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WATER-MANAGEMENT MODELS IN FLORIDA FROM ERTS-1 DATA

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16. Abstract

A prototype data acquisition and dissemination network, installed and operated by the U.S. Geological Survey, is a viable approach for providing the near real-time data needed to solve hydrologic problems confronting the nearly 2.5 million residents of southern Florida. Water-stage and rainfall data from ground stations are transmitted from the Everglades via ERTS, the NASA tracking stations, and the U.S. Geological Survey to the users in less than 2 hr, a significant improvement over conventional techniques requiring up to 2 months. ERTS imagery significantly enhances the utility of the ground station measurements. Water stage (depth) is correlated with water-surface areas from the imagery to obtain water stage-volume relations in near real-time for management decisions concerning the distribution of water to the people, fauna, and flora of southern Florida.

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PREFACE

The objective was to evaluate the usefulness of ERTS-1 in improving the overall effectiveness of collecting and disseminating hydrologic data. To achieve this objective, the U.S. Geological Survey utilized ERTS MSS imagery and in situ monitoring by DCS to evaluate their separate and combined capabilities in the Hydrologic Data Network.

Twenty data collection platforms were established in southern Florida. Water level and rainfall measurements were collected and the data were disseminated to users in less than 2 hr, a significant improvement over conventional techniques requiring up to 2 months. The improved network performance is having a significant and beneficial impact on the development of water budgets and the water distribution to the people, fauna, and flora of southern Florida.

ERTS imagery was found to significantly enhance the utility of ground measurements. Water stage is correlated with water surface areas from imagery in order to obtain water stage-volume relations. As an adjunct to the point sampling, the imagery provides an economical basis for extrapolating water parameters from the point samples to unsampled data and provides a synoptic view of water mass boundaries that no amount of ground sampling or monitoring can provide. Additional hardware and software developments are needed, however, to fully achieve the benefits available in the combined use of DCS and MSS data.

A glossary of terms used in this report can be found in Section 4.

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1. BACKGROUND

The water supply for southeastern Florida, with a population of over 2.5 million and the Everglades National Park, depends on the management of water within the Everglades basin (Figure 1-1). Decisions affecting the control of this supply are based on water budgets developed from hydrologic data acquired and disseminated by the Water Resources Division of the US Geological Survey as part of the Hydrologic Investigation and Network Program.

The goal of this investigation is to evaluate the usefulness of ERTS-1 in improving the overall effectiveness of this collection and dissemination network. Resulting network improvements in data timeliness and accuracy would have a direct beneficial impact on the water distribution to the people, fauna, and flora of southern Florida. To accomplish this goal, the US Geological Survey used imagery from the ERTS Multispectral Scanner (MSS) and Data Collection System (DCS) to evaluate their utility in supporting near real-time acquisition and dissemination of hydrologic information. This paper reports on the work accomplished and results achieved in establishing and operating this prototype network.

1.1 MANAGING THE WATER SYSTEM

The storage and flow of water in southeast Florida is controlled by the Central and Southern Florida Flood Control District, which maintains and operates a system of levees, canals, control structures, pumping stations, and water storage areas. The control of this system (Ref 1)* is based on water budgets developed from hydrologic data collected and disseminated by the US Geological Survey.

The levees in southern Florida retain water in four major impoundment areas (Figure 1-2); (1) Lake Okeechobee, (2) Conservation Area 1, (3) Conservation Area 2, and (4) Conservation Area 3. Shark River Slough (Figure 1-2), an important source of water for Everglades National Park, at the downstream end of these interconnected water bodies, also depends on overland flow from adjoining Conservation Area 3.

The four major impoundment areas prevent sheet flow from the Everglades and Lake Okeechobee through agricultural and urban areas during the rainy season, June through October. Pumping stations at the edges of the three conservation areas provide flood protection by pumping excess rainfall from the Everglades agricultural area and other flood-prone areas into Lake Okeechobee and the three conservation areas. Thus, the system

* References can be found in Section 5.

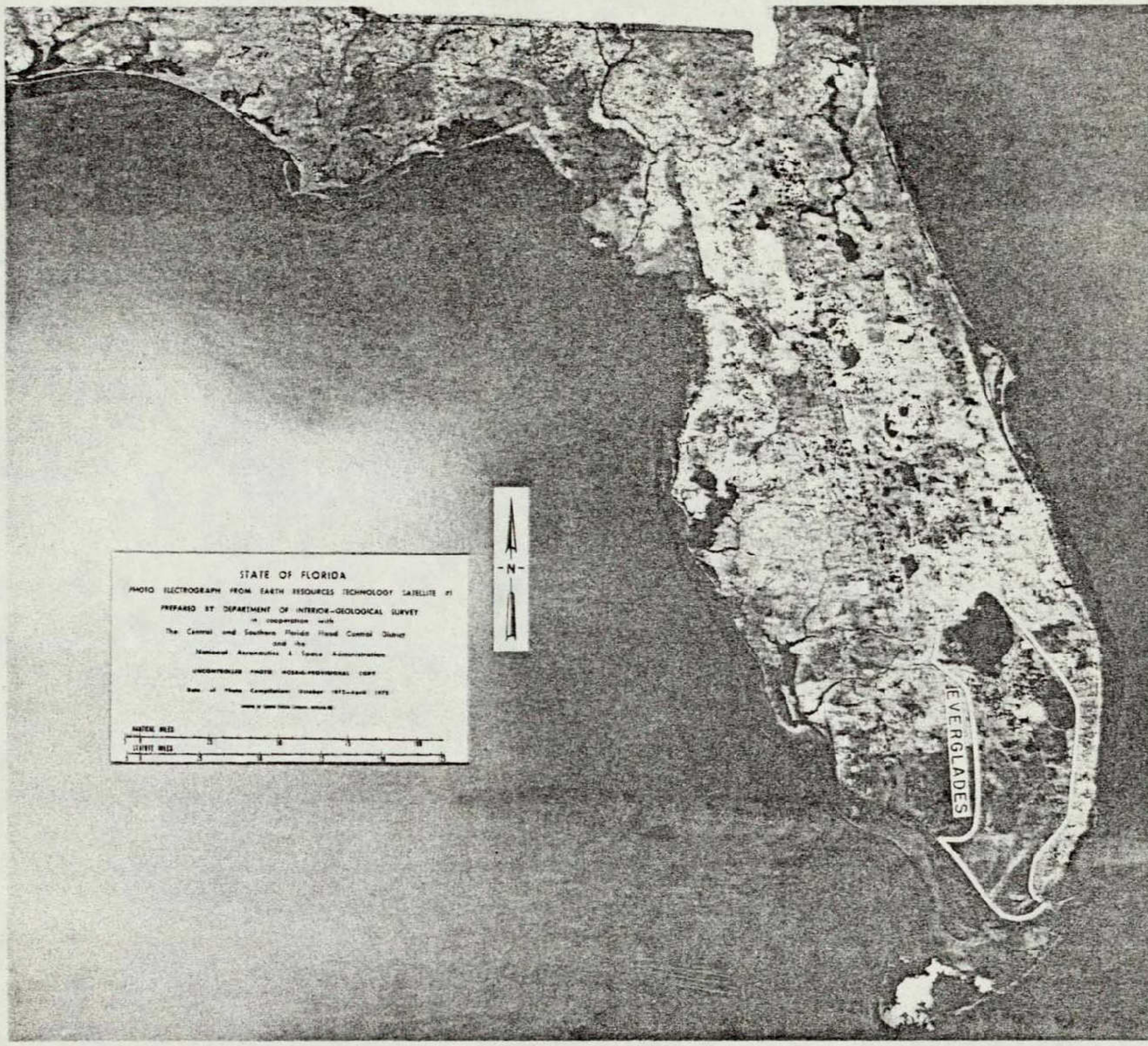

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Figure 1-1. Photo Mosaic of Florida, Compiled from 16 ERTS-1 Images between October 1972-April 1973 of Band 7 of the Multi-spectral Scanner. The Delineated Area is the Everglades Water Basin.

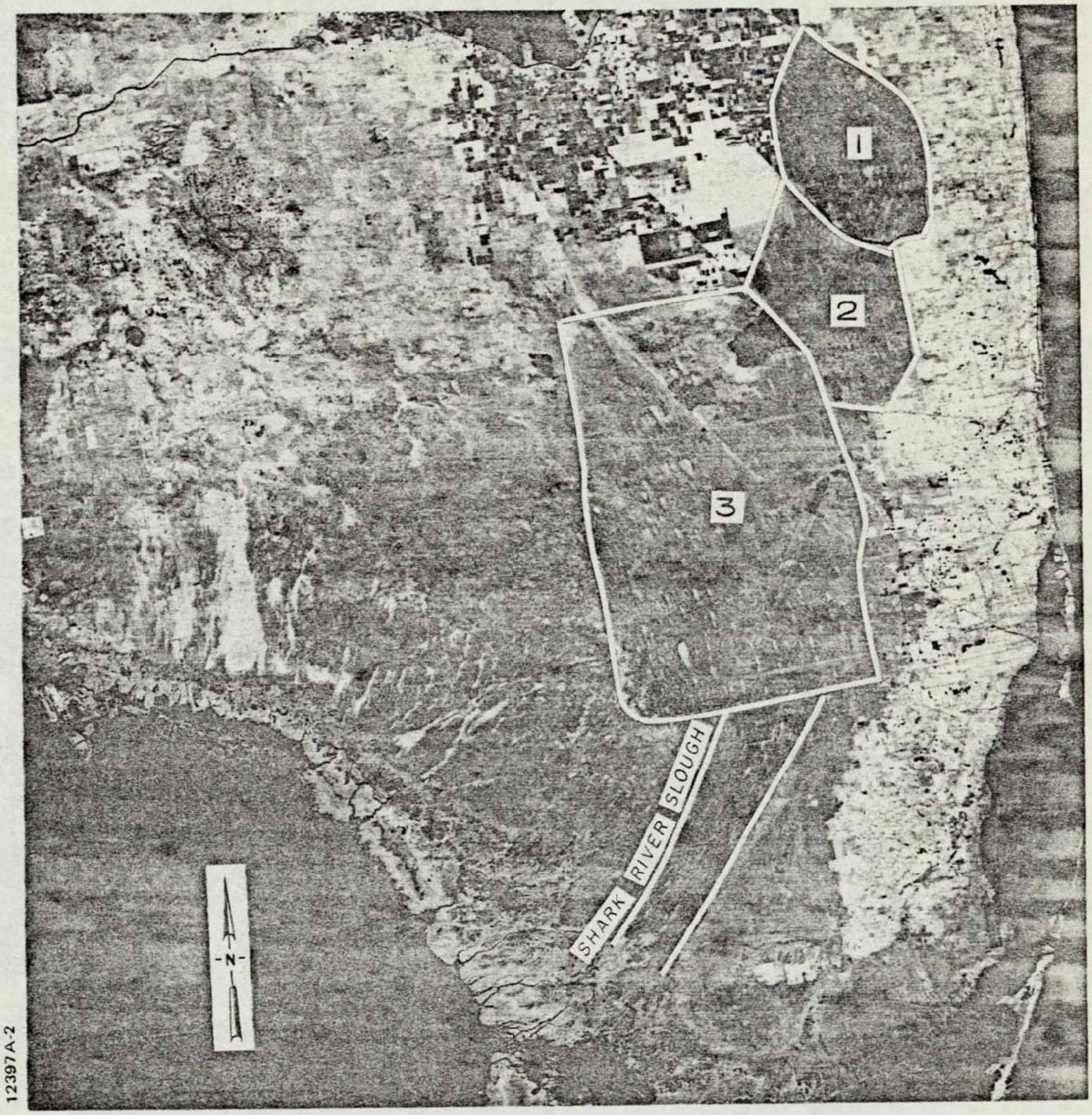

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Figure 1-2. An ERTS-1 Multispectral Image, Band 7, March 22, 1973, NASA, E-1242-15240, of South Florida. The Areas Outlined Are: Conservation Areas 1, 2, and 3 and Shark River Slough and Lake Okeechobee (Southern End Can Be Seen in Photo).

not only protects against flooding, but also conserves water. Water is transferred from the conservation areas into Everglades National Park or to coastal cities as needed.

Canals drain the urbanized strip along the coast. They also transfer water from Lake Okeechobee and the conservation areas to the Everglades agricultural area and to the east coast to replenish ground-water reservoirs near municipal well fields and to prevent sea-water intrusion. Flow in the canals is regulated by coastal control structures which are normally open or partly open during the rainy season. The structures are generally closed during dry seasons to prevent the inland movement of salt water.

Scheduled releases from one of the conservation areas are made during the year to sustain plants and animals in Everglades National Park. Late in the dry season, water is also released from the conservation areas to the canals, as required, to maintain water levels near the coast and to sustain well fields. During much of the dry season, eastward flow in canals is maintained by water seeping under the levees of the water conservation areas. However, water in the canals is not discharged to the ocean; rather it recharges the Biscayne aquifer along the coast. During prolonged drought, some water can be transferred directly from Lake Okeechobee through the conservation areas to points of need along the coast. Usable storage in the lake is usually shared by municipalities, agricultural interests, and Everglades National Park.

1.2 WATER BUDGET

Management decisions as to where and when to store and release water in this Everglades basin are based on an accounting of the amount of water in surface storage. This accounting procedure (Refs 2 and 3) relates basin water inputs and outputs as modeled in Figure 1-3 and results in a water budget for the basin.

Monthly water budgets for Lake Okeechobee and the three Everglade conservation areas are computed by the Central and Southern Florida Flood Control District and the Corps of Engineers and are disseminated to the public by the district. Two budgets are prepared; one for a condition of normal rainfall for the remainder of the dry season and the other for a condition of last year's rainfall for the same period.

The budget inputs (Figure 1-3) includes surface flow into the basin (inflow) and rainfall on the basin. The outputs are the combined losses; evaporation, evapotranspiration (water released to the atmosphere as part of the life process of vegetation), surface water seepage into the ground water, and the beneficial outflow for irrigation and municipal supply.

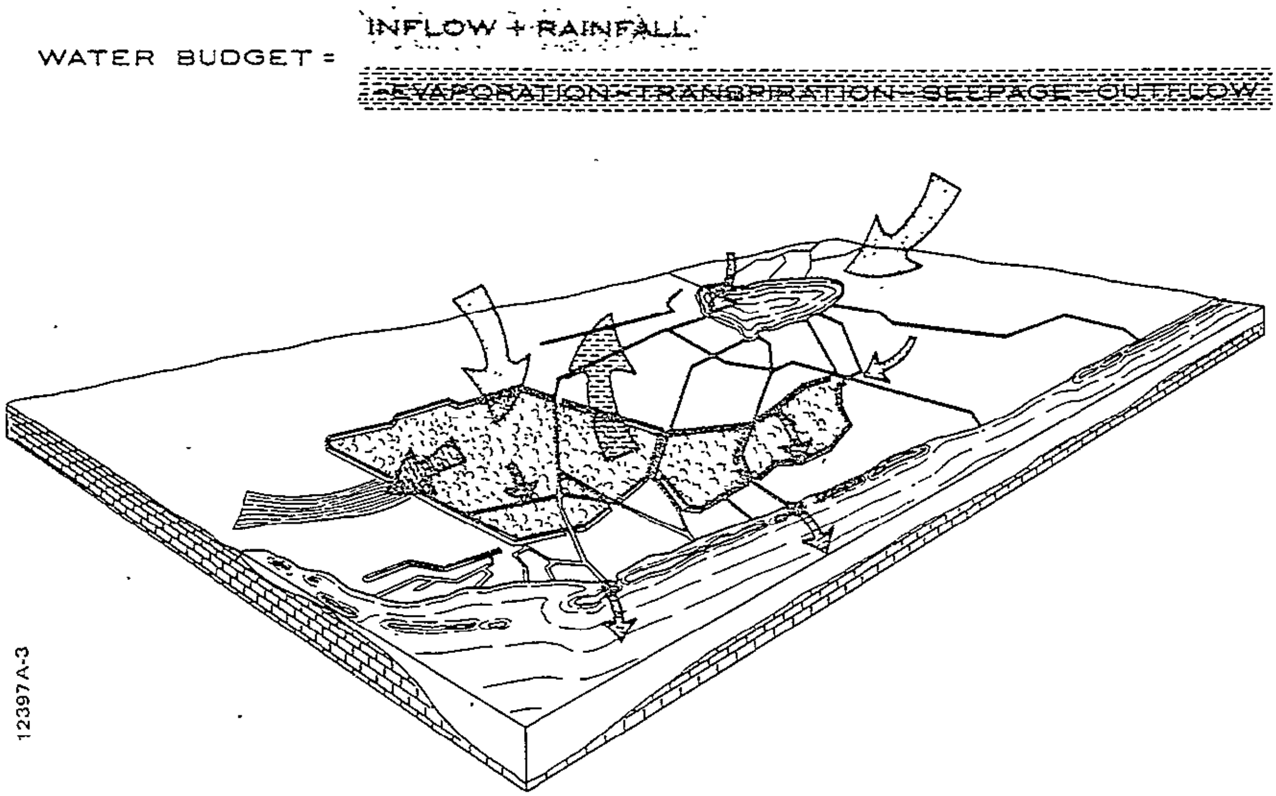

Figure 1-3. Schematic Diagram of a Water Budget for the Everglades Water Basin

Subtracting output from input, as shown in the model of Figure 1-3, gives a surplus (gain) or a deficiency (loss) in the water storage for a specified storage area and time period.

Several water budget studies for the conservation areas by Federal (US Corps of Engineers) and State water-management agencies (Central and Southern Florida Flood Control District) are underway.

The major problem in developing a good water budget is to establish the input and output quantities. A good budget analysis requires large amounts of accurate and timely hydrologic data. It is this data need which the Hydrologic Data Network strives to satisfy.

1.3 HYDROLOGIC DATA NETWORK

Hydrologic data used in developing water budgets are collected and disseminated (Ref 4) in southern Florida by the Water Resources Division of the US Geological Survey, as part of the nationwide Hydrologic Data Network. The network is operated by the survey in cooperation with local, state, and other Federal agencies and gathers data on a wide variety of environmental phenomena. In the Everglades basin alone, more than 100 gaging stations provide daily records of gage height (water surface height) or discharge. Overall, the Geological Survey has nearly 18,000 such stream-gaging stations, of which approximately 10,000 have digital water stage recorders. These small field instruments continuously monitor stream stage via linkage to a float in a stream-connected stilling well. Periodically, at 15, 30, or 60-minute intervals, the recorder punches the real-time stage value on a 16-channel paper tape, a machine-readable record.

Prior to ERTS, data from a particular field instrument would be retrieved by field engineers and technicians who visit the station about once a month, calibrate the instrument, perhaps take supplementary measurements and samples, and conduct general maintenance. The data, many of which are in machine-readable form, are returned to the office, checked for quality control, transferred onto punch cards or magnetic tape for entry into the computer system, analyzed, plotted, and disseminated to users. Time from data collection to dissemination to users is about two months after initial recording. These long delay periods reduce the utility of the data for water budgets and, consequently, management decisions affecting the storage and flow of water. The time required to develop water budgets is becoming increasingly important in Florida, as in other areas of the nation, where water managers are attempting to satisfy the water demands of an ever-increasing population while still retaining sufficient water in the system to meet the needs of the aquatic environments and upgrade and maintain the water quality in the water storage areas, canals, and aquifers.

The US Geological Survey, in addition to disseminating hydrologic data to users in southern Florida, also stores the data in the National Water Data Storage and Retrieval System (Ref 5) in Washington, D.C. and Reston, Virginia. From this system the data are made available nation-wide. US Geological Survey offices, such as the Miami office, are interlinked with the National Water Data Storage and Retrieval System by means of a national telecomputing system which provides general data processing support for the National Water Data Storage and Retrieval System. The national telecomputing network consists of the computer centers in Washington, D.C. and Reston, Virginia, and nearly 100 remote computer terminals in survey offices across the country, one of which is in the Miami office of the survey. The Washington, D.C. computer center has an IBM 360/65 computer and the National Center at Reston, Virginia has an IBM 370/155 computer.

Thus, the major hydrologic activity of the Geological Survey; the collection, storage, retrieval, and analyzing of hydrologic data; is accomplished through the operation of three basic systems; the Hydrologic Data

Network, which provides data collection; the National Water Data Storage and Retrieval System, which processes and stores data generated by the Hydrologic Data Network; and a national telecomputing system, which provides general data processing support for the National Water Data Storage and Retrieval System.

2. RESULTS AND DISCUSSION

To achieve the goals of the investigation, the US Geological Survey analyzed ERTS MSS imagery and in situ monitoring by DCS in order to evaluate their separate and combined capabilities in the Hydrologic Data Network. Paulson (Refs 5 and 6), Schumann (Ref 7), and Cooper (Ref 8) applied similar techniques to operational systems with a DCS capability and Graybell (Ref 9) and Deutsch (Ref 10) used MSS to determine surface-water distribution. Anderson (Ref 11) used the MSS imagery to identify and map vegetative communities within wetlands. Reeves (Ref 12) used successive passes of ERTS imagery of playa lakes in the Texas High Plains to demonstrate the dynamics of surface-water distribution within the lakes. However, this investigation combines an operational ERTS data collection system with the multispectral scanner data.

Twenty data collection platforms (DCP's) were established in southern Florida. Water level and rainfall measurements, collected and disseminated in near real-time (less than 2 hrs) from these instruments were also analyzed in conjunction with ERTS imagery enhanced by electronic processing. Results reported in this section show that the combined use of MSS and DCS data provides more benefits than the use of either technique alone.

2.1 DATA COLLECTION SYSTEM

The ERTS Data Collection System (DCS) is a communications system (Ref 13) that consists of three elements; a small low-powered battery-operated radio transmitter called a data collection platform (DCP), a radio transponder aboard the ERTS satellite, and ground-receive sites. The polar-orbiting ERTS makes about 14 orbits of the earth daily and can relay data from a DCP to a ground-receive site whenever both are mutually visible from ERTS, which occurs during a brief period on each of several of the orbits. The DCP transmits a brief data message of 0.04 sec duration once every 90 or 180 sec and can communicate with the satellite during several mutual visibility periods daily. The number of mutual visibility periods is primarily a function of geographical position and local terrain interference. Two ground-receive sites; at the Goddard Space Flight Center in Greenbelt, Maryland and at Goldstone, California; provide good coverage for the contiguous 48 states. They allow data from continental American DCP's to be relayed on three to seven daily orbits during mutual visibility periods lasting 12 to 14 min per orbit.

2.1.1 Data Collection Platform

Twenty DCP's were established in the Everglades basin (Figures 2-1, 2-2, 2-3, and 2-4) and Big Cypress Swamp to measure water level and rainfall. The flow of data from the basin to the US Geological Survey office in Miami starts with the water level and rainfall gages at the DCP.

Housed at the DCP shown in Figure 2-3 are the DCP (Ref 14), water-stage recorder, rainfall recorder, and timer and power supply for both recorders.

Before transmitting the data to the satellite, the DCP receives the data from a sensor (recorder) and then encodes and puts the data into a form transmittable by radio signals. Although the DCP normally transmits a signal every 3 min, the DCP can be set to transmit every 90 sec. When the ERTS-1 satellite (Figure 2-5) is in mutual line of sight of a DCP and a NASA receiving station, data are transmitted from the DCP to the satellite and back to NASA receiving stations at Goddard in Greenbelt, Maryland or in Goldstone, California. In southern Florida, this mutual communication occurs from three to six times per day and, each time, one to four distinct messages can be transmitted if the DCP is transmitting every 3 min.

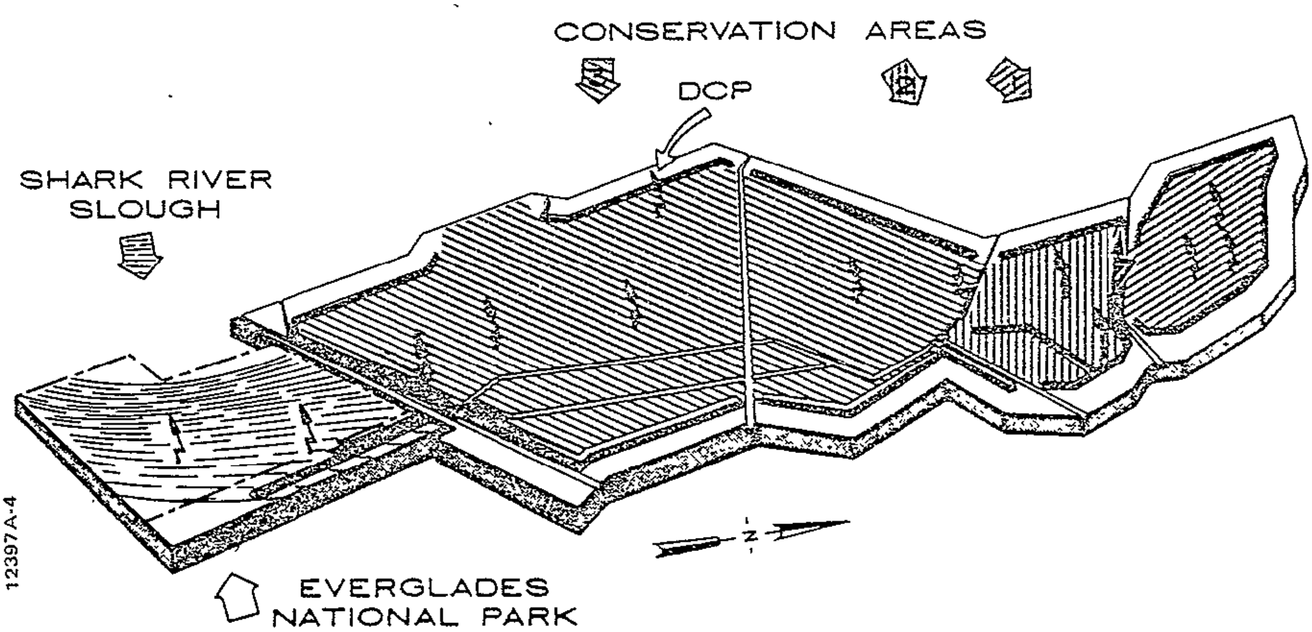

Figure 2-1. Schematic Diagram of the Everglades Basin, Showing Relative Locations of the Data Collection Platforms within the Three Conservation Areas and the Shark River Slough.

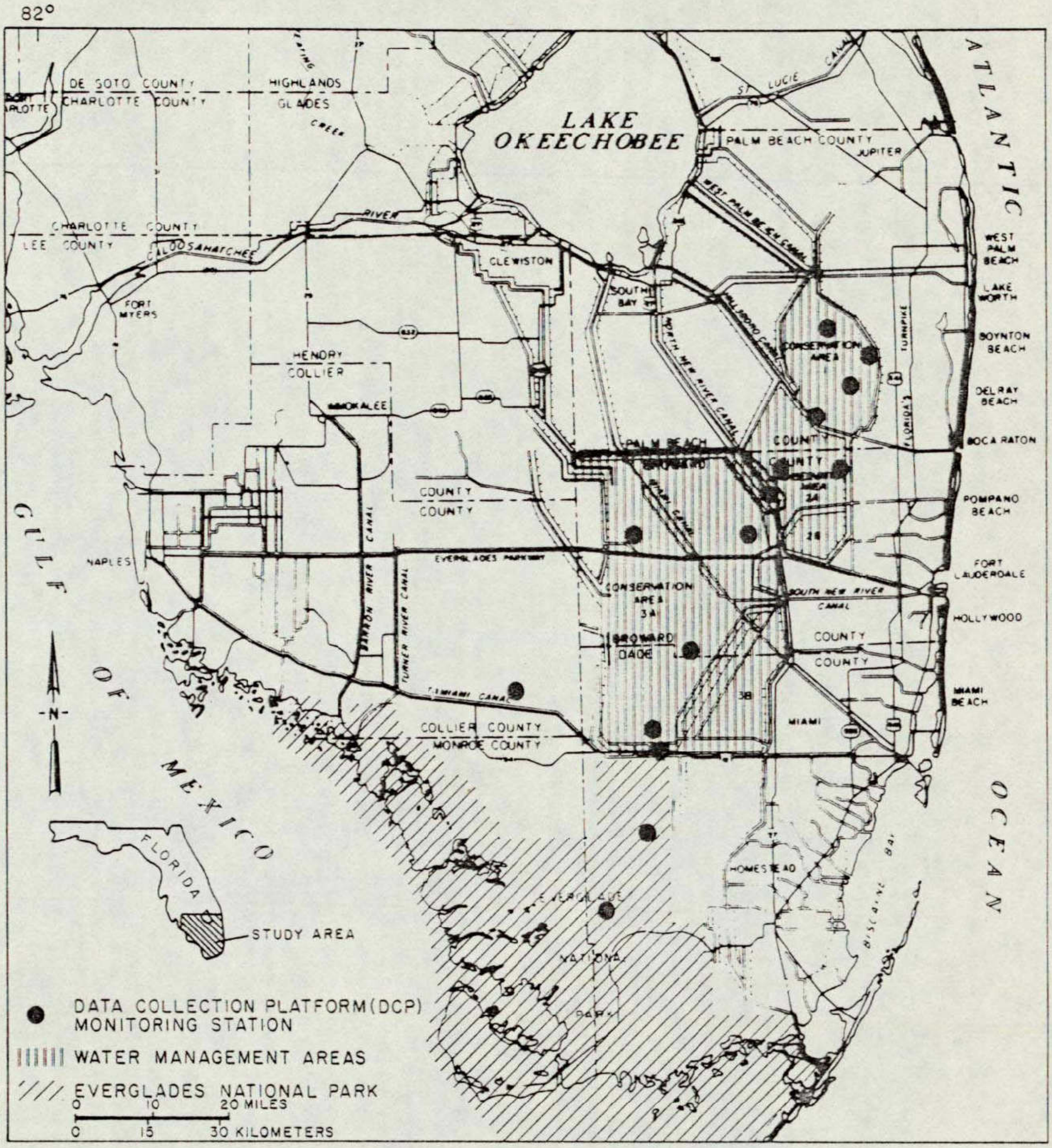

Figure 2-2. Locations of Conservation Areas and DCP Monitoring Stations.

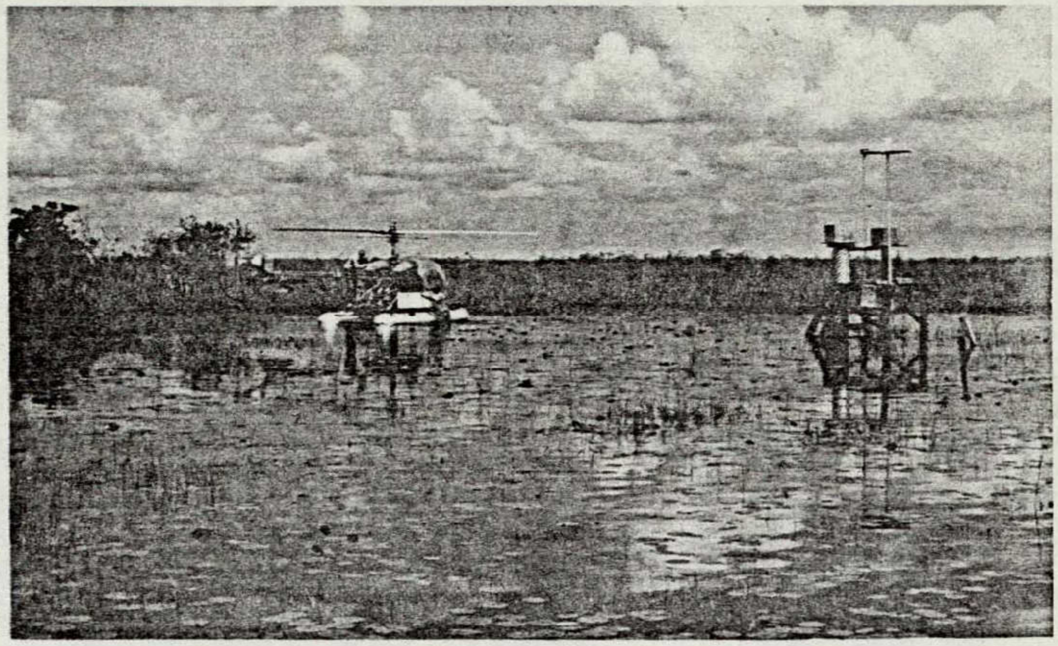

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Figure 2-3. Data Collection Platform in Conservation Area 1. These Stations Collect and Transmit Water Level and Rainfall Data for Relay by ERTS-1.

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Figure 2-4. Ground Truth Team Collecting Data Such as Plant Community Identification and Soil Characteristics in Conservation Area 1.

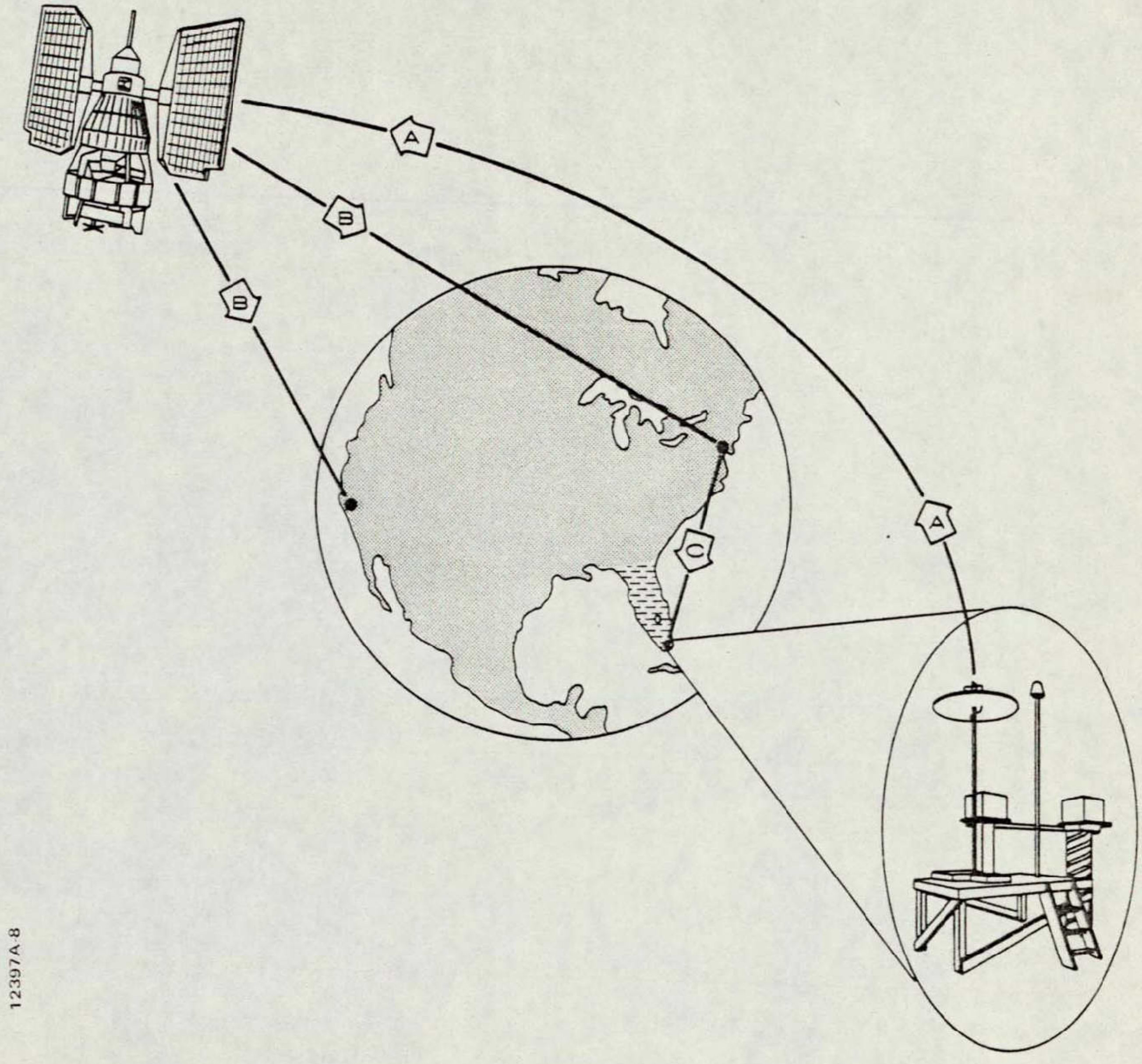

Figure 2-5. Data Are Transmitted from the Data Collection Platforms in the Everglades (A) via ERTS-1 to NASA Tracking Stations at Goldstone, Calif., and GSFC, Greenbelt, Md. (B). The Data Are Then Transferred, via NASA Communications Network, to the Miami Office of USGS (C).

At the receiving station, the data are decoded and sent by NASA communication line to the Operations Control Center and then to the NASA Data Processing Facility at the Goddard Space Flight Center. At the processing facility, the data are verified and put in a form to be teletyped to Miami. The data are received by teletype as perforated tape and printout. The total elapsed time from field measurement to printout in the Miami office is about 45 min.

From the teletype, the data are fed into a programmable calculator, which analyzes the data and produces the finished product, which is telecopied to the water management agencies on the same day.

On an average day, data are received in Miami from two to three times each morning and from two to three times each night. At future stations where parameters such as wind-speed are to be monitored, data will be required more frequently.

2.1.2 Handling of DCS Data

Presently, at the US Geological Survey office in Miami, data are converted from the form in which it is received to more usable forms by a programmable calculator and then stored on cassette tape. Plans are to use a central computer later to store the data where more storage space is available. However, the data will continue to be reduced by programmable calculators locally because of the time factor.

After data are received in Miami by teletype, the perforated tape from the teletype is fed into the calculator through a tape reader. Equipment available in the Miami office include the programmable calculator, thermal printer, paper tape reader, x-y plotter, hopper card reader, cassette memory recorder, extended memory, and acoustic coupler. The cassette memory recorder allows data and programs to be stored outside the programmable calculator. The extended memory is an attachment to the calculator which gives the calculator more capacity for memory storage. The acoustic coupler enables the calculator to be tied to computer by phone. The calculator first translates the teletype data from its octal form into engineering units. At present, these units represent stage in feet or cumulative rainfall readings in feet. Second, the calculator sorts the data chronologically by station. Then it calculates daily rainfall in inches and prints the data in a format requested by the Corps of Engineers (Table 2-1). The data are then scanned for errors. If the data are correct, they are telecopied to the Corps of Engineers in Jacksonville and Clewiston, Florida. The time required for the transmission of data from the Everglades via the satellite, the NASA tracking stations, and the US Geological Survey to the Corps of Engineers is

Table 2-1

Typical Water Level and Rainfall Report Which Is Telecopied to Data Users

USGS MIAMI FLA
DATA FROM ERTS SATELLITE
WATER SURFACE ELEVATION FT MSL

DATE	32	33	34	35	36	37	38
DAY	FRI	SAT	SUN	MON	TUE	WED	THUR
TIME	2343	2348	2354	2359	2221	2227	2355
128	16.62	16.61	16.61	16.59	16.56	16.53	16.52
141	16.48	16.47	16.49	16.46	16.44	16.43	16.42
142	16.44	16.42	16.42	16.41	16.39	16.37	16.35
111	12.36	12.34	12.33	12.30	12.27	12.26	12.23
112	12.10	12.07	12.05	12.02	12.00	11.98	11.97
62	9.42	9.38	9.38	9.36	9.31	9.26	9.21
63	8.67	8.64	8.64	8.61	8.58	8.56	8.54
64	8.47	8.46	8.46	8.44	8.43	8.42	8.41
65	8.41	8.40	8.39	8.38	8.37	8.36	8.35
5	5.67	5.66	5.65	5.64	5.62	5.62	5.61
15	2.77	2.76	2.75	2.74	2.73	2.72	2.71
105	6.71	6.67	6.65	6.61	6.57	6.54	6.50

RAINFALL IN INCHES

128	0.00	0.00	0.00	0.00	0.00	0.00	0.00
141	0.00	0.00	0.25	0.00	0.00	0.00	0.00
142	0.00	0.00	0.00	0.06	0.00	0.00	0.00
111	0.00	0.00	0.19	0.00	0.00	0.00	0.00
112	0.00	0.00	0.06	0.00	0.00	0.00	0.00
62	0.00	0.00	0.06	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NOTE: READINGS WILL BE REVISED AS LATER DATA ARE RECEIVED

* STATION UNDER REPAIR

less than 2 hr, a significant improvement over prior techniques requiring up to 2 months. The National Park Service and the Florida Fish and Wildlife Office receive a full table of data each Friday. The Central and Southern Florida Flood Control District receives its data from the Corps of Engineers in Jacksonville.

After the data have been calculated, sorted, and sent to the users in the form shown in Table 2-1, the data are stored on cassette tape. The data are condensed by eliminating all but daily readings and are stored in annual data files. After the data are loaded into the annual files, data from stations designated as key stations are fed into the plotter, which is on line to the programmable calculator. Figure 2-6 shows hydrographs compiled from data relayed from three DCP's in Conservation Area 1. Hydrographs are usually updated each month and mailed to the users. ERTS programs presently used on the calculator in Miami are:

- Reads teletype tape and converts to gage heights or dial readings.
- Prints out weekly summary table of stage and rainfall.
- Stores midnight readings of stage and rainfall for each day.
- Prints daily calendar year plot.
- Prints daily water year plot of stage.

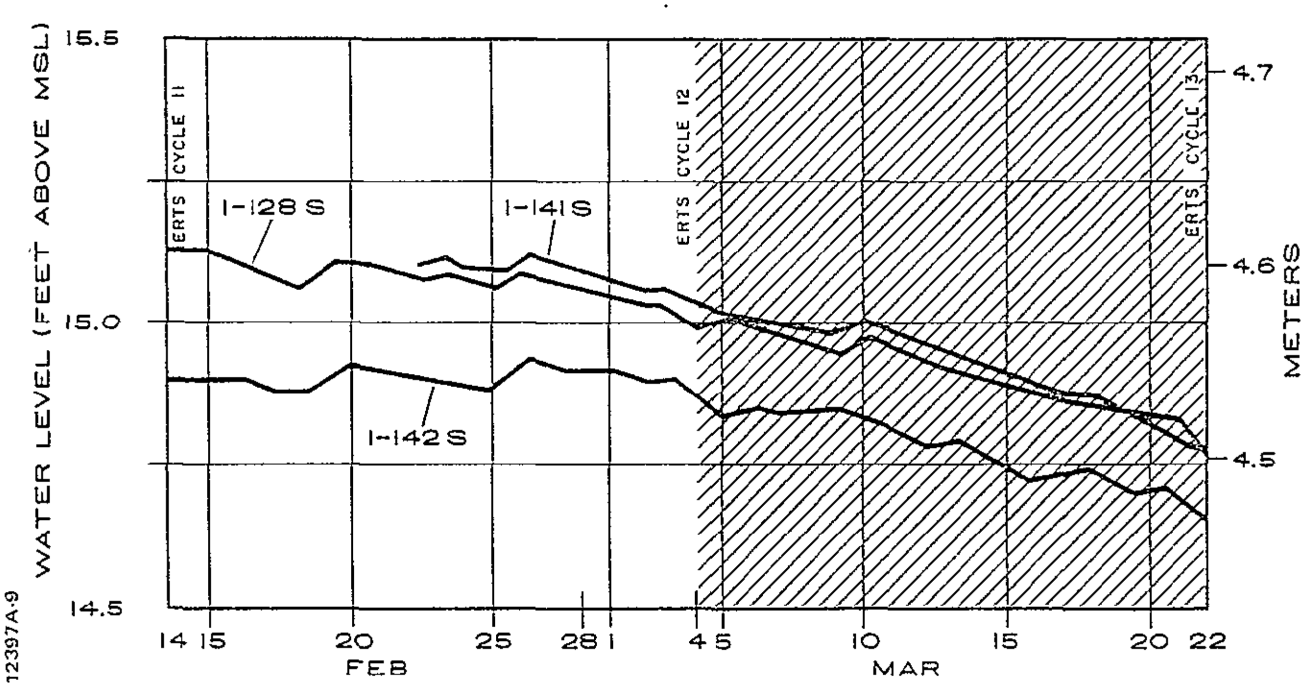

Figure 2-6. Hydrographs Compiled from Three DCPs in Conservation Area 1, February 14 - March 22, 1973. During this Period, there were Three Passes of ERTS-1 to Collect MSS Data of Area 1.

To analyze water-quality and additional meteorological data collected from ERTS-DCS stations now being installed, additional programs for the programmable calculator are being written for the ERTS Program.

2.2 ERTS MULTISPECTRAL SCANNER

ERTS imagery and DCS data acquired on Conservation Area 1 show a complementary application for these data.

2.2.1 Conservation Area 1

Conservation Area 1 covers 221 square miles and is contained within the Loxahatchee National Wildlife Refuge. As seen in the NASA image of Figure 2-7, the area is pear-shaped and bounded by levees on all sides. Just inside the levees are ditches or canals formed by the removal of spoil for the levees. The ditches or canals expedite the movement of water into or out of the refuge whenever rainfall varies.

The vegetation of this area (Ref 15) is shown in Figure 2-8.

This portion of the Everglades (Ref 16) consists of prairie-like flats that are covered with shallow water during most of the year. Stands of sawgrass intersperse the flats. Shallow ponds and sloughs support white waterlilies and other aquatic plants that bloom throughout the year. The landscape is dotted with tree islands that vary in size from a fraction of an acre to several hundred acres. Wax myrtle, redbay, dahoon holly, and ferns on the islands retain their foliage throughout the year. A beautiful cypress "head" in natural condition stands near refuge headquarters. Various air plants grow in profusion within its confines.

Fall and winter migrations result in spectacular bird concentrations. Flocks of herons, egrets, and ibises, often numbering in the thousands, congregate where receding water strands myriads of small fish and crayfish. The tree islands in winter are frequently alive with small birds, including several species that otherwise winter south of the United States. Among the more interesting resident species are limpkin, sandhill crane, wood duck, and mottled duck. Blue-winged teal and ring-necked ducks are the most abundant ducks during winter. Coots are year-round residents, but are abundant only in winter. The cattle egret, an emigrant from the Old World, is now common on the refuge and adjacent pasture lands.

Bobwhites are abundant along the levees. Turkeys have declined in recent years, and now are seldom observed. Otters, whitetail deer, bobcats, raccoons, opossums, marsh rabbits, alligators, and cottonmouth moccasins are among the other animals which may be of interest to watchful observers.

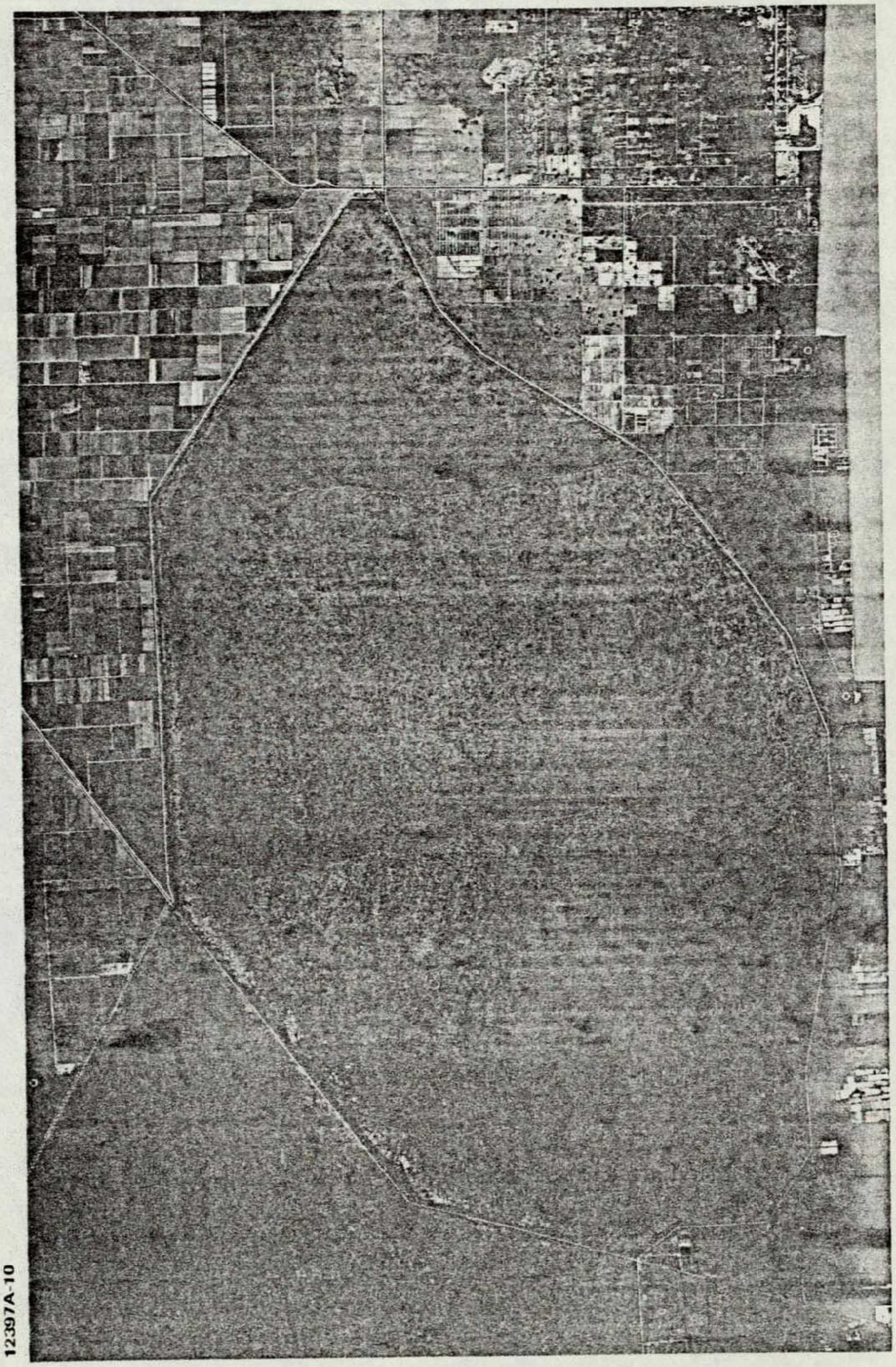

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Figure 2-7. NASA U-2 Photo of Conservation Area 1.

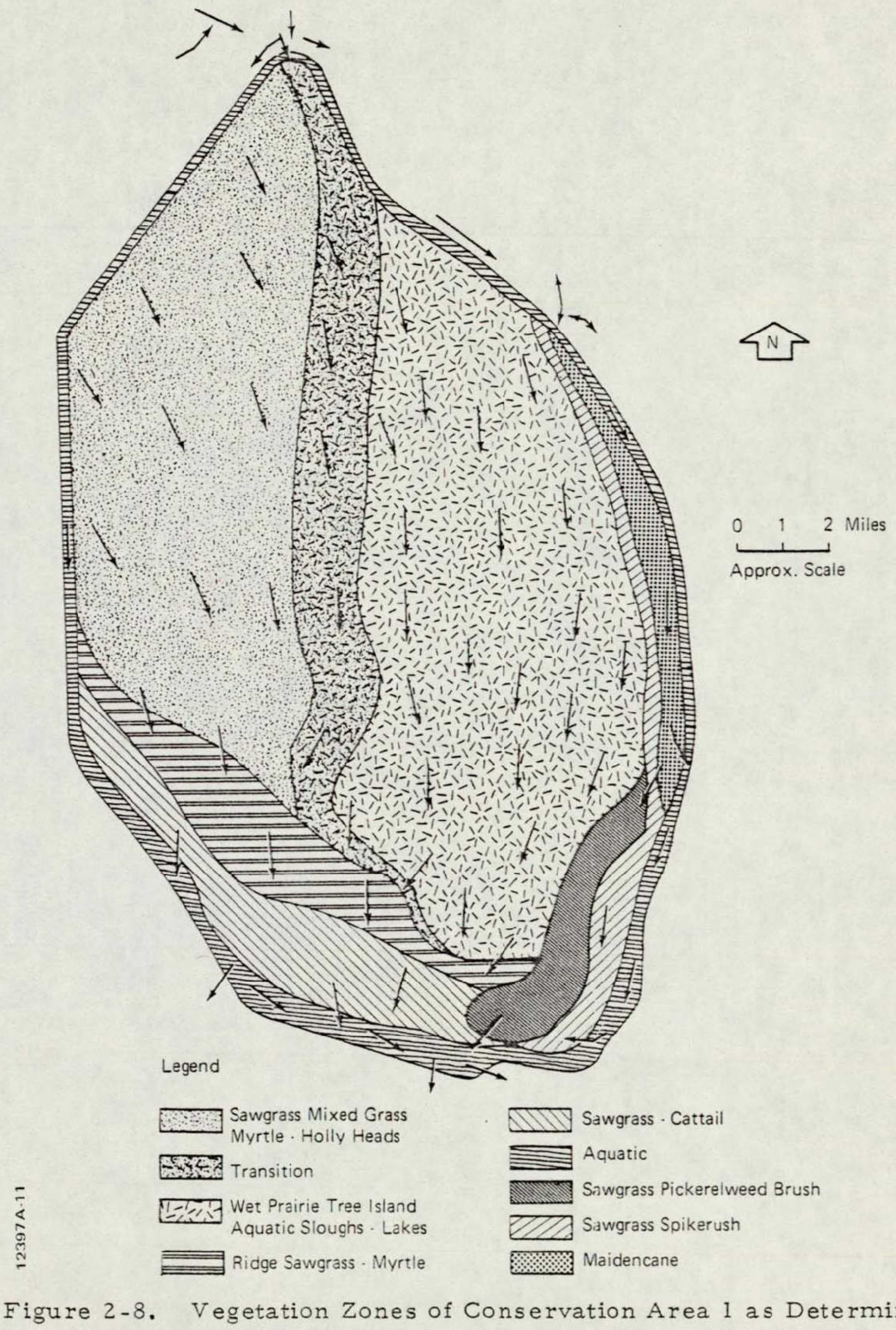

Figure 2-8. Vegetation Zones of Conservation Area 1 as Determined by US Department of Interior Fish and Wildlife Service Bureau of Sport Fisheries and Wildlife.

A noticeable relationship exists between adequate water levels and the abundance of birds requiring an aquatic habitat. Thousands of colonial and water birds nest and roost on the refuge when sufficient water is available to provide the necessary environment.

2.2.2 ERTS Imagery

ERTS multispectral imagery of Florida is obtained every 18 days from an altitude of approximately 900 km. These data are transmitted from the satellite to the NASA Goddard Space Flight Center or the Goldstone Tracking Station in digital format. The digital tapes are then mailed to the Miami office of the US Geological Survey. Several systems were used to extract spectral information from these tapes in order to construct thematic maps. Electronic processing of the ERTS MSS data was accomplished using the computer facilities of the Bendix Aerospace Systems Division, the General Electric Corporation, the Stanford Research Institute, and the IBM Corporation to produce different types of maps by computer.

Figure 2-9 shows radiance (or reflectance) maps of Conservation Area 1 derived from electronic processing of ERTS MSS Band 7 data acquired on 14 February, 4 March, and 22 March of 1973.

For this illustration, the original ERTS radiance levels, which were enhanced and color-coded on film, are shown as gray-scale levels. The darker the gray-scale, the lower the radiance (reflectance) measurement and the deeper the water. The water depth in this area ranges from zero, as denoted by white (lightest), to about 0.6 meters, denoted by black.

The change or loss in water stored in the area from 14 February to 22 March is readily observed by the changes in gray-scale of the enhanced images in Figure 2-9. The water stored in the area for a given time is obtained as illustrated in Figure 2-10, where the DCS (Figure 2-11) is used to provide quantative in situ data on the elevation of each water-depth category and MSS imagery is used to obtain the areal extent of each category. Surface area times elevation (depth) for each category yields directly the desired water volume retained by the area. Additionally, knowing the change in water storage and the surface inflow and outflow (input and output), it is possible to calculate the evapotranspiration and seepage, as illustrated in the model of Figure 2-12.

Between 14 February and 22 March of 1973, three successive sets of ERTS-MSS data were combined with existing ground-truth data and the DCS data for Conservation Area 1. During this period, the water levels were dropping, as noted previously in the hydrograph of Figure 2-6, and the

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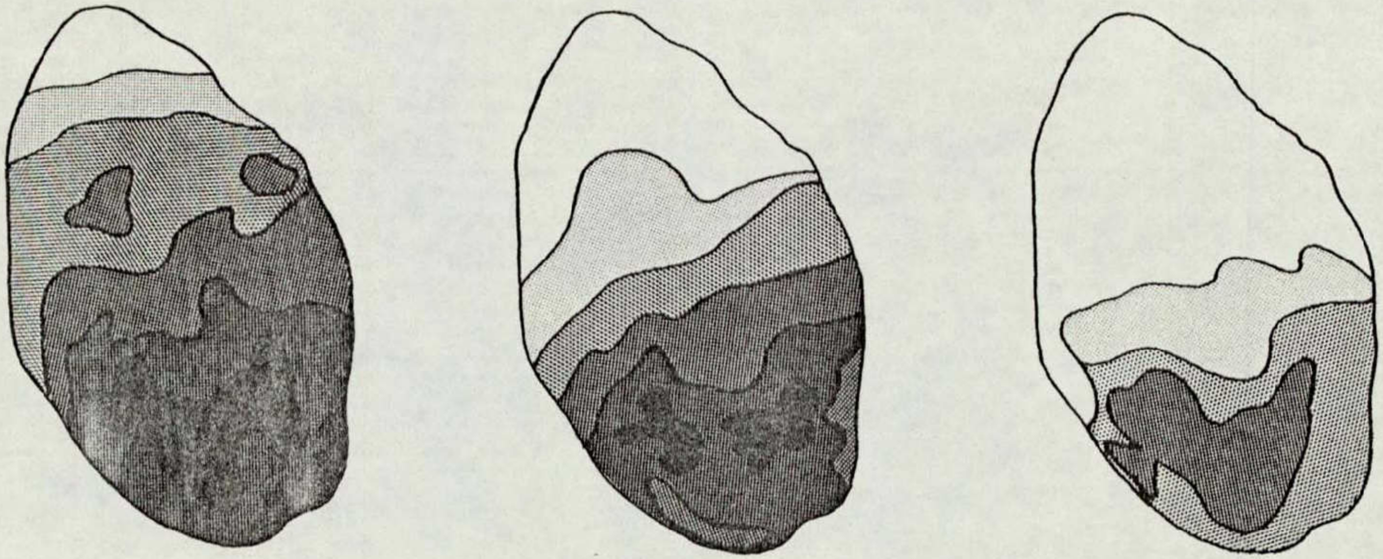

February 14, 1973　　March 4, 1973　　March 22, 1973

Figure 2-9. Radiance (Reflectance) Map of the Loxahatchee Wildlife Refuge (Conservation Area 1) Produced from Enhanced ERTS Band 7 Imagery. Darker Map Tones Correspond to Lower Radiance (Reflectance) and Deeper Water. Black is Deepest (0.6 Meters) and White is Dry Land.

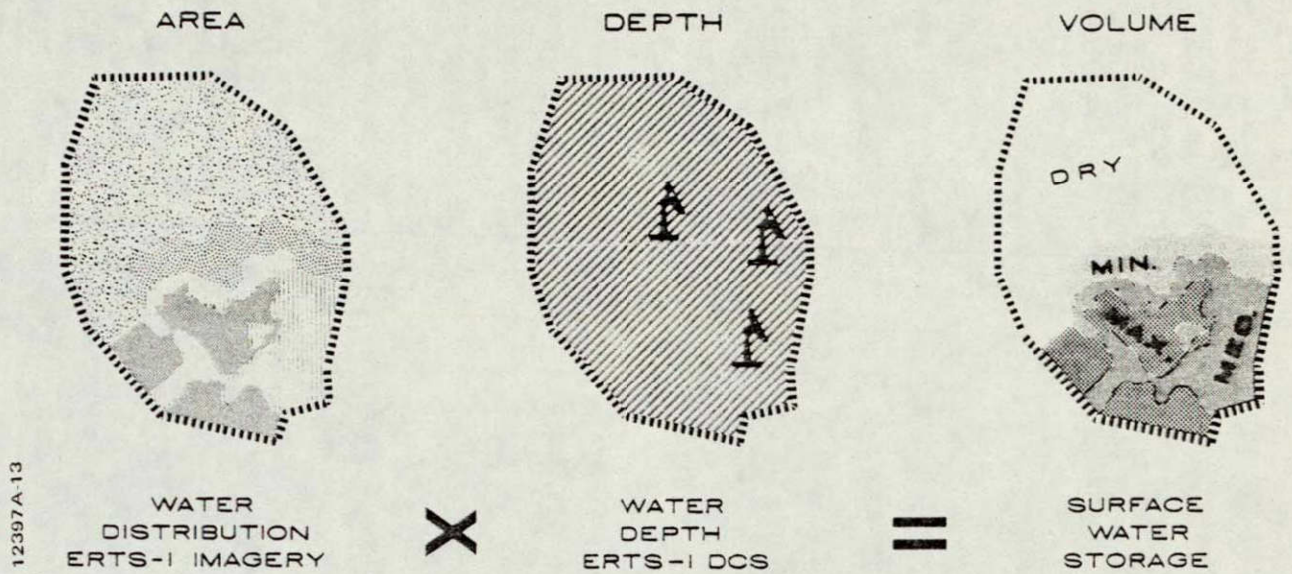

Figure 2-10. Schematic of Use of Space-Relayed Data to Calculate Surface Water Storage. ERTS Data of Three Successive Passes on February 14, March 4, and March 22, 1973, of Conservation Area 1 Were Used to Demonstrate Feasibility of This Method of Determining Surface Water Storage.

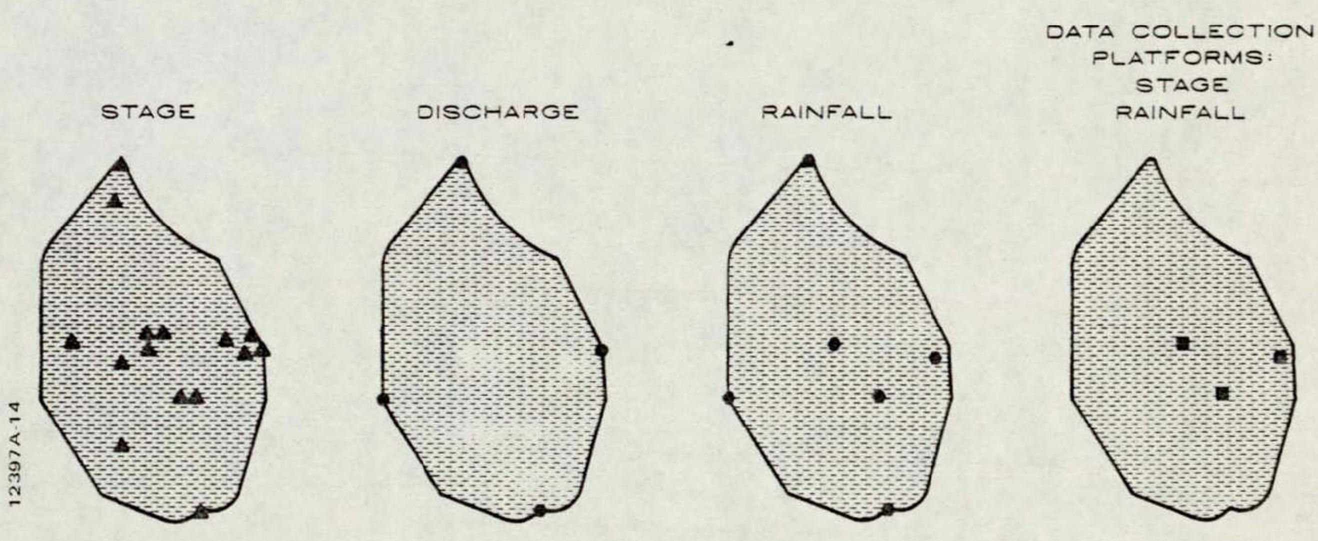

Figure 2-11. Location of Ground Truth Stations Used in the Evaluation of the February 14, March 4, and March 22, 1973, MSS Data for Conservation Area 1.

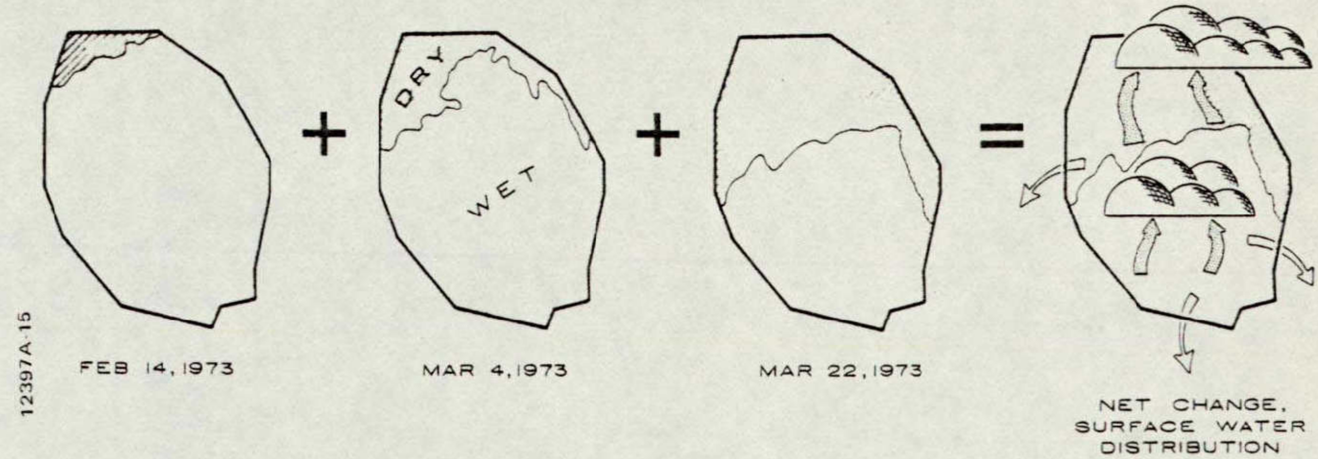

Figure 2-12. Schematic of Use of Space-Relayed Data to Calculate Evapotranspiration and Seepage. ERTS Data of Three Successive Passes on February 14, March 4, and March 22, 1973, of Conservation Area 1 Were Used to Demonstrate Feasibility of This Method of Determining Evapotranspiration and Seepage.

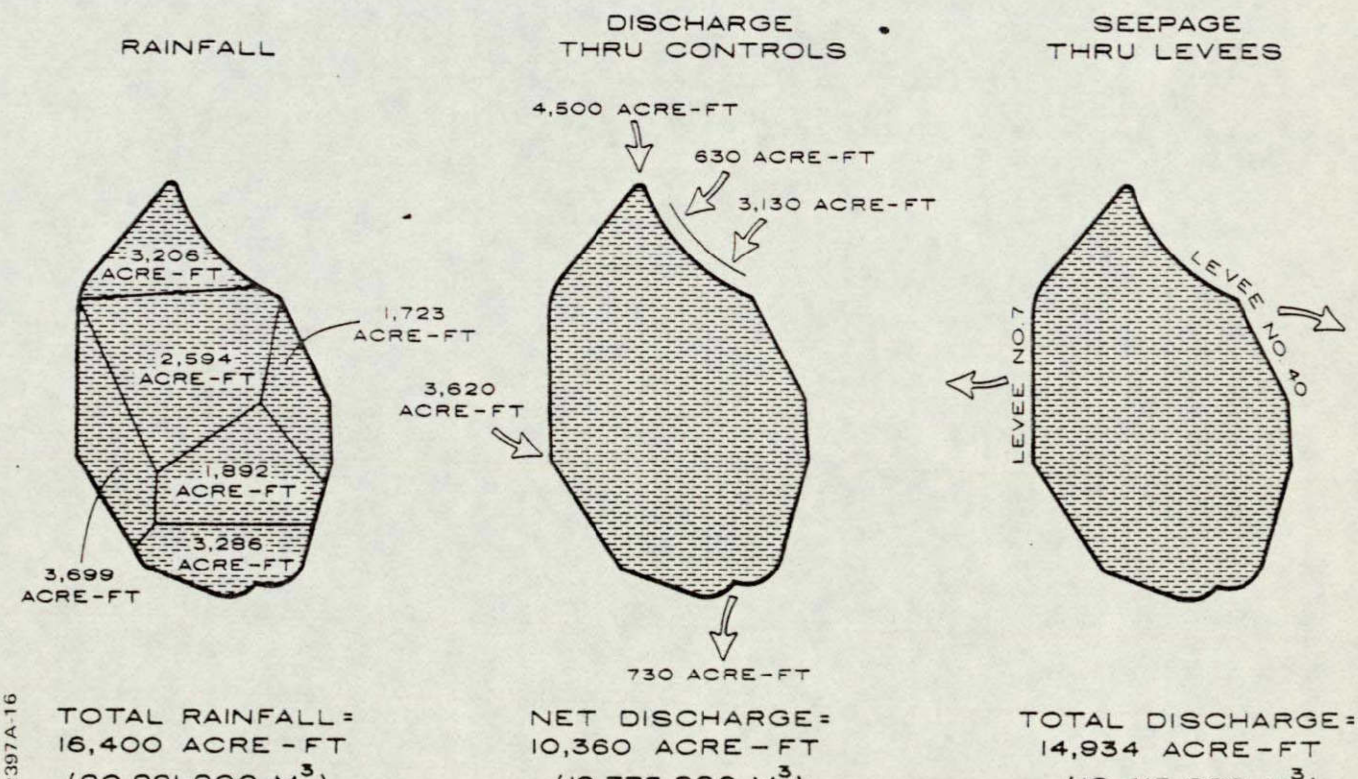

Figure 2-13. Hydrologic Measurements Compiled for Interpreting MSS Data for February 14, March 22, 1973 in Conservation Area 1.

enhanced imagery of Figure 2-9. For 14 February through 22 March, the evapotranspiration and seepage, surface water distribution, and storage for Conservation Area 1 were computer as shown in Figure 2-13. This trial run indicated that an operational water-management model for the Everglades basin is feasible.

3. CONCLUSION

The usefulness of ERTS-1 to improving the overall effectiveness of collecting and disseminating hydrologic data was evaluated. ERTS MSS imagery and in situ monitoring by DCS were used to evaluate their separate and combined capabilities.

Twenty data collection platforms were established in southern Florida. Water level and rainfall measurements were collected and disseminated to users in less than 2 hr, a significant improvement over conventional techniques requiring up to 2 months. The improved network performance is having a significant and beneficial impact on the development of water budgets and the water distribution to the people, fauna, and flora of southern Florida.

ERTS imagery was found to significantly enhance the utility of ground measurements. Water stage is correlated with water surface areas from imagery in order to obtain water stage-volume relations. As an adjunct to the point sampling, the imagery provides an economical basis for extrapolating water parameters from the point samples to unsampled data and provides a synoptic view of water mass boundaries that no amount of ground sampling or monitoring can provide. Additional hardware and software developments are needed to fully achieve the benefits available in the combined use of DCS and MSS data.

3.1 DCS SYSTEM

The DCS System is now an operational element in the Hydrologic Data Network in south Florida. Water-stage and rainfall from ground stations are transmitted from the Everglades via ERTS, the NASA tracking stations, and the US Geological Survey to the Corps of Engineers in less than 2 hr, a significant improvement over prior techniques requiring up to 2 months. Other users receiving water resource data from this network include Central and Southern Florida Flood Control Districts, the United States Park Service, and the Florida Fish and Wildlife Office.

The importance of the space-relayed data can also be shown by a comparison of the accuracy and frequency of data received through the Miami USGS teletype with data from the existing remote radio transmission systems in southern Florida. The great "line-of-sight" distances involved in the radio transmitted systems often provide rare and garbled data messages. The frequent meteorologic disturbances in southern Florida prevent the transmission of the accurate synoptic information on rainfall and water stage that is essential in managing the water for optimum values of conservation.

ERTS-1, on the other hand, has been providing the USGS with five transmissions of these parameters per day and an opportunity to service faulty platform recorders within 24 hr. This enhances the opportunity for a constant flow of information and makes it possible for the US Corps of Engineers to make daily decisions in order to optimize its water-control policy so as to conserve a greater proportion of the seasonally deficient water resource.

The DCS System also makes it possible to develop strategies for more efficient field manpower deployment. For example, with DCS, manpower can be deployed to malfunctioning stations or to stations that are recording extraordinary hydrologic conditions where supplementary manual measurements are highly desirable. The emphasis can be shifted to sending personnel where they are most needed, instead of the routine station-servicing trips. This improves the efficiency of expensive manpower, decreases the down-time of hydrologic instruments, decreases data loss, and frees manpower for new high-priority activities. Also, data from the network can be made available in near-real time to meet the growing data needs of water-resource management agencies.

3.2 SYSTEM DESCRIPTION

A system to satisfy the hydrologic data needs of water resources management is illustrated in Figure 3-1. This system would be configured to achieve the benefits available from the combined use of ERTS MSS imagery and in situ monitoring by DCS.

The DCS portion (Figure 3-2) of the system is operational, however, the imagery portion is not. One reason for this is the long delay (approximately 6 to 8 weeks after an ERTS pass) in obtaining ERTS imagery and computer tapes. The other reason is the difficulty of locating DCP's and other point sampling stations within the ERTS images and tapes. A computer technique (Ref 17) has recently been developed that will permit the earth coordinates (latitude and longitude) of the sampling station to be called up and displayed on the ERTS scene (Figure 3-3).

ERTS MSS images, scene radiance, and changes in scene radiance corresponding to water "color" (reflectances) and changes that may be a result of parameters that include depth, turbidity, chlorophylls, algal population, particulate carbon, etc. In situ measurements by field teams or a DCP are essential to quantify the ERTS image response. ERTS imagery used as an adjunct to the point-sampling provides an economical basis for extrapolating water parameters from the point samples to unsampled areas and provides a synoptic view of water mass boundaries that no

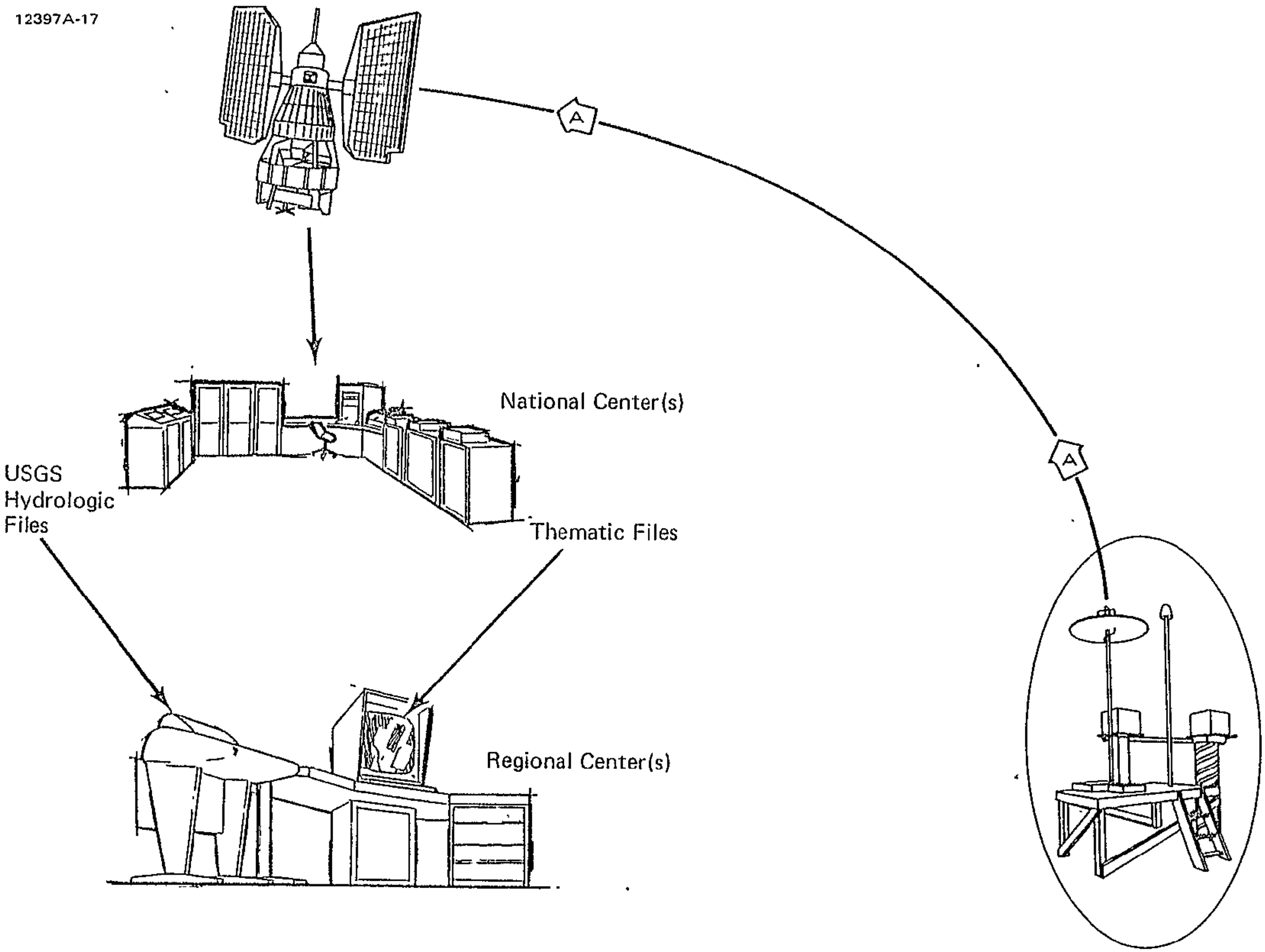

Figure 3-1. Concept of Water Management System Operation.

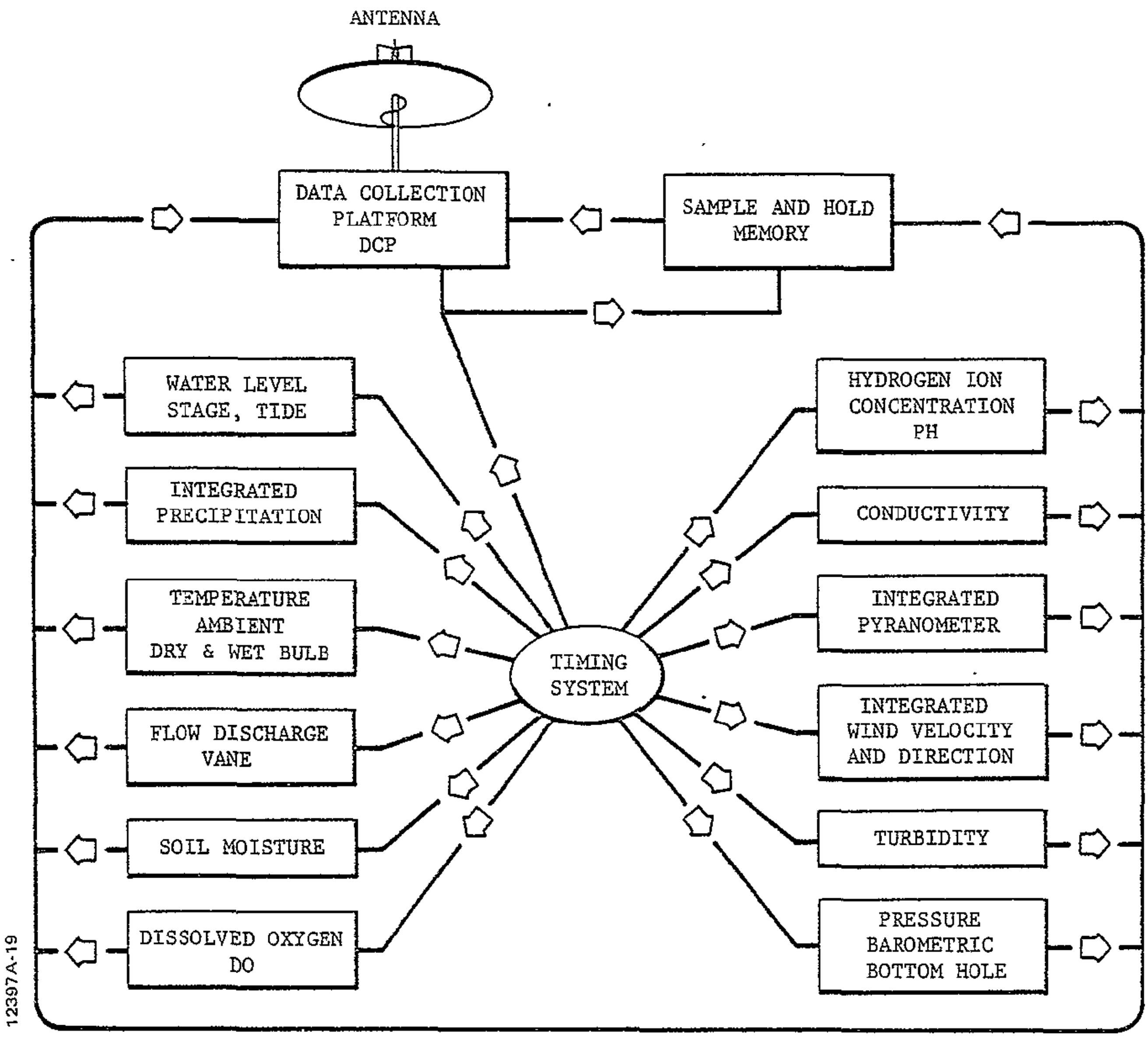

Figure 3-2. Schematic of Proposed System of Parameters That Are Being Connected to Data Collection Platforms in Water Management Areas in Florida. The Sample and Hold Memory System Developed by the USGS-EROS Program Will Allow a Daily Collection of between 18 and 24 Hours of Data on the Needed Parameters to Complete a Water Quality and Quantity Budget.

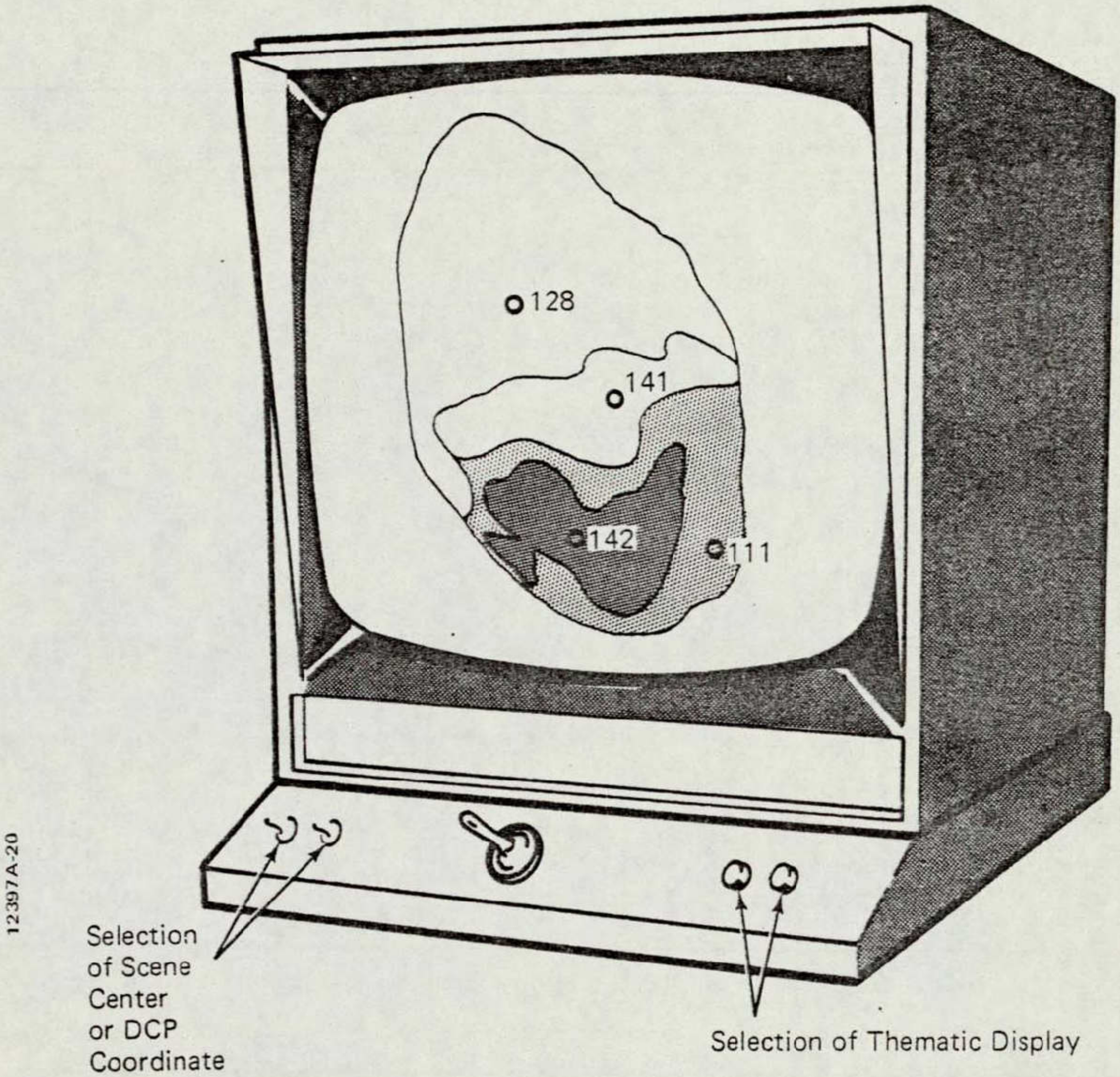

Figure 3-3. Simulated TV Display of ERTS MSS Data with Annotated Location Map of DCP's. Display Inputs Include Latitude and Longitude of Scene Center and Theme (Land-Use Categories).

amount of ground sampling or monitoring can provide. The water budget example developed for Conservation Area 1 uses water stage from DCP's with surface area from imagery to obtain water-stage volume relations. Figure 3-4 shows a color-enhanced image of southern Florida in ERTS Band 7. As in the case of Conservation Area 1, water stage is associated with scene radiance as denoted by color but must be quantified by in situ measurements within each color category. The synoptic view by ERTS and computer processing (Refs 17 and 18) rapidly provides surface area and volume relations.

In addition to using ERTS imagery to extrapolate from DCP measurements, ERTS imagery is also useful for optimizing the deployment of DCP's and field teams. As noted previously, ERTS responds to radiance and differences in scene radiance. Analysis of this imagery may show that two DCP's are occupying a water body of similar radiance, i.e., characteristics. On the other hand, the imagery may show areas in which a significant change has occurred and in which a DCP should, perhaps, be positioned to quantify change. For example, ERTS imagery may be used to monitor a basin wherein mining is occurring. A change in radiance (color) of a water body in the area may be very significant. A field team may be deployed to point sample and to set up a DCP to quantify reasons for change.

The ERTS MSS data also provides an economical base for computerized mapping of land use about DCP's providing water quality indicators, i.e., dissolved oxygen, conductivity, turbidity, etc. Ready access of land use information about these DCP's will permit cause-effect studies which will result in a better understanding of factors causing changes in water quality.

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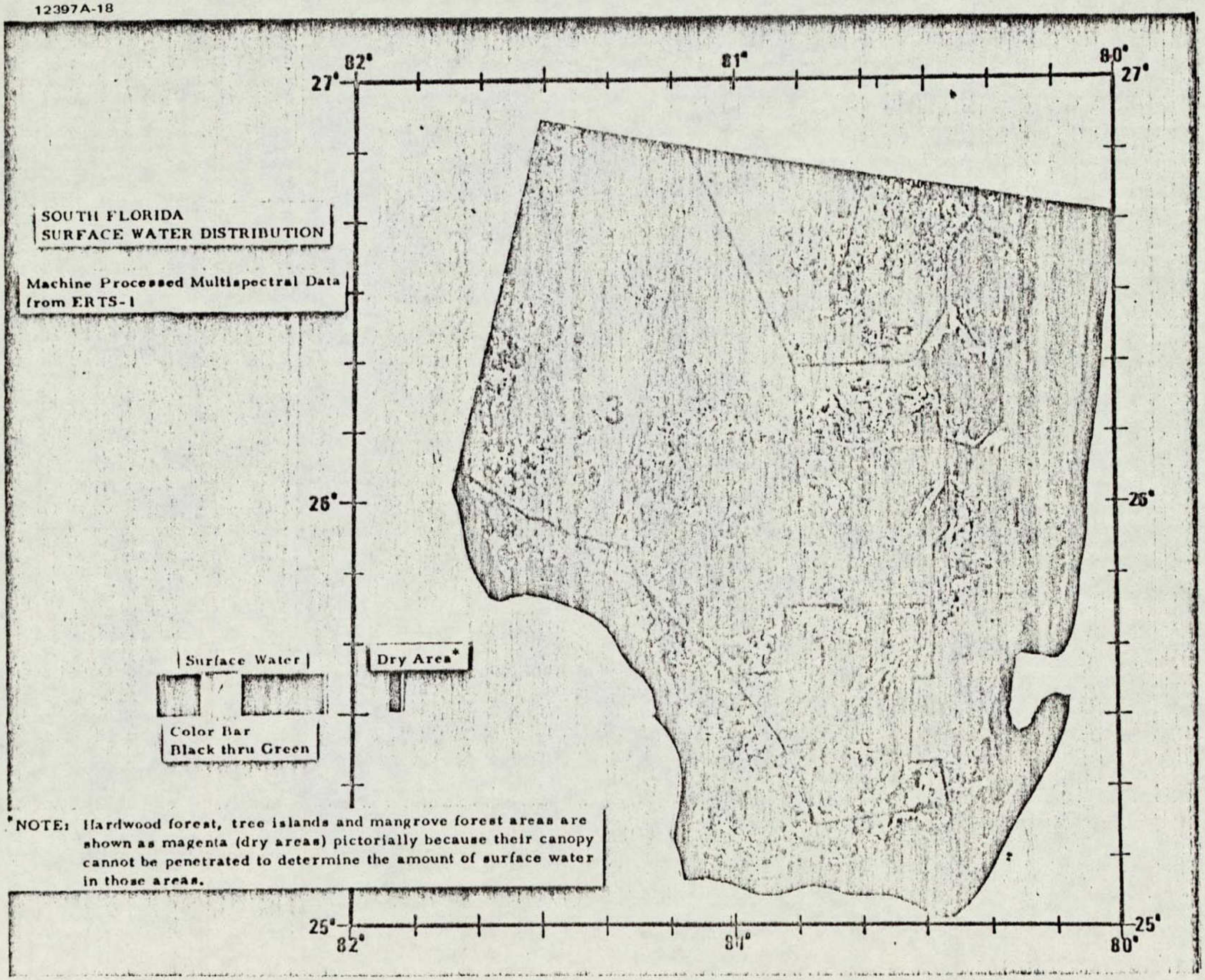

Figure 3-4. Color-Enhanced ERTS Image of South Florida.
ERTS Scene E-1242-15240, March 22, 1973.

4. GLOSSARY

Acoustic Coupler: Device used to link computers by telephone line.

Acre-foot (AC-FT, acre-ft): The quantity of water required to cover 1 acre to a depth of 1 ft, equivalent to 43,560 cu ft or about 326,000 gal.

Analog Mode: In this report, the analog mode is the mode of a DCP in which data are accepted from a sensor as voltage.

Aquifer: Any portion of the earth's crustal layer capable of storing water and yielding water for use on the earth's surface. The water in such formations is called ground water. The Biscayne Aquifer is a shallow "ground water table" aquifer.

Binary Code: Numbering system with a base two.

Carryover Storage: Reservoir storage capacity which will permit the retention of surface water surpluses for carryover to supply needs in subsequent periods of water deficiency.

Cfs-day: The volume of water represented by a flow of 1 cu ft per sec for 24 hr. It is equivalent to 86,400 cu ft, 1.9835 acre-ft, or approximately 646,000 gal, and represents a runoff of approximately 0.0372 in. from 1 sq mi.

Conservation Area: In this report, conservation area refers to water conservation area, an area reserved for the purpose of conserving water.

Contents: The volume of water in a reservoir or lake. Unless otherwise indicated, volume is computed on the basis of a level pool and does not include bank storage.

Control: A feature downstream from the gage that determines the stage-discharge relation at the gage. This feature may be a natural constriction of the channel, an artificial structure, or a uniform cross-section over a long reach of the channel.

Control Structure: As used in this report, control structure is a structure on a stream or canal used to regulate the flow or stage of the stream or to prevent the intrusion of salt water.

Cu ft per sec per sq mi (CFSM): The average number of cu ft of water flowing per sec from each sq mi of area drained, assuming that the runoff is distributed uniformly in time and area.

Cu ft per sec (cfs): The rate of discharge representing a volume of 1 cu ft passing a given point during 1 sec, equivalent to approximately 7.48 gal per sec or 448.8 gal per min.

DCP: Data Collection Platform; An electronic instrument which encodes, formats, and transmits data to the ERTS-1 satellite.

DCS: Data Collection System; A system contrived and operated by NASA, using DCP's, the ERTS-1 satellite, receiving stations, and a data processing facility.

Digital Mode: In this report, digital mode is the mode of a DCP in which data are encoded, formatted, and transmitted numerically.

Discharge: The volume of water (or more broadly, total fluids), passing a given point within a given period of time.

Discharge, Daily Mean: The mean discharge for one day.

Discharge, Mean Daily: The arithmetic mean discharge for the same day during a specific period of years.

Discharge, Mean: The arithmetic mean of individual daily mean discharges during a specific period.

Drainage Area of a stream at a specified location: That area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point. Figures of drainage area given herein include all closed basins or noncontributing areas within the area unless otherwise noted.

Encode: To convert a message into code.

ERTS: Earth Resources Technology Satellite.

Gage Height (G. H.): The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term "stage", although gage height is more appropriate when used with a reading on a gage.

Gaging Station: A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained. When used in connection with a discharge record, the term is applied only to those gaging stations for which a continuous record of discharge is computed.

Interface: To form a common boundary between electronic equipment so that the equipment functions as a unit.

NASA: National Aeronautics and Space Administration.

NASA Progress Report: Periodical report required by NASA contract.

NDPF: NASA Data Processing Facility.

Nutrients: Although many chemical constituents are required for plant growth, nitrogen and phosphorus are considered to be the primary nutrients. Both occur in inorganic and organic forms. The inorganic forms of nitrogen found in solution in water bodies are nitrates, nitrites, and ammonia.

Octal Code: Numbering system with a base of eight.

One million cubic feet (mcf): The volume of water represented by a flow of 11.57 cu ft per sec for 24 hr.

One million gallons per day (mgd): Equal to flow of 1.547 cu ft per sec of water for 24 hr.

Parallel Digital Mode: Mode in which data in digital form are accepted simultaneously by the DCP.

Partial-Record Station: A particular site where limited stream-flow data are collected systematically over a period of years for use in hydrologic analyses.

Programmable Calculator: Electronic calculator that has a programming mode.

Runoff in inches (IN.): Runoff in inches shows the depth to which the drainage area would be covered if all the runoff for a given time period were uniformly distributed on it.

Serial Digital Mode: Mode in which data in digital form are accepted in a series, one bit at a time.

Stage-Discharge Relation: The relation between gage height and the volume of water per unit of time, flowing in a channel.

Telecopier: Device used to copy and transmit by telephone to another telecopier, at a distant station, the print from a page.

Telemetry: System for measuring a quantity by an electrical apparatus, transmitting (usually by radio signal) the result to a distant station and there indicating or recording the quantity.

Transpiration: A vital natural element of the hydrologic cycle; the return of water to the atmosphere in the form of water vapor as a result of the growth process of vegetation.

Water Budget: For any water system, an accounting over any fixed time span of where water comes from and where it goes.

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