from red vegetation, whereas on panchromatic images wet soils and vegetation have similar gray tones and much information is lost because gray tone variations are hard to perceive.
2. Late summer is the best time to identify irrigated versus non-irrigated crops since non-irrigated crops are dry and appear tan in color, while irrigated crops are still red on the CIR image. However, early season is the best time for discrimination between irrigation methods on an aerial photograph. Crops are emerging and cultivation and wetting patterns can be seen. During

TABLE XIV. SUMMARY OF CIR AERIAL PHOTOGRAPH ANALYSIS

Object of Interest	May 12, 1979 (1:30,000)	June 28, 1973 (1:30,000)	July 9, 1979 (1:23,000)	Aug. 2, 1978 (1:130,000)	Aug. 5, 1979 (1:23,000)
I. IRRIGATED VS. NON-IRRIGATED					
Irrigated crops.	Crops are emerging, very little field coverage, so wetting patterns of furrows, border strips and sprinklers can be seen.	Crops are in different stages of growth and appear in red hues.	Except for harvested blue grass and clipped garlic everything else is red.	Anything red is irrigated. Irrigation pattern is seen in harvested fields.	Irrigated crops either red or harvested. If harvested fields are tan or blue in hue with wetting pattern or mottled texture.
Non-irrigated crops.	Bare soil signatures predominates, slightly red in color.	Slightly red.	Poor growth, slightly red.	Tan in hue.	Tan in hue.
II. INDIVIDUAL IRRIGATED CROPS -- Not identified as crops were not required for identification.					
III. IRRIGATION SYSTEMS					
Center pivot.	Easily identified by circular field shapes and wheel tracks.		Easily identified by circular field shapes.		Easily identified by circular field shapes and wheel tracks in harvested fields.

TABLE XIV (Continued)

III. IRRIGATION SYSTEMS (continued)

Rectilinear fields 40+ acres in size.	Each sprinkler system can be easily identified by its characteristic wetting pattern, i.e., sprinkler diameter, width and length of wet strip.		Wetting patterns are subdued by vegetation, but linear strips and sometimes wheels can be seen.	Shapes and sizes can be used to identify, wetting patterns can be seen in harvested fields.	Most crops are harvested and wetting patterns are visible in fields.
Rectilinear fields up to 40 acres in size .	Each method easily identified by its characteristic wetting pattern (described in the key).		Vegetation subdues wetting patterns, but crop health and shape and size can be used to identify methods.	Only fields up to 20 acres in size can be identified by shape and size.	Each method is identified on harvested fields only.
Other field shapes.	Each method identified (see key).		Field shape can be used for identification.	Scale too small for fields less than 20 acres in size.	Each method identified by its wetting pattern in harvested fields (see key).
Other details: wheel lines, furrows, etc.	Visible.	Visible.	Subdued by vegetation, only wheel lines seen if present.	Scale too small for these details.	Visible in harvested fields, wheel lines seen if present.

mid- and late-growing season, these patterns are subdued by irrigated crop vegetation and, although the size and shape of a field can be used in interpretation, confusion often results due to the similar field shape and size for surface irrigation, hand move, and solid set systems. Late season proves better than mid-summer for identification of irrigation systems, since the cultivation and wetting patterns are visible after harvesting. But when crops are in the senescing stage, details are lost. However, it should be noted that the timing and rate of development of plant varies among crop types with the result that the optimum date of imagery identifying irrigation methods can vary according to the crop(s) that are involved.

3. The usefulness of image scale is subject to the level of information desired, and image availability. If the purpose is to identify irrigated versus non-irrigated crops and center pivot irrigation, multidate Landsat color composites on 1:1,000,000 scale can be used. They are easily available, each frame covers a 185 by 185 km area, and the interpreter does not have to handle many images. However, if mapping of irrigated land is desired, then enlarged prints of Landsat color composites and RBV images will prove more useful. These enlarged prints can also be used for separating side-roll systems from other systems. Although U-2 CIR photographs at the 1:130,000 scale have sharper field outlines and much better resolution, they are not as easy to

obtain as Landsat products and have to be flown for specific purposes. For discrimination between methods of irrigation, CIR aerial photographs at 1:30,000 proved the best scale. Surface irrigation wetting patterns and sprinkler wheel lines can be seen, and stereo images aid in the identification of surface methods used on different slopes. Photographs at larger scales, such as 1:10,000, provide additional information such as wheels and motors on a side-roll system, cultivation patterns, furrow spacing, and siphon tubes.

Table XV summarizes the mission parameters for different desired levels of details based on these conclusions.

Development of the Image Interpretation Key

After examining different kinds of images, the next step was to synthesize all the information helpful in the identification methodology in the form of an image interpretation key. This key could be used not only for the specific sensor and scale it is designed for, but also for other sensors and scales with certain modifications. An image interpretation key is "a set of guidelines used to assist interpreter in rapidly identifying photographic features" (Avery, 1968). They are useful interpretation techniques that can be used as a training aid for new students, as an introduction into new areas for trained personnel, and as a comprehensive library reference for the experienced interpreter (Bigelow, 1963). Much emphasis was laid

TABLE XV. MISSION PARAMETERS FOR ACQUISITION OF IMAGES

Level of details desired	Image type	Smallest usable scale	Ground area covered (one Landsat frame/ one 23*23 cm frame using 152 mm focal length)	Flying height	Approximate date (growing season)
					multidate:
Irrigated vs. non-irrigated	MSS FCC	1:1,000,000	185 * 185 km	920 km	May 20-31
	RBV	1:500,000	99 * 99 km	920 km	June 20-30
	CIR photo	1:130,000	30 * 30 km	19,812 m	July 20-30
Separate center pivot	MSS FCC	1:1,000,000	185 * 185 km	920 km	July 20-30
	RBV	1:500,000	99 * 99 km	920 km	
	CIR photo	1:130,000	30 * 30 km	19,812 m	
Separate side-roll	MSS FCC	1:250,000	185 * 185 km	920 km	June 20-30
	RBV	1:125,000	99 * 99 km	920 km	
	CIR photo	1:130,000	30 * 30 km	19,812 m	
Separate different methods	CIR photo	1:30,000	6.8 * 6.8 km	4,572 m	June 20-30
See details like wheels, motors, and cultivation patterns	CIR photo	1:20,000	4.5 * 4.5 km	3,048 m	June 20-30

on the development of keys in the 1950's and they were developed for diverse purposes. To the author's knowledge no attempt was made to develop a key for irrigation method identification. With the automation of data gathering and data analysis systems in the 1960's, efforts in manual interpretation suffered a set back. However, technology did not succeed in providing either satisfactory data gathering instrumentation or analysis techniques, for such subtle, intricate, and analytical procedures as are needed in irrigation method discrimination and which can only be resolved by a coordinated effort of human eyes and brain. Mental operations involved in photo interpretation fall under two categories: recognition/identification and interpretation. The interpreter recognizes the presence of objects because of some prior knowledge or experience. Identification is based on an analytical approach. "The analyst takes the pattern apart and studies its elements from the standpoint of what each represents and from the standpoint of the relationship of the elements to each other" (Frost, 1952). This involves several image characteristics: tone or color, texture, pattern, shape, and size. If these elements, either by themselves or in combination, are so characteristic of a feature that it is recognized instantaneously, there is no problem. But this seldom happens, for images are not selective in nature, and the photo interpreter has to find his way through a maze of information and must proceed systematically to arrive at a decision. This systematic approach to recognition uses a key. A professional, well-informed person with the specifics of irrigation practices and fundamentals of image interpretation, uses it mentally, but for a neophyte it has to be presented in an organized form with illustrated text for maximum advantage. Interpretation follows recognition and uses such supporting materials as crop calendars, soils, and topographic maps to complete a detailed analysis of the object with respect to its site and situation. The key may enable the interpreter to recognize some methods such as center pivot and side-roll on a small-scale image, but confusion is created by the similar shape and size of fields for many systems. Confusion can only be resolved by knowing field situation with respect to its natural setting. With the help of a soils map the interpreter can deduce that the field, situated on a light-textured soil, is irrigated by sprinkler, and by using a topographic map, can be reasonably sure that the field with rough topography is using a hand move instead of a side-roll system.

Organization of the Key

Image interpretation keys are of two types: selective and elimination keys.

> Selective keys are so arranged that the photo interpreter simply selects the example corresponding to the image he is trying to identify. Elimination keys are so arranged that a photo interpreter follows a prescribed step-by-step process that leads to the elimination of all items except the one he is trying to identify (Colwell, 1952).

Elimination keys are usually dichotomous in nature, they rely heavily on text, and are preferred by most users since they present a series of two choices in a continuing sequence. Selective keys rely heavily on illustrations and text is peripheral in nature.

When making a choice for the organization of the key, it was felt that with irrigation methods the interpreter may be forced to choose between two alternatives such as agricultural versus non-agricultural or irrigated versus non-irrigated and, in the process, may include or overlook some of the confusing classes. It may become necessary to include an indeterminate class and thus sacrifice the dichotomous nature of the key to avoid confusion. The key could not be selective in nature as it was not possible to provide illustrations for all kinds of methods, and heavy reliance on text was necessary. Thus, the organization of the key does not confirm to any prototype model. The success of a key depends on its users. It is meant to be used not only by irrigationists, water resources managers, and experienced photo interpreters, but also for training new personnel and students of image interpretation. All efforts have been made to organize it in a logical way, with illustrations wherever possible, explanation of image characteristics used in the key, and notes on interpretation techniques to accommodate the entire spectrum of users.

All the background material, that is, the spatial, spectral and temporal characteristics of irrigated fields and irrigation methods that were critical to identification, were then organized, with the aid of several committee members, in a graphic form on a large sheet of paper so that it could be easily followed. This material was discussed and re-discussed with the same committee members who were also familiar with irrigation practices. After several discussions and interpretations, the key was refined to its present form.

The arrangement of the key is shown in Figure 66, which precedes the text of the key. It is organized in three steps. Each step takes the interpreter from a macro-level to the next micro-level of classification, which is also tied to the scale of the imagery in the sense that step 1 can be used with small-scale, steps 1 and 2 with medium-scale, and steps 1, 2, and 3 with large-scale imagery.

It is also consistent with psychologists' understanding of mental abilities of interpreters. People normally gain an understanding by grasping the hierarchical arrangement of the subject under study. They view the subject under its broadest context, and in simplest terms first, then they proceed to increase their perception of the subject through understanding its structure at increasing levels of detail. Applied in the context of image interpretation, if a key is organized in a hierarchical order, it not only improves interpreter's efforts, but also provides a sound basis for quantitative analysis of the key itself by delineating the level of frequent problems encountered either in the arrangement of the key or in the interpretation of the image.

Proceeding from the macro- to micro-level, the first step involves the full scene and subsequent discrimination of land surface from water, agricultural land from all other land uses, and separation of irrigated from non-irrigated agricultural land. Identification of these specific conditions uses the spectral and temporal characteristics of the image. The second step uses the spatial characteristics, and by bringing shapes and sizes into argument, it classifies the irrigation scene into broad categories. This serves two purposes: first, it provides an intermediate step which eliminates the direct jump from macro- to micro-level, and second, it simplifies further processing by eliminating certain possibilities by associating circular shapes with center pivots and rectilinear more than 40 acres with sprinkler irrigation. The third step uses locational and relational information for classification into various categories.

The key is developed for CIR photographs at 1:23,000 scale (the largest scale of available CIR imagery) and can be used without changes for 1:20,000 to 1:30,000 scale images. It can be adapted to smaller or larger scales, keeping in mind the resulting modifications due to scale. Basic parameters such as shape and size are applicable to small-scale Landsat images and U-2 photographs ranging in scale from 1:125,000 to 1:250,000. Texture and pattern are discernible on U-2 photographs at the 1:130,000 scale. Greater details like sprinkler sprays and siphon tubes are visible at 1:8,000 scale, even on black-and white photographs. Field data were collected in North Unit Deschutes Irrigation District and the key is based on cultivation practices followed there, but it can be used as an inferential key for other semi-arid regions or for regions with similar environment during the dry season, with modifications resulting from cultivation practices.

Methods and Materials Used with the Key

The key provides useful reference material for identification, but it should not be used for complete interpretation. There is no substitute for an analytical mind. The decision-forming process in the mind determines what components, representations and strategies should be applied to various problems. Obviously this decision-making process is subject to the materials and methods available to the interpreter, including his experience and familiarity with the scene. The materials include: photographs and explanatory text; crop and irrigation calendars; light tables, magnifiers and stereoscopes; measuring devices; and definitions of terminology used in relationship to image characteristics.

Photographs and Explanatory Text

Some remote sensing experts are of the opinion that "keys generally should not be developed for photo interpreters who have no familiarity with either the land area to be studied or the nature of management and scientific problems" (Tueller, 1979). Although the reasoning behind this opinion is sound, its ensuing recommendation is impracticable. In most situations, the turnover of personnel is so high that keys have to be used to train neophytes. The problem of acquiring familiarity with the scene can be partially overcome by using oblique ground photographs, slides, sketches, and explanatory text as is provided in Chapter II of this study.

Crop and Irrigation Calendar

The usefulness of crop and irrigation calendars cannot be overemphasized (see Chapter IV). It familiarizes the interpreter with the temporal variability of the agricultural scene and with what should be expected on a particular date in the growing season. This preconditioning simplifies the interpreter's job and helps him to choose the right time for photo acquisition for the discrimination of a specific crop or irrigation method.

Light Tables, Magnifiers, and Stereoscopes

Light tables, magnifiers, and stereoscopes are useful technical aids for examining images. Light tables provide a convenient way of viewing the transparencies without straining the interpreter's neck and eyes. Light that comes from under the image helps preserve the photographic integrity of the image. Overhead light sources, on the other hand, result in extreme attenuation of light from some parts of the image, making it difficult to analyze the image.

A good quality lens is used to enhance images which cannot be viewed with stereoscopes. Agricultural lands are generally flat, but on sloping lands, vertical exaggeration of depth, utilizing a stereoscope, makes it possible to detect small details that are insignificant when compared to the scale of the image. It is possible to detect the drop from one terrace to another in the case of terraces and contour ditches, or to detect the surface roughness of the field to arrive at a conclusive identification. Except for Landsat images, stereo pairs can normally be obtained for photographic missions.

Measuring Devices

The simplest measuring device is an engineer's scale from which one can obtain all needed measurements. In order to increase the speed and efficiency of interpretation, transparent templates of some typical field shapes and sizes can be made, as shown in Figure 65. These templates were made for 1:23,000 scale images, and proved very effective in determining the spatial dimensions of almost all rectilinear fields, thus reducing the need for measurements with the engineer's scale.

Terminology Used in Relation to Image Characteristics

The key uses basic image characteristics of tone and color,

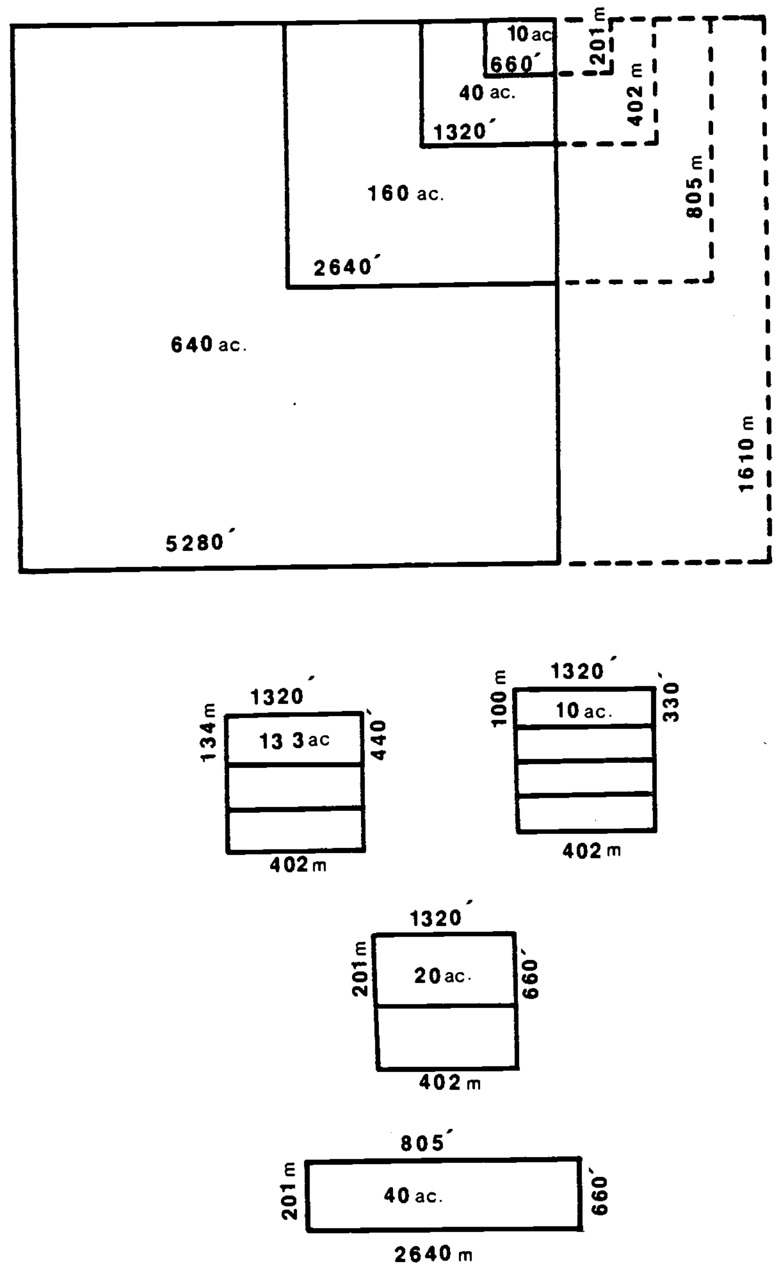


Figure 65. Templates used for some typical field shapes and sizes for rectilinear fields for 1:23,000 scale imagery.

texture, pattern, shape and size, defined in Chapter III. Some of these are hard to measure quantitatively and are usually assessed in relative terms. No two photographic missions are identical and image characteristics are modified by time of photography, flying height, view angle and film-filter combination. They are also affected by film processing techniques. Terminology associated with tone and color, texture and pattern may be confusing if not properly understood. While shape and size can be easily identified and measured, tone, color, texture, and pattern present special problems. These problems stem from the subjectivity associated with the qualitative assessment of these elements, which, in turn, is governed by physiological and psychological behavior of the interpreter. Physiological and psychological aspects will be discussed later in this chapter. In this section the terminology is defined in relation to interpretation.

1. Tone and Color

The brilliance with which light is reflected by an object is called tone (Colwell, 1952). On a black-and-white image, tone is expressed by different shades of gray. A standard gray scale contains ten different tones ranging from white to black. Changes in tone will result with varying view angle, sun angle, and exposure for the same date of imagery. Thus, any definite tone associated with a certain object does not remain constant.

Color, like tone, is also affected by the same factors and undergo frequent changes in chroma and hue with changes in spectral quality of light, thus no definite color can be associated with an object. Although the Munsell Color Chip set contains 1450 different colors, they can only be used for qualitative differentiations. The author thought it best to use it in comparative measures, associating a certain color with an object on comparative terms, thereby providing flexibility of association to the prospective user with his own set of images. Thus references, like lighter hues of recently cultivated fields as opposed to darker blue-gray or greenish-gray hues of abandoned agricultural fields or darker red hues for forests than for field crops, are found throughout the text of the key.

2. Texture

The word texture is derived from a Latin verb, "textere," which means, "to weave," and conveys the impression of roughness or smoothness. O'Neill (1953) suggested the use of fabrics to convey the idea of texture: smooth, fine, and coarse. Texture on an image refers to the frequency of tone change in the image. A form of microstructure, texture is scale dependent. An object that can be recognized on a large-scale image contributes to the texture of the image as the image scale becomes smaller. Recognition of textural differences is very important. They result from uneven reflectance. The composite expression of soil, water and vegetation, as well as irrigation hardware present in the field, often resulting in textural variations that cannot be described by simple anologies. The terms used in this key are explained here and photographic illustrations for each can be seen in the key. Water has a smooth texture compared to land. On land, objects differ in texture: field crops have finer textures than orchards; forests have coarser textures than orchards. If the texture does not change over a given segment of an image, it is uniform in nature, otherwise it is uneven. Mixture of water and vegetation, presence of wheel lines and sprinklers, uneven grazing, uneven water distribution, or a mixture of soils with uneven water-holding capacity results in uneven texture. When the degree of unevenness is very prominent, the texture is referred to as "mottled." Irrigated fields are often mottled because of variable soil water retention or because of uneven water distribution. When the soils are dry the texture appears uniform.

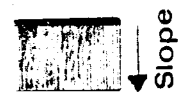
3. Pattern

Pattern is seen when the spatial arrangement of an object is repeated. Each pattern thus signifies the presence of that object. Agricultural and irrigation practices tend to repeat certain arrangements which can be identified by the pattern created. Different stages of tilling, crop growth and harvesting give distinctive field patterns which are characteristic of varied agricultural land uses. When crops are small, most cultivation and irrigation patterns can be seen. Wet soils have variably dark tones, which help to identify wetting patterns. Uncontrolled flooding in basins and terraces differ from the fine lineations of furrows and the wide strips of border strips and corrugations. On a sloping land surface, irrigation methods produce a terrace-like pattern. The sprinkler wetting pattern for a single sprinkler differs from the overlapping wetting pattern of multiple sprinklers that often appears as wide, wet strips. For the same field size, wet strips for side-roll systems cover the entire length of the field, whereas for hand move systems the wet strip is in two halves. Tables XVI and XVII show these wetting patterns, and some of their photographic counterparts can be seen in photographs in the text of the key.

4. Shapes

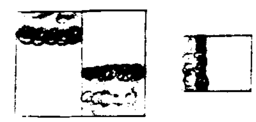
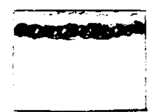
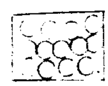
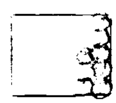
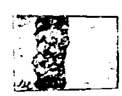
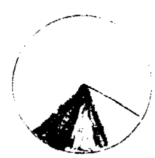
Shapes are used for broad classification. They are described in geometric terms and three categories are used in this study: circles and partial circles, rectilinear, and other shapes. Rectilinear includes all symmetrical four-sided, four-corner figures, where opposite sides are parallel and equal in length. Other shapes include all figures which are not circles or partial circles or rectilinear. They have at least one side that is non-symmetrical (irregular) and/or have either fewer or more than four corners. There are numerous variations within these three broad categories and it is not possible to examine all of them within the scope of this work. They are easy to visualize and when seen on a photograph can be easily categorized.

TABLE XVI. WETTING PATTERNS FOR DIFFERENT TYPES OF SURFACE IRRIGATION

Basin	uncontrolled water distribution	
Border strip	controlled flooding in strips, narrow wet strips	
Furrow	water applied in furrows, fine lineations	
Corrugation	water applied to corrugations through cross ditches	
Terraces	small lengths of fields, ditches follow contour	
Contour furrow	short lengths of furrows, furrows follow contour	
Contour ditch	ditches parallel to contour, wide terrace-like pattern	
Graded border	short run of border, length of strip along the slope	
Contour border	length of strips along the contour, like narrow terraces	

Note: Patterns are not drawn to scale.

TABLE XVII. WETTING PATTERNS FOR DIFFERENT TYPES OF SPRINKLER IRRIGATION

Hand-move	short length of wet strip with overlapping sprinkler pattern seen (subject to scale)	
Side-roll/ straight moving lateral	wet strips covering full length of field, with overlapping sprinkler pattern seen (subject to scale)	
Gun	individual sprinkler pattern seen, no regular wet strip pattern	
Traveller	wet strips are much wider than in other sprinklers	
Solid set	wetting pattern usually in wide band as more than one strip is being irrigated	
Center pivot	wetting pattern in conical shape	

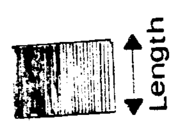
Note: Patterns are not drawn to scale.

They provide a very important element in the identification methodology and, along with size and pattern, provide positive clues for identification.

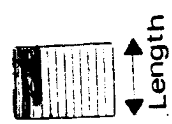
5. Size

Size refers to the spatial dimensions of an object. It is one of the most important elements in identification. The interpreter usually looks for two types of information: the kind of things and the size of things (McNeill, 1952). Recognition of the "kind of thing" is qualitative analysis and may be affected by the interpreter's biases. By using metrics the subjectivity can be reduced and the interpretation will have less variation from person to person. Measurement of furrow spacing, border width, cross-ditch spacing, corrugation width, sprinkler diameter, and length of wet strips, all provide decisive clues in differentiating between different kinds of irrigation, especially when they have the same shape and size fields. Terms associated with the spatial dimensions of the field are important to understand. The length of the field always refers to the side of the field corresponding to:

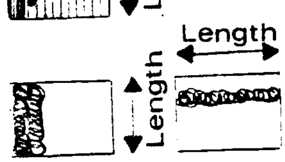
a. Length of furrow



b. Length of border strip



c. Length of wet strip in sprinkler system



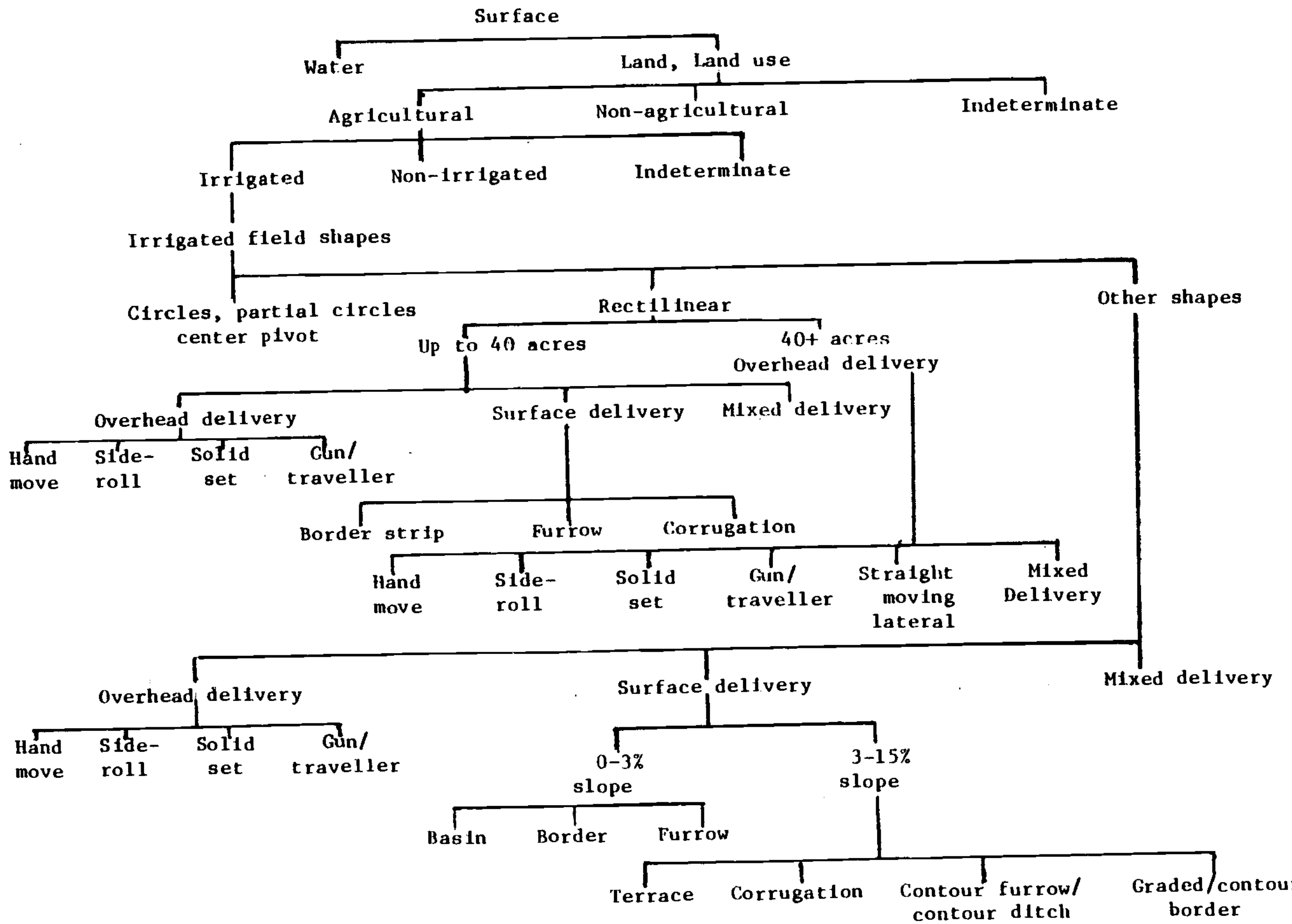


Figure 66. Arrangement of the image interpretation key for irrigation methods.

IMAGE INTERPRETATION KEY FOR IRRIGATION METHODS

Surface

Water

a. Rivers
b. Lakes and reservoirs
c. Snow and ice

1. Water: blue to black in hue
2. Snow and ice: white without shadows
3. Smooth in texture

Land

a. All surface area that is not water

1. Vegetation: red
2. Cities: blue to gray
3. Rock and soil: brown, yellow, tan, greenish and bluish hues
4. Coarser texture than for water

Land use

(see page 202)

Land use

Agricultural

a. All row, field and hay crops
b. Orchards and vineyards
c. Fallow
d. Pastures

1. Sharp, distinct field patterns due to different stages of growth and harvest
2. Lighter hues of recently cultivated fields, as opposed to darker blue-gray, greenish-gray hue of abandoned agricultural fields
3. Presence of farm activity
4. Presence of growing crops, finer in texture than forests and wood lots
5. Orchards have slightly coarser texture than field crops but finer than forests
6. Fallow lands appear blue, if not sown with a cover crop

Non-Agricultural

a. Forests
b. Range
c. Urban
d. Industrial
e. Mining
f. Commercial
g. Miscellaneous

1. Forests appear darker red in hue and coarser in texture, without rectilinear shapes except when:
   a. trees are harvested
   b. wood lots with rectilinear shapes but can be distinguished from their coarser texture and darker tones
2. Range: gray, greenish-gray in hue, usually sage brush, cheatgrass and herbs etc., with scattered junipers or seeded with crested wheat grass
3. Most other uses appear in different shades of blue and white
4. Settlements may show some red (parks, trees and open spaces)

Indeterminate

a. Abandoned agricultural
b. Improved ranges
c. Wet lands
d. All others that may create confusion

1. Rectilinear shapes of abandoned agricultural lands, but blue-gray-greenish gray in hue
2. Improved range--seeded with crested wheat grass, sometimes fenced ranges may appear as agricultural lands
3. Naturally wet lands may appear as agricultural lands

Figure 67. Different land uses: the image on the top shows reservoirs, range, and agricultural fields. Letters stand for types - water (W), range (R), side-roll (S), hand move (H), terrace (T), contour ditch (C), dry farming (D). The lower image shows forests and various age clearcuts. Compare the texture - smooth for water, coarse for forests, and fine for crops. Approximate scale is 1:26,000.

Agricultural

Irrigated

(Early summer)

1. Very light tones of recently cultivated fields
2. Mottled soil texture
3. Dark toned wetting pattern visible
4. Presence of canals, ditches, re-use reservoirs or other water sources
5. Annual crops may be emerging, very little field coverage, bare soil predominates signature which is usually mottled in texture because of wet soils

(Mid-summer)

6. Healthy crops as shown by bright reflectance, any field with high chroma, medium value, red hue is most likely irrigated, even though supporting evidences may be lacking (sub-surface irrigation)
7. Cultivation pattern may be subdued because of predominance of vegetation

(Late summer)

8. Wetting pattern visible in harvested fields
9. More soil moisture as shown by dark tone and mottled texture, in harvested fields

Non-Irrigated

(Early summer)

1. Blue to gray appearance of fallow lands and bare soils
2. Uniform soil texture as soils are dry
3. Absence of any kinds of wetting pattern
4. No sign of canal, ditch or reuse reservoir
5. Very little field coverage by vegetation, dry soil signature dominates

(Mid-summer)

6. Poor growth, low reflectance because of moisture stress
7. Sparse, poor growth may still expose cultivation pattern

(Late summer)

8. Harvested fields do not show wetting patterns
9. Soils are very dry as shown by lighter tones and uniform texture

Indeterminate

(Early summer)

1. Late season improved pastures may appear blue
2. Wet land may have mottled coarse texture with standing water
3. Standing water may appear as flood
4. Drainage ditches may appear as irrigation ditches
5. Signature of wetlands are of water and vegetation mixed

(Mid-summer)

6. Late season improved pastures which may have appeared as dry land or fallow in early summer may now show signs of irrigation and growth
7. Sub-irrigated wet lands start drying up, appearing red and may be interpreted as irrigated land

(Late summer)

8. Sub-irrigated pastures are grazed (shown by uneven texture) or may be harvested, but wetting strips or sprinkler patterns are absent
9. Soils have more moisture shown by very dark tones and mottled texture

Figure 68. A mid summer scene - July 9, 1979. Most patterns are subdued by vegetation, especially in fields F and H. Damaged crops (blue) near supply ditch in F indicates furrow or border strip. H has hand move system which is hard to tell unless viewed very closely. Straight wetting strips can be seen, length of strips indicates that it is hand move system. Furrow irrigated fields at M shows effects of uneven water distribution, crops in the lower middle part of the field are poorly developed. B is a harvested bluegrass field that is being irrigated by furrow irrigation. Also see fallow land at X. The dark blue field at G is a clipped garlic field, which looks like a dry field. Approximate image scale is 1:23,000.

Figure 69. A late summer scene - August 5, 1979. Harvested fields (whitish) show many details. Wetting patterns of overlapping sprinklers are seen both in S (side-roll) and H (hand move) systems. Furrow lineations can be seen at F. Side-roll laterals can be seen at X shown by thin white lines. Also notice the mottling in field Z as a result of uneven water retention. Approximate scale of the image is 1:23,000.

Irrigated Field Shapes

Circles, partial circles

Overhead delivery
Center pivot irrigation
Field size - 40-640 acres
Radius - 201-805 m
(660-2640 ft)

Rectilinear

Up to 40 acres

Overhead delivery

1. Slope from 0-15%
2. Distinct wet strips with sprinkler patterns, shown by overlapping small rings
3. Wet strips may follow any direction irrespective of slope and crop rows
4. Water source may be located without any regard to slope
5. Width of field up to 402 m (1320 ft)
6. Sprinkler pattern may not be visible on a small scale photograph or when vegetation subdues the pattern. Wet strips may still be visible. In the case of guns, individual sprinkler pattern without wet strip can be seen

(see page 209)

Surface delivery

1. Slope 0-3%
2. Uneven water distribution, evidenced by mottling. Lineation and wet strips may be present but without sprinkler patterns. Crops may be damaged due to excess water application near the supply ditch, or at the other end shown by white, yellow or pale reflectance
3. Water runs down the slope and along the crop rows
4. Water source located upslope
5. Width of field varies from 91-201 m (300-660 ft) sometimes up to 805 m (2640 ft)

(see page 210)

Mixed delivery

Evidence of both:
1. Both overhead and surface system present
2. Several kinds of sprinkler system in use

40+ acres

(see page 210)

Other shapes

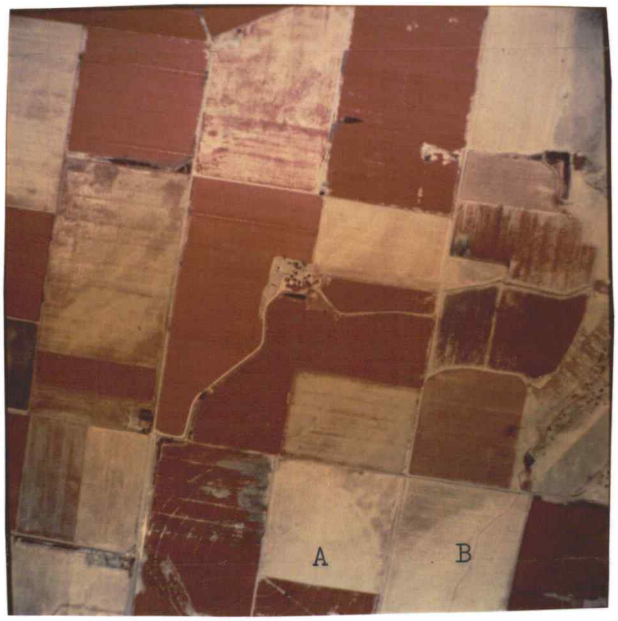


Figure 70. A late summer scene - August 5, 1979. Center pivot system with irrigated corners using different methods. There are two center pivot systems at A and B. The corner of A is irrigated by guns. The wetting pattern of individual guns without a strip is seen in the harvested corner. The corner of B is irrigated by hand move as can be seen in the wetting strip with faint sprinkler patterns. Approximate image scale is 1:23,000.

Rectilinear
Overhead delivery up to 40 acres
(continued)

Hand-move

1. Sprinkler wetted diameter 24 m (80 ft)
2. Length of wet strip usually up to 201 m (660 ft), but can be up to 305 m (1000 ft)
3. Big fields may be divided into smaller sections by canals or other features
4. Much smoother texture over most of the field
5. Crops: all crops

Side-roll

1. Sprinkler wetted diameter 24 m (80 ft)
2. Wet strips cover full length of the field and are 305+ m (1000+ ft)
3. No obstacles in the field
4. Wheels and sometimes wheel tracks result in coarser texture over part of the field
5. Crops: all except tall crops and orchards

Solid set

1. Sprinkler wetted diameter 18 m (60 ft)
2. Sprinkler/lateral fixed. Nicely placed pattern, individual sprinklers can be seen on the whole field
3. Only part of the field irrigated at a time
4. Permanently installed system gives a coarser texture for the whole field than for hand-move and side-roll systems
5. Crops: potatoes, berries, orchards

Gun/ traveller

1. Sprinkler wetted diameter 36-152 m (120-500 ft)
2. One or more guns may be sprinkling in different parts of the field
3. Obstacles may be present in the field
4. Individual sprinkler irregularly placed results in mottled texture when guns are being used. Characteristic wet strip may not be visible with guns in use. With travellers the wide strips can be seen with sprinkler pattern

Rectilinear
Surface delivery up to 40 acres
(continued)

Border strip

1. Width of rectangular strips 7-18 m (24-60 ft), no cross ditch
2. Field length: 61-402 m (200-1320 ft)
3. Width of field: up to 402 m (1320 ft)

Furrow

1. Furrow spacing 45-122 cm (18-48 in), no cross ditch
2. Field length: 91-402 m (300-1320 ft), usually 91-201 m (300-660 ft)
3. Field width: up to 805 m (2640 ft)

Corrugation

1. Cross ditches approximately 60+ m (200+ ft) apart
2. Corrugations 45-91 cm (1.5-3 ft) apart, may be obliterated during field operations
3. Field length: 61-402 m (200-1320 ft)
4. Field width: up to 402 m (1320 ft)

Rectilinear 40+ acres
Overhead delivery

Hand-move | **Side-roll** | **Solid set** | **Gun/traveller**

(same arguments as for fields up to 40 acres in size)

Straight moving lateral

1. Field size: 160 acres
2. Length of wetting strip: 805 m (2640 ft)
3. Field width: 805 m (2640 ft)
4. Field length: 805 m (2640 ft)

Mixed delivery

Several kinds of sprinkler systems used in one field

Other shapes

Overhead delivery

1. Wet strips visible with sprinkler pattern shown by overlapping rings. In the case of gun individual sprinkler pattern without strip may give a mottled appearance
2. Sprinkler pattern may be subdued by vegetation, or may not be visible on a small-scale image, wet strips may be seen
3. Wet strips may follow any direction irrespective of slope or crop rows
4. Surface may be uneven or smooth
5. Slope up to 15%

Surface delivery

1. Irregular wetting pattern, uneven water distribution as seen by mottling
2. Wetting pattern may be subdued by vegetation, crops may be damaged due to excess water near the supply ditch or at the other end shown by white, yellow or pale reflectance, border strips may show wet strips but sprinkler pattern absent
3. Water flows down the slope and along the crop rows
4. Surface is rather smooth though field may be small to avoid surface roughness
5. Modification found in mode of operation with slope (see page 212)

Mixed delivery

Evidence of

1. both overhead and surface delivery
2. Several kinds of sprinkler systems used in one field

Overhead delivery branches into:

Hand-move | Side-roll | Solid set | Gun/traveller

(same arguments as for rectilinear shapes up to 40 acres)

Other shapes surface delivery (continued)

Slope 0-3%

Basin

1. More mottled texture than borders, furrows and corrugations, lineations of borders, furrows and cross ditches absent
2. Flooding with least control, check dams may be seen
3. Crop: rice, pastures

Border strip

1. Broad lineations of borders can be seen
2. Rectangular strips slight grade lengthwise, level across, 7-18 m (24-60 ft) wide, water flow confined in strips, check dams may be seen
3. Crop: all crops

Furrow

1. Furrow lineation can be seen in wetting pattern
2. Furrow length along the slope, spacing varies with crop: 45-122 cm (18-45 in), water flows in furrows, check dams and siphon tubes may be seen
3. Crop: all row crops

Slope 3-15%

(see page 214)

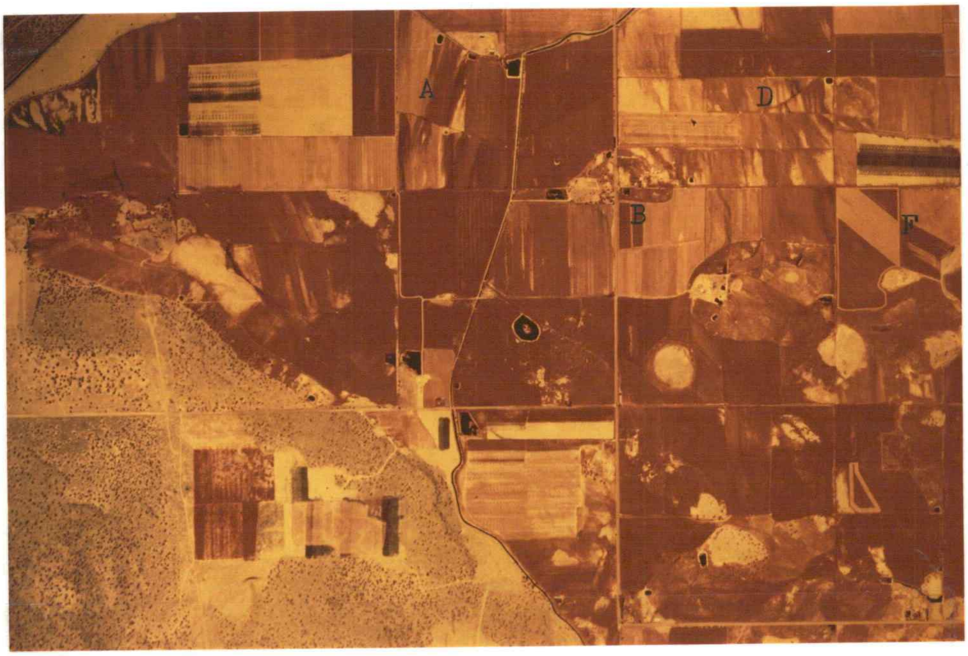


Figure 71. Wild flooding of fields at A and D using basin irrigation. Controlled flooding by furrows at F and by border strip at B can also be seen. Approximate image scale is 1:26,000.

Other shapes surface delivery (continued)

Slope 3-15%

Terraces

1. Small fields across the slope, usually like series of level steps
2. 10-60 cm (4-20 in) drop from one terrace to another
3. Crop: rice, vegetables, orchards

Corrugations

1. Uneven surface with row patterns aligned across the field
2. Down slope: 0.4-8%, cross slope: up to 12%
3. Cross ditches approximately 60+ m (200+ ft) apart, corrugations 45-91 cm (1.5-3 ft) apart
4. Crops: uncultivated crops--forage, small grains, etc.

Contour furrows/ditches

1. Furrows/ditches follow contour and run normal to the slope
2. Gentle slope along the length
3. Usually short lengths for furrows, from 30-201 m (100-660 ft)
4. Furrow spacing varies with crops: 45-122 cm (18-48 in), spacing between ditches from 61-182 m (200-600 ft)
5. Crops: all row crops, grains

Graded/contours borders

1. Graded border-length of strip along the slope with very short lengths, contour border-length of strip across the slope, like narrow steps, 10-60 cm (4-20 in) drop from one terrace to another
2. Width of strip varies with slope, usually narrow up to 9 m (30 ft)
3. Crops: rice, vegetables, orchards

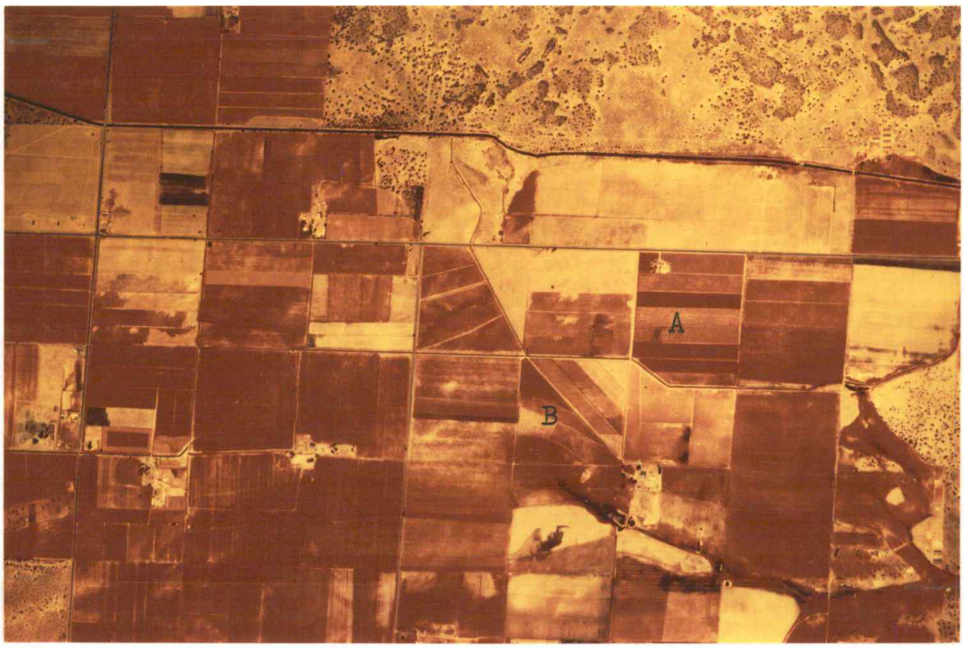


Figure 72. Corrugations are shown on level land and on rough surface at A and B respectively. Approximate image scale is 1:26,000.

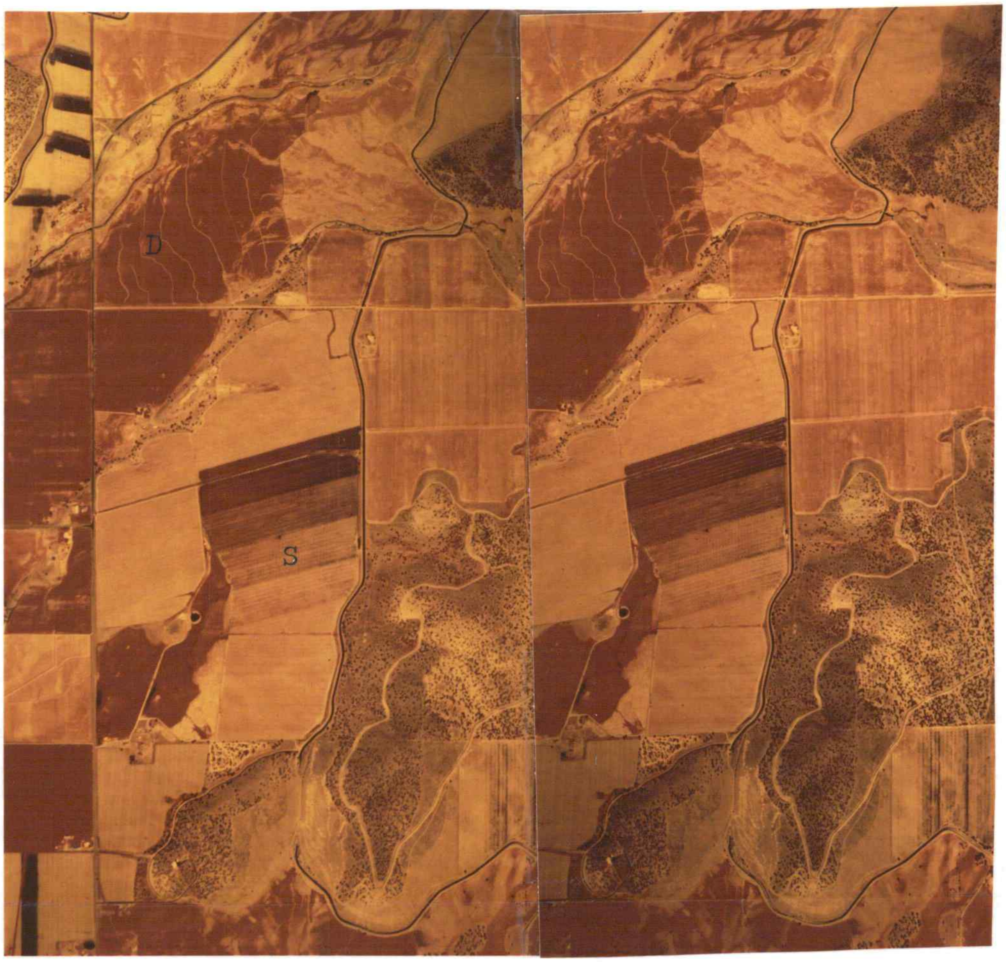


Figure 73. Contour ditch irrigation at D. The ditches follow the contour. Solid set system can be seen at S. Only part of the field is being irrigated at a time. Approximate image scale is 1:26,000.

The width of the field refers to the dimension perpendicular to the length as defined above.

Psychological-Physiological Aspects of Image Interpretation and Evaluation of the Key

Three important parameters of image interpretation are the interpreter's ability to perceive subtle tonal contrast, extract fine details, and see stereoscopically (Colwell, 1965). The ability to perceive hue is called color acuity and is a psychological experience related to the spectral stimuli. The smallest change in radiant energy affects the perceived tone. Not only the spectral wavelength but the intensity of wavelength affects the perception of hue and chroma. When spectral wavelengths are intensified all except three colors shift slightly towards either yellow or blue. This phenomena is called the Bezold Brücke Shift. When a person views a scene, he or she uses three primary colors as they reach his or her eyes to perceive the proportion of mix and, hence, the right hue. This ability to obtain the right proportion and adjusting the eyes with the shift is called trichromatism. Although most people possess normal color vision, about 8.5 percent of the male and 0.5 percent of the female population suffers from some kind of defective color vision. They may be totally color blind (monochromatism), confuse green and red (dichromatism), or they may suffer from analomous trichromatism, i.e., using the three primary colors but perceiving proportions that are different than for normal vision.

The ability to extract fine details is known as visual acuity. There are several forms of visual acuity. Pertinent to image interpretation is detection acuity which enables the interpreter to detect a small object against its background; vernier acuity which enables him to detect two lines, laid end to end, to test if they are continuous or offset from each other; and resolution acuity which enables him to perceive a separation between discrete elements of a pattern.

The ability to perceive depth is called stereoscopic acuity. The psychologist's explanation of a three-dimensional picture is explained by two comprehensive theories (Haber, 1978). The cue theory of Locke and Bishop states that the three-dimensional visual world is compressed onto a flat two-dimensional retinal picture, and the brain has to infer the correct third dimension based on previous experience. The psychophysical theory of Gibson contends that the retinal image is not a snapshot, but a succession of images that contain all the necessary details to view the objects as they are.

Whatever the true physiological explanation of variation in binocular vision, or of a person with normal color vision being unable to detect small features on a color image (Colwell, 1965), most psychologists agree with Schiffman (1975) that,

> the perception of many aspects of the environment is due not only to the biophysical character of the incoming stimulation and the appropriate sensory receptor mechanism but it is also due to a certain disposition and existing intentions within the perceiver.

Human factors are very important. Image interpretation is an extremely complex process. Impinging upon the interpreter's performance are factors of his background, training, aptitude, interest, personality, as well as his momentary state of motivation and fatigue (Saddaca, 1963). No appreciable work has been done by psychologists in this field as it relates to image interpretation. The psycho-physiological aspects affect the quality of his work as much as the techniques available to him. Background, training, and experience are as important as visual and mental acuities. It is highly improbable that a person who cannot distinguish between two irrigation methods on the ground will identify them on the image, or that an irrigationist will do the job any better without some previous knowledge of the fundamentals of image interpretation.

Purpose of Evaluation

The main purposes of the evaluation were:

1. to determine the extent to which the utility of the key depends upon the photo interpretation experience;
2. to determine the extent to which its usefulness depends upon photo interpreters' experiences in farming and irrigation;

3. to determine to what extent its value depends upon the general background of the interpreter;
4. to determine to what extent the organization of the key was successful in delineating confusing classes.

Method of Evaluation

The key was given to eleven students in a remote sensing course. The participants came from five different backgrounds: five were majoring in geography, two in geology, one in oceanography, two in range resources, and one in civil engineering. Their photo interpretation experience ranged from no previous experience to completion of third quarter in photo interpretation. Most of them had only one course in photo interpretation. Their experience in farming and irrigation ranged from none to eight years. Since 55 percent had no such experience, the participants were familiarized with the agricultural scene by means of slides, photographs and sketches of different land uses and irrigation methods. Since all of them except one had successfully completed a term of photo interpretation, it was assumed that they possessed normal visual and color acuity.

Each subject was provided the key, photographs, stereoscope, measuring scale and templates of different field shapes and sizes. Then he or she was asked to identify ten features selected from different organizational levels of the key. All were given the same questions and same photographs to keep visual stimuli-related factors, such as effects of different photographic materials, constant. A copy of the questionnaire is found at the end of this chapter.

Results and Conclusions

Each correct score was given ten points and the participants' performances were evaluated on percentage of accuracy. Results of the test as summary of average score of all participants are given in Table XVIII. The results reflect the biases of a small sample and unequal representation of participants from different fields:

1. The participants with interpretation experience scored better than those without experience, and the more the experience, the better the results;
2. Work experience showed no correlation with performance;
3. Persons with background in resource analysis did better than those with physical science background;
4. Level of organization of the key showed a very strong correlation with performance.

At the level of composite picture, each one responded correctly to the problems. As one moved from macro- to micro-levels, efficiency dropped down to 78 percent in intermediate level and 56 percent in the most detailed level. Most of the confusion was between hand move

TABLE XVIII. INFLUENCE OF VARIOUS FACTORS ON INTERPRETERS' PERFORMANCE

Factor	Score (%)
Background	
Geography	75
Geology	75
Oceanography	80
Range resources	85
Civil engineering	85
P.I. Experience	
No experience	75
One term of P.I.	78
Two terms of P.I.	85
Farming Experience	
No experience	78
Up to 2 years	82
2+ years	75
Organizational level	
First level	100
Second level	78
Third level	56

and furrow systems and within sprinkler types. Most of this confusion can be attributed to the same shape and size with furrow and hand move systems and the reluctance of most interpreters to use metrics and patterns for identification. Also, their unfamiliarity with irrigation, which, although it did not show up in their overall performance, was apparent at this level.

The method of evaluation was restricted by the small number of participants. Hence, the factors used in the analysis were not evaluated statistically using analysis of variance or similar methods.

Chapter Summary

Three different kinds of images were analyzed in order to determine the mission parameters and develop the key. Spectral response of crops and irrigation methods, growing season, time of photography, and scale were discussed as to how they influence mission planning. The organization of the key, methods and materials used in interpretation, and terminology used in the key were explained. The key was evaluated using photo interpretation experience, work experience, general background, and organization of the key as the basis of evaluation. In Chapter VI the possibility of computer-assisted analysis of irrigation methods will be examined.

QUESTIONNAIRE FOR THE EVALUATION OF THE KEY

1. Name______________________________

2. Class______________________________

3. Academic major______________________________

4. Previous experience in photo interpretation

Courses Taken

Course title	Course number	Course level
a.______		
b.______		
c.______		
d.______		

5. Experience in farming

   a. Own a farm   yes   no

   b. Worked on a farm   yes   no

   c. Worked with irrigation   yes   no

   d. Period of work in approximate months/days______________

Please circle the correct answer.

1. What is the land use type of the area inside the box.

   a. Agricultural

   b. Abandoned agricultural

2. Enclosed area shows a newly harvested field. Was it irrigated? Please give the reason why you think so.

   a. Yes

   b. No

   Reason____

   ____

3. Field patterns are subdued on this photograph because of abundant crop growth. It is still possible to identify irrigation methods. What kind of method is used in areas A and B?

   A a. Furrow

   b. Solid set

   c. Hand-move

   d. Side-roll

   B a. Furrow

   b. Solid set

   c. Hand-move

   d. Side-roll

4. What kind of irrigation method is used in this field?

   a. Furrow

   b. Solid set

   c. Hand-move

   d. Side-roll

   e. Both c and d

5. Name the irrigation method used for the area enclosed in the box.

   ____

6. Corner of center pivot irrigation methods are irrigated by some other method. Here are two center pivot systems. What kind of irrigation method is used to irrigate the corner of:

   A a. Hand-move

   b. Gun

   c. Side-roll

   d. Furrow

   e. Solid set

   B a. Hand-move

   b. Gun

   c. Side-roll

   d. Furrow

   e. Solid set

7. Identify the irrigation method used in these two irregular-shape fields and write down their names.

   a.______________________ b.______________________

CHAPTER VI

APPROACHES TO QUANTITATIVE IRRIGATION PATTERN RECOGNITION

There are two quantitative approaches to pattern recognition: the decision-theoretic (statistical) and the syntactic (structural). In the decision-theoretic approach, pattern recognition is a two-step process: (1) training the classifier by selecting prototype measurement vectors for the classes of interest and specifying a discriminant function for each class; (2) assigning each unknown pixel to one of the classes of interest. This process is called "digital classification." Because of the comparatively poor resolution and inherent boundary problems associated with Landsat data, a complete classification seldom results and a large number of pixels are left unclassified.

The syntactic or structural approach provides the capability for describing a large set of complex patterns by using small sets of simple patterns. This is how Fu (1974) describes it:

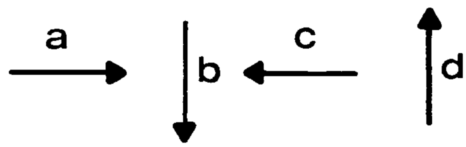
> A pattern described in terms of simpler sub-patterns called 'pattern primitives', should be much easier to recognize than the patterns themselves. The 'language' that provides the structural description of patterns in terms of a set of pattern primitives and their composition operations is sometimes called 'the pattern descriptive language'. The rules governing the composition of primitives into patterns are usually specified by the so-called grammar of the

> pattern descriptive language. After each primitive within the pattern is identified, the recognition process is accomplished, by performing a syntax analysis, or parsing, of the 'sentence' describing the given pattern to determine whether or not it is syntactically (or grammatically) correct with respect to the specified grammar.

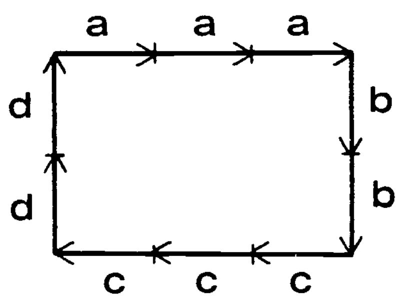
There are three steps in syntactic approach:

1. Preprocessing of the data by filtering, restoration and enhancement so that reasonably good patterns will emerge. Scanner data usually contain unwanted information or noise which deteriorates image quality. Removal of these unwanted values through mathematical procedures is called filtering. Enhancement is done to improve the quality of data so that more information can be extracted. It may involve contrast enhancement, edge enhancement, density slicing or simplifying data by some other means. Restoration improves data quality by compensating for the system's defects, like sixth-line problems, or geometric distortions.

2. Each preprocessed pattern is then represented by a language-like structure (a string of characters). This operation involves first breaking the pattern into subpatterns or pattern primitives and then coding it in a string of representative words or symbols. For instance, if a rectangle is to be divided into subpatterns and coded (see Figure 74), then the unit length of line segments (Figure 74A) are selected and the rectangle (Figure 74B) is represented by the string aaabbccccdd.



A



B

Figure 74. Derivation of pattern primitives.
After Fu, 1974.

3. A syntax analyzer (the classifier) matches a string of primitives representing an input pattern against strings of primitives representing each prototype pattern, and assigns it to the pattern class which matches best to the input string. This is a template matching approach.

The limitations of the statistical approach were recognized early in this study. Most patterns such as wet strips, sprinklers, or furrows cannot be resolved with digital analysis since most pixels are boundary pixels, as explained in Chapter III. Crop associations cannot be used as no single crop is associated with a single method. The only way to discriminate one irrigation method from another is to use shape and size as the elements of identification. Discriminant functions have been used in the classification of agricultural land into irrigated and non-irrigated and into different crop types (Colwell, 1978; Webster, 1978), but they do not provide for shape discrimination.

The syntactical approach might provide a tool for shape discrimination, and could be used with the statistical approach as a preprocessor. Once the data are classified into dry and irrigated crop types, a program could be developed to use the classified data for shape recognition. Bunge (1962) devised a quantitative measure of shape which eliminates all extraneous properties such as size, orientation, and position and measures only shape. He fitted n-sided polygons with equal lengths to different shapes and arrived at a unique set of shape numbers to each shape by summing distances between all vertices lag-one squared, and lag-two squared, etc. Figure 75 illustrates how lag-one, lag-two, etc. are summed. Figure 75a shows an eight-sided polygon with vertices numbered. Figure 75b shows how one vertex is skipped while summing lag-one. Distances between vertices 1 and 3, 2 and 4, 3 and 5, 4 and 6, 5 and 7, 6 and 8, 7 and 1, and 8 and 2 are measured and summed. All these distances are also squared and summed. Figure 75c shows calculation of lag-two, i.e., 1 and 4, 2 and 5, 3 and 6, 4 and 7, 5 and 8, 6 and 1, 7 and 2, and 8 and 3 are summed and their squares are summed. Lag-three is shown in Figure 75d, where three vertices are skipped. Thus, for an eight-sided polygon, a set of six numbers is produced, but each shape will have a one-to-one correspondence with a unique set of sums. By increasing the number of sides in the polygon any shape can be matched, but for most shapes relatively few sides are needed.

Bunge's method involves much computer time in going back and forth, and summing the lag-sums and their squares. A simpler method was devised by Bribiesca and Guzman (1980) who derived a shape number and order for each shape by using segments of a square grid. A square grid may be overlaid on top of a continuous shape to obtain a discrete shape. If 50 percent of the area falls under the square of the grid, it is included within the shape, otherwise it is discarded. Once the shape is derived by means of a given size grid in a fixed orientation, a Freeman chain can be used to derive the shape number.

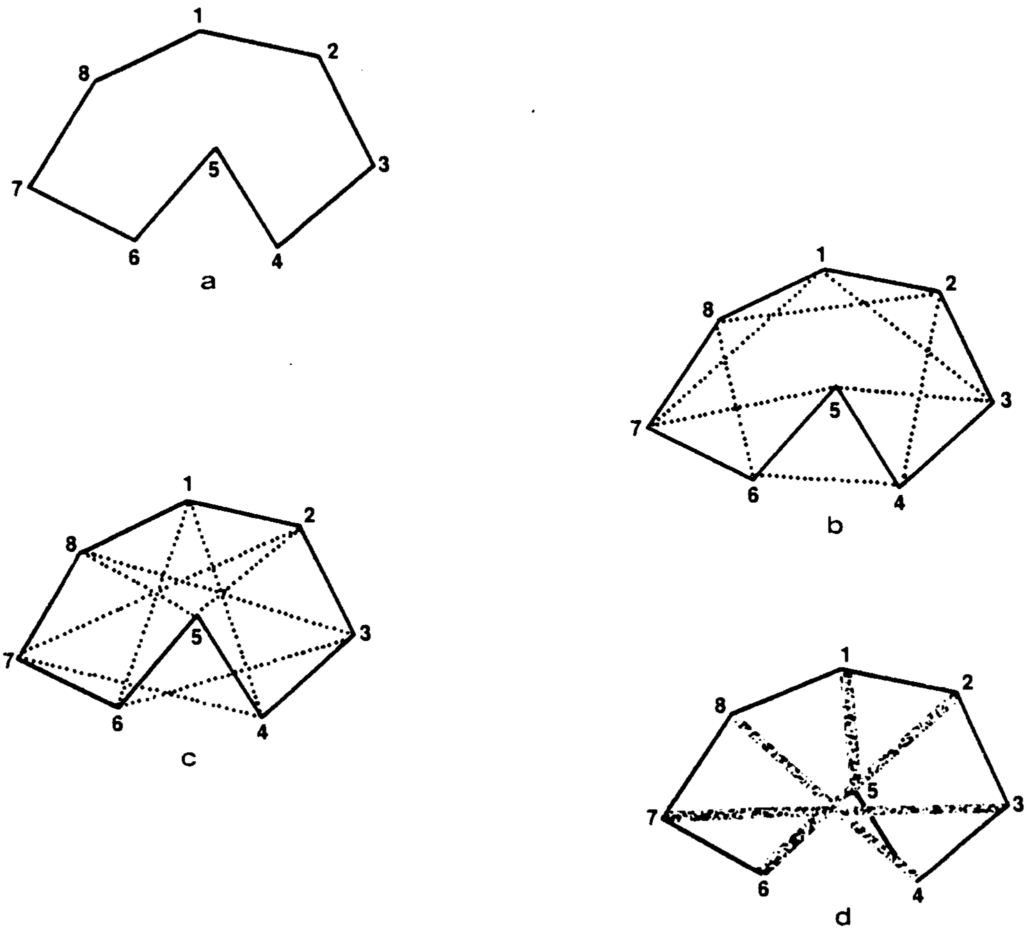


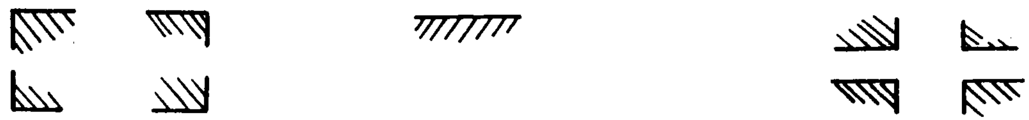
Figure 75. Illustrative aids for calculating lag-sums and their squares. From Bunge, 1962.

A Freeman chain is the curve obtained by moving clockwise on the grid. It derives the shape number by replacing each convex corner by a 1, each straight corner (a straight line segment) by a 2, and each concave corner by a 3, as is shown in Figure 76. For both shapes I and II, there are eight corners, hence eight digits in both shape numbers. The strategy is to choose the shape number which is the smallest when regarded as a number in base 2 and converted to base 10. For shape I, B and D have the smallest value and hence either B or D can be chosen. For shape II, the smallest value is for D. Two different shapes may yield the same shape value, but they have different orders. The order of a shape number is equivalent to the number of digits in it. Hence, in Figure 76 shapes I and II have eight digits and so both belong to order 8. The order of a shape number is always even since the boundary is closed.

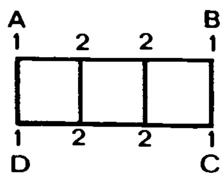
This concept of shape number and order of the shape falls under the syntactic pattern recognition approach and may possibly be applied to identification of irrigation methods when using Landsat. Landsat MSS data are in a grid format; each pixel can be regarded as a grid cell or square. If the computer is assigned the order and shape number it can search the pattern and identify it. The procedure would be as follows:

1. Pre-process the data by using discriminant function and classify the area into irrigated and non-irrigated crop types, and simplify the data so that discrete boundaries emerge.

TYPES OF CORNERS

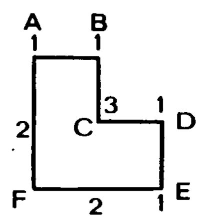


1 CONVEX CORNER	2 STRAIGHT CORNER	3 CONCAVE CORNER



I

SHAPE NUMBER		VALUE IN BASE 2 CONVERTED TO BASE 10
1 2 2 1 1 2 2 1	A	357
1 1 2 2 1 1 2 2	B	306
1 2 2 1 1 2 2 1	C	357
1 1 2 2 1 1 2 2	D	306



II

SHAPE NUMBER		VALUE IN BASE 2 CONVERTED TO BASE 10
1 1 3 1 1 2 1 2	A	324
1 3 1 1 2 1 2 1	B	393
3 1 1 2 1 2 1 1	C	531
1 1 2 1 2 1 1 3	D	297
1 2 1 2 1 1 3 1	E	339
1 2 1 1 3 1 1 2	F	423

Figure 76. Derivation of shape number using a Freeman chain. Modified from Bribiesca and Guzman, 1980.

2. Using the Freeman chain, derive the minimum shape number for a given shape in a given order. There are relatively few shapes that cover most of the irrigated area in the North Unit Deschutes Irrigation District (N.U.D.I. District), as fields are usually rectinlinear in shape. Some examples of typical field shapes, their order, and sizes are shown in Figure 77.

3. After the shapes are determined, they can be assigned to the computer for template matching. An interactive system will provide better communication and may improve the end product. Once the shape is determined, the size of the field can be easily determined by counting the number of pixels included. The field can then be assigned to a given method on the basis of its shape and size.

Although it was not possible to carry on this study because of time and financial limitations, it was felt that given time and resources, the methodology would be successful in discrimination of irrigation methods. However, it was decided to classify the data into different irrigated crops and see what shape orders would correspond to typical shapes of irrigated field in N.U.D.I. District.

Digital Classification

Landsat computer compatible tapes (CCT) for the growing season for the N.U.D.I. District were available in the Environmental Remote Sensing Applications Laboratory at OSU. One was for June 8, 1978 and the other for July 28, 1979. Since no ground truth was

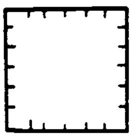
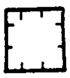
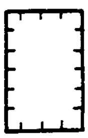
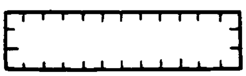
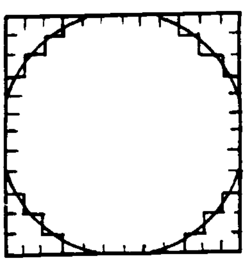
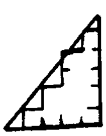
	Order of shape	Number of pixels	Approximate size (in acres)
	16	12	13.5
	18	18	20
	24	36	40
	12	9	10
	20	24	27
	30	36	40
	48	120	135
	18	12	13.5

Figure 77. Some typical field shapes, their order and size in pixel and equivalent acres.

available for 1978, it was decided to use 1979 data. These data have two limitations. First, the tape (Frame ID 510-18151, dated July 28, 1979) is a Canadian product, and data organization is not in the same format as American tapes available at the EROS Data Center. This meant modification of all programs to be used. Second, the data are for the late growing season, which is not the optimum season for separation of different crop types, since at this time all crops except mint and potatoes are either in the senescing stage or are harvested. An earlier date (mid-July) would provide better discrimination between irrigated crops and other cover types.

The classification was done by using various programs available at the OSU Computer center. The BGRAY program was used to generate a gray scale of band 5 and training sites were selected based on this gray scale and ground truth. Then, descriptive statistics for the training site pixels were generated using SEL version of program BYSELPT. This program gives the mean value and the standard deviation for each of the four bands for each class. These values were used by the program STATGEN for calculating the weights and limits for the classifier. Weights are scaling measures to take care of the unequal dispersion of data around their means in individual bands. Limits are selective guard bands which specify the domain of a given class in a given band. The limits use specified threshold values (the minimum value for a class, below which the pixel has to be rejected from being included in that class) to set the guard bands using the following formula:

$$\text{Limit} = u \pm \text{threshold}\ (\sigma)$$

The program CLSFY24 was used for classification. It uses Total Distance or DISTT (D) as a similarity measure. Using the following formula it calculates the similarity between the unknown pixel and each prototype vector:

$$D_{ik} = \sum_{j=4}^{7} \frac{X_{jk} - u_{ji}}{\sigma ji}^{2}$$

where: X = unknown pixel;

u_{ji} = mean values;

σ_{ji} = standard deviations;

k = 1,2,3,.......n, k^{th} pixel from a set of n (unknown) pixels;

j = 1,2,3,4, the band values for four MSS bands;

i = 1,2,3,...m, i^{th} class from a set of m prototype classes.

For each pixel X_k, the computer calculates the value D_{ik} for all m classes and assigns it to the class i for which D_{ik} is the smallest. If the value D_{ik} does not fall within the various guard bands, then it is rejected and an unclassified symbol is assigned to it.

The data were classified into 10 classes: water, non-irrigated and irrigated crops--mint, blue grass, wheat, potato, barley, garlic, alfalfa, and pastures. The result of the classification given in

Table XIX shows the percentage accuracy of the classification within the training site pixels. The accuracy of the classification over the whole area was not determined. Mint and water are the only cover types that were classified satisfactorily. Unclassified pixels in water are attributed to the reflectance from rocks on the sides of the streams, and misclassification in mint resulted because of boundary pixels. Most confusion within the crop types can be attributed to the fact that in late-July most crops, except potato and mint, are either harvested or are in senescing stage. Mint is fully developed and has a very high reflectance. Potatoes are growing and have not yet reached to maturity. Blue grass is harvested, is growing back, and is confused with potatoes. Alfalfa, pasture, and barley overlap in signature. Garlic is clipped and looks like bare soil as does dry farming area. The overall accuracy of initial classification was 42.2 percent, which improved to 48.2 percent by adjusting means and standard deviations. But most improvements were in water, mint and wheat. The rest of the classes remained essentially the same. Although some of the errors may be classed as locational errors as the data were not adjusted to the ground location and were skewed, generally poor results of the classification as shown in Figures 78 through 83 thwarted further attempts at testing the methodology. Data from mid-July will provide better irrigated crop discrimination in a single date analysis, because

TABLE XIX. RESULTS OF CLASSIFICATION FOR TRAINING SITE PIXELS

Cover type	Line printer symbol	Percent accuracy
Water	*	88.8
Non-irrigated crops	D	52.7
Irrigated crops:		
Mint	M	91.1
Blue grass	B	27.7
Wheat	W	64.4
Potato	P	12.5
Barley	/	44.4
Garlic	G	33.3
Alfalfa	A	55.5
Pasture	+	18.5
Overall		48.2

Figure 78. Digital classification of irrigated and non-irrigated crops.

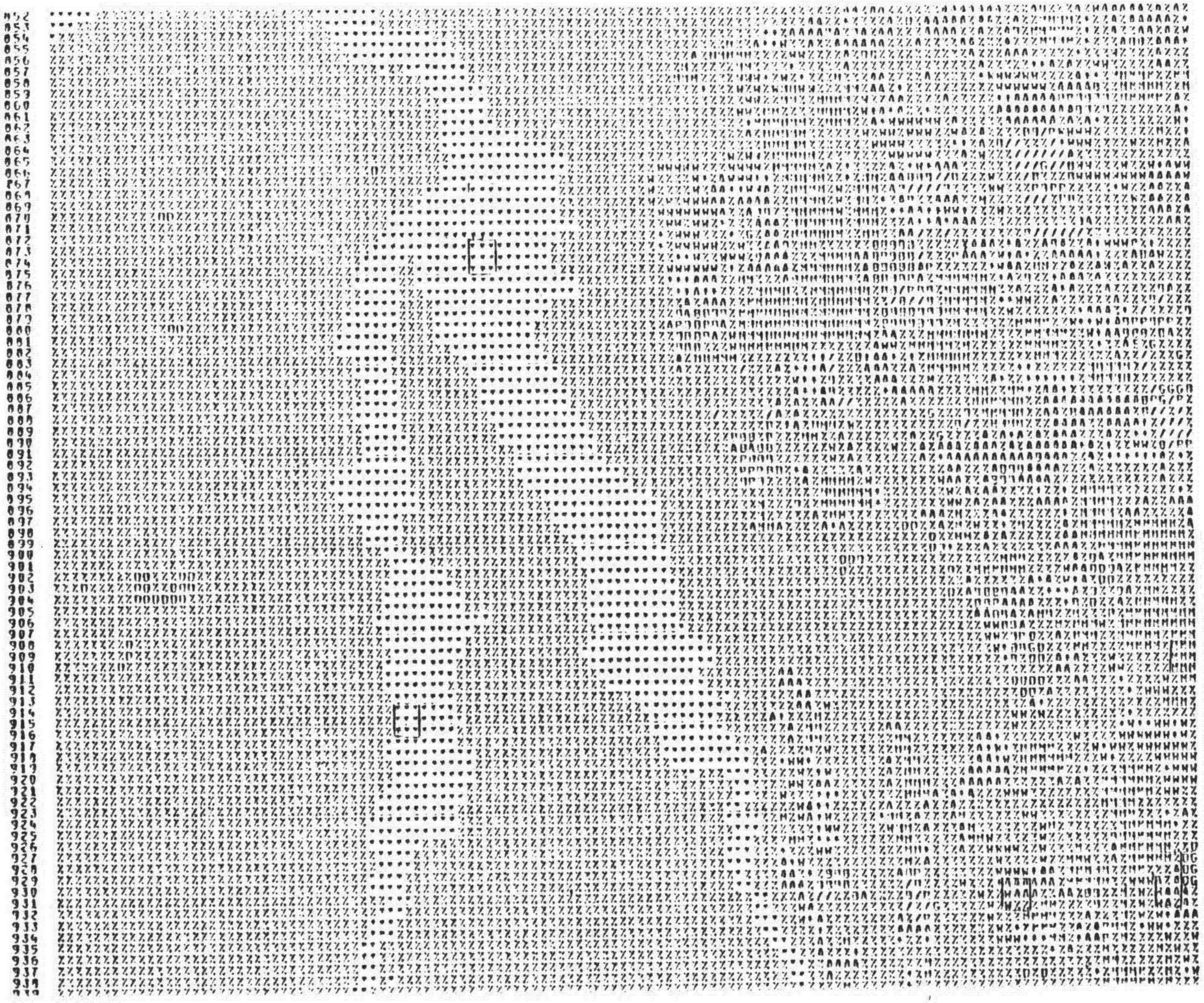


Figure 79. Digital classification of irrigated and non-irrigated crops.

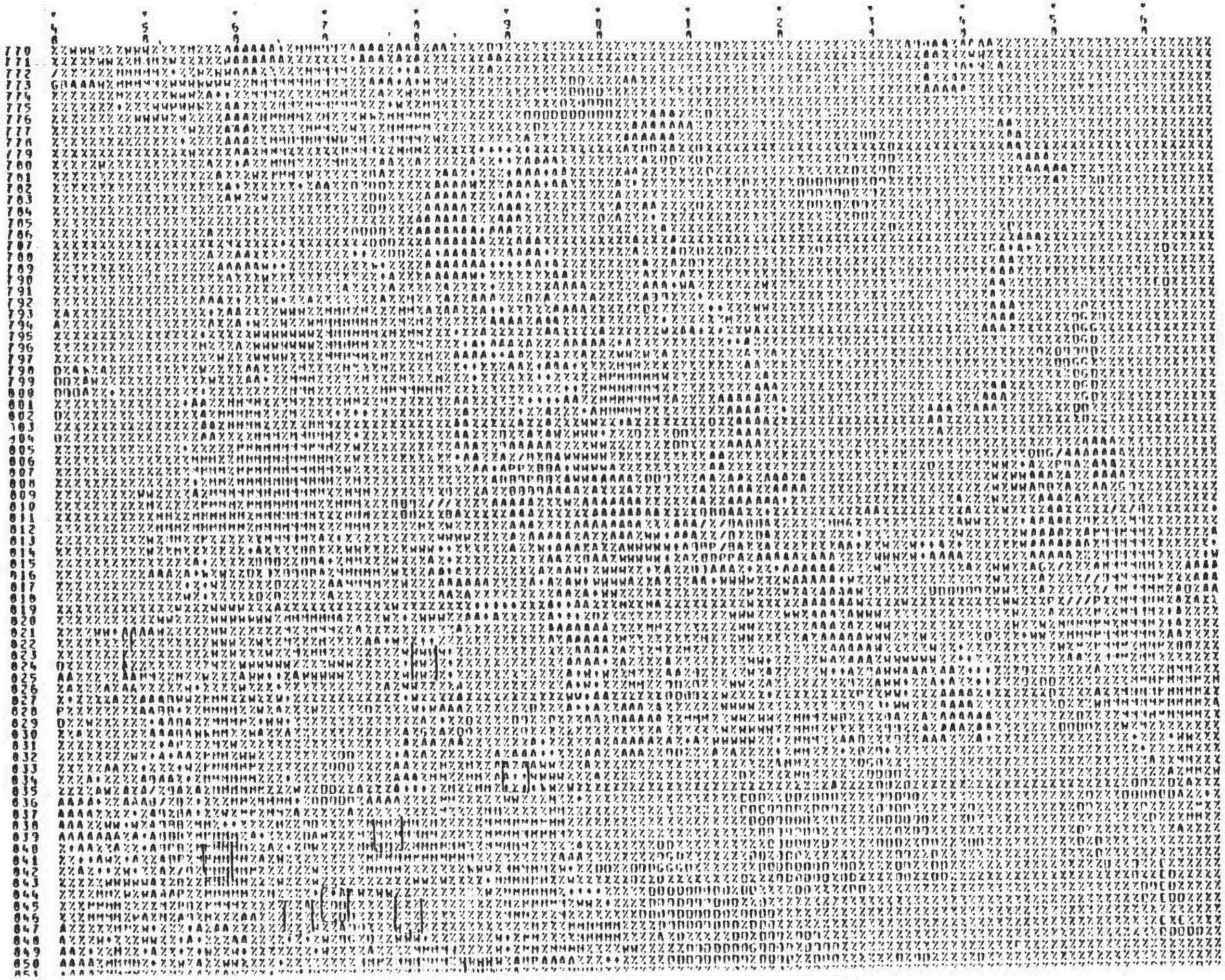


Figure 80. Digital classification of irrigated and non-irrigated crops.

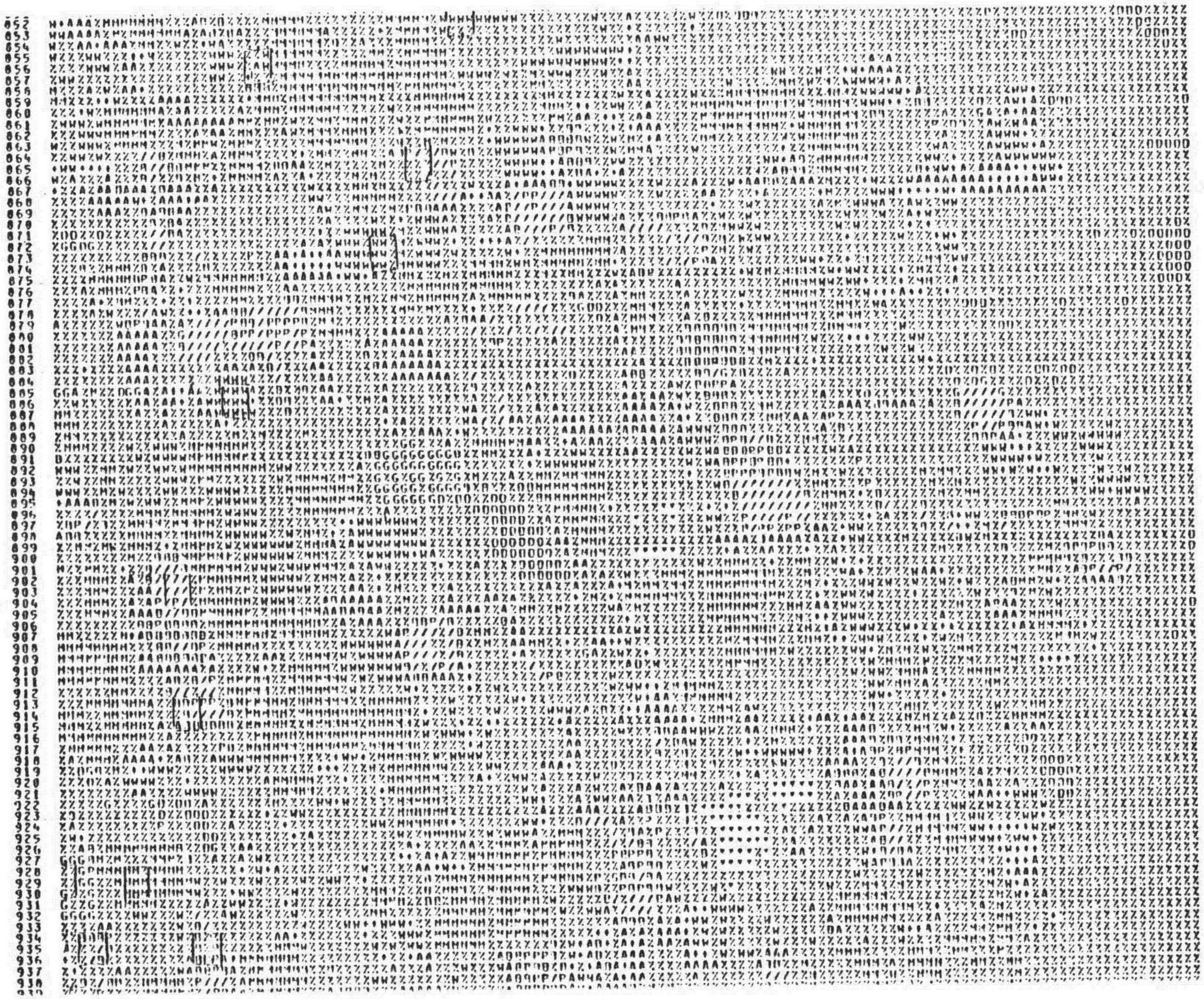


Figure 81. Digital classification of irrigated and non-irrigated crops.

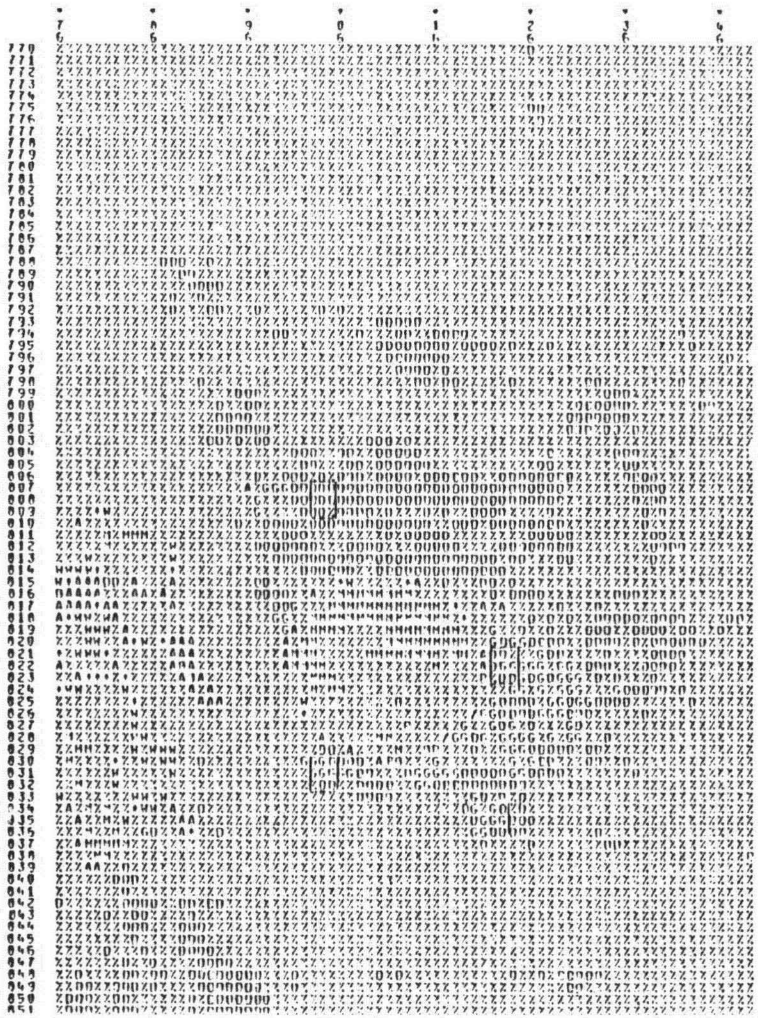


Figure 82. Digital classification of irrigated and non-irrigated crops.

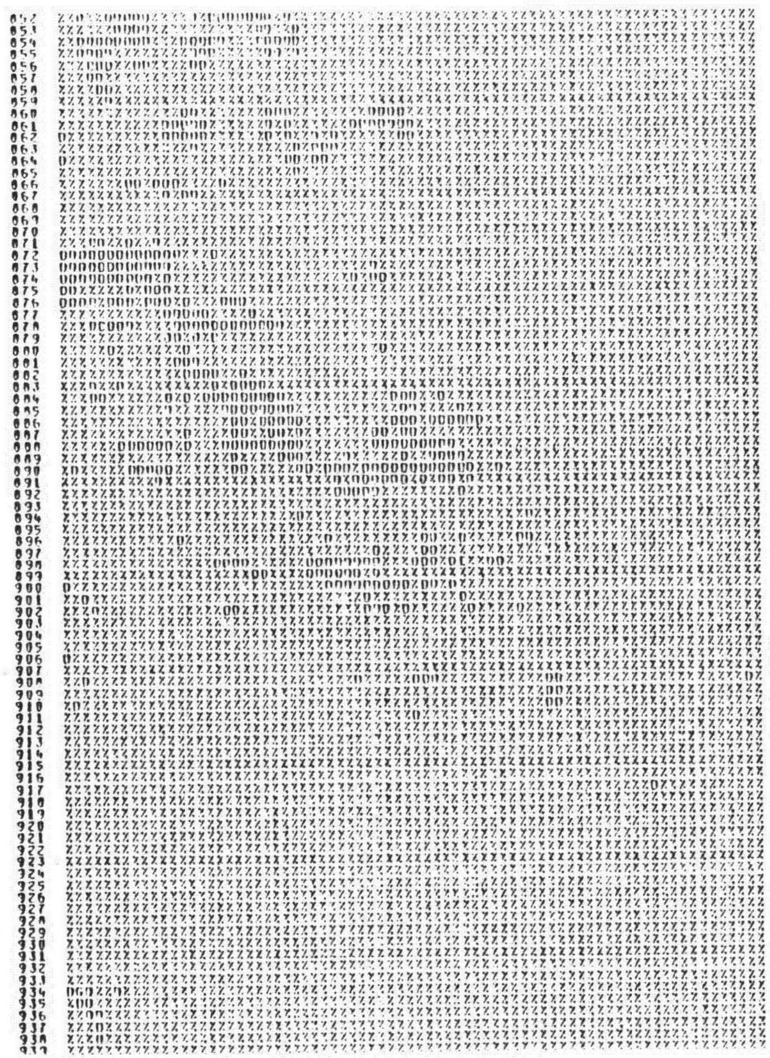


Figure 83. Digital classification of irrigated and non-irrigated crops.

except for harvested blue grass, all other crops appear in different shades of red and dry farmed fields are tan in appearance. Colwell, Hay and Thomas (1978) used data from two different dates, and regressed different band ratio values such as 2*MSS7/MSS5 and MSS4/MSS5, to obtain better classification of irrigated versus non-irrigated crops. For this kind of analysis where better discrimination is possible, early June and mid-July data will be ideal. Whatever procedures are used, a good classification is important to preprocess data for a syntactic approach to irrigation method identification.

Chapter Summary

The possibilities of using quantitative approach for irrigation methods identification were searched and described in this chapter. Shape discrimination is a very complicated problem and requires both statistical and structural approaches to analysis. Limitations of MSS data for the available date hindered further processing and testing of the methodology which may prove helpful in quantitative analysis. In Chapter VII the conclusions of this research will be discussed.

CHAPTER VII

SUMMARY AND CONCLUSION

Irrigation or application of water to the soil for supplying water required for plant growth is essential for permanently profitable agriculture in the arid and semiarid regions of the western United States. Irrigation is the largest consumer of water and power in Oregon. With the scarcity of fossil fuel, more and more reliance will be on hydro-power. Generation of hydro-power is limited by the non-availability of potential sites for dams in the Pacific Northwest. Irrigation not only consumes power directly for lifting, conveying and applying water to crops, but also indirectly, by consuming large amounts of water and thus depriving the hydroelectric plants of water. A careful monitoring and allocation of water resources between conflicting uses is the main concern of water resources managers. Their interest in irrigation is not only monitoring irrigated land use, but also the type of irrigation being used, as it indicates amounts of water and power being consumed.

Irrigation Methods

Commonly used irrigation methods are gravity and sprinkler irrigation. Gravity or surface delivery of water is the traditional method of water application where the soil is a reservoir for storing water as well as conveyor and distributor in the form of ditches. It requires continuous vigil in operation and much labor is required for proper diversion and dispersion of water. Uncontrolled flooding of water in basin irrigation results in much wastage of water, in addition to leaching of nutrients and creating salinity problems. Controlled flooding by border strips and furrows improves water application. Besides these three methods, there are variations of water application to accommodate slope. Basin, border strips, and furrows are usually employed on surfaces with 0 to 3 percent slope, whereas terraces, corrugations, contour borders, graded borders, contour furrows and contour ditches are used on lands with 3 to 15 percent slopes.

Sprinkler irrigation or overhead delivery of water, where water is sprayed into the air and it falls on the ground like rain, is the second main type. It is applicable to all irrigable soils on 0 to 15 percent slopes. Water application efficiency is better than most gravity systems and labor requirements are low. Continuously moving systems cut down on labor requirmenets by an average of 92 percent, but require considerable energy to operate. There are many variations in sprinkler systems, such as hand move, side-roll, solid set, center pivot, continuously moving straight laterals, guns and travellers.

Remote Sensing as Data-Gathering System

Traditionally data about irrigated acreages and irrigation methods have been collected manually. This lacks reliability, is very expensive, and data are outdated by the time they are compiled. A quick, reliable, and comparatively inexpensive method for data collection is provided by remote sensing. The interaction of electromagnetic radiation with irrigated and non-irrigated crops and soils gives them a characteristic tone, color, or spectral reflectance. These characteristics can be used to analyze the remotely sensed data in two manners: by using the pictorial aspects of the data in visible and reflective infrared wavelengths and manual interpretation; and secondly, by using computer analysis and numerical forms of data. This second approach can also be used for image-oriented analysis. Data gathered by the Landsat MSS are in a digital format which can be processed into an image format (MSS color composites and RBV images) and used for manual interpretation, or it could be used for quantitative analysis using computers for preprocessing. The spectral, spatial, and temporal characteristics of the images are used for irrigation method identification. The spatial characteristics of shape, size, texture, pattern and site provide important clues for identification. Spectral characteristics are responsible for perceived color, image contrast, and resolution. They do not remain static, but change with time. Thus, use of remotely sensed data requires consideration of all elements of spatial, spectral, and temporal variability. A methodology was developed whereby these characteristics could be used to discriminate irrigation methods.

The North Unit Deschutes Irrigation District

The North Unit Deschutes Irrigation District (N.U.D.I. District) of central Oregon provided the stage to develop and test the methodology. Several reasons for choosing N.U.D.I. District were: its location in the semiarid intermontane region which typifies arid central Oregon where cultivation of most crops is not possible without irrigation; water scarcity which gives rise to the issue of conservation whereby thousands of acres of additional land might be brought under irrigation; soils and slopes which are generally suitable for both surface and sprinkler systems; natural vegetation of sage brush which provides a dry drab background against which irrigated lands are easily seen on an image; a diversity of crops which is helpful in delineating field shapes which are not possible in a mono-culture environment; irrigation practices which have been changing since irrigation first started in 1946; good Landsat and U-2 growing season coverage which is available for 1973 and 1978; and generally dry climate and clear visibility which provide ideal conditions for flying photographic missions.

The irrigation season in the N.U.D.I. District generally starts in early April and continues through the middle of October, with peak water requirements occurring during June and July. Of the total 50,000 acres of irrigable land, 46,278 acres are irrigated. Approximately 50 percent of the irrigated fields used side-roll, 10 percent hand move, one percent solid set, 6 percent center pivot, 25 percent furrow irrigation, and the rest used mixed systems. Of the irrigated crops, peppermint, blue grass, wheat, alfalfa, irrigated pasture, potato, garlic and barley account for 95 percent of the total irrigated crops. A crop and irrigation calendar for these crops was developed for the region.

Image Analysis and Mission Parameters

Three important criteria that affect image characteristics are: variations in multispectral reflectance from irrigated and non-irrigated crops and soils; growing season and time of the photography; and scale of imagery. Spectral reflectance of crops and soils vary with wavelength. Landsat MSS color composites (simulated color infrared), Landsat RBV (black and white) images, and CIR aerial photographs were analyzed to determine their utility in irrigation method identification. Temporal changes in the spectral response of irrigated and non-irrigated crops and soils affect image characteristics. The crop calendar provided the information about phenological changes in crops. Images used covered the main part of the growing season from May through early August. The image scale determines resolution and is an important factor in determining the cost of analysis versus the level of desired details. The images analyzed ranged from 1:23,000 to 1:1,000,000 in scale.

Each image was analyzed at three levels of detail: (1) to differentiate between irrigated and non-irrigated crops and soils using temporal/spectral characteristics of crops and soils; (2) to distinguish those irrigation methods that can be differentiated into broad classes by using spatial characteristics of shape and size; and (3) to differentiate irrigation methods using fine details such as wetting patterns of sprinklers and surface irrigation; and the presence of wheel marks, laterals, furrows, corrugations, borders or siphon tubes.

The results of analysis indicated that: CIR images provide better discrimination of irrigation practices rather than black and white panchromatic images; late summer is the best time to differentiate irrigated crops from non-irrigated crops, but early growing season proved to be the best time to identify irrigation methods on aerial photographs; variation of image scale needed depends on the detail of information desired.

Image Interpretation Key

Information helpful in identification of irrigated fields and irrigation methods was synthesized in the form of a key. The organization of the key is hierarchical. In three stages it takes the user from the macro- to the micro-level. The first step can be used with small-scale images, the first and second steps with medium scale images, and the first, second, and the third steps can be used with large-scale images. The first step involves the full scene and discrimination of land surfaces into different general land uses, irrigated and non-irrigated crop lands, using temporal spectral characteristics of the image. The second step in addition uses spatial characteristics and classifies irrigation methods in broad categories using shape and size. The third step uses all image characteristics to identify irrigation methods at the most detailed level. The nature of the key conforms to no prototype, it is a hybrid and uses both explanatory text and illustrations to help the interpreter. It is developed for 1:23,000 image scale, but can be adapted to smaller and larger scales. Use of explanatory text, crop calendar, light tables, magnifiers, stereomicroscopes, measuring devices and definition of the terminology provided with the key facilitate its use.

Evaluation of the Key

Image interpretation is a complex task. The interpreter's ability to perceive subtle tonal variations, extract fine details and see stereoscopically are not only governed by his physiological state, but are also governed by his disposition, i.e., his background, training, aptitude, interest, personality, and his immediate state of motivation and fatigue. The key was evaluated to determine the effects of photo interpretation experience, farming and irrigation experience, and general background, on the utility of the key, as well as to determine the extent to which the hierarchical organization of the key was successful in delineating potentially confusing classes.

The conclusions of the test were that interpreters with photo interpretation experience did better than those without experience, work experience in farming and irrigation showed no correlation with overall performance, and participants from resource analysis background did better than those with physical science background. A very strong correlation was noted between interpretation accuracy and the level of details to be interpreted. While 100 percent correct scores were received at the first level of the key, it dropped to 78 percent and 56 percent at the second and third level of details. Although no correlation was noted between work experience and overall performance, it was apparent at the most detailed level that those with work experience did better than those without it.

Quantitative Approach to Irrigation Pattern Recognition

Quantitative analysis of irrigation methods depends on discrimination of shape. It may be posssible to discriminate shapes using both statistical and structural approaches. It was not possible within the scope of this research to explore this type of analysis. Instead, only discrimination between irrigated and non-irrigated crops was attempted. The overall accuracy of the classification was 48 percent. The reason for this low performance is attributed to the lack of best seasonal period of data (July 28) when most crops are either harvested or in senescing stage and thus the spectral crop signatures overlapped internally as well as with non-irrigated crops and sage brush. It may be possible to achieve a good classification by using an early to mid-July date for a one-time analysis, or using two data dates--early June and mid-July--for the analysis. Methods have been developed for achieving a good classification by regressing two different dates of data and using ratioed band analysis for classification. Since a good classification was not possible under the present circumstances, further analysis was dropped. However, it may be possible to use quantitative techniques for irrigation pattern recognition, using a three-step process:

1. Preprocess the data by using statistical pattern recognition techniques, so that discrete shapes emerge;
2. Use a Freeman chain to derive the shape order and shape number;
3. Use a template matching approach that allows a syntax "analyzer" to search for similar shapes and sizes and assign

the unknown shape to a particular irrigation method.

It should be kept in mind that only broad classification is possible; the method should be capable of delineating centerpivots and side-roll systems, but confusion will be created between gravity methods and sprinkler methods with similar field shapes and sizes.

Conclusions

The purpose of this research was to test the applicability of photographic and optical mechanical scanning systems in the identification of irrigation practices. Conclusions drawn from this study are:

1. Of the two approaches to the analysis of remotely sensed data, image-oriented analysis rather than quantitative analysis is best-suited for irrigation methods discrimination. Image characteristics such as texture and pattern which, along with shape, size, tone, and color, provide important diagnostic clues for detailed irrigation method analysis in photographic products, cannot be used in mechanical scanners because of their poor resolution. Quantitative analysis of irrigation pattern recognition depends on shape discrimination that is not practical with the present stage of technology.

2. CIR images provide better discrimination than black and white panchromatic images because discrimination of crop types and dry or

wet soils is easier in near-infrared than in the visible band of the spectrum. It is easier to perceive color differences than gray tone variations.

3. While irrigated and non-irrigated crops can be differentiated using multidate imagery on 1:1,000,000 scale, for satisfactory discrimination of all irrigation methods, 1:30,000 or larger scale imagery is needed.

4. The best time for irrigation method discrimination is the early growing season when irrigation patterns can be seen while crops are still very young and wetting patterns are not subdued.

The key developed in this study for discrimination of irrigation methods is applicable in several ways. Provided is an efficient, inexpensive, and timely data-gathering technique to the water resources manager. The key can be used for training personnel for the specific job, or can be used in the classroom as an instruction aid. Applicability is not limited to the intensive study area. It can be used, with only slight modifications resulting from prevalent cultivation practices in all the dry and semiarid regions, whether they are in the heartland of America, in Egypt, or in the Indian Subcontinent. It is not tied to the scale range that it is developed for. In its various stages, it is applicable from smaller to larger scale.

It is said that civilizations have risen on irrigated lands and have also decayed and disintegrated on irrigated lands. While this empirical generalization cannot be denied, it is also true that the perpetuity of civilized nations is dependent on permanently profitable agriculture. Profitable agriculture without irrigation is not feasible in arid and semiarid lands. The bread baskets created by irrigation can easily revert to dust bowls and repeat the history once again if the irrigation practices are not maintained properly. Water is becoming a scarce resource with conflicting uses. A changing climate may result in diminishing supplies, and scarcity of fossil fuel is increasing the demand for hydro-power. It is advisable to monitor where and how we use our water resources and develop means to use it in such a way as to prevent another Mesopotamia to be added to the list of lost civilizatons.

BIBLIOGRAPHY

American Society of Photogrammetry. Manual of Photographic Interpretation. Vol. 1. Falls Church, Virginia: American Society of Photogrammetry, 1960, pp. 90-126.

American Society of Photogrammetry. Manual of Color Aerial Photography. Falls Church, Virginia: American Society of Photogrammetry, 1968, 550p.

American Society of Photogrammetry. Manual of Remote Sensing. Vols. 1 and 2. Falls Church, Virginia: American Society of Photogrammetry, 1975, pp. 1-25, 235-320, 869-1071, 1715-1804.

Avery, T. E. Interpretation of Aerial Photographs. Minneapolis, Minnesota: Burgess Publishing Company, 1977, 392p.

Bribiesca, E., Guzman, A. "How to Describe Pure Form and How to Measure Differences in Shapes Using Shape Numbers." Pattern Recognition. Vol. 12, 1980, pp. 101-112.

Benedict, R. A. "Scale of Operation on Farms in a New Irrigation District. Jefferson County, Oregon. 1949-1953." Master's thesis, Oregon State University, 1955, 58p.

Bigelow, G. F. "Photographic Interpretation Keys--A Reappraisal." Photogrammetric Engineering. Vol. 29, No. 6, 1963, pp. 1042-1051.

Bilanski, W. K., Kidder, E. H. "Factors that Affect the Distribution of Water from a Medium Pressure Rotary Irrigation Sprinkler." Transaction of the American Society of Agricultural Engineers. Vol. 1, No. 1, 1958, pp. 19-23.

Bunge, William. Theoretical Geography. Lund Studies in Geography. Ser. C. General and Mathematical Geography No. 1. The Royal University of Lund, Sweden. Lund: C. W. K. Gleerup, 1962, 289p.

Colwell, R. N. "Report of Commission VII (Photographic Interpretation) to the International Society of Photogrammetry." Photogrammetric Engineering. Vol. 18, No. 3, 1952, pp. 375-399.

________. "The PI Picture in 1955." Photogrammetric Engineering. Vol. 21, No. 4, 1955, pp. 720-724.

________. "Aids for the Selection and Training of Photo Interpreters." Photogrammetric Engineering. Vol. 31, No. 2, 1965, pp. 326-339.

Colwell, R. N.; Wall, S. L.; Brown, C. E.; Daus, S. J.; and Vesterby, V. L. Determining the Usefulness of Remote Sensing for Estimating Agricultural Water Demand in California. Annual Report (1 January 1977-28 February 1978). Berkeley: Space Sciences Laboratory, University of California, 1978, 71p.

Colwell, R. N.; Hay, C. M.; and Thomas, R. W. Advanced AI Aids and Key Development. Annual Progress Report (15 November 1977 to 14 November 1978). Series 19, Issue 66. Berkeley: Space Sciences Laboratory, University of California, 1978, 130p.

Colwell, R. N. Some Basic Considerations in Remote Sensing. Sixth Alberta Remote Sensing Course. University of Alberta (February 27 - March 3, 1978). Berkeley: Space Sciences Laboratory, University of California, 1978, 167p.

Collins, M. Sprinkler Irrigation Development in Oregon. Special Report 496. Corvallis: Oregon State University Experiment Station, February 1978, 9p.

Davis, S. "Subsurface irrigation today and tomorrow in California." Proceedings of National Irrigation Symposium (November 10-13, 1970). Lincoln, Nebraska: Nebraska Center for Continuing Education, 1971, pp. H1 - H8.

De Lancie, R.; Steen, W. W.; Pippin, R. E.; and Shapiro, A. "Quantitative Evaluation of Photo Interpretation Key." Photogrammetric Engineering. Vol. 23, No. 5, 1957, pp. 858-864.

Draeger, W. C. "Monitoring Irrigated Land Acreage using Landsat Imagery: An Application Example." Proceedings of the Eleventh International Symposium on Remote Sensing of Environment. Vol. 1 (25-29 April 1977). Ann Arbor, Michigan: Environmental Research Institute of Michigan, 1977, pp. 515-524.

Estes, J. E., and Senger, L. W. Remote Sensing: Techniques for Environmental Analysis. Santa Barbara: Hamilton Publishing Company, California, 1974, 339p.

Evans, Michael A., and Marrs, R. W. Identification of Irrigated Crop Types from ERTS-1 Density Contour Maps and Color Infrared Photography. Springfield, Virginia: Clearinghouse for Federal Scientific and Technical Information, 1977, 11p.

Frost, R. E. "Discussion of Photo Recognition Analysis and Interpretation and Photo Keys." Photogrammetric Engineering. Vol. 18, No. 3, 1952, pp. 502-505.

Fu, K. S. Syntactic Methods in Pattern Recognition. New York: Academic Press, 1974, pp. 1-20.

Grabau, W. E. Pixel Problems. Misc. Paper M-76-9. Vicksburg: Mobility and Environmental Systems Laboratory, U.S. Army Engineers Waterways Experiment Station, 1976, 61p.

Haber, R. N. "Visual Perception." Annual Review of Psychology. Vol. 29, 1978, pp. 31-32.

Hansen, E. G.; Williams, B. C.; Fangmeier, D. D.; and Wilke, O. C. "Influence of subsurface irrigation on crop yields and water use." Proceedings of National Irrigation Symposium (November 10-13, 1970). Lincoln, Nebraska: Nebraska Center for Continuing Education, 1971, pp. D1 - D9.

Hoffer, R. M., and Johannsen, C. J. "Ecological Potentials in spectral signature analysis." Remote Sensing in Ecology. Johnson, P. L. (ed.). Athens: University of Georgia Press, 1969, pp. 1-15.

________. "Biological and Physical Considerations in Applying Computer-aided Analysis Techniques to Remote Sensor Data." Remote Sensing: The Quantitative Approach. Swain, P. H., and Davis, S. M. (eds.). New York: McGraw Hill International Book Company, 1978, pp. 227-289.

Israelson, O. W. Irrigation Principles and Practices. New York: Wiley, 1962, 447p.

Keller, J. "Design, Use and Management of Solid Set Systems." Proceedings of National Irrigation Symposium (November 10-13, 1970). Lincoln, Nebraska: Nebraska Center for Continuing Education, 1971, pp. AA1 - AA9.

Kimbal, N. D. "The Impact of Economic and Institutionsl Forces on Farmer Adjustments in the North Unit Deschutes Irrigation Project." Ph.D. Dissertation, Oregon State University, 1961, 54p.

Kimbal, N. D., and Castle, E. N. H. Historical Development and Adjustments of the North Unit Deschutes Irrigation Project Farms. Misc. Paper 133. Corvallis: Oregon State University, Agriculture Experiment Station, 1962, 38p.

Knipling, E. B. "Leaf Reflectance and Image Formation on Color Infrared Film." Remote Sensing in Ecology. Johnson, P.L. (ed.). Athens: University of Georgia Press, 1969, pp. 17-29.

Künecke, B. H. Distribution of Irrigation in Eastern Oregon. Corvallis: Water Resources Research Institute, 1974, 29p.

McNamara, J. B. "Sub-irrigation--The Basis of Tomorrow's Agriculture." Proceedings of National Irrigation Symposium (November 10-13, 1970). Lincoln, Nebraska: Nebraska Center for Continuing Education, 1971, pp. C1 - C7.

McNeill, G. "Size Language and Military Photo Interpretation." Photogrammetric Engineering. Vol. 18, No. 3, 1952, pp. 502-505.

Michael, A. M.; Mohan, S.; and Swaminathan, K. R. Design and Evaluation of Irrigation Methods. New Delhi: Water Technology Center, Indian Agricultural Research Institute, 1972, 208p.

Naval Reconnaissance and Technical Support Center. Image Interpretation Handbook. Vol. 1. Washington, D.C.: Government Printing Office, December 1967, 302p.

Nunnally, Nelson R. "Introduction to Remote Sensing: The Physics of Electromagnetic Radiation." The Surveillant Science, Remote Sensing of the Environment. Holz, R. K. (ed.). Boston: Houghton Mifflin Company, 1973, pp. 18-27.

O'Neill, H. T. "Keys for Interpreting Vegetation from Air Photographs." Photogrammetric Engineering. Vol. 19, No. 3, 1953, pp. 422-424.

Osborn, H. A. "Land Use and Farm Organization on a New Irrigation Project, Jefferson County, Oregon." Master's thesis, Oregon State University, 1951, 78p.

Oregon Department of Geology and Mineral Industries. Geological Map of Oregon West of 121st Meridian, 1961.

Oregon State Water Resources Board. Oregon's Long-Range Requirements for Water, General Soil Map, Report for irrigable areas, Deschutes Drainage Basin. Appendix I-5. Salem: State Water Resources Board, 1969, 116p.

Packer, M. R. "Developing Operational Techniques for the Use of Landsat Data in Identifying Irrigated Agriculture in Idaho." Proceedings of American Society of Photogrammetry and American Congress on Surveying and Mapping. Seattle, Washington (September 28 - October 1, 1975). Falls Church, Virginia: American Society of Photogrammetry, 1975, pp. 262-272.

Pair, C. H. "Mechanized Sprinkler Systems, Their Applications and Limitations--What Next?" Proceedings of National Irrigation Symposium (November 10-13, 1970). Lincoln, Nebraska: Nebraska Center for Continuing Education, 1971, pp. CC1 - CC8.

Pair, C. H.; Larsen, D. C.; and Kohl, R. A. Center Pivot Sprinkler Systems. Current Information Series No. 192. Cooperative Extension Service University of Idaho, February 1973, 4p.

Pair, C. H. Sprinkler Irrigation. Washington, D.C.: Sprinkler Irrigation Association, 1975, 615p.

Pinchot, J. D. "The Technology and Management of Travelling Sprinklers." Proceedings of National Irrigation Symposium (November 10-13, 1970). Lincoln, Nebraska: Nebraska Center for Continuing Education, 1971, pp. EE1 - EE12.

Reyna, L. J. "The Psychologist Interprets the Photo-Interpreter." Photogrammetric Engineering. Vol. 18, No. 3, 1952, pp. 467-468.

Sabins, Floyd F. Remote Sensing: Principles and Interpretation. San Francisco: W. H. Freeman and Company, 1978, 426p.

Sadacca, R. "Human Factors in Image Interpretation." Photogrammetric Engineering. Vol. 29, No. 6, 1963, pp. 978-988.

Scharback, R. Resource Atlas--Jefferson County, Oregon. Corvallis: Oregon State University Extension Service, June 1973, 78p.

Schiffman, H. R. Sensation and Perception: An Integrated Approach. New York: Wiley, 1976, 434p.

Silva, L. F. "Radiation and Instrumentation in Remote Sensing." Remote Sensing: The Quantitative Approach. Swain, P. H., and Davis, S. M. (eds.). New York: McGraw Hill International Book Company, 1978, pp. 21-130.

Shoemaker, Ed. "Where We are Now and Where We are Headed with Solid Set Irrigation." Proceedings of National Irrigation Symposium (November 10-13, 1970). Lincoln, Nebraska: Nebraska Center for Continuing Education, 1971, pp. 2-1 to 2-5.

Sternberg, R. J. "The Nature of Mental Abilities." American Psychologist. Vol. 34, No. 3, 1979, pp. 214-226.

Swain, P. H. "Fundamentals of Pattern Recognition in Remote Sensing." Remote Sensing: The Quantitative Approach. Swain, P. H., and Davis, S. M. (eds.). New York: McGraw Hill International Book Company, 1978, pp. 136-187.

Tueller, Paul T. "Some Aspects of the Use of Dichotomous Keys to Aid in the Interpretation of Color Aerial Photographs for Vegetation Mapping." Proceedings of Seventh Biennial Workshop on Color Aerial Photography in the Plant Science and Related Fields (May 15-17, 1979). Davis, California. Falls Church, Virginia: American Society of Photogrammetry, 1979, pp. 189-200.

United States Bureau of the Census. Census of Agriculture, Oregon State and County Data. Vol. 1, part 37. Washington, D.C.: U.S. Government Printing Office, 1974, pp. 11-1 to 11-25.

United States Department of Agriculture. Soil Conservation Service. Soil Survey: Deschutes Area, Oregon. Washington, D.C.: Government Printing Office, 1958, 155p.

United States Geological Survey. Landsat Data Users Handbook. Revised Edition. Arlington, Virginia: Branch of Distribution, U.S. Geological Survey, 1979, 195p.

United States National Oceanic and Atmospheric Administration. Cimatological Data, Oregon. Vol. 76-87 (January through December 1979). Asheville, N.C.: National Climatic Center.

Watts, D. G.; Dehlinger, C. R.; Wolfe, J. W.; and Shearer, M. W. Consumptive Use and Net Irrigation Requirements for Oregon. Circular of Information 628. Corvallis: Oregon State University Agricultural Experiment Station, March 1968, 40p.

Webster, Kirk B.; Lucas, James R.; Musgrove, Richard J.; and Higer, Aaron L. Selected Irrigated Acreage Estimates in Northern Florida from Landsat Data. Unpublished copy received from the author, 1978, 12p.

Wenderoth, S.; Yost, E.; Kalia, R.; and Anderson, R. Multispectral Photography for Earth Resources. Huntington, West Hill Printing Company, New York, 1972, 183p.

Williams, T. H. Lee, and Poracsky, Joseph. Mapping Irrigated Lands in Western Kansas from Landsat. Lawrence, Kansas: Kansas Applied Remote Sensing Program, University of Kansas, 1974, 24p.

Withers, B., and Vipond, S. Irrigation: Design and Practice. London: B. T. Batsford Limited (1974), 306p.

Yost, E., and Wenderoth, S. "Ecological Applications of Multispectral Color Aerial Photography." Remote Sensing in Ecology. Johnson, P. L. (ed.). Athens: University of Georgia Press, 1969, pp. 46-62.

Young, H. E. "The Need for Quantitative Evaluation of the Photo Interpretation System." Photogrammetric Engineering. Vol. 21, No. 4, 1955, pp. 712-713.

Zimmerman, J. D. Irrigation. New York: Wiley, 1966, 516p.