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USE OF ERTS-1 DATA AS AN AID IN SOLVING WATER RESOURCE MANAGEMENT PROBLEMS IN CALIFORNIA (UN317B)

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E75-10217
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E75-10218
CR-142404
N75-21743

A report of work done by scientists at the
Department of Water Science and Engineering,
University of California, Davis, under
NASA Contract No. NAS 5-21827

1317B

Final Report
14 July 1973
Space Sciences Laboratory Series 16, Issue 46

UNIVERSITY OF CALIFORNIA, BERKELEY

Final Report

USE OF ERTS-1 DATA AS AN AID IN SOLVING WATER RESOURCE MANAGEMENT PROBLEMS IN CALIFORNIA (UN317B)

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle USE OF ERTS-1 DATA IN IDENTIFICATION, CLASSIFICATION AND MAPPING OF SALT-AFFECTED SOILS IN CALIFORNIA		5. Report Date 14 July 1973 6. Performing Organization Code
7. Author(s) Robert H. Burgy, et al.		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Water Science and Engineering University of California Davis, California 95616		10. Work Unit No. 11. Contract or Grant No. NAS5-21827, Task 2
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771		13. Type of Report and Period Covered Type 3: 15 July 1972- 15 July 1973 14. Sponsoring Agency Code

15. Supplementary Notes Originally prepared as Chapter 3 in "An Integrated Study of Earth Resources in the State of California Based on ERTS-1 and Supporting Aircraft Data", Robert N. Colwell, principal investigator, Space Sciences Laboratory, Univ. of Calif., Berkeley, Calif.

16. Abstract

The co-investigator received ERTS-1 imagery of the Sacramento-San Joaquin Delta Test Site for most of the period for the purpose of assessing the potential applications and usefulness of the satellite imagery in water resources monitoring and management. After initial surveys of imagery, the test areas were reduced to three primary sites where water-related parameters were observed to be important and prominent. The term of the study covered somewhat less than a full hydrologic year with no repetition of annually cycling responses. Imagery was shown to have excellent characteristics for identifying selected water quality and quantity properties, as well as being a valuable synoptic tool for watershed hydrologic interpretations. Enhancement techniques devised by concurrent co-investigations indicate excellent possibilities for utilizing the ERTS-type imagery as new and effective data source in water resource management.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Water resources Management Water quality Hydrology	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	20	

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1 INTRODUCTION

Water requirements for both urban (municipal and industrial) and agricultural uses have led to comprehensive programs of water development. Planning and development of large water systems together with their operation are perhaps summarized in terms of where the water occurs, when, how much and in what form, and logically where, how much and when water is needed by users. Remote sensing offers a potential new dimension to this field of endeavor. A strong effort needs to be directed toward concepts of quantification of data derived from remote sensing, especially for water resource and hydrologic use. Remote sensors of the imaging type permit qualitative comparison or evaluation quite readily and thus are useful for monitoring and for comparative analysis. While many investigators are seeking to provide insight and methodology for the useful measurement of water-related phenomena, these results are not yet fully developed nor in operational use; the need for the interpretation of ERTS-1 imagery and data extraction is of highest priority.

The opportunity to assess the potential of remotely sensed data from a satellite platform for application to a broad array of operational tasks has been pursued during the study. This report summarizes the applications of ERTS-1 and supplementary imagery sources which have been found applicable to water resources planning, operations and management.

In earlier assessments, made prior to the ERTS Program, work was undertaken to define the parameters involved in the hydrologic processes and subsystems of the water cycle. Parameters of the subsystems were defined on the basis of the operational tasks performed currently by water resource agencies. These components were reduced to the fundamental hydrologic process or function. This procedure provided a listing of parameters designed to be responsive to the needs of users of data. The parameters were further defined in terms of the type of measurement required, and the magnitude, resolution and frequency of data acquisition needed for several levels of intensity in operational tasks.

The continuing phases of this research have now been centered in developing alternative parameters or analytical methods to adapt remotely sensed information to the user tasks. ERTS-1 imagery was studied intensively for these purposes, exploiting the fact that the ERTS-1 satellite provides a synoptic level coverage of study areas in California on a repetitive cycle of eighteen days, weather permitting.

2 OBJECTIVES

Specific objectives of the investigation were to use and test ERTS-1 imagery for:

a) The detection and qualitative assessment of gross water quality parameters and changes in deltaic regimes.

b) The application of the data source for possible input to large water resource systems management.

3 PROCEDURE

Several specific areas in the Sacramento-San Joaquin Delta Test Site were used in evaluating ERTS-1 imagery for application to typical water resource management problems (Figure 1). Although results to date are only for a partial year of analysis, completion of a longer cycle is expected to yield additional bases for interpretation. Longer term operational analysis of ERTS-1 data will produce a wider range of experience for hydrologic interpretation and applications, embracing greater extremes of natural processes and increasing the data base for quantification of sensor response with ground truth studies.

The test area includes: mountain watersheds; foothill and valley basins; snow pack regions; large river systems; flood-water control facilities; deltaic areas; agricultural lands, both irrigated and non-irrigated; dams and reservoirs operated for multiple purposes including water supply, flood control and recreation; urban areas; lakes, both eutrophic and oligotrophic; and further provides examples of most of the important water conditions of concern to hydrologists.

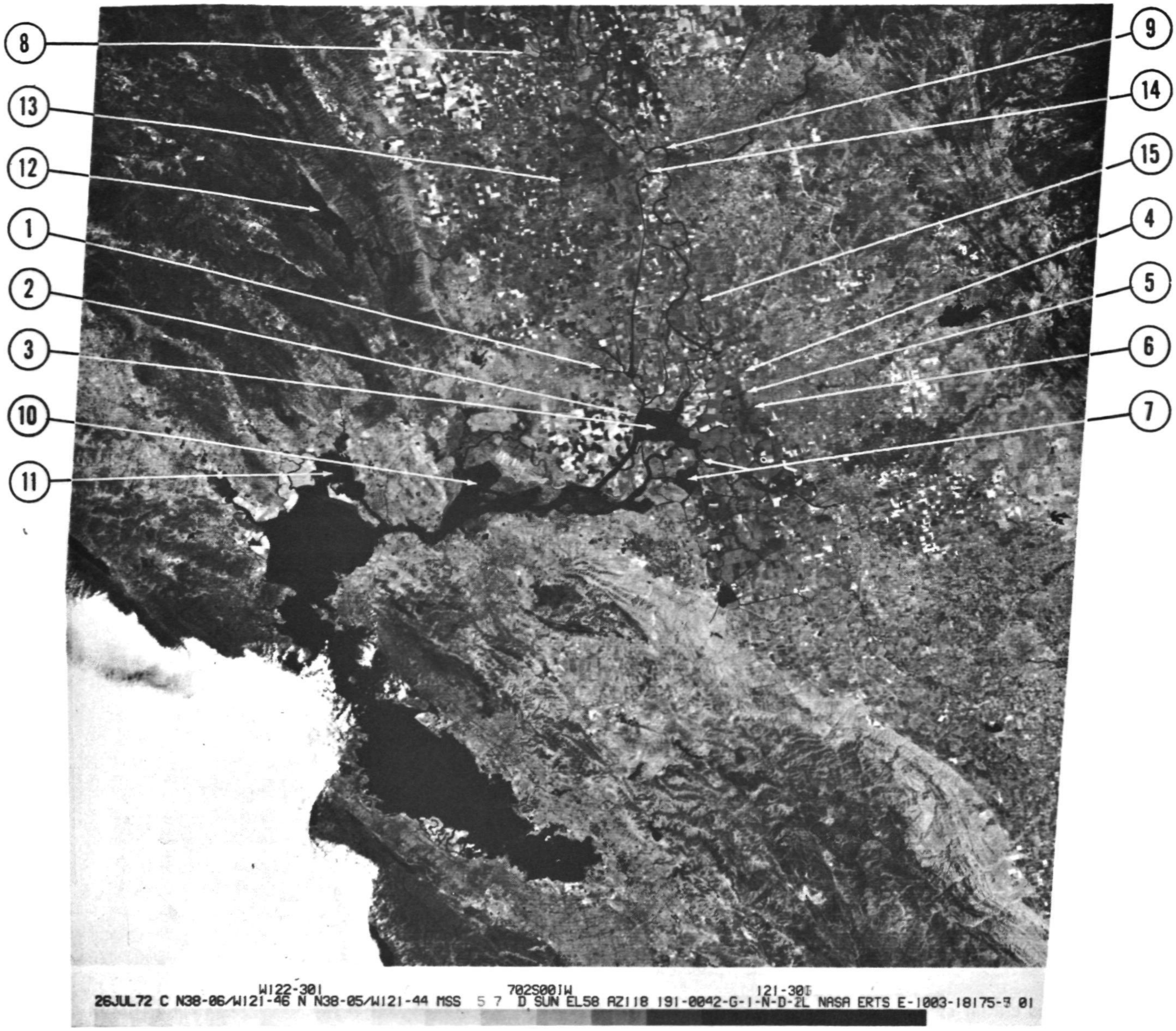
All of the aforementioned water-related components were contained in the images, and may be directly compared for the extremes of seasonal effect.

Specific hydrologic elements that were discerned include:

-- watershed physiography (drainage network) features
-- water body locations (natural and man-made)
-- canals
-- large and small river systems
-- deltaic areas
-- flood control works
-- flooded delta islands
-- snow on higher mountain slopes
-- wet lands (seasonal)
-- irrigated agriculture
-- dry land agriculture
-- many additional water-related features

Seasonal effects in terms of both atmospheric attenuation and sun angle tend to reduce the image quality in the winter at this latitude. Figure 1 depicts the general location and specific areas defined for study within the test site.

Analysis of the imagery was made both on the four Multispectral Scanner bands provided and also on color composites prepared by the diazo process and then enlarged photographically.



1. Lindsey Slough
2. Sacramento River near Rio Vista
3. Andrus Island (Brannan Island)
4. Beaver Slough
5. Hog Slough
6. Sycamore Slough
7. Frank's Tract
8. Colusa Basin Drain into Sacramento River
9. Discovery Park (Confluence of American & Sacramento Rivers at Sacramento)
10. Suisun Bay
11. San Pablo Bay (Salt concentration ponds)
12. Lake Berryessa
13. Davis - Municipal Sewage Stabilization Ponds)
14. Lake Washington (Port of Sacramento)
15. Stone Lake

Figure 1. Selected Study Areas in San Francisco Bay and Sacrmanto-San Joaquin River Delta Test Sites.

Three specific characteristics of this satellite are valuable for the test site conditons:

1. Repetitive coverage over seasonal and annual cycles.

2. The imagery format is readily adaptable to a variety of enhancement procedures to increase the derivative results.

3. Resolution characteristics and spectral band coverage provide great opportunity for detailed examination of other target subjects and other interpretive techniques.

3.1 Methods of Image Analysis

Limited equipment is available to the group; hence most of the analysis is made by close visual interpretation of ERTS-1 images in different formats.

-- The 70 mm. images are enlarged to 10 by 10 inch prints.
-- The 70 mm. images are projected on a rear projection screen and selected areas are photographed under controlled lighting conditions to give maximum enhancement for water details.
-- The test site portions are enlarged and printed at a uniform scale. A sequential record of lakes, reservoirs, ponds and river conditions is assembled and comparisons can be made both between bands (multispectral analysis) and between dates (multidate analysis).
-- Color composites are made with a diazo machine.
-- Additional enhancement methods from co-investigators' studies have been utilized whenever available.

3.2 Data Acquisition

In order to perform a more refined analysis of selected parameters, the scope of action was narrowed to several carefully selected test sites where a large variety of conditions were encountered. Three test sites were intensively monitored: Folsom Lake, Discovery Park, and Lake Berryessa. Other areas in the general San Francisco Bay - Delta Test Site were also closely followed on the images.

The transient nature of many water quality parameters required the presence of the sampling crew in the field at the time of the overpass (real-time data).

Measurements made on the ground included:

-- Secchi Disk Transparency is measured at selected points across the water body.
-- Water samples are taken at the same points; Jackson Turbidity Units (JTU) and Total Dissolved Solids (TDS) were measured in the

laboratory. Additional analysis of water samples for other factors which can influence the optical characteristics of the water were included.

-- A photographic record of the water color as well as a general view of the area was taken.
-- Water stages were acquired from responsible water agencies.
-- Low flight oblique images in color and in infrared of the water surface conditions were taken at selected dates.
-- Intermediate-height flight imagery was occasionally acquired.

3.3 Image Analysis Results

3.3.1 Surface Water Evaluation

Evaluation of surface water components of the hydrological cycle over large geographic areas was studied with morphological parameters relating surface area with shape and volume of the water bodies. The applicability of available volume/area curves for artificial reservoirs depends upon the capability to perform accurate planimetric image measurements. Variations in the level of reservoir can easily be followed; they are generally accompanied by peculiar characteristics which are readily observed on the images. Some of those characteristics are:

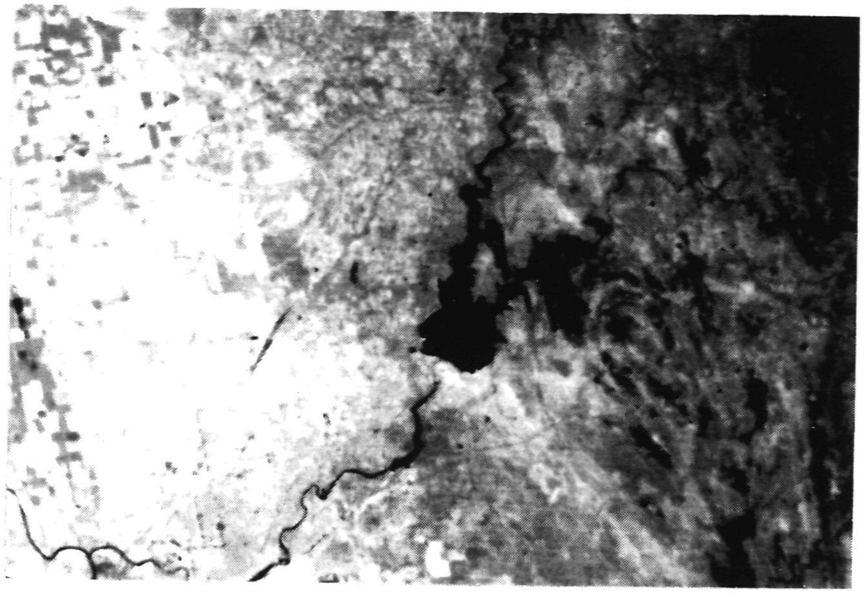
-- change in the shape of the contour line
-- appearance of islands
-- change in the position of the water line in backwater channels
-- appearance of a bright line along the shore (in Bands 5 and 4) denoting a denuded area.

Folsom Lake (See Fig. 2a, b) storage changes were followed. Acquisition of appropriate data would allow use of that test site as a calibration site for studying image surface area/volume relationships.

ERTS-1 imagery gives hydrologists the capability not only to analyze water bodies themselves but also the entire surrounding watersheds to which lakes, reservoirs and river systems are intimately linked. Data for several important watershed parameters can be obtained by image analysis: drainage pattern, land use and changes in land use, vegetation type, moisture distribution, plant water use, change in surface detention storage.

The delineation of drainage networks and the study of their characteristics requires multispectral analysis to extract maximum information from the images. Distinction between the stream and its environment is not always very apparent. Confusion can indeed occur between dry beds of ephemeral streams and roads. Furthermore, the ground resolution of the imagery limits the number of channels or rills of smaller order that can be detected. Enhancement techniques would be valuable for refinement of the analysis. As previously noted, mapping of the drainage network by multispectral analysis is based on:

a



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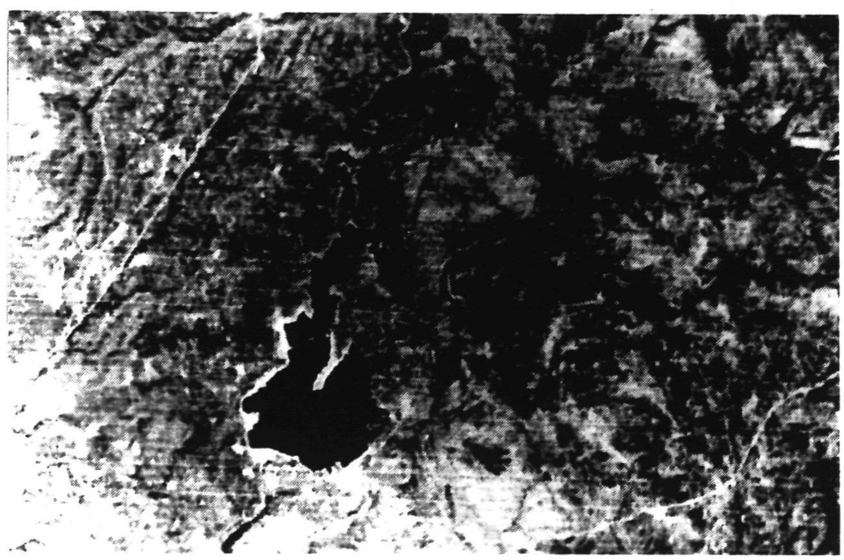


Figure 2. Folsom Lake - a - MSS 6 July 25, 1972
b - MSS 5 October 24, 1972
Summer drawdown can be followed on the images. Notice on Band 6 many ponds around Folsom and the absence of landscape features along the shoreline. Band 5 enhances landscape details around the lake.

1. The tonal contrast between the watercourse and the surrounding lands.

2. The interpretation of some conspicuous features of the stream morphology.

3. Some intuitive feeling for the environment.

The applications of drainage basin patterns and conditions analysis are numerous. The drainage network is a result of specific interaction between precipitation and watershed conditions such as vegetative cover, topography, soil infiltration and geologic parameters. The yield of water from an area can be estimated from the study of its drainage network characteristics. Determination of watershed conditions such as land use and vegetation cover, is actually carried on by other investigative teams of this integrated study.

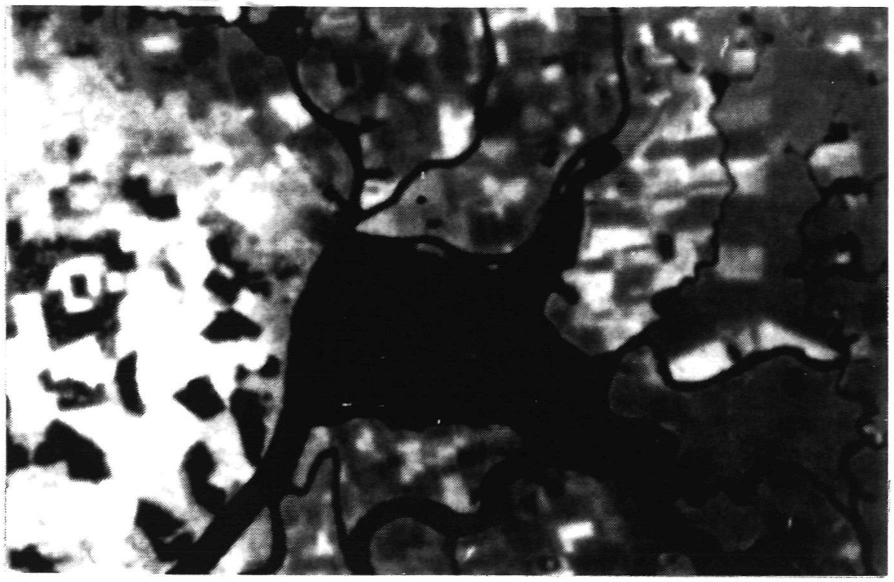
3.3.2 Flood Evaluation

Several problems related to floods in the Delta area have been given some consideration. The first ERTS-1 images above central California were taken after a break in a levee occurred, causing the flooding of Andrus and Brannan Islands in the Sacramento-San Joaquin Delta. The flooded area was a prominent feature readily detectable on any imagery taken over Central California (Fig. 3a, b).

Changes in water stages from one date to another are easily followed (see July 25 and October 24). Band 6 is the most useful in this respect. Different storage depressions have been delineated. By taking each of the depressions as individual basins, a closer evaluation of the area flooded, and depth of the water can be made. The progressive appearance of drainage features on the images (see October 24) helps to understand the process of the flood recession due to dewatering of the islands. Sediment flow out of the area can be followed by observing tone difference in several sloughs draining the area. Image enhancement techniques will provide more insight on the dispersion phenomenon. Band 5 allows better underwater detail recognition and shows greater tonal differences between different qualities of water (principally in terms of sediment concentration).

3.3.3 Water Quality Evaluation

It must be emphasized that research is still needed to calibrate tonal densities of the transparencies with the type and concentration of impurities in the water. Some results have been obtained by other investigators but spectral signatures of complex aquatic systems with sediments, algae, dissolved solids and other pollutants are very difficult to define. Sediment is by far the major pollutant in terms of mass. Millions of tons of soil are transported by water every year. Sediment is also by far the major element influencing the optical properties of the surface water and, therefore, the more readily detectable pollutant a



b

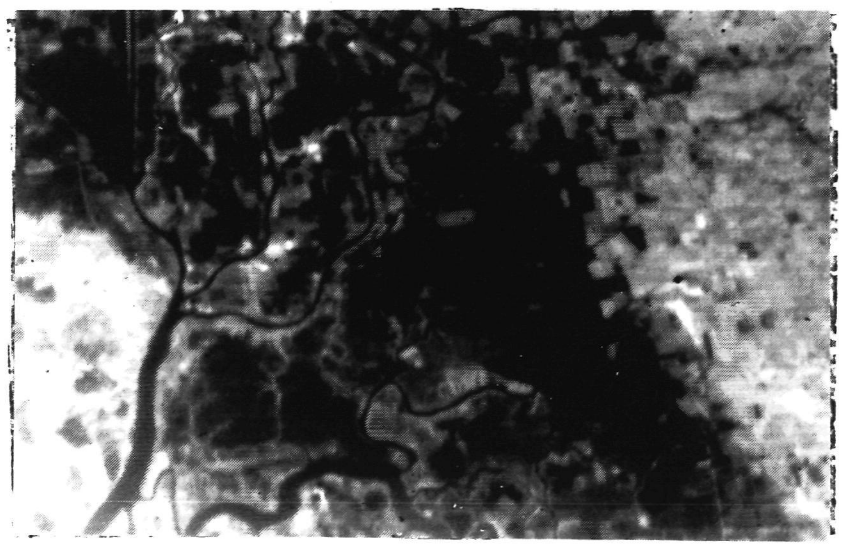


Figure 3. Andrus Island Flood
a. MSS6 July 25, 1972
b. MSS6 October 24, 1972
Notice the recession of the flood and the appearance of underwater features on October 24.

on ERTS-1 images. Due to the highly transient nature of most of the water related parameters, it is essential to reduce the time lag between the overflight and the ground truth data acquisition. A valid correlation between water spectral signature and water characteristics can only be obtained if ground data are "real-time data." That goal was not always achievable due to physical limitations, and the different test sites could not always be visited simultaneously; thus, some discrepancies may occur between the ground data and the information provided by the images.

The following parameters were measured in the field and their values used as ground truth for comparative image analysis:

- -- Secchi Disk transparency: a standard 31 cm. diameter white disk is lowered in the water, and the depth of disappearance is recorded. Values as low as 10 cm. are found in extremely turbid water.
- -- Jackson Turbidity Units (JTU) were measured in laboratory on water samples brought back from the field. Turbidity measurements do not correlate well with Secchi Disk Transparencies, and the comparison with tonal density must be made.
- -- Total Dissolved Solids (TDS) is sometimes measured on selected samples. The influence of dissolved solids on the optical properties of the water has not been ascertained.
- -- The color of the water is recorded on photographic film. A general view of the sampling area is also photographed from the ground.

Lake Berryessa has attracted particular interest because of other studies performed on the site by this research team. Two major objectives are kept in mind when analyzing the images of that site:

1. The dynamics of sediment inflow and dispersion patterns in the body of the lake is studied to assess major changes in Berryessa water quality. The ERTS-1 images have the potential to provide valuable time-sequential information.

2. Runoff and sediment inflow in the lake is intimately associated with watershed use and conditions. Image evaluation of the watershed condition should enable an integrated study of the terrestrial-aquatic system interrelationships.

Early observation (August and October 1972) has revealed the presence of tonal variations across the water surfaces especially in Bands 4 and 5. Early in the season, (August - October) when rainfall on the watershed was still very low, those variations were associated with shallow areas of the lake. The water was still very transparent at that time, (Secchi Disk Transparency 2-3 m) and bottom reflection caused the water to appear lighter in those shallow areas. The comparison between depths of light penetration in the green and in the red wavelength yields valuable information on some optical characteristics of the water.

Figure 4 is a schematic representation of the difference in depth penetration between the two wavelengths. The infrared wavelengths are generally absorbed in the upper layer of the water.

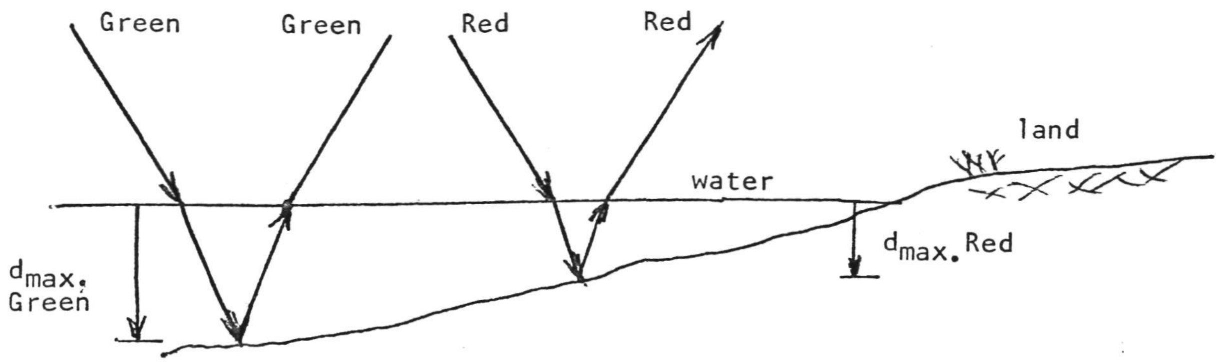


Figure 4. Water Penetration in the Green and Red Wavelengths.

Figure 5 is the image of Lake Berryessa on ERTS-1, MSS5, October 25 showing a slight change in reflection along the upper Northeast shore of the Lake. No other features were apparent across the Lake until October 24, 1972.

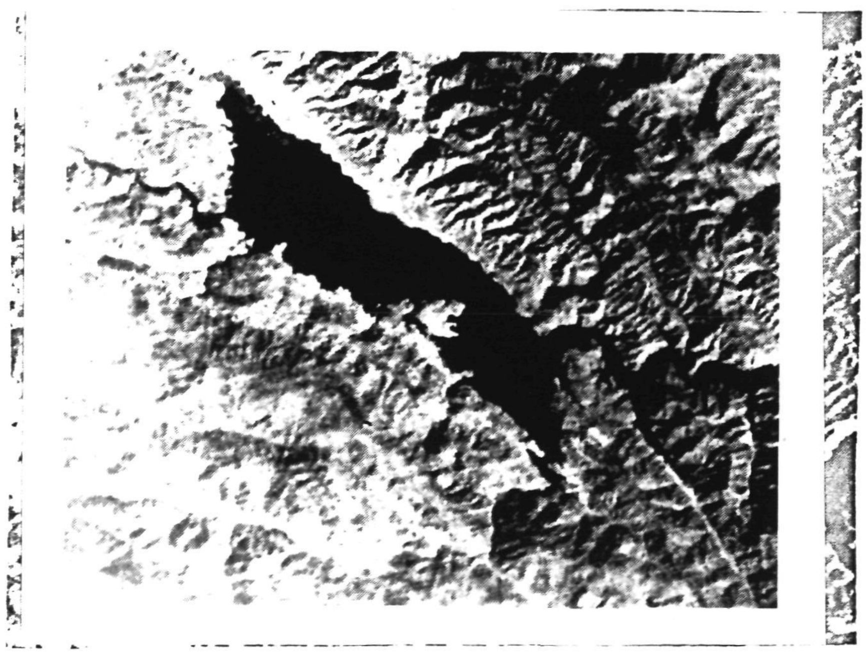


Figure 5. Lake Berryessa - October 25. MSS5
Notice the change of reflection along the upper shore of the lake.

3.3.4 Discovery Park Site

The confluence of Sacramento and American Rivers is a test site exhibiting peculiar features which are interesting to monitor by remote sensing.

During a large part of the year, the Sacramento River draining an extensive agricultural area is generally turbid as compared with the clear American River flowing out of Folsom and Nimbus reservoirs where most of the sediments have been deposited. The two rivers are monitored at Discovery Park (Sacramento). The difference in tone between the two rivers is due to a change in reflectivity caused by the presence of sediments. That difference in tone, very much apparent on the ground, is discernible on ERTS-1 imagery mainly in Band 5 (See Fig. 6) (Band 5 combines best tone differentiation and good ground resolution.). Figure 7 depicts the same confluences noted in Figure 6, where the American River enters the Sacramento River.

Figure 6. This image is an enlargement from MSS band 5 of October 6, 1972, at the river confluence shown in Figure 5. Note the tonal differences (gray) due to turbidity in the Sacramento River.

Figure 7. The junction of the American and Sacramento Rivers at Sacramento, California, on October 6, 1972, shows the characteristic turbidity of the Sacramento River, which receives return flows from irrigated lands upstream.

4 SUMMARY

Summarizing the kinds of water resource-oriented uses of ERTS-1, effective use of the imagery has been demonstrated for defining a variety of subjects and features in this test area including:

-- the presence and location of water bodies
-- the boundaries of watersheds
-- the quantity of water
-- the relative quality of water
-- the sources of water quality constituents.

An evaluation of the imagery for delineating the water features of interest and determining conditions in lakes, reservoirs, streams and watersheds has been summarized in Table 1. The analysis of some of the parameters presented in the table are not within the scope of this investigation but some significant results obtained by other investigators have been summarized and are used in the analysis.

As can be noted in Table 1, the Band 6 (infrared) is the best for delineating water features, and Bands 4 and 5 for determining conditions of the water itself. Band 5 combines the best ground resolution and detection of in-water details. The color composites are very useful for delineating streams, lakes and ponds, but are best used to evaluate the general characteristics of the watersheds such as land use, vegetation types, moisture, distribution, etc.

Significant points derived from the studies may be listed thusly:

1. The synoptic coverage of the earth provided by ERTS-1 is ideal for regional water resources planning and operations.

2. ERTS-1 imagery lends itself directly to water resource and hydrologic interpretations.

3. The spectral ranges (bands) provided by ERTS-1 are directly useful for both qualitative and quantitative evaluation of water-related parameters.

4. The sequential coverage of ERTS-1 provides the capability to assess and quantify seasonal changes, specific responses and changes on watersheds and in both large and relatively small water system components.

5. The potential applications and the data quantification capabilities of ERTS-1 image analysis are extremely broad-scoped. Enhancement techniques becoming available will make the imagery adaptable for many additional uses.

6. In combination with intermediate elevation platforms, including the high flights by U-2 aircraft, ERTS-1 should be continued in operation to provide a valuable source of data for hydrologic and water resource applications.

TABLE 1

EVALUATION OF ERTS-1 - MSS 4, 5, 6 FOR WATER RESOURCES ANALYSIS

Test Sites	MSS 4	MSS 5	MSS 6, 7	Color composite 4, 5, 6 or 7
Folsom Reservoir	Fair delineation. Poor detection of changes in level and associated features.	Very good delineation. Very good detection of changes in water level and associated features.	Very good delineation. Good detection of changes in level and associated features.	Very good delineation. Good detection of changes in level.
Clear Lake	Poor delineation. Good detection of changes in reflection due to algae and/or sediments	Good delineation. Very good detection of changes in reflection due to algae and/or sediments.	Very good delineation. Poor detection of changes in reflectivity.	Very good delineation. Poor detection of changes in reflectivity.
Lake Berryessa	Poor delineation. Very good detection of shallow area and sediment plumes. Good water penetration.	Very good delineation. Very good detection of shallow areas and sediment plumes. Less water penetration.	Very good delineation. No detection of changes in reflectivity. Uniform tone. No water penetration.	Very good delineation. No detection of changes in reflectivity.
Putah Creek Watershed	Poor drainage network delineation. No detection of ponds and streams. Poor to fair land use analysis.	Good drainage network delineation. Fair detection of ponds and streams. Fair contrast between land uses, vegetation types.	Good drainage network analysis. Very good detection of ponds. Fair land use analysis, vegetation types.	Fair to good drainage network delineation. Very good detection of ponds and streams; moisture distribution. Good distinction between vegetation types, land uses.
Discovery Park	Poor delineation. Good contrast between two rivers.	Good delineation. Good contrast between two rivers.	Very good delineation. No contrast between two rivers.	Very good delineation. No contrast between two rivers.

Evaluation of ERTS-1 - MSS 4, 5, 6 for Water Resources Analysis (continued)

Test Sites	MSS 4	MSS 5	MSS 6, 7	Color composite 4, 5, 6 or 7
Andrus Island	Poor delineation. Best for detecting changes in water depth, quality.	Good delineation. Good for detecting changes in water depth, quality and appearance of drainage features with dewatering.	Very good delineation. Fair to good for detecting changes in reflectivity.	Very good delineation. Fair to good detection of changes in reflectivity.
Davis Municipal Sewage Ponds	Not detectable.	Good delineation; shows tone variations.	Good delineation; shows tone variation.	Very good delineation. No tone variations.

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

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ID

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PRINCIPAL INVESTIGATOR R.N. Colwell/R.H. Burgy

GSFC UN 643

ORGANIZATION University of California

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS	
	Delta	Sediments	Flood	Lakes	Drainage
100218131M				X	X
100318175M		X	X	X	
102118165M	X	X	X	X	
102118172M	X	X	X	X	
105718170M	X	X	X	X	
105718172M	X	X	X	X	
107518170M	X	X	X	X	
107518173M	X	X	X	X	
109318173M	X	X	X	X	
109418231M		X		X	X
112918174M		X		X	X
113018233M		X		X	

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