MEASURING CROPLAND STRESS IN THE SAN JOAQUIN VALLEY AS DOCUMENTED BY GIS, GPS, REMOTE SENSING, AND FIELD INSPECTIONS

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CHAPTER I

INTRODUCTION

The eight-county San Joaquin Valley (SJV) is one of the most prolific, productive farming areas in the world. It contains more than 30,000 farms and 5.2 million acres of farmland (SJV Crop Report, 1992). Cotton historically is grown on more than one million acres (96 percent of the state's total acreage for that crop), orchard crops on 1.4 million acres (64 percent of the total), and vegetable crops on 0.3 million acres (35 percent of the total). The area is also a major livestock producer, with nearly two million dairy and range cattle and calves (about 43 percent of the state's total).

Over the last two decades, there have been important changes in the cropping patterns in the SJV. Acreage of feed and food grains have declined, while those of vegetables, orchards, and other high-value crops have increased. These trends derive from many factors, including crop prices, water availability and cost, land values and rents, and labor costs.

SJV agriculture serves three markets - the California population, the rest of the United States (U.S.) and the rest of the world (Cook, 1990). In doing so, the sector spends more than $5 billion annually on machinery, chemicals, labor and other inputs to produce more than $6 billion of goods, many of which are produced in few or no other locations in the U.S. For example, the SJV accounts for over 90 percent of U.S. production of raisins, almonds, walnuts, nectarines and pistachios.

SJV agriculture is a basic industry with links to many other service and support industries in the local economy. Besides the direct value of goods it produces, agriculture is linked to suppliers of farm machinery, chemicals and other inputs to food processors, truckers and other distribution businesses.

Over time, SJV agriculture has attained an important role in the national and international economies. Through its productivity and efficiency, it makes available an abundant, diverse supply of food that helps keep "food scarcities" out of our domestic vocabulary. It also enables the American consumer to enjoy a healthy diet for a much lower share of its income, more so than in any other nation. Moreover, as the domestic population has changed - growing more slowly and placing greater emphasis on a wider variety of healthier foods - SJV agriculture has utilized its productive resources base and competititve advantage to grow and market the many products demanded.

In addition, SJV and California agriculture play a significant role in the U.S. balance of trade. In 1990, the state's exports of food and agricultural products rose to $4.5 billion, representing 25 percent of total California agricultural production for the year. Cotton, almonds, grapes and oranges, all of which the SJV dominates in state production accounted for 47 percent of total state exports (California Department of Food and Agriculture, 1990). While total irrigated agricultural acreage in California has fallen about five percent since 1980, that devoted to the production of crops for export has increased significantly.

While expanding and adapting to important changes in the domestic and international economics, SJV agriculture has faced many other pressures, both short and long term. In the short term, farmers have been forced annually to adjust to six years of drought conditions in a variety of ways - idling lands, changing crop patterns, applying minimum quantitites of water in some instances to sustain trees and vines, etc. Farm machinery, chemicals, seed and other input suppliers and processors have also had to adjust to the drought conditions.

Among long-term issues, the SJV is undergoing tremendous urbanization pressures, as populations from the coastal urban areas spill into once rural areas. The resultant dynamics add a critical element to the demands on all the SJV's resources including housing, land, and water.

Statement of the Problem

A new scientific era is opening for a greater understanding of the patterns of crop productivity. Agricultural producers need precision, timely applications of information to identify areas of reduced productivity caused by drought, poor seeds, fertilizer misapplications and pests, and enough time to solve these problems to maximize crop yields. Ranchers and agricultural researchers share interest in these technologies to integrate computers, electronic sensors, satellite navigation, hydraulic systems and agronomic science. The result is intelligent farm implements capable of selecting optimal combinations of seed population, fertilizer levels and other cultural techniques according to changing site-specific constraints.

Since rainfall in the SJV is inadequate to produce acceptable crop yields, irrigation has been critical in making SJV agriculture productive. The region is served by two major surface water projects, the Federal Central Valley Project (CVP) and the State Water Project (SWP). In addition, many water districts have developed or have rights to local surface water supplies (San Joaquin Valley Agricultural Water Committee) (AWC). CVP water is dedicated primarily to agriculture, with small amounts contracted for municipal and industrial purposes. In contrast, SWP water is used primarily for municipal customers, with only about 30 percent to agriculture in the SJV. Both projects have been severely impacted by the 1987-1993 drought. In 1992, agriculture received only 25 percent of its normal CVP supplies and 0 percent of its SWP supplies. Farmers in some irrigation districts were forced to rely solely on ground water. Some farmers with no ground water for a backup supply utilized water purchased from the State Water Bank (SWB). Hence, while surface water normally accounts for about 60 percent of agricultural water supplies and ground water for 40 percent, figures for 1992 indicate this relationship has reversed. Further, while ground water use in the SJV typically exceeds replenishment by an average overdraft of 1.5 million acre feet (MAF) per year, the overdraft has exceeded 2.5 MAF for the last three years.

Although irrigation districts measure the amount of water delivered, it is not an accurate picture of actual demand. Much of the water used for agricultural purposes, and a large percentage of the water used for irrigation actually returns to the ground water table. The only water that is actually lost is in the product produced and evapotranspiration through the leaves of the plant. This percentage varies depending on the type of plant under irrigation, wind, temperature, and hours of sunlight.

Purpose of the Study

The purpose of the study was to measure cropland stress during the 1987-1993 San Joaquin Valley drought. The six consecutve years of drought in California had profound effects on the state's agricultural sector, particularly in the SJV. Not only have farmers been affected, but the economy of the entire region has suffered.

This study uses the AWC reports, remote sensing, geologic information systems (GIS), global positioning system (GPS), and field inspections to analyze the effects of the drought on cropland, abandoment and water demand.

Previous estimates of drought impacts have relied heavily on computer models and anecdotal information. This study integrates traditional agricultural reports, ground information from field surveys of growers and water agencies; and ground truthing with aerial photography, GIS, GPS and remote sensing technologies.

Objectives

In order to achieve the purpose of this study, the following specific objectives were established: 1) To measure the acreage of abandoned and non-farmed cropland in 1987, 1991, and 1993. 2) To compare the reliability of GPS, GIS, aerial photography, remote sensing, and field inspections with the actual survey method in determining the acreage of abandoned and fallowed cropland. 3) To determine the effects of the drought on groundwater contours and lake storage capacties. 4) To apply an integrated GIS to automate field-data entry and target agricultural chemical applications.

Hypotheses

In order to achieve the objectives of the study, the following hypotheses needed to be tested. This study focuses on the impacts of the 1987-1993 drought on SJV agriculture. This region was chosen for testing several hypotheses.

Hypothesis 1. The drought caused no significant difference in the acreage of cropland.

Hypothesis 2. There is no significant difference in the acreage of abandoned cropland as identified by actual survey when compared to surveys verified by GPS and GIS technologies, aerial photogaphy, remote sensing, and field inspections.

Hypothesis 3. The drought caused no significant difference in the elevation of the ground water table as detected by new wells drilled, or lake storage capacities as verified by satellite.

Limitations

Certain limitations characterized in the study were:

1. The survey was conducted on a systematic sample of 110 irrigation, water conservation, and water storage districts in the AWC association.

2. The survey approach was used to measure the varying impacts of the drought on different sub-regions in the SJV. Data at the zone level were obtained on acreage grown, water application rates, acreage fallowed or abandoned due to the drought, ground and surface water supplies, pumping costs, well costs and related information.

3. Atmospheric dust particles and light reflectants were limiting factors in this study. A horizontally homogeneous atmosphere was assumed, so that transmittance and path radiance are constant over the scene and their value can be determined for each image. By using a combination of two TM bands, the actual aerosol model is established through the wave length dependence of the aerosol path radiance. In this way, an approximate knowledge of the atmosphere composition and structure is possible, and the retrieval of actual reflectants from the sensed images can be carried out. These reflectants $R_s(\lambda)$, as measured from satellite, can be approximated by the expression

$$R_s(\lambda)=[k\pi L_s(\lambda)]/[E_g(\lambda)\cos\theta_o]$$

where

$R_s(\lambda)$ is the reflectants of the surface at wave length λ (dimensionless):

$L_s(\lambda)$ is the radiance of the surface, that is the radiance of light transmitted downward through the atmosphere and reflected on the surface ($Wm^{-2}\mu m^{-1}sr^{-1}$);

$E_g(\lambda)$ is the global solar irradiance ($Wm^{-2}\mu m^{-1}$) on the horizontal surface;

θ_o is the solar zenith angle; and

k is a factor (dimensionless) which accounts for the change in the sun-earth distance.

Assumption of the Study

The study was based on the following assumption:

Remote sensing may be used to measure the water surface area of reservoirs. Multispectral data, especially the mid-infrared band (Landsat band 7), absorbs energy in that region.

Definition of Terms

The following definitions were selected and used in this study.

Accuracy if applied to paper maps or map data bases, degree of conformity with a standard or accepted value, accuracy relates to the quality of a result as distinguished from precision. If applied to data collection devices such as digitizers, accuracy is the degree of obtaining the correct value.

Algorithm is a step-by-step procedure for solving a mathematical problem. For instance, the conversion of data in one map projection to another map projection requires that the data be processed through an algorithm of precisely defined rules or mathematical equations.

AF (Acre-Foot) is the quantity of water required to cover one acre of land to a depth of one foot (325,872 gallons). This amount of water is normally used by a family of five during a 1-year period for residential use.

Aquifer is the geologic formation or parts of formations containing significant saturated permeable material able to yield significant quantities of water.

Area is a closed figure (polygon) bounded by one or more lines enclosing a homogeneous area and usually represented only in two dimensions. Examples are states, lakes, census tracts, land use areas, aquifers and smoke plumes.

Attributes is a (1) numeric, text, or image data field in a rational data base table that describes a spatial feature such as a point, line, node, area or cell or (2) a characteristic of a geographic feature described by numbers or characters typically stored in tabular format and linked to the feature by an identifier; for example, attributes of a well (represented by a point) might include depth, pump type, location and gallons per minute.

AWC is the San Joaquin Valley Agricultural Water Committee.

AWDS is the San Joaquin Valley Agricultural Water District Survey to study the impact of the 1987-1993 California Drought.

cfs is the cubic feet per second, a rate of flow.

one cfs = 450 gallons per minute

= 646,360 gallons per day

= 1.983 acre-feet per day

Band is one layer of a multispectral image representing data values of a specific range of the electromagnetic spectrum of reflected light or heat. Also, other user-specified values derived by manipulation of original image bands. A standard color display of multispectral image displays three bands one each for red, green and blue. Satellite imagery such as Landsat TM and SPOT provide multispectral images of the earth, some containing seven or more bands.

Base Station is a stationary GPS receiver.

Cell is the basic element of spatial information in a grid data set. Cells are always square. A group of cells form a grid.

Change in Ground Water Storage is the change in volume of water retained by subsurface aquifers within the groundwater basin. A negative change reflects the fact that extractions have exceeded recharge.

Confined Aquifer is the ground water bearing strata located below an impermeable layer of clay.

Contiguity is the topological identification of adjacent polygons by recording the left right and polygons of each arc.

Corcoran Clay is a thick, impermeable layer of clay which lies under much of the San Joaquin Valley. This clay layer separates the ground water basin into two distinct aquifers. One region, referred to as the "unconfined" aquifer, lies above the Corcoran Clay. The other region, referred to as the "confined" aquifer, lies entirely below the Corcoran Clay.

Coverage (1) A digital analog of a single map sheet forming the basic unit of data storage in ARC/INFO. In a coverage, map features are stored as primary features, such as arcs, nodes, polygons, and label points, and secondary features, such as tics, extent, and annotations. Map feature attributes are described and stored independently in feature attribute tables. (2) A set of thematically associated data considered to be a unit. A coverage usually represents a single theme or layer, such as soils, streams, roads, and land use.

Crop Signature is a (1) method of ensuring that the field verified crops are similar (in terms of morphology, biomass, and canopy cover) to the crops for which spectral measurements are taken by the ARS, NASA, and near-infrared (IR) wave band, or (2) TM band 4, which is used as a key to match appropriate ground-derived radiometry samples with field verified satellite samples.

CVC is the cross valley canal.

CVP is the Federal Central Valley Project. The Friant-Kern Canal is its major feature in Kern County.

Data Base is usually a computerized file or series of files of information, maps, diagrams, listings, location records, abstracts or references on a particular subject or subjects organized by data sets and governed by a scheme of organizations. "Hierarchical" and "relational" define two popular structural schemes in use in a GIS. For example, a GIS data base includes data about the spatial location and shape of geographic entities as well as their attributes.

Differential Positioning (DGPS) is the determination of relative coordinates of two or more receivers which are simultaneously tracking the same satellite.

Digitize is a means of converting or encoding map data that are represented in analog form into digital information of X and Y coordinates.

DWR is the California Department of Water Resources. The operators of the State Water Project (California Aqueduct).

EC is electrical conductance, a measure of the ability of water to conduct an electric current, which can be related to the concentration of total dissolved solids. The normal units of measurement is micromhos per centimer.

Elevation Mask Angle is that angle below which is not recommend for tracking satellites. This angle is normally set to 15 degrees to avoid interference problems caused by buildings, trees and multipath errors.

Feature is a representation of a geographic entity such as a point line or polygon.

Four-Basin Index is an index used by the California Department of Water Resources to forecast available water supplies and SWP delivery capabilities. The index consists of the forecasted or computed unimpaired flows of the Sacramento River near Red Bluff, Feather River at Oroville Reservoir, Yuba River at Smartville and American River at Folsum Reservoir.

Geocode is the process of identifying an x, y coordinate location from another geographic location description such as an address. For example, an address for a farmer can be matched against a DIME or TIGER street network to locate the farmer's home.

GIS is Geographic Information System, and is an organized collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information. Certain complex spatial operations are possible in a GIS that would be very difficult, time-consuming, or impractical otherwise.

GPS is Global Positioning System. The GPS consists of the NAVSTAR satellites (24 satellites plus three spares) in six different orbits, five monitor stations, and the user community.

Ground Water Basin is an area underlain by one or more permeable formations (aquifers) capable of furnishing a substantial and beneficial water supply. The basin referred to in this thesis is within the San Joaquin Valley portion of Kern County, but is connected hydrologically and geologically to a larger basin.

Ground Water Recharge is any act of nature or man which replenishes or adds water to that supply which is stored within the natural subsurface aquifer system.

Hardware components of a computer system such as the CPU, terminals, plotters, digitizers and printers.

Image a geographic representation or description of an object that is typically produced by an optical or electronic device. Common examples include remotely sensed data such as satellite data, scan data and photographs. An image is stored as a raster data set of binary or integer values representing the intensity of reflected light, heat or another range of values on the electromagnetic spectrum. Remotely sensed images are digital representations of the earth.

Irrigation Efficiency is the amount of applied irrigation water that actually goes to satisfy net crop water demands, expressed as a percent.

KCWA is Kern County Water Agency.

Kriging is an interpolation technique based on the premise that spatial variations continue with the same pattern.

Layer is a logical set of thematic data, usually organized by subject matter (e.g. soils, roads and wells).

MAF is million acre feet.

Metric Conversions Acre feet (x) 1,233.5 = cubic meters

Acre feet (x) .0012335 = cubic hectometers

Feet (x) .0348 = meters

Inches (x) 2.54 = centimeters

One million gallon per day (x) .043813 = one cubic meter per second

Overdraft is a long-term condition in which ground water extractions exceed ground water recharge.

Pen-Based Computers are hand-held or notebook computers that use an electronic pen as their primary means of input and control.

Pixel is one picture element of a uniform raster or grid file. Often used synonymously with cell.

PM-10 refers to atmospheric particles with an aerodynamic diameter less than or equal 10 microns. Such common agricultural particles such as plowing and harvesting creates PM-10; large agricultural areas such as the San Joaquin Valley has been asked to submit control plans and show attainment of federal standards by deadlines which range from December 1994 to December 2001.

Point (1) a single X,Y coordinate that represents a geographic feature too small to be displayed as a line or area - for example, the location of a mountain peak or a building located on a small scale map. (2) some GIS systems also use a point to identify the interior of a polygon.

Polygon a vector representation of an enclosed region, described by a sequential list of vertices or mathematical functions.

Precision (1) If applied to paper maps or map data bases, it means exactness and accuracy of definition and correctness of arrangement. (2) If applied to data collection devices such as digitizers, it is the exactness of the determined value (3) the number of significant digits used to store numbers.

Quadrangle a four-sided region, usually bounded by a pair of meridians and a pair of parallels.

Raster Data machine readable data that represents values usually stored for maps, images, and organized sequentially by rows and columns. Each "cell" must be rectangular but not necessarily square, as with grid data.

Rectify the process by which an image or grid is converted from image coordinates to real-world coordinates. Rectification typically involves rotation and scaling of grid cells, and thus requires resampling of values.

Resolution (1) The accuracy at which the location and shape of map features can be depicted for a given map scale. (2)The size of the smallest feature that can be represented in a surface (3) The number of points in X and Y in a grid.

Roving Receiver is a transported GPS receiver located in an unknown location.

Scale is the relationship between the distance on a map and the corresponding distance on the earth.

Spatial Models are analytical procedures applied with a GIS. There are three categories of spatial modeling functions that can be applied to geographic data objects within a GIS. (1) Geometric models (such as calculations of Euclidian distance between objects, buffer generations, area, and perimeter calculations): (2) Coincidence models (such as polygon overlay): and (3) Adjacency models (pathfinding, redistricting, and allocation). All three model categories support operations on geographic data objects such points, lines, polygons, TINs, and grids. Functions are organized in a sequence of steps to derive the desired information for analysis.

State Plane Coordinates is a Northing (N), Easting (E) coordinate system based on a conformal map projection that simplifies the task of converting from latitude and longtitude to a rectangular coordinate system.

SWB is the State Water Bank. The intent of banking programs is to store surface water in the underground during times of surplus and extracting it during times of need.

SWP is the State Water Project. In Kern County, its major feature is the Edmund G. Brown California Aqueduct.

TDS is total dissolved solids. A measurement of the dissolved matter in water, consisting mainly of inorganic salts, and small amounts of organic matter and gases.

Usually measured in parts per million (PPM).

Topology is the spatial relationships between connecting or adjacent coverage features (e.g., arcs, nodes, polygons and points). For example, the topology of an arc includes its from- and to- nodes and its left and right polygons. Topological relationships are built from simple elements into complex elements: Points (simplest elements), arcs (sets of connected points), areas (set of connected arcs), and routes (sets of sections that are arcs or portions of arcs), redundant data (coordinates) are eliminated because an arc may represent a linear feature, part of the boundary of an area feature, or both. Topology is in GIS because many spatial modeling operations do not require coordinates, only topological information. For an example, to find an optional path between two points requires a list of which arcs connect to each other and the cost of traversing-along each arc in each direction. Coordinates are only necessary to draw the path after it is calculated.

Unconfined Aquifer is the groundwater bearing strata located above an impermeable layer of clay.

USBR is the United States Bureau of Reclamation, the operators of the Federal Central Valley Project.

CHAPTER II

REVIEW OF LITERATURE

The purpose of this chapter is to provide an overview of the literature as it pertains to, and relates to, documentation of abandoned cropland due to drought conditions in the San Joaquin Valley from 1987 through 1993. Materials from books, professional journals, magazines, and other research studies compile the review. For the review to be more understandable, these topics will be reviewed: (1) Introduction, (2) Drought Profile, (3) Geographical Information System (GIS), (4) Global Positioning System (GPS), (5) Remote Sensing, (6) Field Inspections, (7) Technical References, (8) Similar Studies, and (9) Summary.

Introduction

Despite record low temperatures and intense snow this winter, easterners and midwesterners knew they could walk into their grocery stores and find fresh fruits and vegetables. Much of this produce is grown in the warm, arid climate of the San Joaquin Valley. However, these fruits and vegetables can only be grown if they are irrigated by water from the Sierra snows. While the eastern and midwestern states are usually over-endowed by frozen water, it is still a precious commodity in the Sierra mountains, receiving only 40 to 80 percent of normal precipitation since 1987.

Last year, 1993, marked the sixth consecutive year of the severest drought in California history. Statewide precipitation was only 76 percent of normal, and runoff was 29 percent (Table I). Reservoir storage was 61 percent of normal and 13 million acre feet below 1986 levels (Bureau of Census, 1994).

Determining agricultural water demand is labor-intensive and requires Department of Agriculture reports. This involves taking the county agricultural reports of what was grown, and determining water consumption by multiplying acres covered by a given crop by its evapotranspiration rate (Hough, 1994). In this thesis, remote sensing methodology was used to measure water consumption through the use of both Landsat and SPOT imagery. Remote sensing was used to integrate drought information with GIS and GPS technologies in detecting water level changes in lakes.

TABLE I

SUMMARY OF NATURAL RUNOFF FROM RIVERS AND CREEKS IN THE SAN JOAQUIN VALLEY

River/Creek	Water Year Runoff 1,000 Acre-Feet Average	1992	1992 as % of Average
San Joaquin River (52 Years) Below Friant	692.9	122.8	18
Kings River (30 Years) Below N. Fork	1,358.0	550.0	41
Kern River (31 Years) Near Democrat Springs	471.9	68.3	14
Mill Creek (34 Years)	30.2	5.9	20
Cottonwood Creek (7 Years) Near Elderwood	3.7	1.2	32
Dry Creek (32 Years) Near Lemon Cove	16.1	1.8	11
Deer Creek (24 Years) Near Fountain Springs	22.6	4.1	18
White River (49 Years) Near Ducor	6.8	0.8	12
TOTALS	**2,602.2**	**754.9**	**29**

Drought Profile

Several government agencies, profit and non-profit organizations, and individual authors have analyzed the effects of California's recent drought on sectors of the state's economy. The California Department of Food and Agriculture (1992) estimates that the state's gross cash receipts fell $1 billion in 1991 due to the combined effects of the drought and the December 1990 freeze. Total crop production was down six percent. Field crop production fell six percent due to reduced planting and harvesting, and the value of production fell more than $500 million. The value of fruit and nut production fell about $350 million, while that of vegetables and melons fell $72 million (SJV Crop Report 1992).

The California Department of Water Resources (1991) reported that the state overall, suffered minimal economic impacts through 1990, but the impact was substantially greater in 1991. The DWR estimated losses to agriculture of $500 million and another $500 million in increased consumer energy costs due to the loss of hydroelectric power generation. Drought-idled cropland statewide was estimated to be 455,000 acres in 1991.

Cannon (1991) estimated that total California cash receipts from farming in 1991 would decline $600 million relative to 1990 - combined results of the effects of the freeze, the drought and lower dairy prices. He noted that in general, the prices for drought-related commodities are less sensitive to changes in output than freeze-damaged crops (citrus in particular) and consequently gross income for drought-reduced crops would fall.

Howitt (1991) utilized the California Agriculture and Resources Model and several assumptions regarding surface water supplies and ground water pumping by agriculture, water cost paid by farmers, and availability of water for perennial crops in forecasting that statewide acreage in 1991 would be 14 percent below a normal year. He forecasted that the largest reduction in acreage would be in pasture, alfalfa, and cotton. Those reductions translated into an estimated loss of $304 million in net farm income in the eight-county SJV; the largest percentage loss in return to land and management was predicted for the Southern SJV, namely Kern County. It was also predicted that consumers' food bills at the farm gate last year would be $220 million higher, a number that would be considerably higher after retail distribution and margins were considered.

The DWR (1991) stated that California's economy overall withstood five years of drought without major dislocations. It asserted that the overall economic impacts on agriculture have been relatively small though unequally distributed across regions. They claimed that agriculture has escaped major impacts to date due to reservoir storage and ground water reserves, which they acknowledge, however, have been largely depleted. As noted in the DWR study, the higher consumer energy costs were due to the loss of hydroelectric power. Their estimate was $3 billion.

Gollehon and Aillery (1991) offered a drought review of the entire Western region of the nation. They showed that the drought in California has unfortunate parallels in several other states, pointing out that while the size of the nation's drought-stricken areas has declined since 1990, drought conditions remain severe in several regions. They reported on California's reservoir levels and referred generally to the crops and sectors on which the drought has had its greatest overall impacts (based in part on DWR's information). Specific economic loss impacts were not included.

Archibald, et.al. (1992) are preparing an in-depth analysis of the short-and-long-term effects of water shortage on California's agriculture as input into the proposed water quality standards for the San Francisco Bay-Sacramento-San Joaquin Delta. They are utilizing a case-study approach, surveying water districts, growers and representatives from related industries to assess the overall economic and financial effects of water shortage on agriculture.

Northwest Economic Associates (1992) study found that the impacts of the drought on SJV agriculture were much greater than previously thought. On-farm revenues fell

$281 million and on-farm water costs rose $163 million, causing a reduction of $444 million in receipts to production agriculture. While certain areas of the Valley staved off disaster in 1991, they did so only at great financial stress and are now extremely vulnerable to the effects of continued drought. The most vulnerable areas are located where agriculture is the single or primary employer and where farmers have limited sources of water. In these areas, there is little opportunity to diversify, particularly in the short term. For SJV, the NEA (1992) study estimated 172,000 acres were idled, and 33,000 acres suffered reduced yields.

The California Department of Resources (1993) surveyed agricultural commisioners to measure the impacts of the drought in several agricultural regions, SJV among them. For SJV, DWR estimated 167,000 acres were idled, and gross revenues declined by $164 million because of the drought.

Geographical Information System

GIS is a tool to create and update maps. It's a technology for combining and interpreting maps. It's a revolution in map structure, content and use. Like other new technologies, GIS concepts are simple; the terms are complex. In the real world, the landscape is composed of soils, crops, water, biological life, etc. In the paper world, these are represented by words, numbers and graphics.

GIS may be described by its processes, data, and analytical functions. The GIS processes involve incoding, storage, processing and display of computerized maps. Processing functions include computer mapping, spatial data base management, spatial statistics and cartographic modeling. These functions are descriptive and interpretative, as well as perceptive in nature.

Computer mapping is descriptive as it rapidly creates and updates map products. Spatial data base management combines and interprets map data. A data base map can be searched for map compartments with certain requirements (such as low water values in a certain soil type), then produce a map locating these areas. Map compartments can have both a locational attribute and a thematic attribute -- what and where.

Templet maps can be summarized for typical characteristics (such as crop for each mapping compartment), which can be added as a new field in the data base. Part of the revolution in GIS simply involves "digitizing" familiar maps. GIS map analysis involves spatial statistics and map-ematics, allowing users to model a complex resource or environmental system -- describing, interpreting and prescribing its use.

In the San Joaquin Valley's 4,779,000 acres of irrigated cropland, we deal with a wide range of crops, including nut and fruit trees, grapes, cotton, grains, alfalfa, fresh vegetables, processing vegetables and small fruits. GIS layers were assembled, covering such themes as general field locations, primary and secondary roads and hydrological features. The layers were linked to various data bases that provide detailed and descriptive information about the fields, such as crop type, grower identification, and other important data.

Global Positioning System

GPS is a navigation system consisting of a constellation of 24 satellites in six orbital planes that provide accurate three-dimensional positioning and velocity, as well as precise time to users anywhere in the world, 24 hours a day. Each of the satellites transmits on the L-band frequencies (1575.42 MHz) using independent Pseudo Random Noise codes for their spread spectrum modulation. Satellite data consisting of system status, ephemeris and clock characteristics is also transmitted using NRZ modulation at 50 bits/sec.

User receivers measure their apparent range to the satellites by processing the received signals to determine transit time and correcting for atmospheric delay using stored and broadcast models. Since the location of the satellites, at the time of signal transmission, is known from the broadcast ephemeris, the location of the receiver can be triangulated from the range measurements. The user receiver's local clock error can be estimated from the solution by incorporating one more satellite's range measurement to the number of dimensions being solved.

The user receivers velocity can be solved by comparing the measured Doppler shift of the received signals to the expected Doppler shift based on the satellites' velocity vector, calculated from the ephemeris, projected on the line of sight to the satellite. After the user receiver's clock error is eliminated by over determination, the residual Doppler is attributed to the user velocity.

The accuracy of position determined by GPS is highly variable, depending on the mode employed. A single receiver which records the commonly degraded (selective availability) signal will provide geodetic position accuracy of approximately 100 meters. If the signal is not degraded (a security consideration), the accuracy may be in the range of 25 meters. If differential GPS (DGPS) is utilized, the accuracy approaches (or surpasses) one meter. This mode involves one of two receivers being located on a control point, with the other on the point to be located. The distance between the two receivers should not be more than 100km (Colvocoresses, 1993). GPS for environmental applications using inexpensive three-channel GPS receivers derived within 75 meters of true coordinates without differential correction, and within 6 meters with correction (August, 1994).

The Smart-Track Precision Parallel Swath Guidance System designed for aerial applications consists of a GPS receiver, a radio receiver for differential corrections, and a Smart-Track Light Bar, gives a current ground accuracy of +/- 30 cm (ag/Innovator, 1994).

Using the increased accuracy and availability of GPS, the National Geodetic Survey (NGS) is establishing a nationwide High Accuracy Reference Network (HARN) survey. In Georgia, NGS is establishing stations to A-and B-order accuracy standards that are spaced no more than 50 km spacing between all stations in the HARN (Johnson, 1994).

The Illinois University reported that on September 19, 1994, U. S. Military activities in Haiti prompted elimination of the signal-degrading effects of selective availability - increasing the accuracy of GPS by ten fold (Sennott, 1994). This is fueling the flame to replace the U. S. Department of Defense-controlled GPS with an international civilian system.

Remote Sensing

High altitude photography has helped document changing crop conditions for decades. These photos are available from the Soil Conservation Service (SCS) offices in each county. Thanks to multi-spectral sensing, especially in the near and mid-infrared range Landsat and SPOT satellites, allow you to identify types of crops being grown.

All plants reflect sunlight differently. These differences are sensitive to Landsat bands four, five and seven, and are especially valuable as they measure the variances in the infrared range. Each crop has a major impact on the unique spectral signatures that are produced. Variations within crops can be considerable; for instance, a well-watered crop in one field will reflect more infrared light than a poorly watered field next to it. The same is true if one field has healthy plants, and an adjoining field is infected with disease or pests.

The spectral response of plants is affected by outside factors such as atmospheric particles, PM-10 produced by common agriculture particles from plowing and harvesting (Flocchini, 1994), plant spacing, and dust and moisture residue. Despite these problems, remote sensing is useful in monitoring vegetation because the variations in infrared reflectants between homozygous crops are less than variations in infrared reflectants in heterozygous crops (Hough, 1994).

Until now, land cover and land use data have been mainly acquired from terrestrial surveying and visual aerial photo interpretation. Photo interpretation is based on human vision and pattern recognition capacities. Identification of terrain objects is based on nine interpretation keys: pattern, tone, texture, shadow, site, shape, size, association, and resolution.

The interpretation process can be facilitated by viewing the photographs stereoscopically. Air photo interpretation keys also assist the interpreter by offering guidelines for the identification of certain information classes. Objects are distinguished by a combination of both geometric and thematic properties. A good example is the delineation of individual trees in a forest stand.

As a result of an interpretation process, a representation of the world is obtained consisting of terrain objects with a geometric and thematic component. Therefore, both visual photo interpretation and terrestrial surveying are typically directed to vector-based data of terrain objects describing land cover or land use.

Remote sensing is a data acquisition technique by earth observation satellites, such as Landsat and SPOT, that measure the relative amount of electromagnetic radiation as reflected by the earth's surface. This is a simple process dividing the earth's surface into equal areas called scene elements. The corresponding image representation of a scene element is known as a picture element or pixel. The measurements of these elements in several spectral bands are converted and stored in a limited number of quantization levels. The stored values are referred to as digital numbers (DN).

A remote sensing image can be characterized by an image space and a feature space. The portion of a pixel represented in the image space is determined by a unique row and column index (i, j). The relative spectral reflection values (DN_1, ...,DNn) can be represented in the N-dimensional feature space.

In most projects, remote sensing images undergo two transformations:

*a registration of the image coordinate system into a certain map projection, enabling other geodata to be used; and

*a classification of the continuum of spectral data into nominal user desired classes (the most subjective transformation).

The classifications or interpretations of remote sensing images can be performed in a visual and a digital way. Visual interpretation offers more or less the same characteristics and properties as visual photo interpretations. Until now, most digital interpretations have been based solely on the per-pixel multivariate data. These per-pixel classifications are limited to the interpretation element "tone" as used in visual interpretation. This limitation has two major implications:

*per-pixel classifications by definition yield spectral classes mainly relate to land cover, where land use is mainly determined from contextual and associative information. Land cover designates the visual evidence of land use to include both vegetative and non-vegetative features.

*per-pixel classifications yield thematic information per raster element. When looking at a classification result, although one can distinguish fields for instance, it should be noted that terrain objects as such are not explicitly stored. The raster data derived from remote sensing should be considered as point data that have a certain spatial extent (Janssen, 1994).

Landsat satellite imagery records the average spectral characteristics of a 30 x 30 meter area. There are other methods of remote sensing with greater accuracy; for example, the Panasonic 3 CCD S-VHS camera filmed from a height of 2400' at full lens field of view gives a 2000' wide film path with a resolution of 2.86' per pixel . At full 16-X telephoto magnification, the flight film path width can be reduced to 125' with a resolution of 2.25" per pixel. Where precise measurements are needed, individual scenes are geo-referenced using GPS procedures (Becker, 1993).

Field Inspections

Although the computer generated data can separate crops, field inspectors are still needed on the ground to identify the specific crops. Field inspectors usually verify crops two days before and two days after the satellite imagery is collected (Waits, 1991).

Technical References

This section is to review some of the studies that have been done on developing vegetation maps and sampling frames for agricultural surveys. Two studies will be reviewed; one in Florida and the other in Oklahoma and California.

In Florida, SPOT imagery, ERDAS image processing software, GPS and error analysis techniques were used to develop a base line vegetation map for water conservation. A hybrid unsupervised/supervised classification routine was performed, utilizing the GPS for ground truthing and accuracy assessments. Differentially corrected GPS data were an essential part of the overall effort. Cluster busting techniques were utilized to properly refine confused classes, and KAPPA statistics programs were used for error analysis. Results suggest a relationship between agricultural nurtrient inflow and vegetation changes from sawgrass to cattail and/or willow monoculture in areas nearest to the inflow (Rutchey, 1994).

The National Agricultural Statistics Service (NASS) has been developing area sampling frames as a vehicle for conducting surveys to gather a variety of agricultural data nationwide. In 1987, NASS was awarded a National Aeronautics and Space Administration research grant to develop a digitally-based system to automate this process which had been conducted using a labor-intensive, paper-based technique. This system, The Computer Aided Stratification and Sampling (CASS) system, was developed by NASS and the Aims Research Center Ecosystem Technology Branch, and has now been implemented into NASS' operational program. The paper discusses and compares the manual procedure and the new methodology and the results of this research effort.

Once the initial CASS sytem was developed (hardware and software), two pilot tests were conducted in portions of Missouri and Michigan. Following completion of the Michigan test, CASS became operational. Since then, two states' area frames have been developed in CASS for Oklahoma and California. Oklahoma's new area frame was used for enumeration purposes beginning in June, 1993, and California's new area frame was used for enumeration purposes starting in June, 1994.

The researcher concluded that stratification in CASS is better for several reasons: First, satellite data provides more recent data (potentially available every 16 days) than aerial photography (may be five years old). Because an area frame is used for about 15 years, the most recent image at the time of stratification is desired. Second, the land use determination is more accurate as the scale of TM data has gone from 1:250,000 on paper, to 1:100,000 scale digital data. Finally, a dynamic color map is available to emphasize the image and bring out the cultivation.

The digital nature of the data is a benefit. First, primary sampling units (PSU) can be more easily revised in CASS by moving digital boundaries, and because the size of the PSU is known immediately, it can be resized if it does not fall within the suggested limits. Next, it will allow a frame to be updated, rather than having to start from scratch. Finally, sample segment locations are being identified because they are now geo-referenced. They can be used as data layers in other Geographic Information Systems.

As various state and federal agencies get involved with GIS, agricultural data might be used to make a state's stratification more accurate. Also, the remote sensing section of NASS could provide crop-classified satellite imagery to assist in the development of area frames.

Ground truthing for each CASS state will be limited to those sample segments visited by enumerators each June. Any state getting a new area frame will have an analysis done to see how that new frame affects agricultural statistics. Also, the percent cultivation found by the enumerator in each segment is compared to the stratum assigned during the frame development (Cotter, 1994).

Similar Studies

The University of Arkansas, Fayetteville, began a cooperative project," Rural America 2000" to implement geologic technology in September, 1994. The project allows farmers, local and county government officials, and federal service agency employees to work with the University's Center for Advanced Spatial Technologies (CAST) staff to develop and implement GIS projects. Rural America is often forgotten in discussions of computer technology and the National Information Infrastructure, but rural communities are getting on the information superhighway through the Center's services. Such systems are having an increased impact on rural America's agribusinesses, transportation, forestry and land use analysis and planning.

Two Rural America 2000 projects are in the developmental stages. One is being developed by farmers and U.S. Soil Conservation Service (SCS) employees to track conservation districts. The second project would link assessor information to farm fields so that ownership and parcel information will be integrated with soils, and crop and acreage data. Any group with a developed GIS plan can use the University's facilities and technical staff to help implement projects. Rural America 2000 facilities include $2 million of hardware, software, training and support service for DOS, Windows NT, UNIX, and CAST. Participants have access to CAST's digital data archives, including global, continental and regional data bases. CAST's staff re-formats digital data and makes them available on a statewide digital network. ARKNet users eventually will be able to search the data electronically and download select databases.

European agriculture will be monitoring via satellite imagery under a contract awarded in October, 1994 to the National Remote Sensing Center, LTD. (NRSC), Farmborough, UK. The imagery will check claims for agricultural support payments. Farmers' claims will be verified by digital multispectral images from SPOT, Landsat satellites and Synthetic Aperture Radar, which is capable of imaging through clouds and at night.

Each farmer's individual field boundaries will be digitized and overlayed unto a series of satellite images. A visual interpretation of the images will determine area and land use. The resulting information will be compared with farmers' claims to identify illegal claims of compensatory payments. Satellite imagery is a highly cost effective and unobtrusive means in monitoring large areas.

The U.S. Department of Agriculture has uncovered widespread fraud in relief programs that compensate farmers for crop disasters. The "New York Times" reports $92.5 million in suspicious disaster relief payments (Killman, 1994). Remote sensing will be an effective tool in documenting agricultural fraud.

The Community Coffee Company (Baton Rouge, LA) is using satellite imagery and NASA's remote sensing expertise to create detailed maps of coffee crops in the mountains of Latin America. Community Coffee concluded that the satellite imagery and maps were useful for detecting and analyzing coffee crops, but they must be used in conjunction with the analytical capabilities of a GIS, a region specific knowledge of agricultural geography and some field verification. With these components, the company can analyze images of coffee crops in a particular country, map and measure their cultivation, and estimate their production. They anticipate marketing these forecasting data to other agricultural service organizations which could potentially use the data to guide fertilizer, pesticide applications and irrigation techniques to maximize crop yields and reduce costs (Barnes, 1994).

Many producers travel the information superhighway every day. That was the emerging story as a team of business partners - including Monsanto, Apple Computer, John Deere and Environmental Systems Research Institute - gathered at the "Field of Dreams" movie site in Iowa to launch The Infielder Crop Records System, a data collection and analysis system designed for farming applications.

The system, developed for midwest corn and soybean growers, includes the

Newton Message Pad, prototypes of satellite-linked GPS and Infielder Crop Records System software, which runs on both a Windows PC and the Newton. By taking the palm-sized Newton into the field, producers can record vital farm records throughout their work day. These data can then be downloaded into the producers' PCs and combined with a data base of more than 3,000 soil types, hundreds of corn hybrids, dozens of soybean varieties and formats for recording environmental data and compliance records. Producers can use Infielder to keep such records as: total acres planted, crop and soil histories, soil and seed attributes, planting dates, EPA permit numbers, weeds, insect and weather data, harvest year, tillage tools, high and low temperatures, rainfall, and wind speed and direction.

The Infielder development team selected ESRI's Arc View GIS as the application development environment for the project, which is one of the largest cooperative projects in the history of U.S. agriculture. Because of GIS core technology, farm managers can generate maps and reports related to field activities, nutrient applications, and weather studies to complete yield comparisons and make scientifically-based decisions for future planting and maintenance activities (Barnes, 1994).

Summary

The primary challenge of the project was to link the various components, i.e, water district surveys, GIS, GPS, remote sensing, aerial photography and field inspections into an integrated information management system. Linking GIS into all data collection activities provided a unified approach to information retrieval. The GIS served as an integrated framework for data gathering, analysis, storage and product development.

Through computer image processing of the photos and satellite imagery, it should be possible to highlight differences in light absorption, revealing variability of crop health, water stress, and non-farmed cropland. Although the computer-generated data can separate the crops, field inspections are still needed on the ground to identify specific crops.

CHAPTER III

METHODOLOGY

Introduction

The central purpose of this study was to measure cropland stress of the 1987-1993 California drought on San Joaquin Valley Agriculture. Combining the color infrared satellite imagery with traditional ground truthing provided a diagnostic system for evaluating stress in agricultural crops. Through computer image processing of the imagery, it was possible to highlight differences - not visible to the naked eye - in light absorption, which reveals variability of crop health. This variability can be caused by soil, water, nutrients, diseases, and other factors. Soil testing, calibrated with problem areas identified from the satellite imagery should provide a means for determining the areas where fertilizer applications should be targeted.

An analysis of the diagnostic soil test plots to be collected and registered to the data base may provide a way to explain the variability in crop health that is visible in the imagery. Computer analysis of the soil samples and imagery will be used to correlate difference in such nutrients as nitrogen, phosphate, and potash with the variability evident in the imagery. This information will be used to produce a stress map of the individual field with detailed information on the status of specific locations within the field.

The stress map will provide a detailed understanding of the variation in crop vigor levels across the field. For the growers, this approach may be a tool to control the application of agricultural chemicals so they are administered in the correct dosage at the required locations. With the stress map of the field, the grower will receive an explanation about which problems were most likely related to the stress observed. The process should be very visual, which makes it easy for the grower to understand. It should be only necessary to draw a perimeter around a problem area. If the ground sample shows an infestation of nematodes and that information is correlated with a lack of vigor, then the problem is obvious to the farmer.

To achieve the purposes of this study, the researcher established the following specific objectives:

1. To measure the acreage of abandoned and non-farmed cropland in 1987, 1991, and 1992.

2. To compare the reliability of GPS, GIS, aerial photography, remote sensing, and field inspection with the actual survey method in determining the acreage of abandoned and fallowed cropland.

3. To determine the effects of the drought on groundwater contours and lake storage capacities.

4. To apply an integrated GIS to automate field-data entry and target agricultural chemical applications.

Research Hypotheses

Research hypotheses stemming from the research objectives listed in Chapter I were developed and tested.

The null hypotheses dealing with the questions are:

Hypothesis 1. The drought caused no significant difference in the acreage of cropland in the San Joaquin Valley.

Hypothesis 2. There is no significant difference in the acreage of abandoned cropland as identified by actual survey when compared to surveys verified by GPS and GIS technologies, aerial photography, remote sensing, and field inspections.

<u>Hypothesis 3.</u> The drought caused no significant difference in the elevation of the ground water table as detected by new wells drilled or lake storage capacities as verified by satellite.

Description of the Population

Districts of the San Joaquin Valley Agricultural Water Committee served as the population for this study. These districts are combinations of 110 irrigation districts, water storage districts and water conservation districts. The AWC is divided into five zones, four of which cross county lines. Table II reflects the crop acreage for the SJV by zone, while the study area is shown in Figure I.

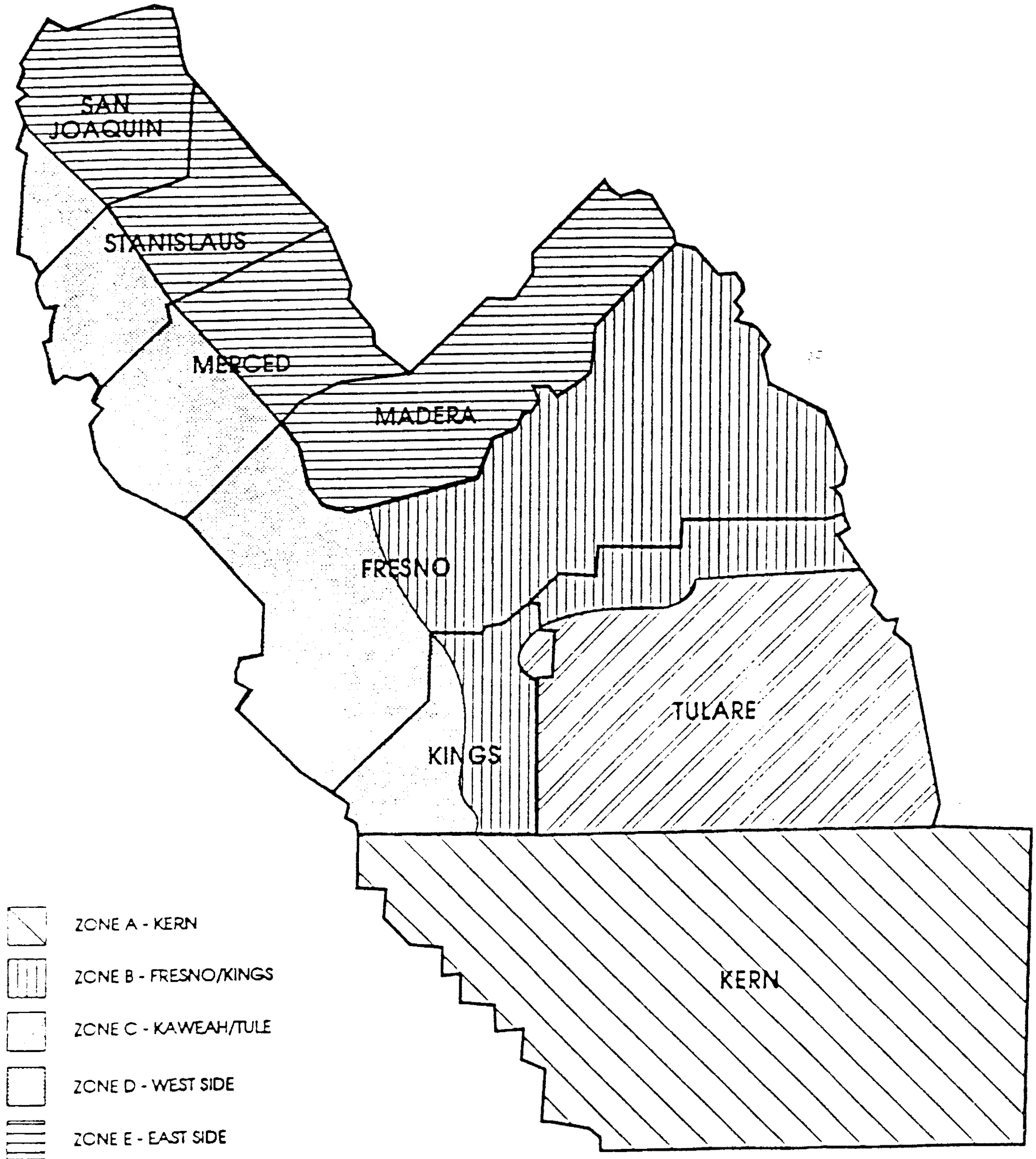
PERCENT OF PRODUCTION REPRESENTED BY DISTRICTS RESPONDING TO SURVEY

TABLE II

Zone	Total Acreage	1991 Survey Acreage	1991 Percent Surveyed	1992 Survey Acreage	1992 Percent Surveyed
A - Kern	842,384	842,384	100%	842,384	100%
B - Fresno/Kings	1,108,737	740,615	67%	936,011	84%
C - Kaweah/Tule	716,009	293,089	41%	168,649	24%
D - West Side	1,213,491	775,932	64%	750,618	57%
E - East Side	898,615	426,655	47%	443,951	50%
Total	**4,779,236**	**3,078,675**	**64%**	**2,299,229**	**66%**

FIGURE I

San Joaquin Valley Agricultural Water Committee Membership Zones



Instrumentation

In order to better understand the impacts of the 1987-1993 drought on SJV crop acreage, surveys were conducted on 4,779,239 acres, crop water use, crop acreage impacts, district water supplies, increased pumping costs, and increased well costs. The survey was designed to determine how acreage and water supplies under the drought had deviated from what could have been expected with normal water supplies.

The survey instrument (Appendix A) was first reviewed by members of the SJV AWC subcommittee overseeing the study, after which it was mailed to the membership of over 100 water districts. Where possible, personal contacts were made with the water district managers and farmers to further clarify the content of the survey.

GIS layers were assembled covering such themes as general field locations, primary and secondary roads, and hydrological features. The layers were linked to various data bases that provided detailed, descriptive information about the fields such as crop type and grower identification. The GIS provided a direct link to GPS systems. This allowed field inspections to gather precise positional information for building the data bases because the information was directly stored in a digital format. Field digitization was used to update or correct the GIS base maps and to provide exact locations on crop status.

Color infrared (CIR) aerial photography collected for the years 1985-1993 were used to provide a record of the crops' assessments and changes over time. A portion of the CIR photography was digitized and computer processed to simulate the pixel sizes of SPOT multispectral 20-meter (Appendix B) and Landsat TM satellite imagery (Appendix C) to determine the most extensive vegetation stresses. This information was entered into the computerized image processing system, corrected for distortion and diplacement, then accurately registered to the ground coordinate system.

In addition to using multispectral imagery to identify crops, SPOT panchromatic imagery was used to create and update a GIS of field boundaries for all the study area.

These computer-generated boundaries were overlayed over the multispectral imagery to locate and classify the type of vegetation in each field. Since SPOT and Landsat frequently overfly the area, crops were monitored throughout the drought years.

This project was divided into two phases. The first phase described in this thesis involved production of a GIS data base; the second phase will produce detailed GIS data layers. The primary objective of phase two is to produce GIS coverages and maps of homogeneous units of vegetation. GIS layers produced include hydrology, crop site locations, species, current vegetation types, boundaries and historical distribution of vegetation.

The data base is developed for mapping soil and crop characteristics. All image classifications were performed on SUN and PC-based workstations, with Landsat TM data which has been geo-coded and terrain corrected. These image classifications emphasize integration of analog and digital ancillary data using the ERDAS image processing system, statistical analysis software, SAS, and ARC/INFO GIS. Spectral and vegetation variations were analyzed using integrated data in ARC/INFO, ERDAS, and SAS. Information which describes the vegetation of each crop site was entered into ARC/INFO, then passed to SAS. The location and spectral signatures of each training site were captured in ERDAS and ARC/INFO, and the attribute data were also passed to SAS. SAS was then used to identify variables significantly affecting vegetation distribution and relate spectral variations to vegetation variations. In addition, spectral pattern analysis was used as a diagnostic tool to aid in selecting the best spectral bands to use for each classification. A supervised and unsupervised classification were performed in ERDAS, and similarities between the spatial statistics for each classification were compared using a clustering algorithm and methodology (Chuvieco, 1988).

The analysis results in the choice of the best Landsat TM band combination to map each vegetation characteristic, i.e., species, size, class, stand, structure, and the development of spectrally and informationally unique crop signatures.

The accuracy assessment of land cover classifications derived from remote sensing data was based on positional and thematic accuracy. The registration of satellite images is relatively straightforward. Positional accuracy defines the relationship between the registered image and the applied source data (map). The spatial resolution of the present land observation satellites circumscribes the identification precision of Ground Control Points (GCPs) and therefore, the potential registration accuracy. The registered image information labels included: source of reference, GCPs number, GCPs types of transformation, root-mean-square (RMS), error or standard deviation, and resampling method.

In the assessment of thematic accuracy, the error metrix is based on simple random sampling of individual pixel, binomial distribution for determination of confidence limits, hypothesis testing, and determination of the optimal sample size. Attention was given to the characteristics of the method of sampling and its effect on estimated accuracy.

Positional and thematic accuracy are used to describe the accuracy of land cover because registration and classification are completely independent. The registration accuracy of satellite images are based on the residuals that are calculated during the registration. The selection of GCPs is rather objective, and measures can be calculated from the registration process itself.

Thematic accuracy is much more complex. The crop stage in a classification is very subjective, therefore, the distance measures as calculated during the classification cannot be used for accuracy assessments. Because of this, thematic accuracy should be assessed by comparing a sample of the classification results with reference data. Results of a per-pixel classification were considered as point classifications, and validations were based on the sampling of individual pixels.

Data Collection

Measurements of abandoned cropland as documented by GIS, GPS, remote sensing and field inspections were compared to the district surveys and county agricultural commissioner's reports. Results of the surveys were aggregated to the five membership zones of the SJV AWC. Based on 4,779,236 estimated crop acreage of the SJV, approximately 64 percent of production in the SJV were represented by the district superintendents responding to the 1991 drought survey, and approximately 66 percent of production were represented by the 1992 drought survey (Table II). However, 5,014,172 crop acreage were reported in the eight counties' 1992 Agricultural Commissioners' Reports; this compares with 5,200,189 crop acreage reported in 1990 (Davis, 1990).

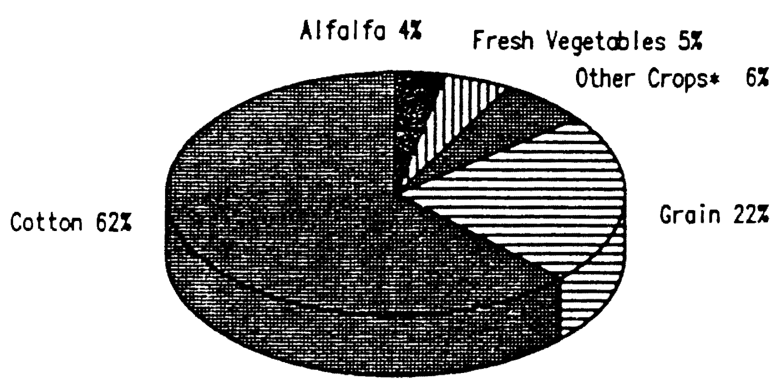
Information from the survey was used to qualify the following district-characteristics:

1. Crop acreage that was either not planted or removed from production as a result of limited water supplies or high water costs (Figure II):

FIGURE II

CROPLAND IN SAN JOAQUIN VALLEY NOT PLANTED OR ABANDONED IN 1991 DUE TO DROUGHT

Total Acres: 253,207



2. Average pumping lifts in 1985 and 1992 (Table III):

TABLE III

Increases in On-Farm Pumping Costs, 1985-1992

I. Increase in Water Bill Related to Increased Pumping Lifts

Zone	Increase in Depth to Water (Feet)	Energy Cost Cost$/AF	Groundwater Affected (AF)	Increased Pumping Costs
A - Kern	82	$14.15	913,994	$12,933,000
B - Fresno/Kings	49	$ 7.99	1,201,509	$9,604,000
C - Kaweah/Tule	52	$ 8.54	867,844	$ 7,413,000
D - West Side	146	$23.91	57,368	$1,372,000
E - East Side	44	$ 7.17	193,768	$ 1,390,000
TOTAL	**+61***	**$10.11***	**3,234,483**	**$32,712,000**

Note: *Increase in Depth to Water* measures the change in pumping lifts from 1985 to 1992. *Groundwater Affected* is assumed to be the total acre-feet that would have been pumped in a normal year.

II. Increase in Water Bill Related to Increased Groundwater Pumping

	1992 Pump Lift (Feet)	Energy Cost Cost$/AF	Groundwater Affected (AF)	Increased Pumping Costs
ZONE A	408	$70.19	903,678	$63,428,000
ZONE B	136	$23.40	1,025460	$23,995,000
ZONE C	155	$26.61	1,003,112	$26,689,000
ZONE D	422	$72.53	1,607,064	$116,568,000
ZONE E	117	$20.07	620,789	$12,458,000
TOTAL	**274***	**$47.12***	**5,160,103**	**$243,138,000**

Note: Groundwater affected is assumed to be the additional water pumped, beyond normal requirements, because of the drought.

Source: San Joaquin Valley irrigation districts, with energy costs computed by Northwest Economic Associates, Inc., October 1993.

3. The year 1985 was selected as "normal" by being between drought cycles and following the 1982-1983 wet season. The 1985, 1991 and 1992 crop acreage, crop acreage affected by the drought, not planted, abandoned, reduced yields and irrigated acreage (Tables IV and V):

TABLE IV
CROP ACREAGE AFFECTED BY THE DROUGHT

Crop Type	A Kern	B Fresno/ Kings	C Kaweah/ Tule	D West Side	E East Side	Total
TREE NUTS						
Not Planted					38	38
Abandoned	1,000			962		1,962
Reduced Yields	39,524			4,256	1,337	45,117
TREE FRUITS						
Not Planted						
Abandoned	200					200
Reduced Yields	13,450			296		13,746
GRAPES						
Not Planted					245	245
Abandoned	1,860					1,860
Reduced Yields	16,700				3,796	20,496
COTTON						
Not Planted	73,107	6,000	11,000	66,800	737	157,644
Abandoned	1,066					1,066
Reduced Yields	19,583				865	20,448
GRAINS						
Not Planted	22,371	8,000	16,100	11,067	80	57,618
Abandoned			200			200
Reduced Yields						
ALFALFA						
Not Planted		1,000	4,000	755		5,755
Abandoned	1,314	2,000	40			3,354
Reduced Yields	11,410	2,600				14,010
FRESH VEGETABLES						
Not Planted	5,879			1,606		7,485
Abandoned	4,304					4,304
Reduced Yields	10,000					10,000
PROCESSED VEGETABLES						
Not Planted				1,920		1,920
Abandoned				160		160
Reduced Yields				900		900
OTHER						
Not Planted		400		5,916		6,316
Abandoned				3,080		3,080
Reduced Yields				160		160
TOTAL						
Not Planted	**101,357**	**15,400**	**31,100**	**88,064**	**1,100**	**237,021**
Abandoned	**9,744**	**2,000**	**240**	**4,202**		**16,186**
Reduced Yields	**110,667**	**2,600**		**5,612**	**5,998**	**124,877**
IRRIGATED ACREAGE	**842,384**	**1,108,737**	**716,009**	**1,231,491**	**898,615**	**4,779,236**

Source: San Joaquin Valley Irrigation Districts, January 1992.

TABLE V

SJV Crop Acreage Affected by the 1992 Drought

Crop Type	A Kern	B Fresno/ Kings	C Kaweah/ Tule	D West Side	E East Side	Total
TREE NUTS						
Not Planted			121			121
Abandoned	3,300			500		3,800
Reduced Yields				6,000		6,000
TREE FRUITS						
Not Planted				500		500
Abandoned	400					400
Reduced Yields						
GRAPES						
Not Planted						
Abandoned	1,140					1,140
Reduced Yields						
COTTON						
Not Planted	36,500	8,100	12	40,444		85,056
Abandoned						
Reduced Yields	16,000					16,000
GRAINS						
Not Planted	4,600	15,100		18,192		37,892
Abandoned				1,838		1,838
Reduced Yields		1,200				1,200
ALFALFA						
Not Planted	400	8,000	230	14,000		22,630
Abandoned		1,962	40			2,002
Reduced Yields	2,420	2,526		5,000		9,946
FRESH VEG.						
Not Planted	3,100					3,100
Abandoned	1.200			600		1,800
Reduced Yields						200
PROCESSED VEG.						
Not Planted				1,800		1,800
Abandoned				200		200
Reduced Yields						
OTHER						
Not Planted		100		9,416		9,516
Abandoned						
Reduced Yields				148		148
TOTAL						
Not Planted	**44,600**	**31,300**	**363**	**84,352**	**N.R.**	**160,615**
Abandoned	**6,040**	**1,962**	**40**	**3,138**	**N.R.**	**11,180**
Reduced Yields	**18,420**	**3,762**	**N.R.**	**11,148**	**N.R.**	**33,294**
IRRIGATED TOTAL	**842,384**	**1,108,737**	**716,009**	**1,231,491**	**898,615**	**4,779,236**

N.R. No reported impacts from districts surveyed.

Source: San Joaquin Valley irrigation districts, October 1993.

4. Applied water coefficients under two scenarios: 1) normal water supplies and 2) drought water conditions as experienced in 1992

5. Quantities of district supplied surface water and ground water under normal water supplies and in the 1992 drought period (Table VI):

TABLE VI
Estimated Ground and Surface Water Usage In San Joaquin Valley 1992 Drought and Normal Year*

Zone	Water Usage Normal Water Year in Acre-Feet	Water Usage Drought Water Year in Acre-Feet	Change in Supply in Acre-Feet	Percentage Change, Drought Compared to Normal
A - Kern				
Groundwater	1,008,000	2,149,000	1,141,000	+113
Surface Water	1,941,000	782,000	(1,159,000)	- 60
Total	2,949,000	2,931,000	(18,000)	- 1
B - Fresno/Kings				
Groundwater	1,227,000	2,281,000	1,055,000	+ 86
Surface Water	2,099,000	921,000	(1,178,000)	- 56
Total	3,326,000	3,202,000	(124,000)	- 4
C - Kaweah/Tule				
Groundwater	869,000	1,871,000	1,002,000	+ 115
Surface Water	1,279,000	276,000	(1,003,000)	- 78
Total	2,148,000	2,147,000	(1,000)	- 0
D - West Side				
Groundwater	98,000	1,824,000	1,726,000	+1760
Surface Water	3,704,000	1,727,000	(1,977,000)	- 53
Total	3,802,000	3,551,000	(252,000)	- 7
E - East Side				
Groundwater	446,000	1,050,000	604,000	+135
Surface Water	2,220,000	1,616,000	(604,000)	- 27
Total	2,666,000	2,666,000	0	0
All Zones				
Groundwater	3,648,000	9,175,000	5,528,000	+152
Surface Water	11,243,000	5,322,000	(5,921,000)	- 53
Total	14,891,000	14,497,000	(393,000)	- 3

* - Figures are not comparable to 1991 drought study's because of the following: 1) The 1992 survey made a distinction of groundwater between on-farm wells from district wells. 2) Surface water usage for the normal water year was compiled from 1991 and 1992's responses since some districts responded to the surveys only one of the years.

- Estimates for non-respondent districts were included by proportionately adjusting the respondents' data using percentages for the number of respondents compared to total number of districts.
- "Normal" water conditions were defined as 1985 conditions.
- Total water use is acreage times 3 acre-feet/acre. Drought water use is based on an adjustment for land idled due to the 1992 drought. On-farm water use is calculated by subtracting estimated irrigation district deliveries from the total crop requirement.

Source: San Joaquin Valley irrigation districts, January 199[illegible] and October 199[illegible]

6. Average cost for district supplied water under normal water conditions and under the drought (Tables VII and VIII):

TABLE VII

Groundwater and Surface Water Costs Paid by Irrigation Districts 1992 Drought and Normal Years*

Zone	Average Cost Per Acre-Foot Normal Water Year	Average Cost Per Acre-Foot 1992 Water Year	Percentage Change
A-- Kern			
Groundwater	$57.00	$66.57	+17
Surface Water	$36.76	$72.10	+96
Total	$37.69	$70.46	+97
B-- Fresno/Kings			
Groundwater	$37.61	$57.00	+52
Surface Water	$19.90	$46.81	+135
Total	$20.11	$47.38	+136
C-- Kaweah/Tule**			
Groundwater	$25.00	$0.00	0
Surface Water	$32.89	$54.80	+ 67
Total	$32.89	$54.80	+ 67
D-- West Side			
Groundwater	$8.88	$44.23	+398
Surface Water	$24.74	$50.40	+104
Total	$24.56	$49.88	+103
E-- East Side			
Groundwater	$9.61	$9.64	<1
Surface Water	$3.97	$7.07	+ 78
Total	$4.54	$7.40	+ 63
All Zones			
Groundwater	$22.05	$44.16	+100
Surface Water	$22.15	$40.04	+76
Total	$22.07	$40.57	+79

* Figures are not comparable to the 1991 drought study's because of the following: 1) The 1992 survey made a distinction of groundwater costs from on-farm and district sources. 2) Surface water costs for the normal water year were derived from 1991 and 1992's responses since some district responded to the surveys only one of the years.

** Groundwater made up only a marginal share of water deliveries by Zone C irrigation districts in 1992.

Source: San Joaquin Valley irrigation districts, January 1992 and October 1993.

TABLE VIII

Water Payments to Districts

In Million Dollars

Zone	Normal Water Year	Drought Year	1992 Net Change
A - Kern	$76.7	$78.4	$1.7
B - Fresno/Kings	42.7	46.2	3.5
C - Kaweah/Tule	42.1	15.1	(27.0)
D - West Side	92.0	94.1	2.1
E - East Side	11.2	13.7	2.5
TOTAL	**$264.7**	**$247.5**	**($17.2)**

7. Expected change in pumping lifts for alternative water supply scenarios (Table III):

8. District expenditures for new and rehabilitated wells (Table IX):

TABLE IX

INCREASED WATER COST TO FARMERS FROM THE SHIFT TO GROUNDWATER SOURCES

In Million Dollars

Zone	Water Payments to Irrigation Districts: Normal Water Year	Water Payments to Irrigation Districts: 1991 Drought Year	Water Payments to Irrigation Districts: Net Change	Increased On-Farm Cost from Deeper Pumping	Increased On-Farm Cost from Additional Groundwater Pumping	Total Increase in On-Farm Water Costs
	(1)	(2)	(3)	(4)	(5)	(6)=(3)+(4)+(5)
A - Kern	$67.6	$55.9	($11.7)	$5.9	$52.4	$46.7
B - Fresno/Kings	24.5	16.3	(8.2)	15.5	19.1	26.4
C - Kaweah/Tule	24.2	12.2	(12.0)	7.8	21.4	17.2
D - West Side	99.9	69.6	(30.3)	0.03	79.3	49.0
E - East Side	12.0	18.0	6.0	2.0	15.6	23.5
TOTAL	**$228.2**	**$172.0**	**($56.2)**	**$31.2**	**$187.8**	**$162.8**

Source: San Joaquin Valley Irrigation Districts, January 1992.

TABLE X

IRRIGATION WELL DRILLING & REHABILITATION BY SAN JOAQUIN VALLEY IRRIGATION DISTRICTS FROM 1989-91

	New Wells		Rehabilitated Wells	
Zone	Number	Total Cost	Number	Total Cost
A - Kern	40	$9,240,000	18	$400,000
B - Fresno/Kings	32	4,130,000	58	871,000
C - Kaweah/Tule	38	2,160,000	116	1,390,000
D - West Side	32	2,490,000	41	1,586,000
E - East Side	8	2,440,000	19	941,000
TOTAL	**150**	**$20,460,000**	**252**	**$5,188,000**

Source: Survey of San Joaquin Valley Irrigation Districts, January, 1992.

TABLE XI

Increased Water Cost to Farmers From the Shift to Groundwater Sources

In Million Dollars

Zone	Payment to Districts: Net Change	Increased On-Farm Cost from Additional Groundwater Pumping	Increased On-Farm Cost from Additional Groundwater Pumping	Total Increase in On-Farm Water Costs
A - Kern	$1.7	$12.9	$63.4	$78.0
B - Fresno/Kings	3.5	9.6	24.0	37.1
C - Kaweah/Tule	(27.0)	7.4	26.7	7.1
D - West Side	2.1	1.4	116.6	120.1
E - East Side	2.5	1.4	12.5	16.4
TOTAL	**($17.2)**	**$32.7**	**$243.2**	**$258.7**

Source: San Joaquin Valley irrigation districts, October 1993.

One of the project's requirements was to gather information about the specific problem areas within fields. The ability of a GIS to spatially reference and organize information offered a new approach for collecting information in the field. The process of translating this information into digital form was accomplished by lap top and mobile pen-based computers. The mobile computer system provided a way to take a subset of the GIS data base and maps into the field, allowing corrections and updates of current files, creating maps and sketches, handling queries and editing, and creating linked data bases. Information captured in the field was then transferred electronically to the main computer.

Measurement and Statistical Analysis Procedures

Western Rosedale Specific Plan was the study area used to predict the cropping patterns of the San Joaquin Valley. Located west and adjacent to Bakersfield, CA, the site consists of 36,657 acres, of which 30,059 acres are under cultivation (Chang, 1988). The area is characterized by considerable agricultural diversity. It is dominated by irrigated crops, especially alfalfa, barley, cotton, almonds, cole crops, peas, pistachios, pecans, potatoes, grapes, carrots, sugarbeets, and tomatoes. Other uses include hobby farms, oil fields and fallowed cropland.

Satellite field imagery interpretations were verified by land truth data collection on farm sites in the following counties/towns: **Kern County:** Arvin, Wheeler-Ridge Maricopa, Rio Bravo, Shafter, Button Willow, Delano, Old River; **Tulare County:** Porterville, Lindsay, Tulare, Visalia, Lindcove, Woodlake, Dinuba, and Orosi; **King County:** Kettleman City, Corcoran, Lemoore, and Hanford; **Fresno County:** San Joaquin: Five Points, Raisin City, Caruthers; Kingsburg, Selma, Fowler, Sanger, Clovis, Fresno, and Kerman; **Madera County:** Chowchilla, Madera and Fairmead; **Merced County:** Los Banos, Dos Palos, Merced, Atwater, Delhi, Stevinson, and Ballico; **Stanislaus County:** Turlock, Denair, Crows Landing, Petterson, Oakdale, Modesto and Hughson; **San Joaquin County:** Escalon, Ripon, Manteca, Tracy, Stockton, and Lodi.

Map accuracy assessment of crop signatures was initiated by generating 2,050 random points from the final classification using a systematic random sampling technique stratified by class. The number of points selected was based on the required minimum number of 216 points for an 85 percent map accuracy level with an error of + or - five percent. This minimum required number was based on binomial probability formulas.

Each site was evaluated for majority pixel status that identifies specific crop signatures. Data were deemed acceptable as long as there was a five pixel class majority within the center of a 3 x 3 pixel block with the site being the center pixel. Land truth data were checked against the map vegetation class pixel block and deemed correct if they fell within the pixel majority class and incorrect if they did not.

Kappa-coefficient was computed by running the KAPPA FORTRAN program. Variance of the Kappa statistics has been corrected in this program. The Kappa-coefficient of agreement is a measure of the actual agreement minus chance agreement. It takes into account both commission and omission errors, and is a measure of how well the classification agrees with the reference data.

A pairwise test of signifance was performed utilizing the Kappa-coefficent from two of the class vegetation maps to determine if the two error matrices were significantly different. The formula used to test for significance between the two independent Kappas was $Z = (K_1 - K_2)/[V(K_1) + V9K_2)]^{1/2}$ where K is the Kappa-coefficient, V is the large sample variance of the Kappa-coefficients, and Z is the standard normal deviate. If Z is less than or equal to 1.96, then there is no significant difference between the two independent Kappa-coefficents at the 95 percent confidence level.

Producers' accuracy was computed by taking the number of correctly classified samples of a particular class and dividing by the total number of reference samples for that class. Producers' accuracy indicates the probability of a reference pixel being correctly classified and is really a measure of omission error. Users' accuracy was computed by taking the number of correctly classified samples of a particular class and dividing by the total number of samples being classified as that class. Users' accuracy or reliability, is indicative of the probability that a pixel classified on the map actually represents that class on the ground, and is really a measure of commission error.

Other mathematical formulas used in this study as fundamental building blocks of GIS algorithms include the distance formula between two points based on Pythagoras' Theorem from the sixth century B.C.: $D = (|X_1 - X_2|^2 + |Y_1 - Y_2|^2)^{-1/2}$. If the exponents are replaced by R, then R is known as the Minkowski metric. When R = 1, we have the so-called city block, or Manhattan distance. This formula has been used ingeniously in location-allocation modeling and is an important building block in GIS.

The intersection of two lines: $Xi = -(a1 - a2) / (b1 - b2)$, $Yi = a1 + b1\ Xi$. This formula providing the X and Y coordinates of the point of intersection is from the field of coordinate geometry. It is the cornerstone for many point-n-polygon and polygon overlay routines. The b terms represent the slope of the first and second lines, and the a terms represent the Y intercepts.

The gravity model 1: $Iij = (Pi)(Pj) / dij$ was used to predict traffic flows in the transportation models from the 1950s. It states that the intersection between two places i and j is equal to their population product divided by the distance between them.

The Entropy maximizing model: $Tij = AiOiBjDj / e^{(b\ cij)}$, was the basis of the entropy maximizing models developed in the late 1960s and provided statistical respectability for the trip distribution model, because it was possible to show that the model predicted the most likely distribution of trips. Oi and Dj are the number of workers in the origin zone and number of jobs in the destination zone, Ai and Bj are weights, e is the irrational number 2.718...., b measures the friction of distance and c is the cost of travel.

CHAPTER IV

PRESENTATION AND ANALYSIS OF DATA

The purpose of this study was to evaluate the AWC reports, remote sensing, GIS, GPS, and field inspections to analyze the effects of the 1987-1993 drought on crop land abandonment and water demand.

The SJV is not a homogeneous area, but rather it is comprised of many soils, climate types and water availabilities. Over time, cropping patterns have changed within some regions of the Valley in response to crop prices, land prices, water costs and proximity to processors. Ongoing urbanization pressures represent the dominate influence, while water costs and land prices are the primary forces causing land substitution among crops.

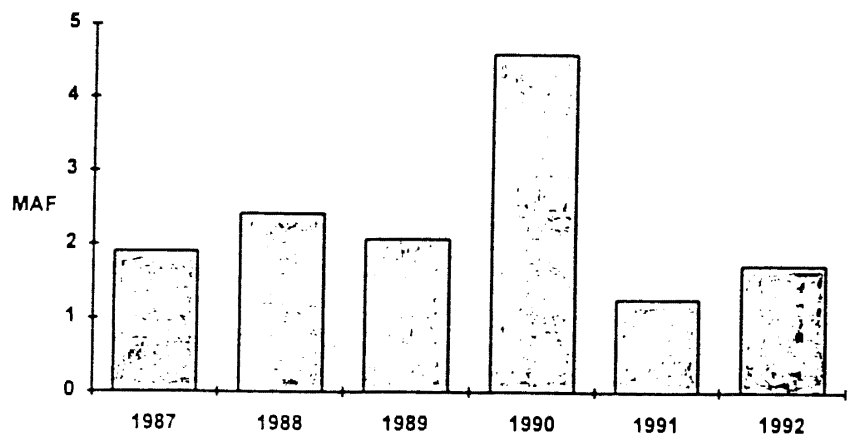
The drought directly affected the continued feasibility of farming in certain areas of the SJV, particularly since 1989. During the drought years, particularly 1991, surface water supplies were severely limited or cut off, and many farmers were forced to rely primarily or solely on ground water to sustain their operations. Pumping lifts and costs increased sharply, and those higher costs have reduced growers' returns for many traditional crops. Both the quantity and quality of ground water have become important issues as increased pumping has burdened the normal overdraft situation, and has resulted in pumping lower quality water (Figure III).

Farmers without ground water or alternative surface water supplies have been forced to idle their lands, with the most severe examples being in Kern County. Some of that land will be re-cultivated after the drought, but other crop lands in Kern County have been lost to urbanization. For example, the McAllister Ranch of 2,070 acres, and the San

Emidio Ranch of 9,447 acres have been converted to home sites (Speir, 1991). Until water costs stabilize or decline, some land will remain fallow since returns from the land will not justify the expense of farming. To the extent that crop land is converted to non-farm use, such as houses and commercial properties, these losses are mitigated; however, crop land is usually converted to commerical use and permanently lost from agricultural production. This process has been accelerated due to increased water costs and decreased productivity on marginal crop land.

FIGURE III

Groundwater Overdraft in San Joaquin Valley Counties During the 1987-1992 Drought



Notes: Measured during spring of each year. Does not include San Joaquin County.

Source: DWR, 1993b.

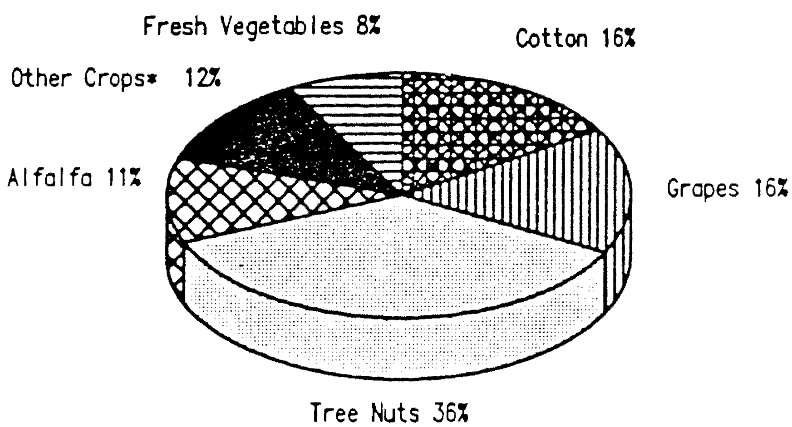
Findings of the Survey

For those districts that responded to the January 1992 survey, it was found that 253,200 acres were either not planted, or were abandoned after planting as a result of the 1991 drought. Estimates of non-respondent districts were included by proportionately adjusting the respondents' data using percentages for the number of respondents compared to total number of districts. Of the 253,200 acres that were abandoned, 4,300 acres were identified as permanent crops, and the remainder as annual crops. Cotton was the single crop most affected by acreage reduction. Over 157,700 acres were identified as not planted. Grains were also significantly affected with 57,600 acres not planted. The largest acreage reductions were in the surface water area of Kern County and the west side of the San Joaquin Valley. An additional 124,900 acres of crop land were identified as having reduced yields (Figure IV). Permanent crops at 79,400 acres comprise the largest share of acreage with reduced yields.

FIGURE IV

CROPLAND IN SAN JOAQUIN VALLEY WITH REDUCED YIELDS IN 1991 DUE TO DROUGHT

Total Acres: 124,877



* Other Crops Include: Grains, Tree Fruits, Processed Vegetables, and Other Miscellaneous Crops

In some areas of the SJV, ground water was not fully substituted for the diminished surface water supplies (Figure V). With less water available, many growers found it necessary to remove acreage from production. Alternatively, with less water available, some growers experienced reduced yields on crop acreages that were planted. Information from the 1992 survey was used to qualify these acreage reductions and yield losses, both by crop type and SJV location. Reported crop acreage affected by the drought represented about two-thirds of the total harvested area. This represents a minimum estimate of actual drought-related acreage reductions. Of the 42.6 percent of the districts that responded to the survey, it was found that 172,000 acres either were not planted or were abandoned after planting as a result of the drought. Of these, 6,000 acres were identified as permanent crop land, and the remainder in annual crops. An additional 33,000 acres were identified as having reduced yields, with cotton at 16,000 acres comprising the largest share of acreage with reduced yields. Cotton was most affected by acreage reduction with 85,000 acres identified as not planted (Figure VI). Grains were next with 37,900 acres not planted. These crops are grown on the west side of the San Joaquin Valley, including the western parts of Fresno, Kings and Kern counties.

FIGURE V

SURFACE WATER USE BY ZONE
NORMAL AND DROUGHT WATER CONDITIONS

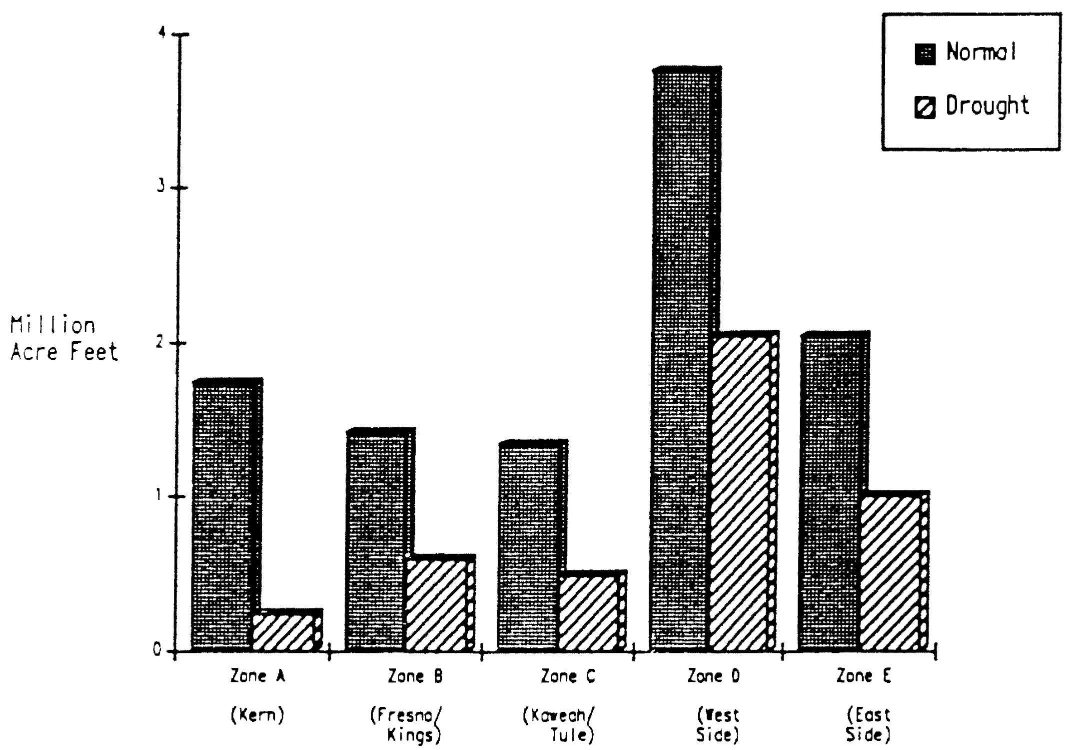
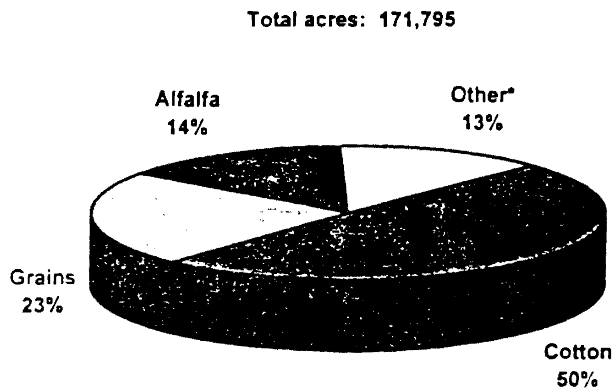


FIGURE VI

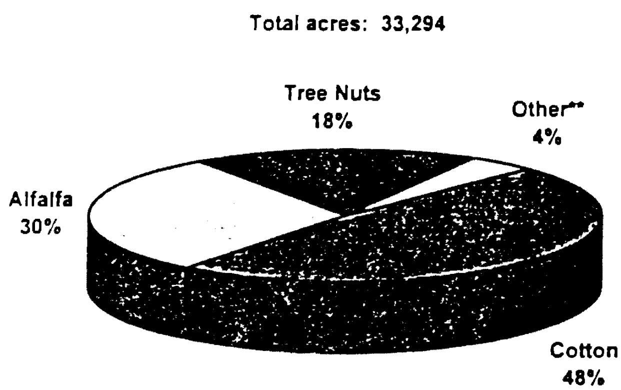
Cropland in San Joaquin Valley Affected by the 1992 Drought

Acreage Abandoned or Not Planted



* Other crops include: tree nuts, tree fruits, grapes, fresh and processed vegetables and other miscellaneous crops

Acreage with Reduced Yields



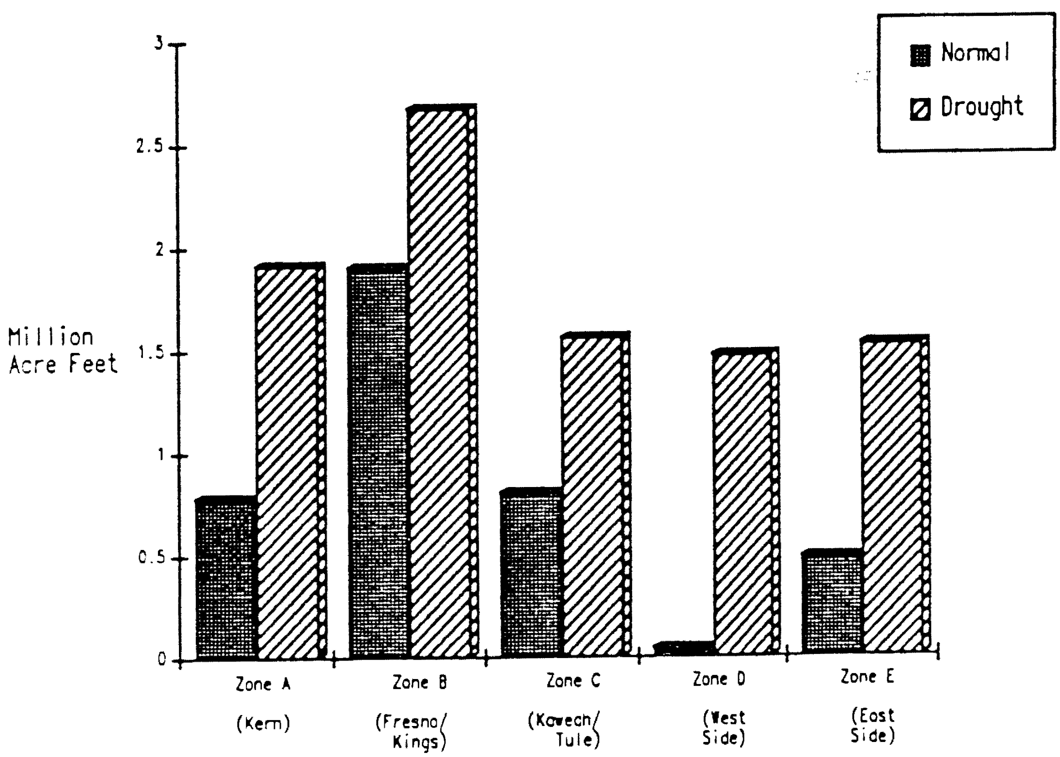
* Other crops include: fresh vegetables and other miscellaneous crops.

The surveys revealed the complications of the drought. Other significant impacts are listed below.

1. Surface water deliveries declined 5.9 million acre feet (MAF), down 57 percent from normal year deliveries. As a result, farmers were required to use an additional 5.1 MAF of groundwater, an increase of 127 percent over normal usage (Figure VII). Total water usage by SJV agriculture declined 0.8 MAF.

FIGURE VII

GROUNDWATER USE BY ZONE
NORMAL AND DROUGHT WATER CONDITIONS



2. On-farm water costs rose a net $163 million (Figure VIII).

3. Farmers invested $124 million in new wells in 1991, and $78 million in 1992 (Figure IX). Additional expenditures for reconditioning wells in 1992 was $105 million for 102 on-farm wells. Total on-farm expenditures related to well drilling and rehabilitation in 1992 was $79.5 million.

FIGURE VIII

Water Costs
Paid by Irrigation Districts by Zone
Normal and 1992 Drought Conditions

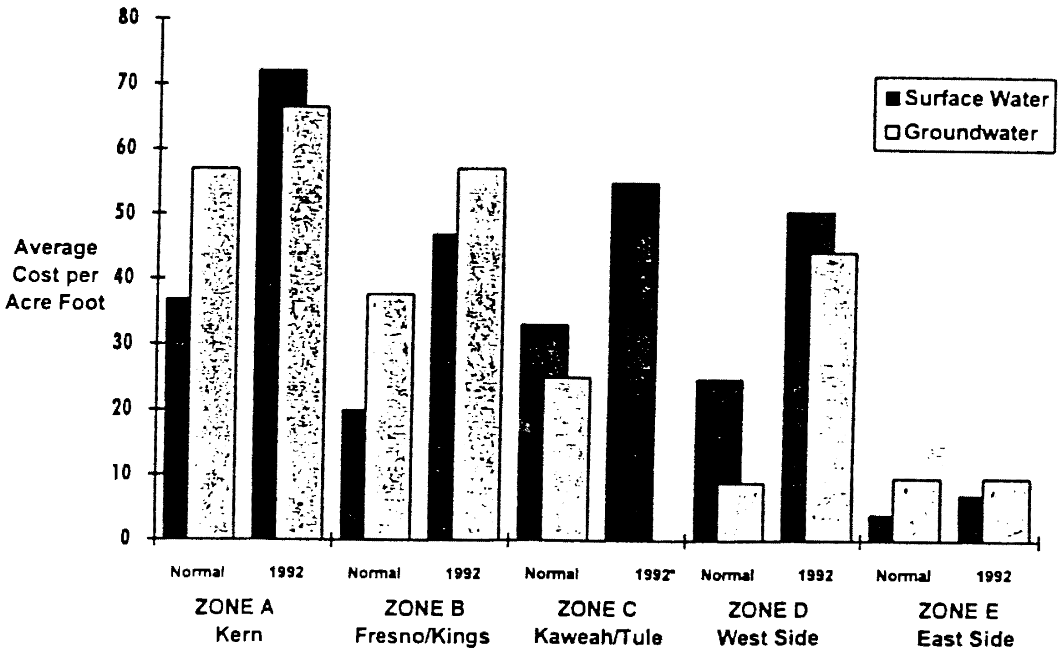
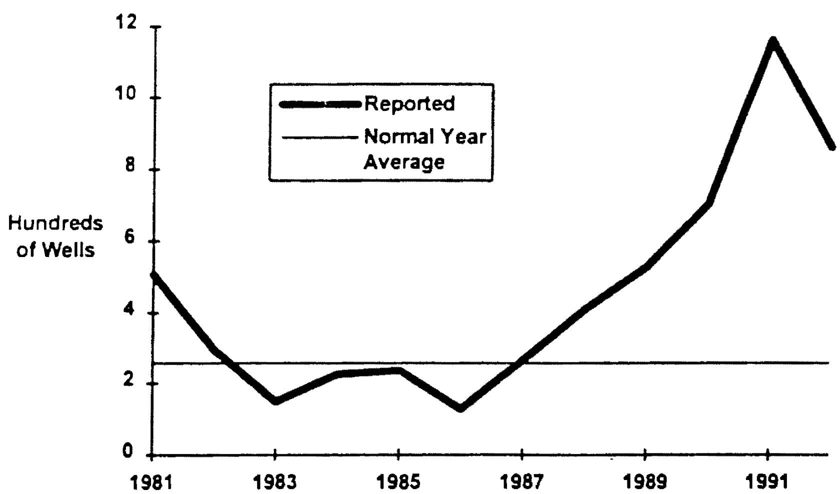


FIGURE IX

Irrigation Wells Drilled
In the San Joaquin Valley



Note: Graph presents figures that are different from the 1991 drought study because above includes figures from San Joaquin County.

Source: Well Drillers Logs Received from SJV Counties by Department of Water Resources, San Joaquin and Central Districts.

4. Irrigation districts spent more than $24 million for new and existingwells.

The drought has not been equal in its treatment of farmers, local communities or regional economics of the state. Various business sectors linked to the economic impacts of agricultural production levels have been affected:

1. Approximately 4,900 jobs (Table XII) were lost at the farm level, representing nearly three percent of the farm labor force. An additional 4,050 jobs were lost in related support industries (Bureau of Census, 1994).

TABLE XII

Impact Summary

I. Revenue Losses ($ millions)

Impact	On-Farm	Indirect	Total
Related to Increased Water Costs		70.0*	70.0*
Related to Acreage Reductions	157.1	144.6	301.7
Total	**$157.1**	**$214.6**	**$371.7**

II. Income Losses ($ millions)

Impact	On-Farm	Indirect	Total
Related to Increased Water Costs	258.7	32.0*	290.7*
Related to Increased On-Farm Well Drilling	79.5		79.5
Related to Acreage Reductions	63.7	74.1	137.8
Total	**$401.9**	**$106.1**	**$508.0**

III. Job Losses

Impact	On-Farm	Indirect	Total
Related to Increased Water Costs		1,000*	1,000*
Related to Acreage Reductions	1,600	2,300	3,900
Total	**1,600**	**3,300**	**4,900**

* Impacts from the decline in sales of goods and services which support farm households not included.

2. Loss of farm revenues in 1991 was $282.9 million (Table XIII) reduced sales of farm machinery, fertilizer, and other inputs, causing an additional $264 million decline in SJV's business activities. Lost wages and salaries in related businesses totaled $84 million (Bureau of Census 1994).

Where land has been idled, the entire revenue stream to agriculture and related industries has been lost . Farm machinery and fertilizer/chemical purchases have been cancelled. Farmer defaults on district bonds occurred more frequently in 1992, stressing some water districts whose financial reserves have already been stretched.

Farmers who were able to use ground water have kept land in production that would have otherwise lain fallow. However, by being forced to pump more ground water, their cost of water has risen sharply. New wells have been drilled and older wells reconditioned. Thus, farmers' capital reserves have been seriously depleted because of lower revenues and increased costs.

While the economic data summarized above documents the direct, short term impacts of the SJV economy, it does not reflect the long term consequences of agricultural water shortages. As these shortages continue in 1994, the agricultural industry, which provides 50 percent of the Valley's jobs, will still suffer. Economists are seeing a continuation of the economic downturn in which the number of farmers remaining in business continue to decrease.

The farmers who survive will face substantially higher water costs, further depleting cash reserves and threatening the small businesses that rely on farmers as their customer base.

TABLE XIII

Farm-level and Total Revenue Losses Related to Crop Reductions

I. Losses Related to Acreage Reductions

Zone	Acreage	Farm-Level Revenue Loss ($ million)	Total Revenue Loss ($ million)
A - Kern	50,640	$63.6	$121.1
B - Fresno/Kings	33,262	19.8	37.2
C - Kaweah/Tule	403	0.4	0.8
D - West Side	87,490	63.9	123.8
E - East Side*	0	0	0
TOTAL	**171,795**	**$147.7**	**$282.9**
Tree Crops	**5,961**	**$12.2**	**$24.7**
Annual Crops	**165,834**	**$135.5**	**$258.2**

II. Losses Related to Yield Declines

Zone	Acreage	Farm-Level Revenue Loss ($ million)	Total Revenue Loss ($ million)
A - Kern	18,420	$2.9	$5.7
B - Fresno/Kings	3,726	1.1	2.0
C - Kaweah/Tule*	0	0	0
D - West Side	11,148	5.3	11.2
E - East Side*	0	0	0
TOTAL	**33,294**	**$9.3**	**$18.9**
Tree Crops	**6,000**	**$3.9**	**$8.7**
Annual Crops	**27,294**	**$5.4**	**$10.2**

III. Combined Losses I and II

Zone	Acreage	Farm-Level Revenue Loss ($ million)	Total Revenue Loss ($ million)
A - Kern	69,060	$66.5	$126.8
B - Fresno/Kings	36,988	20.9	
C - Kaweah/Tule	403	0.4	0.8
D - West Side	98,638	69.2	35.0
E - East Side*	0	0	0
TOTAL	**205,089**	**$157.0**	**301.8**
Tree Crops	**11,961**	**$16.1**	**33.4**
Annual Crops	**193,128**	**$140.9**	**$268.4**

* Surveyed districts reported no acreage-related impacts.

Findings of Remote Sensing

Land-use classification error matrices were generated by quantitatively comparing results of the land-use classifications from the image data sets with field verification classes. The matrix for the raw radiance data (RAW) was tabulated by ESRI (1993) where the overall classification accuracy (85.72 percent accurate) was tabulated along with the accuracy for each land use class (ESRI, 1990).

By examining class to class agreement, it is possible to gain some insight within class spectral variability which is a function of such factors as canopy cover, stage of crop maturity, biomass, soil types and moisture conditions. The raw radiance data classification also establishes a base line or a control for making comparisons with the individual class results obtained from radiometrically corrected image data sets. Those classes that have low within-class spectral variability, are more likely to have high classification accuracy levels (Waits, 1991).

Computations of this research required gathering several types of data, various manipulations of the data, extensive image processing and statistical analysis. The highest accuracy for individual classes from the RAW were for potatoes (98.81 percent, grapes (98.03 percent), sugarbeets (97.88 percent), strawberries (95.86 percent), turf (95.81 percent), rose plants (94.79 percent), nursery stock (94.78 percent), christmas trees (94.73 percent), apples (93.84 percent), citrus (93.72 percent), sweet potatoes (93.41 percent), walnuts (93.25 percent), kiwi (93.16 percent), corn (92.48 percent), bare soil (91.05 percent), cotton (91.21 percent), almonds (90.42 percent), pecans (90.15 percent). These accuracy levels were not unexpected, as during the field verification process, fields containing these crops were all observed to be irrigated and having relatively uniform canopy cover and a similar growth stage among fields.

The next classes in terms of high RAW classification accuracy were: abandoned cropland (89.47 percent), pasture (87.84 percent), tomatoes (87.67 percent), figs (87.23

percent), wood lots (87.23 percent), asparagus (86.34 percent), olives (84.92 percent), grains (84.39 percent), pistachios (84.09 percent), peaches (83.70 percent), alfalfa (82.73 percent). These were relatively homogeneous classes in all of the observed fields. The abandoned cropland was easily distinguished from other land use classes during the ground truth processes. However, the fields of verified alfalfa did have variability in stages of crop maturity. For instance, some fields of alfalfa were full bloom, whereas others were recently cut. Some variability was noticed across peaches, especially in plant biomass and pruning methods as observed visually.

Below average RAW classification data include the following crops: apricots (79.42 percent), carrots (78.34 percent), watermelons (78.34 percent),beans (73.60 percent), lettuce (73.32 percent), persimmons (71.43 percent), onions and garlic (71.04 percent), pears (68.82 percent), plums (68.73 percent), and pomegranates (63.17 percent). The classification error matrix for the vegetables occurred because of immature crops where the spectral response signatures of the underlying soil overwhelmed the spectral contribution of the vegetable crop. The classification error matrix for the tree crops was due to inexperience in recognizing the canopy structures.

Abandoned cropland had only 89.47 percent accuracy classification for the RAW data. The fields were verified first as bare soil were characterized as being summer-fallowed with various levels of sporadic weed growth. The commonality among the bare soil fields is that all were not in production at the time of image acquisition. The variabilities of weed growth, soil type, surface moisture and residue lessened the classification accuracy of abandoned cropland. This data verified 279,201 acres as abandoned cropland in 1991, and identified 8,632 acres as permanent crops and the remainder as annual crops consisting of cotton and grains. The abandoned areas were concentrated on the west side of Kern, Kings and Fresno Counties. Remote sensing imagery viewed between 1985 and 1994 detected a significant increase in the number of small farming operations that specialized in labor-intensive crops.

Determining Changes in Ground Water Contours

Agricultural water shortages in the Valley has significantly changed the normal distribution of water throughout the region. For example, the drought combined with excess ground water pumping has led to critically low ground water levels. The San Joaquin of DWR, which encompasses of the SJV counties except San Joaquin County, estimates that cumulative ground water storage from 1970 to the spring of 1993 decreased more than 12 MAF (DWR 1993). During the drought years, overdraft averaged between one million and nearly five million acre-feet per year (Figure 6). Analysis of ground water supplies have been monitored by the U. S. Bureau of Reclamation since 1950. Their GIS service center has digitized ground water contours as generated from well data information as inputs to ARC/INFO software (Appendix D). This map shows contours, surface models cross-section profiles and related water district boundaries in the Valley. In this study the location of new and abandonedwater wells was accomplished with speed, accuracy and economy by utilizing portable GPS receivers coupled with lap top computers.

Satellite Verification of Water Storage Capacities

Individuals are attempting to create remote sensing models to measure water surface areas of reservoirs. Multispectral data, especially mid-infrared Landsat band 7 clearly delineates water surfaces because water absorbs energy in that region. Selections were made of specific satellite data bases on a need to provide the representative water surface at levels ranging between the minimum draw down level and full reservoir levels.

Density slicing in the near-IR band of Landsat TM was performed for all the data. Histogram analysis of individual band data reveals that the near-IR band data could provide a distinct grouping of water pixels and a sharp contrast between water and land pixels.

Selection of the decision boundary from the contrast zone with the near-IR band data can be effectively made by verifying the resulting land-water boundary line on the False Color Composite (FCC) of the near-IR band and two visible bands. By doing this, inclusion of shallow water pixels and high proportionate water pixels usually distributed along the land-water boundary is possible.

The land-water contrast environment will not be the same along the entire water boundary. This is due to bank steepness variations, different soil types and soil moisture conditions. All these will influence the selection of the decision boundary. The total number of water pixels obtained from each data was converted into geographical area by multiplying it with the ground resolution of each pixel from Landsat TM.

Near-IR band data prove to be a simple and useful technique for the area estimation of reservoir water surface area (Appendix E). The reservoir shape factor and the ground resolution of the satellite data have a significant influence on the magnitude of the error component of the water surface estimation - the higher the satellite spatial resolution, the more accurate the water surface estimations.

Land Truth Accuracy Assessment

In remote sensing it is assumed that land truthing is more accurate than the data base being assessed. The land truthing process must be a model of precision and provide a quantitative measure base that is near the same resolution as the data base being tested for accuracy. In practice, it is often assumed that field observations are more accurate than aerial phtographic interpretation, and aerial photographic interpretation is more accurate than satellite imagery analysis. In reality, each of these sources has its strengths and weaknesses.

Land truthing tends to be good at recognizing attributes and land cover types, but poor at positional accuracy. The GPS can help with positional accuracy, but it will not tell the observer how much of the landscape to incorporate in the field of view for each observation. The strength of aerial photogaphy lies in spatial resolution and resemblance to the natural human view. Therefore, photographic interpretation tends to be good at human pattern recognition of landscape features. Also, positional accuracy of photographic products is poor. The strengths of satellite imagery include excellent positional accuracy, consistent coverage and substantially more spectral information than what is available in photographs or direct field observations (Appendix E). Spectral crop signatures are highly reliable for most land cover types, but must be administered by a skilled agricultural interpreter. Land cover, independent of data source, is unreliable in four areas: categorical, spatial, temporal and observational.

GPS Accuracy

The Magellan 5000 receiver was tested by using both the remote and the base station. An accuracy range of one meter was obtained within 50 miles of the base station in both horizontal and vertical coordinates. Submeter accuracy was attained by using differential mode and post processing (Wu, 1992). "The Truth" software package for lap top and notebook computers links the Magellan 5000 receiver with a color-screen equipped lap top. "The Truth" directly integrates GPS positional data with raster imagery in the field. Other receivers tested included Garmin, SRVY II, Magellan, ProMark V, Motorola, LGT 1000, Sokkia S100, the Trimble Geo Explorer and Pro XL.

When working with quadmaps at a scale of 1:24,000, even 10 meter accuracy is better than hand-drawn maps where the width of a line may exceed 20 meters or more.

Atmospheric Corrections

In this study two major problems were encountered: ground fog and valley haze. PM-10 is a new term to add to the list of historic challenges facing agriculture. PM-10 refers to atmospheric particles with an aerodynamic diameter less than or equal to 10 microns. Such common agricultural practices as plowing and harvesting creates PM-10. Areas of the San Joaquin Valley have been asked to submit control plans and show attainment of federal standards by deadlines which range from December of 1994 to December of 2001. Both federal and state standards were set using data from urban sites. PM-10 includes elements such as lead, nickel or selenium. Organic compounds may be present such as sulfates or nitrates. Recommended solutions for the problem have included paving roads, screening cropland with windbreaks and changing harvesting equipment practices (Flocchini, 1994). In September of 1993, this was a major problem in comparing remote sensing scenes for optimum accuracy.

Thematic mapper (TM) data were obtained from five Landsat 5 overpasses taken from different seasons (Appendix F). These five TM datas allowed the use of images with different sun zenith angles as to consider quite different illumination conditions. A horizontally homogeneous atmosphere was assumed so that transmittance and path radiance are constant over the scene and their value can be determined for each image. On the basis of the presence of dark points (reflectants approximately zero) in the imaged scene and using a combination of two TM (TM1 and TM3) bands, the actual aerosol model is established through the wave length dependence of the aersol path radiance. In this way, an approximate knowledge of the atmospheric composition and structure is possible, and the retrieval of actual reflectants from the scened images can be carried out (Gilabert, 1992).

The use of this deterministic approach in the present project can find its maximum potential when coupled with a method to compute surface reflectants from satellite imagery.

A knowledge of the atmospheric conditions at the time of the satellite overpass is needed in order to establish beam transmittance and diffuse light. Two Landsat 5 overpasses in December, 1993 and March, 1994, were land truthed and atmospheric-conditioned documented at the time of the satellite overpass (two days before through two days after the satellite overpass).

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Introduction

The San Joaquin Valley experienced one of its most severe droughts in history during the six-year period from 1987 through 1993. Precipitation was about three-fourths of normal and runoff was about one-half of average. Surface water deliveries to agriculture via the State Water Project and the Federal Central Valley Project were reduced or eliminated during the period. Ground water levels fell more than one hundred feet in some areas, and pumping and well renovation costs increased dramatically. At the end of the 1991-1992 water year, reservoir levels throughout the state were 56 percent of normal and the lowest during the six-year drought period.

Heavy precipitation in the 1992-1993 water year finally broke the drought, but the cumulative costs were considerable. Individuals and farmers throughout the state were impacted and were forced to reduce their water use. Some parts of the SJV agriculture survived the drought better than others, but costs to all sectors has been significant. Crop acreage in some areas were maintained at near-normal levels by use of alternative high-cost water supplies. Large acreage in other areas simply went out of production because of the continued lack of water.

Governor Wilson declared the hydrologic drought over in 1993. However, water supplies remain highly uncertain for California's agriculture. This uncertainty and unreliability are the results of new federal laws and the application of existing regulations governing management of water throughout the state. Farmers are facing a lower water allocation in the future because of increased allocations of water for environmental and urban use.

Agriculture is changing. Public concern about ground water chemical compounds, particularly those used in agricultural production, intensified during the drought. Current regulatory pressure and the need to maintain profitability in a competitive business environment have generated increased pressures for management efficiency. Modifying agricultural production systems and practices to reduce environmental hazards while still maintaining profitability, requires improved knowledge on the part of growers, agricultural consultants and other specialists in the agricultural community. At the beginning of the drought, most growers uniformly applied chemicals to their crops. Substantial gains in efficiency are possible by adjusting applications to better match the specific needs within fields. Precise applications of chemicals and fertilizer, seed spacing and harvest data can increase farm profits and reduce environmental hazards.

Western Farm Services, Merced, CA, a national agricultural management firm, offers diverse agricultural services including soil analysis, pest identification and advice on applying fertilizers and pesticides. Responding to increasing environmental concerns and the growing complexity of the water shortage in agricultural operations, Western Farm Services management is seeking new methods to improve the company's services. In March of 1989, the company required adequately assembling and manipulating a broad array of spatial information on sugarbeets, corn, cotton, tomatoes, and sweet potatoes. For example, understanding fertilizer and pest applications requires detailed knowledge of specific areas within the field (Appendix F). Land truthing was necessary to map specific problem areas. Because this approach for documenting field inspections requires extensive paperwork and inadquacies are inherent in transcribing this information to a map base, Western Farm Services was searching for a way to streamline this process and make better use of the information to understand crop dynamics and target chemical applications.

With the analytical power of GIS, it is now possible to merge traditional field-data collection methods with other information sources, such as remote sensing, aerial photography, and GPS technologies to provide a powerful tool for describing and operating agricultural systems. Using GIS technology, soil test maps, test areas and crop health estimates, this data can be overlayed to draw correlations between physical characteristics, yield responses and management solutions.

Purpose

The purpose of the study was to measure cropland stress during the 1987-1993 San Joaquin Valley drought. The six consecutive years of drought in California had profound effects on the state's agricultural sector, particularly in the SJV. Not only have farmers been affected, but the economy of the entire region has suffered.

This study uses the AWC reports, remote sensing, Geographic Information Systems (GIS), Global Positioning System (GPS), and field inspections to analyze the effects of the drought on crop land, abandonment and water demand.

This study integrates traditional agricultural reports, ground information from field surveys of growers, water agencies and ground truthing, with aerial photography, GIS, GPS and remote sensing technologies.

Objectives

In order to achieve the purpose of this study, the following objectives were formulated: 1) To measure the acreage of abandoned and non-farmed cropland in 1987, 1991, and 1993. 2) To compare the reliability of GPS, GIS, aerial photography, remote sensing, and field inspections with the actual survey method in determining the acreage of abandoned and fallowed cropland. 3) To determine the effects of the drought on groundwater contours and lake storage capacities. 4) To apply an integrated GIS to automate field-data entry and target agricultural chemical applications.

Scope of the Study

This study was conducted in the irrigated portion of the eight-county region of the San Joaquin Valley. The survey was conducted on 110 irrigation, water conservation and water storage districts. An integrated GIS to automate field-date enry and target field stress was developed. The results of this survey were then verified by remote sensing, GIS, GPS and land truthing techniques.

Procedures

This study compared a survey, three technologies and physical observation techniques to determine the acreage of abandoned and non-farmed crop land created by the drought of 1987 through 1993 in the San Joaquin Valley. A GIS was created to identify several annual and permanent crops. GIS layers were assembled covering such themes as general field locations, primary and secondary roads, and hydrological features which were linked to data bases providing detailed descriptive information about the fields such as crop type and grower identification. A mobile GIS provided a direct link to GPS systems. This approach allowed field personnel to gather precise information for building the data base. Remote sensing and color infrared aerial photographs were used to provide a record of the crop status. This sytem was ideal for reviewing changes over time for crops where the status can change from year to year in response to water shortages, diseases, nutrients, and other environmental stresses. Colored infrared photos of individual fields were digitized, entered into the computerized image processing system, corrected for distortion and displacement, and then accurately registered to the ground coordinate system. These raster images were then viewed in the field, providing a check for specific problem areas on the ground. By linking the field image to the GPS unit, it was possible to walk the field and determine the exact location on the image.

Summary of Findings

This study focused on the impacts of the 1987-1993 drought on SJV agriculture. In order to achieve the objectives of this study, the following hypotheses were tested:

Hypothesis 1. The drought caused no significant difference in the acreage of cropland in the San Joaquin Valley. A survey was conducted on the population of irrigation districts in 1992 and 1993. The results of the survey found that 253,200 acres were either not planted or were abandoned after planting as a result of the drought compared to the 1987 base data. Of these, 4,300 acres were identified as permanent crops, and the remainder as annual crops. Thus, the first null hypotheses, the drought caused no significant difference in the acreage of cropland was rejected.

Hypothesis 2. There is no significant difference in the acreage of abandoned crop land as identified by actual survey when compared to surveys verified by GPS and GIS technologies, aerial photography, remote sensing and field inspections. The combination of remote sensing, GIS and GPS is the most effective alternative to traditional agricultural reports. There was a significant difference in the documentation of abandoned cropland as a result of combining the technologies of remote sensing, GPS and GIS. The remote sensing RAW classification accuracy for abandoned cropland was 89.47 percent, and the bare soil accuracy was 90.5 percent. The abandoned cropland was easily distinguished from other land use classes through remote sensing technology. This data verified 279,201 acres as abandoned cropland in 1991, and identified 8,632 acres as permanent crops, and the remainder as annual crops consisting of cotton and grains.

Several aerial photography sources were utilized in this study, including SCS historical aerial photography and Panasonic video tape photography. This photography gave a maximum resolution of 2.25 inches per pixel. Each scene was geo-referenced using GPS procedures. Video imagery had the advantage of being operator friendly. Data could be collected at any scale that was needed which facilitated the monitoring of land use changes.

Land truthing is the best method for recognizing attributes and land cover types. Through the mobile GIS, the raster remote sensing imageries were viewed in the field, providing an overview check for specific cropland characteristics on the ground. By linking the field's image to the GPS unit, it was possible to walk the field and determine exact locations on the image of abandoned or non farmed crop land.

The mobile GIS provides a direct link to GPS systems. This approach allows field personnel to gather precision information for building the data base. Field digitization was used to update or correct the GIS base map and to provide exact locations on crop status. The system's GPS receiver would send positional information to the main computer as often as once every second. The user collected GPS points or polygons automatically by specifying an elapsed time or distance as commanded manually. These techniques enabled the user to document abandoned or non-farmed cropland acreage. Thus, the second null hypotheses, there is no significant difference in the acreage of abandoned crop land as identified by actual survey when compared to surveys verified by GPS and GIS technologies, aerial photography, remote sensing and field inspections, was rejected.

Hypothesis 3. The drought caused no significant difference in the elevation of the groundwater table as detected by new wells drilled, or lake storage capacities as verified by satellite. Agricultural water storage in the Valley has significantly changed the normal distribution of water throughout the region. In this study the location of new and abandoned water wells indicated a shift in groundwater elevations as documented by the GPS coordinate system. Agricultural water storage in the lakes of the Sierra watershed which supplies water for distribution to irrigation districts throughout the SJV showed extreme fluctuations in water surface area as determined by mid-infrared Landsat band 7 satellite imagery. Thus, the null hypotheses, the drought caused no significant difference in the elevation of the groundwater table as detected by new wells drilled, or lake storage capacities as verified by satellite, was rejected.

Conclusions

The primary challenge of the study was to link the various components of survey, GIS, GPS, remote sensing and field inspections into an integrated information management system. Linking GIS into all data collection activities provides a unified approach to information management for decision making. The GIS serves as an integrated framework for data gathering, analysis, storage and product development. Landsat TM and SPOT images were overlayed, then combined with other information such as soil types and nutrient status for a new perspective of specific problems in the field.

Combining the colored infrared imagery with traditional ground sampling provides the ideal diagnostic system for evaluating stress in agricultural crops. Through computer image processing, it was possible to highlight differences - not visible to the naked eye - in light absorption which reveals variability of crop health. This variability can be caused by soil, water, nutrients, disease, and other factors. Soil testing calibrated with problem areas identified from remote sensing, provides a means for determining the areas where fertilizer applications should be targeted.

An analysis of the diagnostic soil test plots collected and registered to the data base provided a way to explain the variability of crop health visible in the imagery (Appendix E). Computer analysis of the soil samples and imagery were used to correlate differences in such nutrients as nitrogen, phosphate, potassium and pH with the visibility evidenced in the imagery (Appendix G). This information was used to produce a stress map of the individual field with detailed information on the status of specific locations within the field.

The objective with variable rate technology is to apply the correct rate of water, fertilizer, herbicides and pesticides in the most advantageous combination to produce the highest yield at a given site, given all the variables at that site. For example, imagine a 40-acre cotton field which has a 10-acre corner of very sandy soil. Those 10 acres produce less because they are always stressed for water before the rest of the field needs irrigation. Because the soil is sandy, leaching of nitrogen will occur. With site specific fertilizer applications, this corner would receive less fertilizer than the rest of the field due to the frequent water stress and the resulting reduced yields. The plants in that area cannot ulitilize as much fertilizer, so why spend the money to put so much out there?

The stress map provides a detailed understanding of the variations in crop vigor levels across the field. This information was used to target fertilizers, pesticides and watering applications to specific areas for maximum returns. This project demonstrates the great potential offered by the integration of field information, GIS/ GPS technologies and remote sensing for a wide variety of environmental and agricultural applications.

Precision farming is in its infancy, and the hardware and software for agriculture have advanced beyond the reach of most farmers to manage this new technology with any profitability. However, farmers still need the right data delivered on the right device to help make the right decisions. On-farm trials are important in precision farming research because small research station plots do not show the variability needed to truly test the technology. The on-farm trial data shows that even on fields that have been well managed on a whole field basis, there can be a large difference in soil tests from one part of the field to another. Much of this variability comes from inherent differences in soil types, but some stems from past management. Not all of this variability is important for farm management.

On-the-go yield monitor data has the potential to close the information loop so that the location-specific effect of an input can be measured. One of the greatest challenges in precision farming is linking on-the-go monitor yield data to agronomic practices to explain and eventually manage variability. Yield data could be used to calculate fertilizer rates based on nutrients removed, refined yield goals, and identifying areas not performing up to potential (Appendix H). The on-farm trial data suggests that raw data from the monitors can be hard to interpret. The monitor seemed to do a good job of measuring the average yield on a strip or block, but performance of measuring yields at a specific point seems more variable.

On-farm trial data indicate that on fields already well managed on a whole field basis, yield increases should not be generally expected with precision farming - the benefit will come in terms of reduced input use. Savings from lower fertilizer and chemical use can cover the costs of soil testing, mapping and precision applications. In monitoring fields, a $7.25 per acre cost would require a 35-lb per acre decrease in average phosphorus fertilizer (.21 per pound) or a 60-lb per acre reduction in potash (at .12 per pound). It is easier to pay for precision farming if the soil testing and map making costs are spread over more inputs.

It is important that users and educators be in the forefront on this new technology and not wait on the sidelines for other industries to define how GIS/GPS and remote sensing should be taught and what allied coursework should be involved. Even lacking technical backgrounds in GIS, etc., leading farmers seem to know this technology better than many industry and public sector leaders. For example, a former Minnesota vo-ag student is presently operating over 4,200 acres with a computer system that controls his fertilizer spreader and planter population while linking to GPS with differential correction. His planter controls and varies corn population from 22,000 to 29,000 seeds per acre, depending on soil type and yield data. This is his second year of variable rate farming and the savings in fertilizers, chemicals and seeds have already paid for a $17,000 computer system. He is also using differential GPS/GIS for a better understanding of his fields and their real productivity. In Arizona, another former ag student turned ag instructor, has introduced precision farming technology within his school district with yield maps and soil testing overlays for decision making. The results for the local cotton growers are increased yields and reduced costs in their operations.

This technology is a go. The question is when. Technology takes longer than expected, finds niches, suffers temporary setbacks, and goes at an unpredictable pace (Schueller, 1994).

Implications for Further Research

1. On-farm trials for precision farming
2. Coursework development for GIS/GPS agricultural education
3. Standardize GIS languages from vendor to vendor
4. Forest area and timber estimates
5. Identifying specie habitats
6. Water resources
7. Robotic harvesting
8. Precision crop dusting by aircraft
9. Combine these technologies with computerized accounting and plant growth modeling to provide the farmer with an integratged, easy to use, comprehensive management environment

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APPENDIXES

APPENDIX A

SAN JOAQUIN VALLEY AGRICULTURAL WATER DISTRICT SURVEY TO STUDY THE IMPACTS OF THE 1987-1993 CALIFORNIA DROUGHT

SAN JOAQUIN VALLEY AGRICULTURAL WATER DISTRICT SURVEY TO STUDY THE IMPACT OF THE 1987-1993 CALIFORNIA DROUGHT

Water District:____

Contact Person:____

NOTE: Please follow the instructions given below each item for assistance in completing the survey form.

SAN JOAQUIN VALLEY AGRICULTURAL WATER DISTRICT SURVEY TO STUDY THE IMPACT OF THE 1987-1992 CALIFORNIA DROUGHT

Water District:______________________________

Contact Person:______________________________

NOTE: Please follow the instructions given below each item for assistance in completing the survey form.

A. CROP ACREAGE 1985 AND 1992

	1985	1992	Comments
Tree Nuts			
Citrus			
Tree Fruits			
Grapes			
Cotton			
Grains			
Alfalfa			
Vegetables: Fresh			
Veg's: Processed			
Other			
Fallow			
Total Irrigable [1]			
Non Irrigable [2]			
TOTAL ACRES			

1/ Adjusted for Double Cropping. 2/ Farmstead, residential, roads, etc.

* Please indicate 1985 and 1992 district irrigated acres in each of the crop groups identified.
* When completed, acreage should sum to total irrigated acreage in 1985 and 1992.
* Provide comments as necessary.

***If you would prefer, attach district acreage summaries for 1985 and 1992 if available.**

B.

CROP WATER USE			
	AF/Ac: Normal	AF/Ac: 1992	Comments
Tree Nuts			
Citrus			
Tree Fruits			
Grapes			
Cotton			
Grains			
Alfalfa			
Vegetables: Fresh			
Veg's: Processed			
Other			

* In the first column indicate total AF applied per acre under normal water supplies.
* In the second column indicate total AF applied per acre under the current conditions of limited water supply if this differs from normal.
* Provide comments as necessary. Identify both drought and non-drought factors that might impact water use, ie frost damage.

C.

CROP ACREAGE IMPACTED BY THE 1992 DROUGHT					
	Not Planted	Abandoned in 1992		Reduced Yields	Yield Loss (%)
		1992	Forever		
Tree Nuts					
Citrus					
Tree Fruits					
Grapes					
Cotton					
Grains					
Alfalfa					
Vegetables: Fresh					
Veg's: Processed					
Other					
TOTAL					

* In the first column, indicate the number of acres not planted this year as a result of the drought and limited, more expensive, or poor quality water supplies.
* In the second and third columns, indicate the number of acres abandoned (planting begun but not continued) as a result of the drought. Indicate if abandoned forever or for 1992 only.
* In the fourth column, indicate the number of acres on which yields have been reduced.
* In the fifth column, indicate the average percentage reduction in yields for the acreage characterized by reduced yields.

D. DISTRICT WATER SUPPLIES 1992

	AF: Normal	Avg $/AF: Normal	AF: Drought	Avg $/AF: Drought
Groundwater				
Surface Water				
Total				

* In the first two columns indicate water supplies and average price per AF under normal water conditions.
* In the third and fourth columns indicate water supplies and average price per AF under the current drought conditions.

E. INCREASED PUMPING COST 1992

	Pump Lift: 1985	Pump Lift: 1992	$Energy/AF	Acreage Affected
Groundwater				

* In the first two columns indicate average ground water pumping lists in 1985 and 1992.
* In the third column indicate current farm level average energy costs per AF of pumped water
* In the fourth column indicate the total number of acres affected by these increased pumping costs.

F. INCREASED PUMPING COST 1993-1995

	Continue Drought	Normal Conditions	Wet Years	Acreage Affected
Groundwater				

* In this section indicate your best estimate of pumping lift for the next 2–4 years based on: continued drought, normal water conditions, and wet years.

G. INCREASED WELL COSTS

	# New Wells	Cost/Well	# Rehabilitated	Cost/Well
1989-1992				
1993-1995				

* In this section estimate the number of new wells and the number of wells that have been rehabilitated as a result of the drought. Please provide estimates for the 1989-1992 period and your best estimate for future 1993-1995 well costs related to the 1989-1992 drought.
* The cost per well should be representative capital cost based on pumping lifts and well capacities for the district.

Thank you for your cooperation. Please return the survey form using the enclosed envelope.

San Joaquin Valley Agricultural Water Committee

APPENDIX B

SPOT IMAGERY REFERENCES

SPOT Image Explanation Sheet

The scene ID appears in parentheses () and is the number used for ordering data. It includes the satellite number, the GRS K and J values, the acquisition date and time, the HRV number and the spectral mode.

SAT -SPOT Satellite number: SPOT 1, SPOT 2....

KJ -Two 3-digit numbers indicating normal K and J values

A-DATE -Acquistion date in year, month, day

A-TIME -Acquisition time in hours, minutes, seconds (GMT)

HRV -High resolution visible instrument used, either 1 or 2

Mode -Spectral mode: P for panchromatic, or X for multispectral

INCID -Incidence angle. The angle between the local vertical at a given point on the ground and the direction of the HRV pointed to the same point. If the incident angle sign is positive, the scene was imaged with the HRV was pointing east. A negative angle refers to a west looking image acquisition.

TQ -Technical quality quote for 1/4 scene: A quote is assigned to each signal (one quote for two octants) and describes the technical quality with the following codes: E: excellent; G: good; P: poor; U: unusable. When only one digit is indicated, it describes the technical quality of the whole scene.

SNOW -Snow cover: Each digit listed below SNOW relates to an octant (one 8th) of the selected scene and describes the snow cover with the following codes: 0: no snow; 1: snow. When nothing is indicated, it means the information about the snow cover does not exist.

CLOUDS -Cloud cover: May be described with letters, or digits:

a: letters: each letter listed below CLOUDS relates to an octant (one

8th) of the selected scene, and describes the cloud cover with the following codes:

A: 0% of the octant is covered by clouds

B: 0% to 10% of the octant is covered by clouds

C: 11% to 25% of the octant is covered by clouds

D. 26% to 75% of the octant is covered by clouds

E. 76% to 100% of the octant is covered by clouds

b: digits: when four digits appear describing the cloud cover, it means that the empty spaces have the same value as the one right above. In other words, each digit describes the cloud cover of a quadrant (one 4th) of the selected scene with the following values:

0: 0% to 10% of the quadrant is covered by clouds

1: 10% to 25% of the quadrant is covered by clouds

2: 25% to 100% of the quadrant is covered by clouds

For TQ, SNOW, and CLOUDS, * signs mean that the scene is incomplete, and that the areas coded with *signs do not actually exist: no data has been acquired by the satellite over these areas.

AZIMUTH -Sun azimuth angle: The origin is geographic North. The angle is positive when the sun is in the NE and SE quadrants, and negative in the NW and SW quadrants.

ELEV. -Sun elevation angle

ORIENT. -Orientation of image center scanline with respect to geographic East. A clockwise rotation corresponds to a positive angle.

GAIN -Sensor gain for the spectral bands, P, XS1, XS2, XS3.

Geographic coordinates of the four corner points and the center point are noted in degrees and minutes. These data are derived from pre-ephemeris data: actual image data may reflect a variance of 0-3 km.

POSSIBLE SHIFTS -Shift along track: minimum and maximum authorized scene shift values.

-The scene can ONLY be ordered with a shift value between the two values indicated.

-A shift of 1 represents a downward shift of the image by one tenth (1) along the satellite track.

-Downshifting is only permitted in tenths of an image, which is defined as the distance between the center points of two consecutive scenes divided into 10 equal increments.

CATALOG SEARCH RESULTS
SPOT IMAGE CORPORATION - CUSTOMER SERVICE
1-800-ASK-SPOT or (703) 715-3100 FAX (703) 648-1813

AZ: SUN AZIMUTH ANGLE EL: SUN ELEVATION ANGLE CLOUDS: CLOUD COVER
OR: ORIENTATION TQ: TECHNICAL QUALITY INCID: INCIDENCE ANGLE
SNOW: SNOW COVER

(SAT K J A-DATE A-TIME HRV MODE) = SCENE ID

(1 532 273 90/06/02 19:07:38 2 P) INCID: +07.7 TQ SNOW CLOUDS
AZ: +139.2 EL: + 70.0 OR: +11.7 GAIN: 5 E 0 0
N38:38 W121:38 N38:31 W120:57
N38:07 W121:49 N38:19 W121:23 N38:00 W121:08 0 0
REF#: P0001047

(1 532 274 90/06/02 19:07:47 2 P) INCID: +07.7 TQ SNOW CLOUDS
AZ: +138.0 EL: + 70.3 OR: +11.6 GAIN: 5 E 0 0
N38:09 W121:48 N38:02 W121:07
N37:37 W121:58 N37:50 W121:33 N37:31 W121:18 0 0
REF#: P0001047

(1 532 275 90/06/02 19:07:55 2 P) INCID: +07.7 TQ SNOW CLOUDS
AZ: +136.8 EL: + 70.6 OR: +11.6 GAIN: 5 E 0 0
N37:39 W121:58 N37:33 W121:17
N37:08 W122:08 N37:20 W121:43 N37:01 W121:28 0 0
REF#: P0001047

(1 537 276 90/06/08 18:52:29 1 P) INCID: -02.3 TQ SNOW CLOUDS
AZ: +130.6 EL: + 70.4 OR: +10.5 GAIN: 5 E 0 0
N37:10 W119:40 N37:04 W119:01
N36:38 W119:50 N36:51 W119:25 N36:32 W119:10 0 0
REF#: P0001053

(1 537 277 90/06/08 18:52:37 1 P) INCID: -02.3 TQ SNOW CLOUDS
AZ: +129.3 EL: + 70.7 OR: +10.4 GAIN: 5 E 0 0
N36:40 W119:49 N36:34 W119:10
N36:09 W119:59 N36:22 W119:34 N36:03 W119:19 0 0
REF#: P0001053

(1 537 278 90/06/08 18:52:46 1 P) INCID: -02.3 TQ SNOW CLOUDS
AZ: +128.0 EL: + 70.9 OR: +10.4 GAIN: 5 E 0 0
N36:11 W119:58 N36:05 W119:19
N35:39 W120:07 N35:52 W119:43 N35:33 W119:28 0 0
REF#: P0001053

(1 537 279 90/06/08 18:52:54 1 P) INCID: -02.3 TQ SNOW CLOUDS
AZ: +126.6 EL: + 71.1 OR: +10.3 GAIN: 5 E 0 0
N35:41 W120:07 N35:35 W119:28
N35:10 W120:16 N35:23 W119:52 N35:04 W119:37 0 0
REF#: P0001053

(1 538 277 90/06/08 18:52:36 2 P) INCID: +02.3 TQ SNOW CLOUDS
AZ: +130.6 EL: + 71.1 OR: +10.9 GAIN: 5 E 0 0
N36:40 W119:10 N36:34 W118:30
N36:09 W119:20 N36:22 W118:55 N36:03 W118:40 0 0
REF#: P0001053

```
(1  538 278  90/06/08  18:52:44  2  P)   INCID: +02.3      TQ  SNOW  CLOUDS
 AZ: +129.3  EL: + 71.3  OR: +10.8         GAIN: 5          E          0 0
   N36:11  W119:19                        N36:05  W118:40
   N35:39  W119:29   N35:52  W119:04      N35:33  W118:50               0 0
                                            REF#:   P0001053

(1  538 279  90/06/08  18:52:52  2  P)   INCID: +02.3      TQ  SNOW  CLOUDS
 AZ: +127.9  EL: + 71.5  OR: +10.7         GAIN: 5          E          0 0
   N35:41  W119:28                        N35:35  W118:49
   N35:10  W119:37   N35:23  W119:13      N35:04  W118:59               0 0
                                            REF#:   P0001053

(1  538 280  90/06/08  18:53:01  2  P)   INCID: +02.3      TQ  SNOW  CLOUDS
 AZ: +126.5  EL: + 71.8  OR: +10.7         GAIN: 5          E          0 0
   N35:12  W119:37                        N35:06  W118:58
   N34:40  W119:46   N34:53  W119:22      N34:34  W119:08               0 0
                                            REF#:   P0001053

(2  539 278  90/06/16  18:49:06  2  P)   INCID: -01.3      TQ  SNOW  CLOUDS
 AZ: +126.5  EL: + 71.1  OR: +10.5         GAIN: 6          E          0 0
   N36:11  W118:50                        N36:05  W118:11
   N35:39  W118:59   N35:52  W118:35      N35:33  W118:20               0 0
                                            REF#:   P0001060

(2  539 278  90/06/21  18:52:59  2  P)   INCID: +04.3      TQ  SNOW  CLOUDS
 AZ: +127.3  EL: + 71.6  OR: +11.0         GAIN: 6          E          0 0
   N36:11  W119:00                        N36:05  W118:21
   N35:39  W119:10   N35:52  W118:46      N35:33  W118:31               0 0
                                            REF#:   P0001065

(2  539 278  90/06/21  18:52:59  1  P)   INCID: +05.3      TQ  SNOW  CLOUDS
 AZ: +127.6  EL: + 71.7  OR: +11.1         GAIN: 7          E          0 0
   N36:11  W118:52                        N36:05  W118:12
   N35:39  W119:02   N35:52  W118:37      N35:33  W118:23               0 0
                                            REF#:   P0001065

(2  539 279  90/06/16  18:49:14  2  P)   INCID: -01.3      TQ  SNOW  CLOUDS
 AZ: +125.1  EL: + 71.4  OR: +10.4         GAIN: 6          E          0 0
   N35:41  W118:59                        N35:35  W118:20
   N35:10  W119:08   N35:23  W118:44      N35:04  W118:29               0 0
                                            REF#:   P0001060

(2  539 279  90/06/21  18:53:08  1  P)   INCID: +05.3      TQ  SNOW  CLOUDS
 AZ: +126.2  EL: + 71.9  OR: +11.0         GAIN: 7          E          0 0
   N35:42  W119:01                        N35:35  W118:22
   N35:10  W119:11   N35:23  W118:46      N35:04  W118:32               0 0
                                            REF#:   P0001065

(2  539 279  90/06/21  18:53:08  2  P)   INCID: +04.3      TQ  SNOW  CLOUDS
 AZ: +125.9  EL: + 71.8  OR: +10.9         GAIN: 6          E          0 0
   N35:41  W119:10                        N35:35  W118:31
   N35:10  W119:19   N35:23  W118:55      N35:04  W118:40               0 0
                                            REF#:   P0001065

(2  539 280  90/06/21  18:53:16  2  P)   INCID: +04.3      TQ  SNOW  CLOUDS
 AZ: +124.4  EL: + 72.0  OR: +10.9         GAIN: 6          E          0 0
   N35:12  W119:19                        N35:06  W118:40
   N34:40  W119:28   N34:53  W119:04      N34:34  W118:50               0 0
                                            REF#:   P0001065
```

```
(2  534 273  91/06/04  19:00:17  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +137.0  EL: + 69.8  OR: +11.2        GAIN: 6          E           0 0
   N38:38  W120:31                      N38:32  W119:51
   N38:07  W120:42   N38:19  W120:16    N38:00  W120:02                0 0
                                          REF#:   P0001317

(2  534 274  91/06/04  19:00:26  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +135.8  EL: + 70.1  OR: +11.1        GAIN: 6          E           0 0
   N38:09  W120:41                      N38:02  W120:01
   N37:37  W120:51   N37:50  W120:26    N37:31  W120:11                0 0
                                          REF#:   P0001317

(2  534 275  91/06/04  19:00:34  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +134.6  EL: + 70.4  OR: +11.0        GAIN: 6          E           0 0
   N37:39  W120:50                      N37:33  W120:10
   N37:08  W121:00   N37:20  W120:35    N37:01  W120:21                0 0
                                          REF#:   P0001317

(2  534 276  91/06/04  19:00:42  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +133.3  EL: + 70.6  OR: +11.0        GAIN: 6          E           0 0
   N37:10  W121:00                      N37:04  W120:20
   N36:38  W121:09   N36:51  W120:45    N36:32  W120:30                0 0
                                          REF#:   P0001317

(2  534 277  91/06/04  19:00:51  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +132.0  EL: + 70.9  OR: +10.9        GAIN: 6          E           0 0
   N36:40  W121:09                      N36:34  W120:29
   N36:09  W121:18   N36:22  W120:54    N36:03  W120:39                0 0
                                          REF#:   P0001317

(2  535 274  91/06/30  19:00:32  1  P)   INCID: +04.6     TQ  SNOW  CLOUDS
 AZ: +132.4  EL: + 70.2  OR: +11.3        GAIN: 7          E           0 0
   N38:09  W120:18                      N38:02  W119:38
   N37:37  W120:29   N37:50  W120:04    N37:31  W119:49                0 0
                                          REF#:   P0001341

(2  535 275  91/06/30  19:00:41  1  P)   INCID: +04.6     TQ  SNOW  CLOUDS
 AZ: +131.1  EL: + 70.4  OR: +11.2        GAIN: 7          E           0 0
   N37:39  W120:28                      N37:33  W119:48
   N37:08  W120:38   N37:20  W120:13    N37:01  W119:58                0 0
                                          REF#:   P0001341

(2  535 276  91/06/30  19:00:49  1  P)   INCID: +04.6     TQ  SNOW  CLOUDS
 AZ: +129.8  EL: + 70.7  OR: +11.1        GAIN: 7          E           0 0
   N37:10  W120:37                      N37:03  W119:58
   N36:38  W120:47   N36:51  W120:23    N36:32  W120:08                0 0
                                          REF#:   P0001341

(2  535 277  91/06/30  19:00:58  1  P)   INCID: +04.6     TQ  SNOW  CLOUDS
 AZ: +128.5  EL: + 70.9  OR: +11.1        GAIN: 7          E           0 0
   N36:40  W120:47                      N36:34  W120:07
   N36:09  W120:57   N36:22  W120:32    N36:03  W120:17                0 0
                                          REF#:   P0001341

(2  536 275  91/06/25  18:56:41  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +130.5  EL: + 70.5  OR: +11.0        GAIN: 6          E           1 1
   N37:39  W119:50                      N37:33  W119:10
   N37:08  W120:00   N37:20  W119:35    N37:01  W119:20                0 1
                                          REF#:   P0001336
```

```
(2  536 275  91/06/30  19:00:39  2  P)   INCID: +09.0     TQ  SNOW  CLOUDS
 AZ: +132.5  EL: + 70.8  OR: +11.7         GAIN: 6         E          0 0
   N37:39  W119:48                       N37:33  W119:07
   N37:08  W119:58   N37:20  W119:33     N37:01  W119:18                0 0
                                           REF#:   P0001341

(2  536 276  91/06/25  18:56:50  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +129.2  EL: + 70.8  OR: +11.0         GAIN: 6         E          0 0
   N37:10  W119:59                       N37:04  W119:19
   N36:38  W120:09   N36:51  W119:44     N36:32  W119:29                0 0
                                           REF#:   P0001336

(2  536 276  91/06/30  19:00:47  2  P)   INCID: +09.0     TQ  SNOW  CLOUDS
 AZ: +131.2  EL: + 71.1  OR: +11.6         GAIN: 6         E          0 0
   N37:10  W119:57                       N37:03  W119:17
   N36:39  W120:08   N36:51  W119:43     N36:32  W119:28                0 0
                                           REF#:   P0001341

(2  536 277  91/06/25  18:56:58  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +127.8  EL: + 71.0  OR: +10.9         GAIN: 6         E          0 0
   N36:40  W120:08                       N36:34  W119:29
   N36:09  W120:18   N36:22  W119:53     N36:03  W119:39                0 0
                                           REF#:   P0001336

(2  536 277  91/06/30  19:00:56  2  P)   INCID: +09.0     TQ  SNOW  CLOUDS
 AZ: +129.8  EL: + 71.3  OR: +11.5         GAIN: 6         E          0 0
   N36:41  W120:07                       N36:34  W119:27
   N36:09  W120:17   N36:22  W119:52     N36:02  W119:37                0 0
                                           REF#:   P0001341

(2  536 278  91/06/25  18:57:07  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +126.5  EL: + 71.2  OR: +10.8         GAIN: 6         E          0 0
   N36:11  W120:17                       N36:05  W119:38
   N35:39  W120:27   N35:52  W120:03     N35:33  W119:48                0 0
                                           REF#:   P0001336

(2  536 278  91/06/30  19:01:04  2  P)   INCID: +09.0     TQ  SNOW  CLOUDS
 AZ: +128.4  EL: + 71.6  OR: +11.5         GAIN: 6         E          0 0
   N36:11  W120:17                       N36:04  W119:37
   N35:40  W120:27   N35:52  W120:02     N35:33  W119:47                0 0
                                           REF#:   P0001341

(2  537 276  91/06/09  19:04:28  1  P)   INCID: +16.9     TQ  SNOW  CLOUDS
 AZ: +136.9  EL: + 72.2  OR: +12.4         GAIN: 7         E          0 0
   N37:10  W119:44                       N37:03  W119:01
   N36:39  W119:55   N36:51  W119:28     N36:31  W119:12                0 0
                                           REF#:   P0001322

(2  537 277  91/06/09  19:04:36  1  P)   INCID: +16.9     TQ  SNOW  CLOUDS
 AZ: +135.5  EL: + 72.4  OR: +12.3         GAIN: 7         E          0 0
   N36:41  W119:54                       N36:33  W119:12
   N36:10  W120:05   N36:22  W119:39     N36:02  W119:23                0 0
                                           REF#:   P0001322

(2  537 278  91/06/09  19:04:45  1  P)   INCID: +16.9     TQ  SNOW  CLOUDS
 AZ: +134.1  EL: + 72.7  OR: +12.2         GAIN: 7         E          0 0
   N36:11  W120:04                       N36:04  W119:22
   N35:40  W120:15   N35:52  W119:49     N35:33  W119:33                0 0
                                           REF#:   P0001322
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(2 537 279 91/06/09 19:04:53 1 P) INCID: +16.9 TQ SNOW CLOUDS
AZ: +132.6 EL: + 73.0 OR: +12.1 GAIN: 7 E 0 0
N35:42 W120:14 N35:35 W119:32
N35:11 W120:24 N35:23 W119:59 N35:03 W119:43 0 0
REF#: P0001322

(2 538 277 91/06/09 19:04:35 2 P) INCID: +20.7 TQ SNOW CLOUDS
AZ: +137.0 EL: + 72.8 OR: +12.7 GAIN: 6 E 0 0
N36:41 W119:18 N36:33 W118:34
N36:10 W119:29 N36:22 W119:02 N36:02 W118:45 0 0
REF#: P0001322

(2 538 278 91/06/09 19:04:43 2 P) INCID: +20.7 TQ SNOW CLOUDS
AZ: +135.6 EL: + 73.1 OR: +12.6 GAIN: 6 E 0 0
N36:12 W119:28 N36:04 W118:44
N35:40 W119:39 N35:52 W119:12 N35:32 W118:55 0 0
REF#: P0001322

(2 538 279 91/06/09 19:04:52 2 P) INCID: +20.7 TQ SNOW CLOUDS
AZ: +134.1 EL: + 73.3 OR: +12.5 GAIN: 6 E 0 0
N35:42 W119:38 N35:34 W118:55
N35:11 W119:49 N35:23 W119:22 N35:03 W119:05 0 0
REF#: P0001322

(2 540 279 91/06/15 18:49:17 2 P) INCID: +02.3 TQ SNOW CLOUDS
AZ: +126.3 EL: + 71.7 OR: +10.7 GAIN: 6 E 0 0
N35:41 W118:28 N35:35 W117:49
N35:10 W118:37 N35:23 W118:13 N35:04 W117:59 0 0
REF#: P0001327

(2 531 274 92/06/02 19:01:25 2 P) INCID: -06.6 TQ SNOW CLOUDS
AZ: +133.9 EL: + 69.4 OR: +10.2 GAIN: 6 E 0 0
N38:08 W122:00 N38:03 W121:19
N37:37 W122:09 N37:50 W121:44 N37:31 W121:29 0 0
REF#: P0001548

(2 531 274 92/06/07 19:05:18 1 P) INCID: -01.0 TQ SNOW CLOUDS
AZ: +134.2 EL: + 70.2 OR: +10.8 GAIN: 7 E 0 0
N38:09 W122:06 N38:02 W121:26
N37:37 W122:16 N37:50 W121:51 N37:31 W121:36 0 0
REF#: P0001551

(2 531 275 92/06/02 19:01:33 2 P) INCID: -06.6 TQ SNOW CLOUDS
AZ: +132.7 EL: + 69.7 OR: +10.2 GAIN: 6 E 0 0
N37:39 W122:09 N37:33 W121:28
N37:07 W122:18 N37:20 W121:53 N37:02 W121:38 0 0
REF#: P0001548

(2 534 273 92/06/27 19:20:35 1 P) INCID: +30.0 TQ SNOW CLOUDS
AZ: +144.2 EL: + 72.4 OR: +14.2 GAIN: 7 E 0 0
N38:40 W120:50 N38:29 W119:58
N38:09 W121:02 N38:19 W120:30 N37:58 W120:10 0 0
REF#: P0001563

(2 534 274 92/06/27 19:20:44 1 P) INCID: +30.0 TQ SNOW CLOUDS
AZ: +142.8 EL: + 72.7 OR: +14.0 GAIN: 7 E 0 0
N38:10 W121:01 N38:00 W120:09
N37:39 W121:13 N37:50 W120:42 N37:29 W120:22 0 0
REF#: P0001563

```
(2  534 275  92/06/27  19:20:52  1  P)   INCID: +30.0     TQ  SNOW  CLOUDS
 AZ: +141.4  EL: + 73.0  OR: +13.9        GAIN: 7          E          0 0
   N37:41  W121:12                      N37:31  W120:21
   N37:10  W121:24   N37:20  W120:53    N37:00  W120:33               0 0
                                          REF#:   P0001563

(2  537 276  92/06/18  18:53:54  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +129.0  EL: + 70.7  OR: +10.5        GAIN: 7          E          0 0
   N37:10  W119:40                      N37:04  W119:00
   N36:38  W119:49   N36:51  W119:25    N36:32  W119:10               0 0
                                          REF#:   P0001556

(2  537 277  92/06/18  18:54:03  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +127.6  EL: + 71.0  OR: +10.4        GAIN: 7          E          0 0
   N36:40  W119:49                      N36:34  W119:09
   N36:09  W119:58   N36:22  W119:34    N36:03  W119:19               0 0
                                          REF#:   P0001556

(2  537 278  92/06/18  18:54:11  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +126.3  EL: + 71.2  OR: +10.4        GAIN: 7          E          0 0
   N36:11  W119:58                      N36:05  W119:18
   N35:39  W120:07   N35:52  W119:43    N35:33  W119:28               0 0
                                          REF#:   P0001556

(2  537 279  92/06/18  18:54:20  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +124.9  EL: + 71.4  OR: +10.3        GAIN: 7          E          0 0
   N35:41  W120:06                      N35:35  W119:27
   N35:10  W120:16   N35:23  W119:52    N35:04  W119:37               0 0
                                          REF#:   P0001556

(2  532 273  90/12/09  19:04:26  1  P)   INCID: +02.0     TQ  SNOW  CLOUDS
 AZ: +166.2  EL: + 27.8  OR: +11.1        GAIN: 7          E          0 0
   N38:38  W121:32                      N38:32  W120:51
   N38:06  W121:42   N38:19  W121:17    N38:00  W121:02               0 0
                                          REF#:   P0001216

(2  532 274  90/12/09  19:04:35  1  P)   INCID: +02.0     TQ  SNOW  CLOUDS
 AZ: +166.0  EL: + 28.3  OR: +11.0        GAIN: 7          E          0 0
   N38:09  W121:41                      N38:02  W121:01
   N37:37  W121:51   N37:50  W121:26    N37:31  W121:11               0 0
                                          REF#:   P0001216

(2  532 275  90/12/09  19:04:43  1  P)   INCID: +02.0     TQ  SNOW  CLOUDS
 AZ: +165.8  EL: + 28.7  OR: +11.0        GAIN: 7          E          0 0
   N37:39  W121:50                      N37:33  W121:11
   N37:08  W122:00   N37:20  W121:36    N37:01  W121:21               0 0
                                          REF#:   P0001216

(2  533 273  90/12/04  19:00:38  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +166.0  EL: + 28.4  OR: +10.7        GAIN: 7          E          0 0
   N38:38  W121:11                      N38:32  W120:31
   N38:06  W121:21   N38:19  W120:56    N38:00  W120:41               0 0
                                          REF#:   P0001213

(2  533 273  90/12/30  19:00:38  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +163.1  EL: + 26.8  OR: +10.7        GAIN: 7          E          0 0
   N38:38  W121:12                      N38:32  W120:32
   N38:06  W121:22   N38:19  W120:57    N38:00  W120:42               0 0
                                          REF#:   P0001228
```

```
(2  533 274  90/12/04  19:00:47  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +165.8  EL: + 28.8  OR: +10.6        GAIN: 7          E           0 0
   N38:09  W121:20                      N38:02  W120:40
   N37:37  W121:30   N37:50  W121:05    N37:31  W120:50                0 0
                                          REF#:   P0001213

(2  533 274  90/12/30  19:00:46  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +162.9  EL: + 27.2  OR: +10.6        GAIN: 7          E           0 0
   N38:09  W121:21                      N38:02  W120:41
   N37:37  W121:31   N37:50  W121:06    N37:31  W120:51                0 0
                                          REF#:   P0001228

(2  533 275  90/12/30  19:00:55  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +162.7  EL: + 27.7  OR: +10.6        GAIN: 7          E           0 0
   N37:39  W121:30                      N37:33  W120:50
   N37:08  W121:40   N37:20  W121:15    N37:02  W121:00                0 0
                                          REF#:   P0001228

(2  533 276  90/12/04  19:01:03  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +165.4  EL: + 29.7  OR: +10.5        GAIN: 7          E           0 0
   N37:10  W121:38                      N37:04  W120:59
   N36:38  W121:48   N36:51  W121:23    N36:32  W121:09                0 0
                                          REF#:   P0001213

(2  533 276  90/12/30  19:01:03  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +162.6  EL: + 28.1  OR: +10.5        GAIN: 7          E           0 0
   N37:10  W121:39                      N37:04  W120:59
   N36:38  W121:49   N36:51  W121:24    N36:32  W121:09                0 0
                                          REF#:   P0001228

(2  535 274  90/12/25  18:56:51  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +163.6  EL: + 27.1  OR: +10.6        GAIN: 7          E           0 0
   N38:09  W120:22                      N38:02  W119:42
   N37:37  W120:32   N37:50  W120:07    N37:31  W119:52                0 0
                                          REF#:   P0001225

(2  535 275  90/12/25  18:57:00  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +163.4  EL: + 27.6  OR: +10.6        GAIN: 7          E           0 0
   N37:39  W120:31                      N37:33  W119:51
   N37:08  W120:41   N37:20  W120:16    N37:02  W120:01                0 0
                                          REF#:   P0001225

(2  535 276  90/12/25  18:57:08  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +163.2  EL: + 28.0  OR: +10.5        GAIN: 7          E           0 0
   N37:10  W120:40                      N37:04  W120:01
   N36:38  W120:50   N36:51  W120:25    N36:32  W120:10                0 0
                                          REF#:   P0001225

(2  535 277  90/12/25  18:57:17  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
 AZ: +163.0  EL: + 28.5  OR: +10.4        GAIN: 7          E           0 0
   N36:40  W120:49                      N36:34  W120:10
   N36:09  W120:59   N36:22  W120:34    N36:03  W120:20                0 0
                                          REF#:   P0001225

(2  537 278  90/12/20  18:53:29  2  P)   INCID: -02.6     TQ  SNOW  CLOUDS
 AZ: +163.4  EL: + 29.0  OR: +10.4        GAIN: 6          E           0 0
   N36:11  W120:01                      N36:05  W119:22
   N35:39  W120:11   N35:52  W119:46    N35:33  W119:32                0 0
                                          REF#:   P0001222
```

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(2  536 279  91/12/13  19:09:38  1  P)   INCID: +22.3     TQ  SNOW  CLOUDS
AZ: +168.0  EL: + 30.7  OR: +12.6          GAIN: 7         E           0 2
   N35:42  W120:21                       N35:34  W119:37
   N35:11  W120:32   N35:23  W120:05     N35:03  W119:48               0 0
                                           REF#:   P0001451

(2  537 275  91/12/14  18:49:46  1  P)   INCID: -09.7     TQ  SNOW  CLOUDS
AZ: +163.7  EL: + 27.9  OR: + 9.8          GAIN: 7         E           1 1
   N37:39  W119:43                       N37:33  W119:02
   N37:07  W119:52   N37:20  W119:27     N37:02  W119:11               1 0
                                           REF#:   P0001451

(2  537 279  91/12/14  18:50:20  1  P)   INCID: -09.7     TQ  SNOW  CLOUDS
AZ: +163.0  EL: + 29.7  OR: + 9.6          GAIN: 7         E           0 2
   N35:41  W120:16                       N35:36  W119:36
   N35:10  W120:25   N35:23  W120:01     N35:04  W119:45               0 0
                                           REF#:   P0001451

(2  534 277  92/12/27  19:02:43  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
AZ: +163.7  EL: + 28.7  OR: +10.9          GAIN: 6         E           0 1
   N36:40  W121:07                       N36:34  W120:28
   N36:09  W121:17   N36:22  W120:52     N36:03  W120:38               0 1
                                           REF#:   P0001684

(2  535 274  92/12/21  19:17:39  1  P)   INCID: +29.3     TQ  SNOW  CLOUDS
AZ: +169.5  EL: + 28.2  OR: +14.0          GAIN: 7         E           0 0
   N38:10  W120:11                       N38:00  W119:20
   N37:39  W120:23   N37:50  W119:52     N37:29  W119:32               0 0
                                           REF#:   P0001681

(2  535 274  92/12/22  18:58:23  1  P)   INCID: -02.3     TQ  SNOW  CLOUDS
AZ: +164.3  EL: + 27.3  OR: +10.6          GAIN: 7         E           0 0
   N38:09  W120:20                       N38:02  W119:40
   N37:37  W120:30   N37:50  W120:05     N37:31  W119:50               1 0
                                           REF#:   P0001681

(2  535 275  92/12/21  19:17:48  1  P)   INCID: +29.3     TQ  SNOW  CLOUDS
AZ: +169.3  EL: + 28.6  OR: +13.8          GAIN: 7         E           0 0
   N37:41  W120:22                       N37:31  W119:31
   N37:10  W120:34   N37:20  W120:03     N37:00  W119:43               0 0
                                           REF#:   P0001681

(2  535 276  92/12/21  19:17:56  1  P)   INCID: +29.3     TQ  SNOW  CLOUDS
AZ: +169.1  EL: + 29.1  OR: +13.7          GAIN: 7         E           0 0
   N37:11  W120:33                       N37:01  W119:43
   N36:40  W120:45   N36:51  W120:14     N36:30  W119:54               0 0
                                           REF#:   P0001681

(2  535 277  92/12/21  19:18:05  1  P)   INCID: +29.3     TQ  SNOW  CLOUDS
AZ: +168.9  EL: + 29.6  OR: +13.6          GAIN: 7         E           0 0
   N36:42  W120:44                       N36:32  W119:54
   N36:11  W120:55   N36:22  W120:25     N36:01  W120:06               0 0
                                           REF#:   P0001681

(2  535 278  92/12/21  19:18:13  1  P)   INCID: +29.3     TQ  SNOW  CLOUDS
AZ: +168.7  EL: + 30.0  OR: +13.5          GAIN: 7         E           0 0
   N36:13  W120:55                       N36:03  W120:05
   N35:41  W121:06   N35:52  W120:36     N35:31  W120:17               0 0
                                           REF#:   P0001681
```

```
(2  536 275  92/12/22  18:58:29  2  P)   INCID: +02.3     TQ  SNOW  CLOUDS
 AZ: +164.8  EL: + 27.8  OR: +11.0        GAIN: 6          E           0 2
   N37:39  W119:49                       N37:33  W119:09
   N37:08  W119:59   N37:20  W119:34     N37:01  W119:20               0 0
                                           REF#:   P0001681

(2  537 276  92/12/01  19:02:31  1  P)   INCID: +10.0     TQ  SNOW  CLOUDS
 AZ: +167.9  EL: + 30.5  OR: +11.7        GAIN: 7          E           0 0
   N37:10  W119:48                       N37:03  W119:07
   N36:39  W119:58   N36:51  W119:33     N36:32  W119:18               0 0
                                           REF#:   P0001669

(2  537 277  92/12/01  19:02:39  1  P)   INCID: +10.0     TQ  SNOW  CLOUDS
 AZ: +167.7  EL: + 30.9  OR: +11.6        GAIN: 7          E           0 0
   N36:41  W119:58                       N36:34  W119:17
   N36:09  W120:08   N36:22  W119:43     N36:02  W119:28               0 0
                                           REF#:   P0001669

(2  537 278  92/12/01  19:02:47  1  P)   INCID: +10.0     TQ  SNOW  CLOUDS
 AZ: +167.5  EL: + 31.4  OR: +11.5        GAIN: 7          E           0 0
   N36:11  W120:07                       N36:04  W119:27
   N35:40  W120:17   N35:52  W119:52     N35:33  W119:38               0 0
                                           REF#:   P0001669

(2  537 279  92/12/01  19:02:56  1  P)   INCID: +10.0     TQ  SNOW  CLOUDS
 AZ: +167.3  EL: + 31.8  OR: +11.4        GAIN: 7          E           0 0
   N35:42  W120:17                       N35:35  W119:37
   N35:10  W120:27   N35:23  W120:02     N35:04  W119:47               0 0
                                           REF#:   P0001669
```

APPENDIX C

LANDSAT TM IMAGERY REFERENCES

Path is between 41 and 43. Row is between 33 and 35. The date of acquisition is between 01-DEC-1990 and 31-DEC-1990 or is een 01-JUN-1990 and 01-JUL-1990. Maximum cloud cover is 30%. Only scenes available for viewing will be returned.

Number of scenes: 7

EOSAT
Scene Locator

Values marked with ** have not been scored

								Cloud Cover Assessment											
			Date					Full		Q1		Q2		Q3		Q4			
S/C	Path	Row	Acquired	Mode	Mux	QA	D/L	Aut	Man	Aut	Man	Aut	Man	Aut	Man	Aut	Man	Microfiche	Scene Coordinates
4	042	033	06/30/90	1	0	8	Y	0	0	0	0	0	0	10	10	10	20		CN: 385423N,1183949W UL: 394847N,1193218W UR: 392952N,1172106W LL: 381839N,1195832W LR: 380008N,1175001W
	Landsat 4 Thematic Mapper										EOSAT Landsat								
5	042	035	06/22/90	1	0	9	Y	0	0	0	0	0	0	0	0	0	0		CN: 361312N,1192923W UL: 365733N,1202005W UR: 363909N,1181335W LL: 352639N,1204512W LR: 350835N,1184104W
	Landsat 5 Thematic Mapper										EOSAT Landsat								
5	042	034	06/22/90	1	0	9	Y	0	0	10	0	0	0	0	0	0	0		CN: 372858N,1191357W UL: 382359N,1195532W UR: 380514N,1174636W LL: 365309N,1202119W LR: 363446N,1181456W
	Landsat 5 Thematic Mapper										EOSAT Landsat								
5	042	033	06/22/90	1	0	9	Y	0	0	0	0	0	0	0	0	0	0		CN: 385423N,1183814W UL: 394848N,1193044W UR: 392940N,1171915W LL: 381802N,1195714W LR: 375918N,1174829W
	Landsat 5 Thematic Mapper										EOSAT Landsat								
5	042	035	06/06/90	1	0	9	Y	0	0	0	0	10	0	0	0	0	0		CN: 361312N,1192910W UL: 365730N,1201955W UR: 363905N,1181319W LL: 352637N,1204502W LR: 350833N,1184048W
	Landsat 5 Thematic Mapper										EOSAT Landsat								
5	042	034	06/06/90	1	0	9	Y	10	10	30	20	10	10	0	0	10	10		CN: 372858N,1191344W UL: 382355N,1195522W UR: 380509N,1174620W LL: 365306N,1202109W LR: 363442N,1181440W
	Landsat 5 Thematic Mapper										EOSAT Landsat								
5	042	033	06/06/90	1	0	9	Y	20	10	20	10	30	30	30	20	10	10		CN: 385423N,1183812W UL: 394843N,1193034W UR: 392934N,1171900W LL: 381759N,1195705W LR: 375913N,1174813W
	Landsat 5 Thematic Mapper										EOSAT Landsat								

Path is between 41 and 43. Row is between 33 and 35. The date of acquisition is between 01-DEC-1991 and 31-DEC-1991 or is een 01-JUN-1991 and 01-JUL-1991. Maximum cloud cover is 30%. Only scenes available for viewing will be returned.

EOSAT
Scene Locator

Number of scenes: 3

Values marked with ** have not been scored

								Cloud Cover Assestment											
			Date					Full		Q1		Q2		Q3		Q4			
S/C	Path	Row	Acquired	Mode	Mux	QA	D/L	Aut	Man	Aut	Man	Aut	Man	Aut	Man	Aut	Man	Microfiche	Scene Coordinates
5	042	035	06/25/91	1	0	9	Y	0	0	0	0	10	10	0	0	10	10		CN: 361312N,1192942W
	Landsat 5 Thematic Mapper									EOSAT Landsat									UL: 365729N,1202025W UR: 363859N,1181349W LL: 352630N,1204537W LR: 350822N,1184124W
5	042	034	06/25/91	1	0	9	Y	10	10	10	10	10	10	10	10	10	10		CN: 372858N,1191411W
	Landsat 5 Thematic Mapper									EOSAT Landsat									UL: 382359N,1195545W UR: 380508N,1174645W LL: 365304N,1202139W LR: 363436N,1181511W
5	042	033	06/25/91	1	0	9	Y	10	10	0	10	20	20	10	10	10	20		CN: 385423N,1183822W
	Landsat 5 Thematic Mapper									EOSAT Landsat									UL: 394852N,1193051W UR: 392938N,1171918W LL: 381802N,1195728W LR: 375912N,1174838W

Path is between 41 and 43. Row is between 33 and 35. The date of acquisition is between 01-DEC-1992 and 31-DEC-1992 or is
een 01-JUN-1992 and 01-JUL-1992. Maximum cloud cover is 30%. Only scenes available for viewing will be returned.

Number of scenes: 9

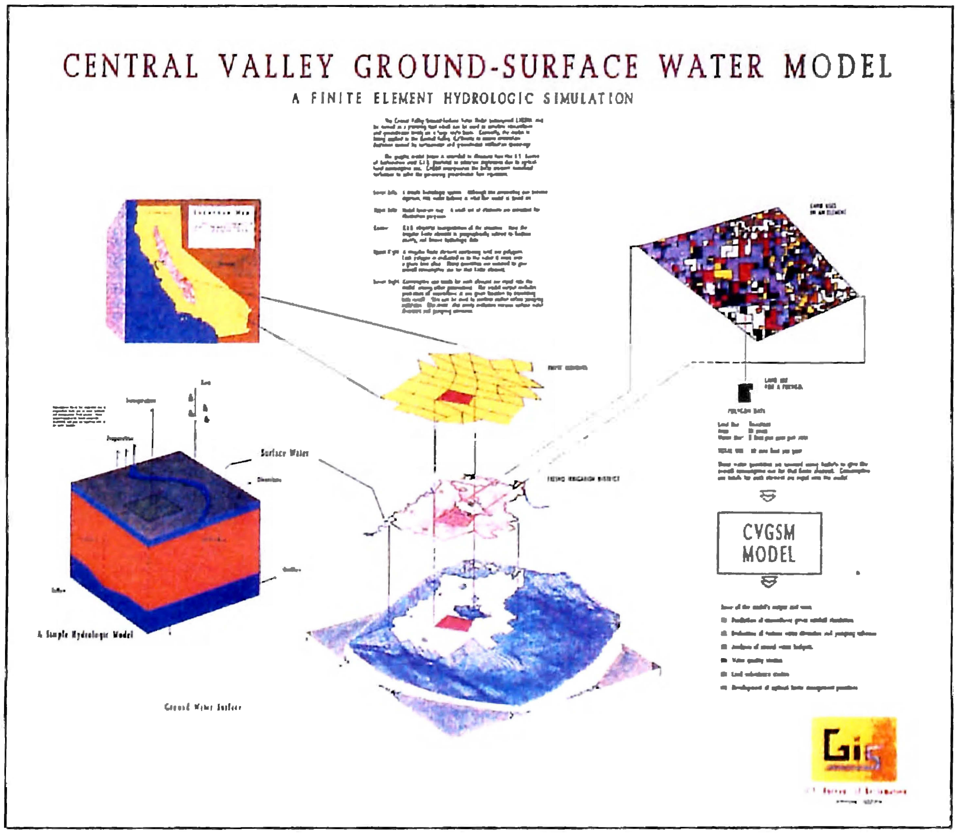
EOSAT
Scene Locator

Values marked with ** have not been scored

								Cloud Cover Assessment											
			Date					Full		Q1		Q2		Q3		Q4			
S/C	Path	Row	Acquired	Mode	Mux	QA	D/L	Aut	Man	Aut	Man	Aut	Man	Aut	Man	Aut	Man	Microfiche	Scene Coordinates
5	042	035	12/20/92	1	0	9	Y	0	0	0	0	0	0	0	0	0	0		CN: 361312N,1192817W
	Landsat 5 Thematic Mapper										EOSAT Landsat								UL: 365746N,1201836W UR: 363922N,1181240W LL: 352632N,1204354W LR: 350829N,1184020W
5	042	034	12/20/92	1	0	9	Y	0	0	20	30	0	0	0	0	10	0		CN: 372858N,1191250W
	Landsat 5 Thematic Mapper										EOSAT Landsat								UL: 382359N,1195401W UR: 380514N,1174541W LL: 365250N,1202000W LR: 363427N,1181411W
5	042	033	12/20/92	1	0	9	Y	30	50	40	50	70	90	20	50	10	20		CN: 385454N,1183657W
	Landsat 5 Thematic Mapper										EOSAT Landsat								UL: 394906N,1192903W UR: 392958N,1171810W LL: 381801N,1195545W LR: 375917N,1174735W
5	042	035	06/27/92	1	0	7	Y	0	0	10	10	0	0	10	10	0	10		CN: 361312N,1193151W
	Landsat 5 Thematic Mapper										EOSAT Landsat								UL: 365758N,1202244W UR: 363933N,1181552W LL: 352654N,1204751W LR: 350851N,1184322W
5	042	034	06/27/92	1	0	8	Y	0	0	10	10	0	10	0	0	10	10		CN: 372959N,1191625W
	Landsat 5 Thematic Mapper										EOSAT Landsat								UL: 382433N,1195811W UR: 380546N,1174853W LL: 365334N,1202358W LR: 363510N,1181713W
5	042	033	06/27/92	1	0	5	Y	0	0	0	10	0	0	0	10	0	10		CN: 385454N,1184042W
	Landsat 5 Thematic Mapper										EOSAT Landsat								UL: 394930N,1193323W UR: 393021N,1172132W LL: 381835N,1195953W LR: 375950N,1175046W
5	042	035	06/11/92	1	0	**	Y	0	0	0	0	10	0	0	0	0	0		CN: 361413N,1193211W
	Landsat 5 Thematic Mapper										EOSAT Landsat								UL: 365809N,1202250W UR: 363945N,1181605W LL: 352705N,1204757W LR: 350902N,1184335W
5	042	034	06/11/92	1	0	3	Y	0	0	10	10	0	10	0	0	10	10		CN: 372929N,1191645W
	Landsat 5 Thematic Mapper										EOSAT Landsat								UL: 382416N,1195826W UR: 380531N,1174916W LL: 365316N,1202414W LR: 363453N,1181736W
5	042	033	06/11/92	1	0	5	Y	0	0	0	0	0	0	0	0	0	0		CN: 385454N,1184052W
	Landsat 5 Thematic Mapper										EOSAT Landsat								UL: 394945N,1193329W UR: 393037N,1172145W LL: 381849N,1200000W LR: 380005N,1175100W

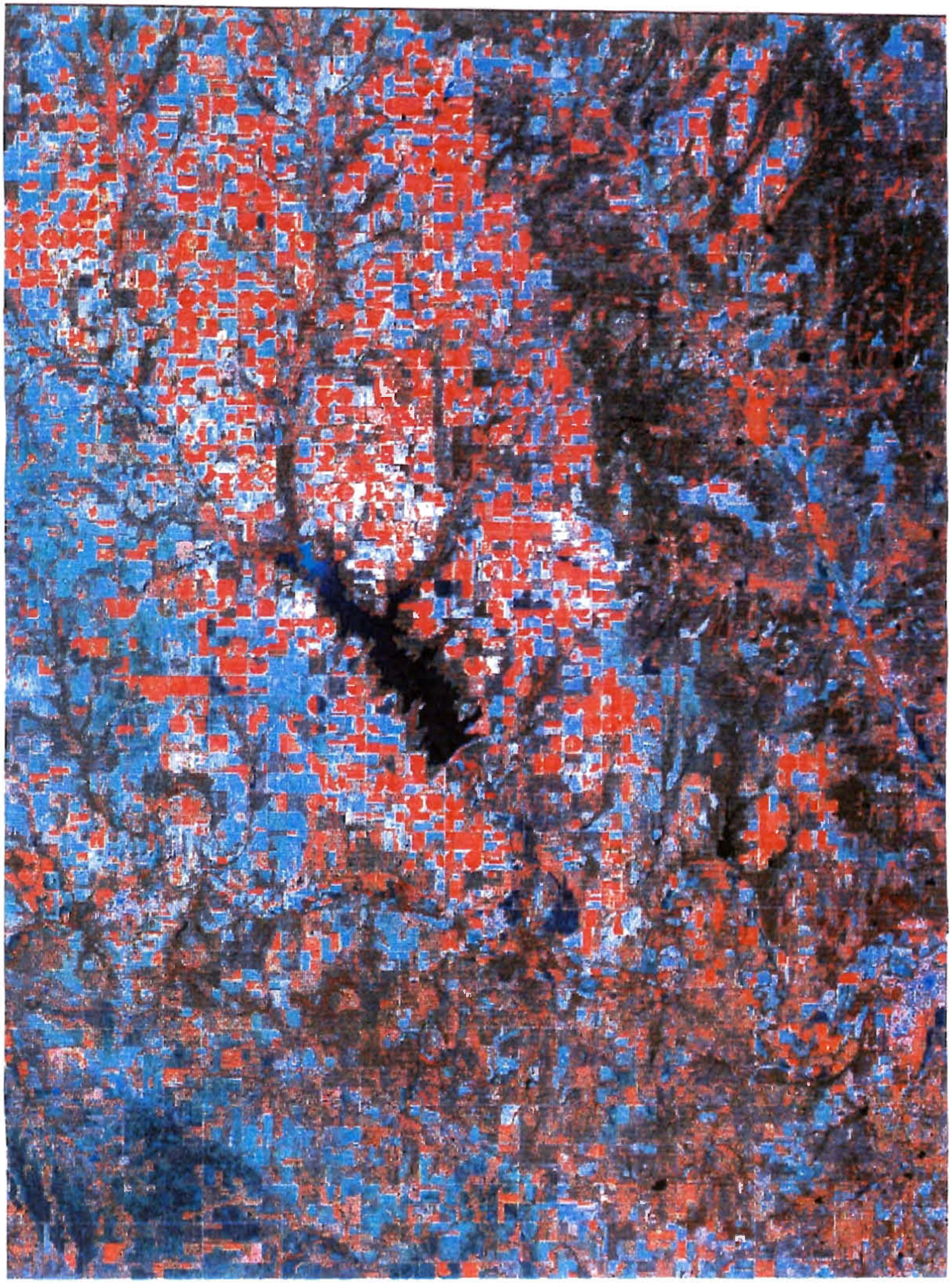
APPENDIX D

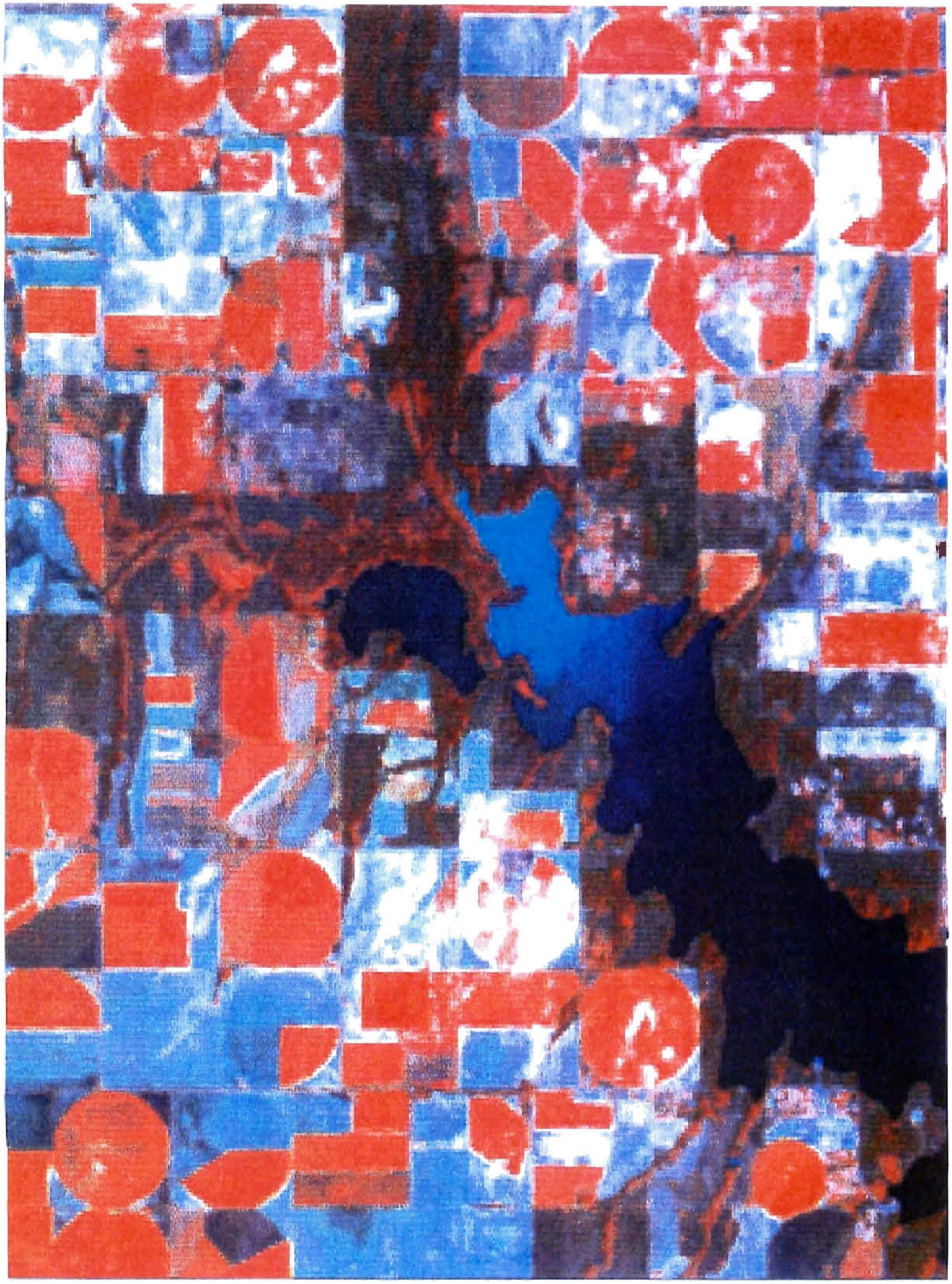
GROUNDWATER MODEL


CENTRAL VALLEY GROUND-SURFACE WATER MODEL
A FINITE ELEMENT HYDROLOGIC SIMULATION
Surface Water
A Simple Hydrologic Model
CVGSM MODEL

APPENDIX E

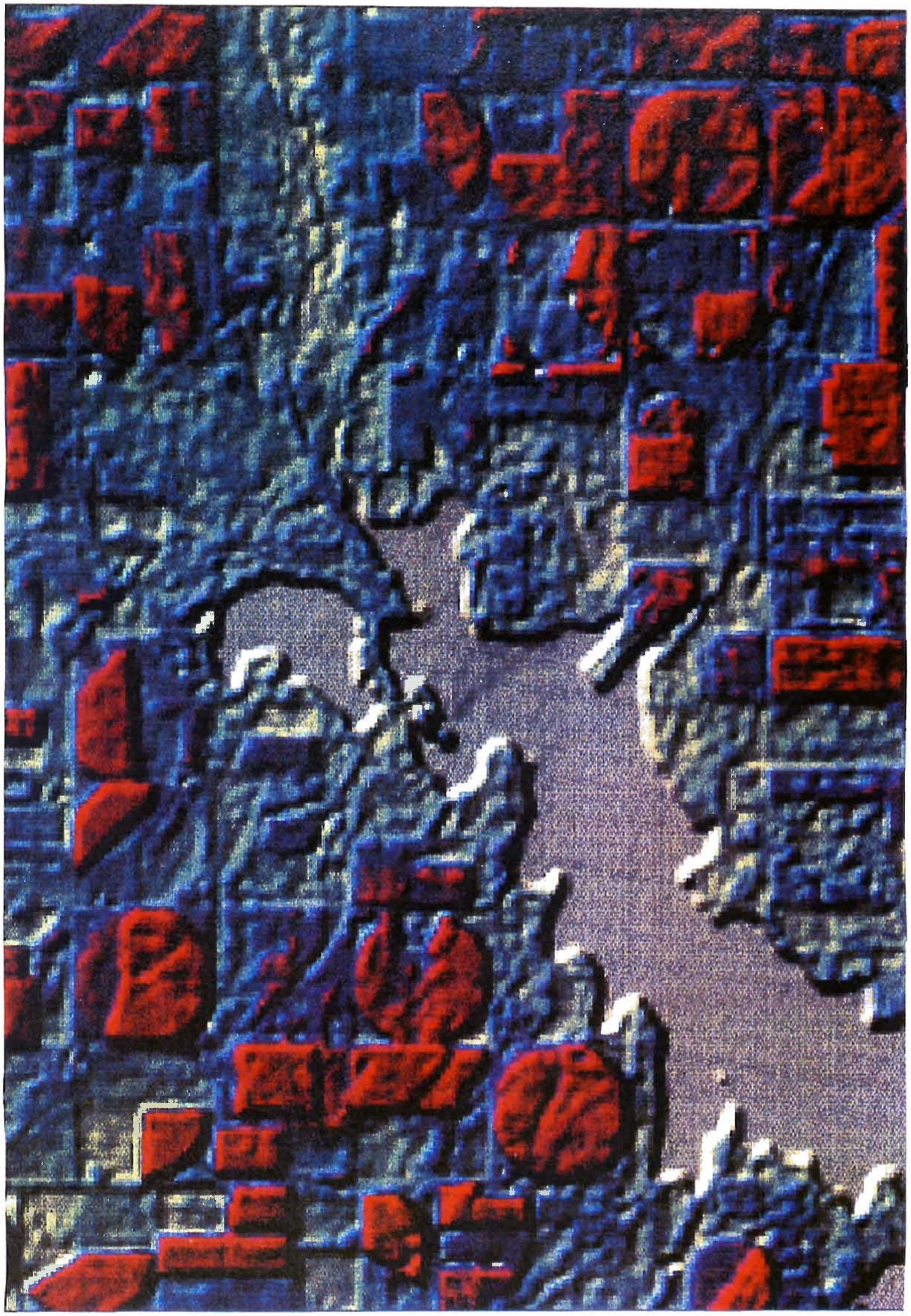
LANDSAT 5 TM IMAGES

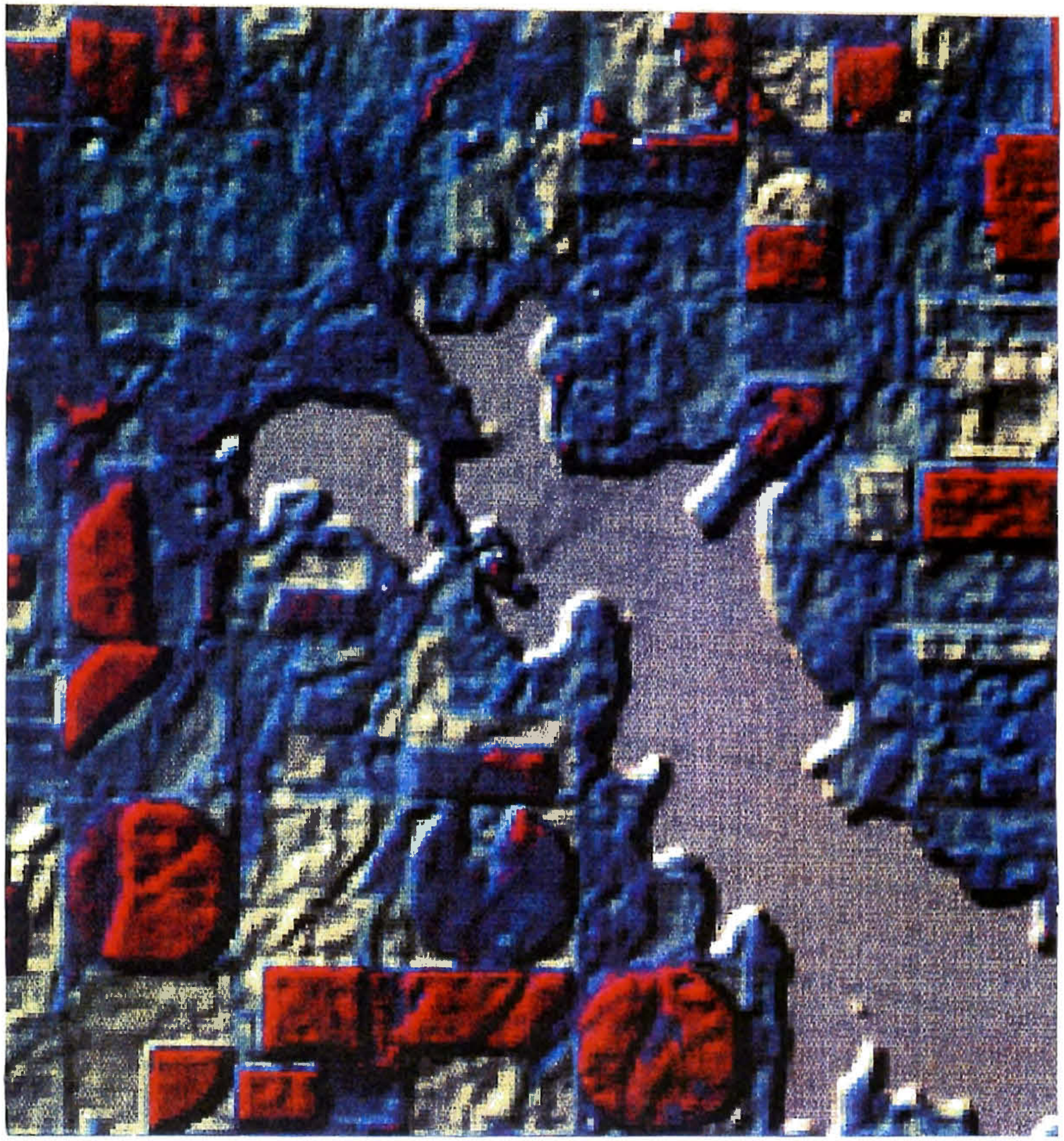




APPENDIX F

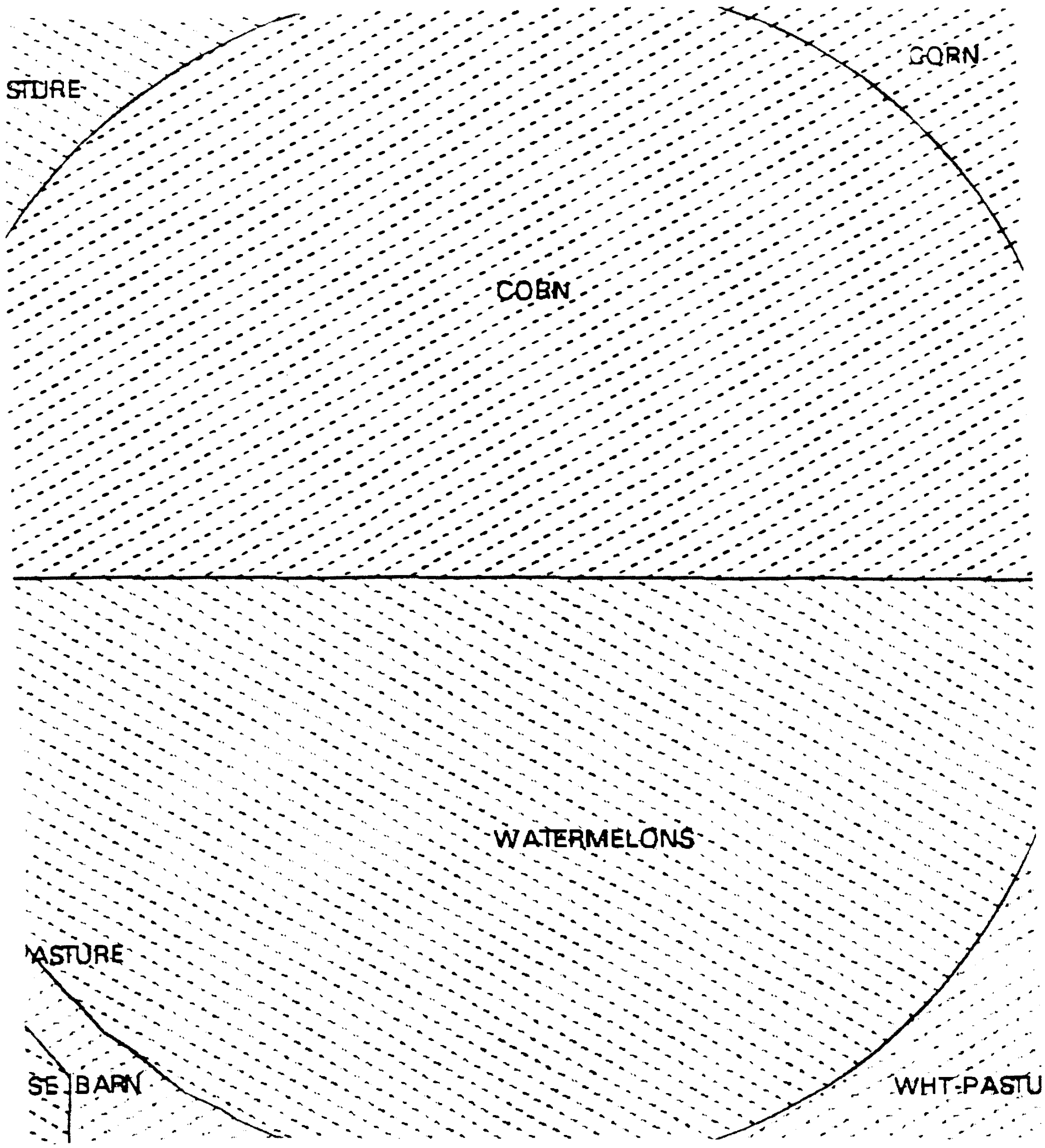
CROP BIMASS LANDSAT 5 TM IMAGES





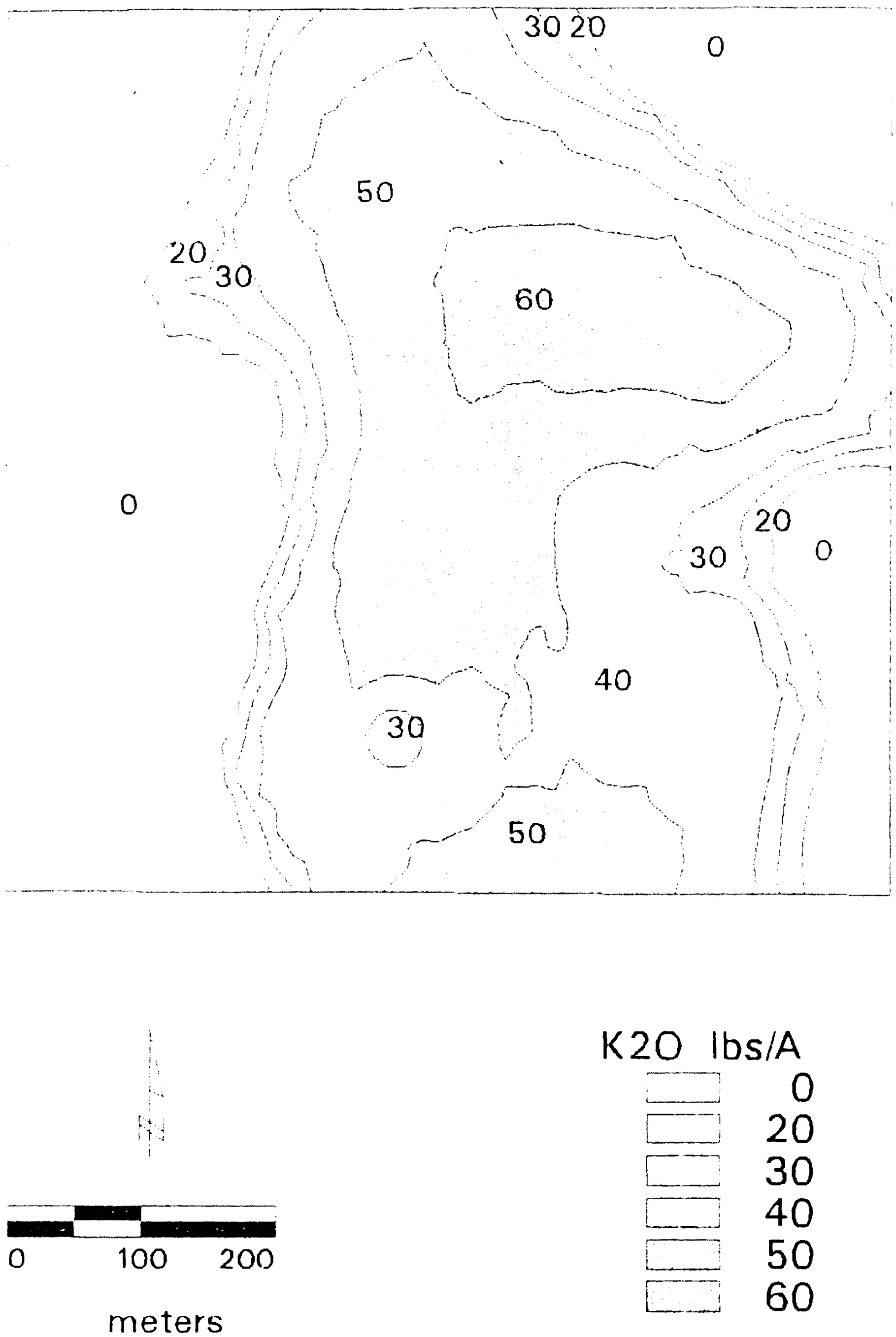
APPENDIX G

CROP AND NUTRIENT, ARC INFO IMAGES

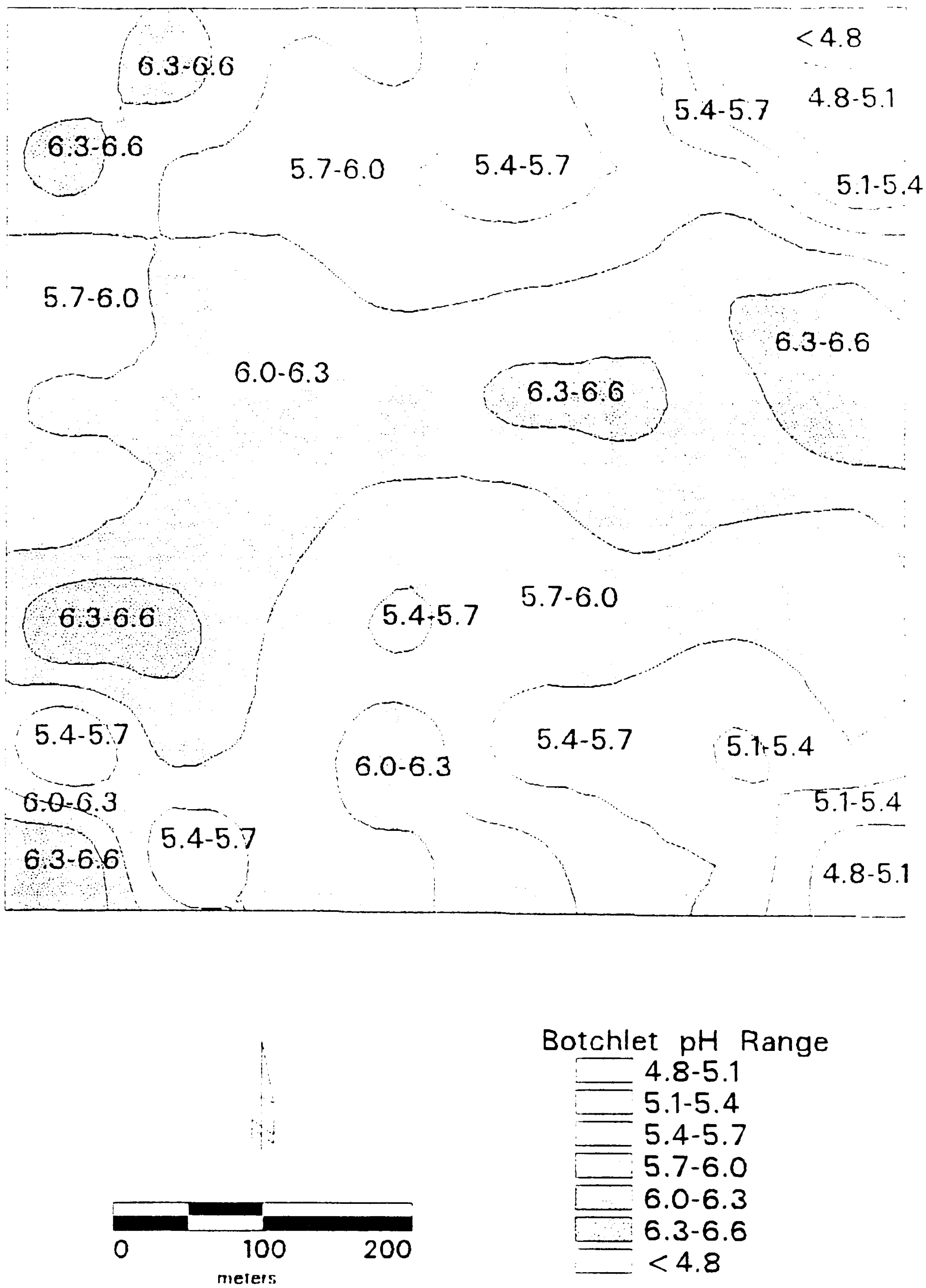


Farm - 1993 cropping

Section 31
Potassium Recommendations



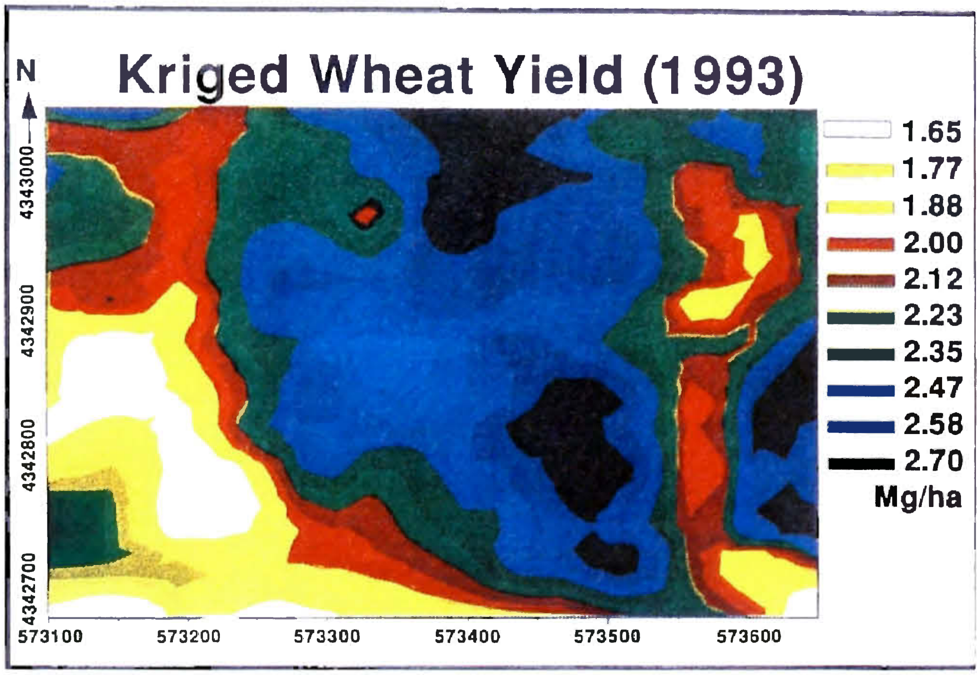
pH Range



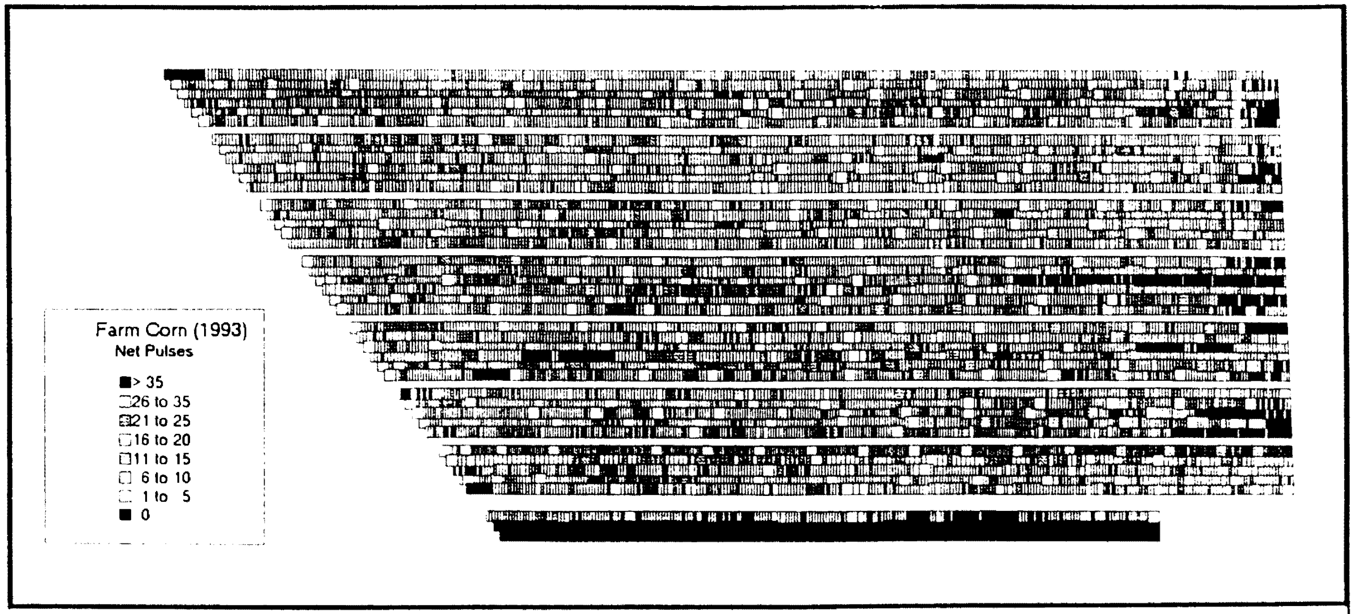
<4.8
6.3-6.6
4.8-5.1
5.4-5.7
6.3-6.6
5.7-6.0
5.4-5.7
5.1-5.4
5.7-6.0
6.3-6.6
6.0-6.3
6.3-6.6
5.7-6.0
5.4-5.7
6.3-6.6
5.4-5.7
5.4-5.7
5.1-5.4
6.0-6.3
6.0-6.3
5.1-5.4
5.4-5.7
6.3-6.6
4.8-5.1
0
100
200
meters
Botchlet pH Range
4.8-5.1
5.1-5.4
5.4-5.7
5.7-6.0
6.0-6.3
6.3-6.6
<4.8

APPENDIX H

KRIGED WHEAT YIELD



Kriged Wheat Yield (1993)
N
4343000
4342900
4342800
4342700
573100
573200
573300
573400
573500
573600
1.65
1.77
1.88
2.00
2.12
2.23
2.35
2.47
2.58
2.70
Mg/ha



Source: University of Michigan, 1994
Considerations for Yield Mapping

VITA

Jerry S. Speir

Candidate for the Degree of

Master of Science

Thesis: MEASURING CROPLAND STRESS IN THE SAN JOAQUIN VALLEY AS DOCUMENTED BY GIS, GPS, REMOTE SENSING, AND FIELD INSPECTIONS

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Organizations: Oklahoma Teachers Association; National Vocational Teachers Association; Lifetime FFA Alumni Member; American Society of Photogrammetry and Remote Sensing; Golden Key National Honor Society; American Society of Agricultural Engineers; National Association of Colleges and Teachers of Agriculture.