OPERATIONAL APPLICATIONS OF SATELLITE SNOWCOVER OBSERVATIONS AND LANDSAT DATA COLLECTION SYSTEMS OPERATIONS IN CENTRAL ARIZONA

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ABSTRACT

Repetitive LANDSAT and NOAA-4 satellite imagery together with aerial surveys are being evaluated to develop an operational capability for mapping snowcover distributions on the Salt-Verde watershed of central Arizona. Satellite telemetry is also being used for near-real time relay of hydrologic data to aid in the management and operation of reservoirs on the Salt and Verde Rivers.

Aerial reconnaissance flights were conducted to collect information on the depth and distribution of snowcover to provide ground truth for use in the analysis of the satellite imagery. A technique for rapid and economical determination of snow depths, using oblique aerial photography of snow markers, has been developed.

The LANDSAT Data Collection System (DCS) is being used to relay hydrologic data from earth-based sensors located at remote and relatively inaccessible sites. The LANDSAT telemetry system is being used to relay information from streamflow and snow-monitoring installations located in the upper parts of the Salt-Verde watershed.

INTRODUCTION

The inability to accurately measure and monitor moisture conditions over large remote areas often presents serious land and water-management problems in Arizona and other semi-arid regions. The lack of timely information about moisture conditions in central Arizona including precipitation, snow-water content, rates of snowmelt, and resultant volumes of runoff presents vexing water-management problems related to multiple-use reservoir operations that have resulted in millions of dollars of downstream property damage and loss of life.

The Salt-Verde River watershed includes approximately 13,000 square miles (34,000 square kilometres) of central Arizona, ranges from 1,325 to 12,670 feet (400 to 3,900 metres) above mean sea level, and receives from 10 to 25 inches (25 to 65 centimetres) of annual precipitation (fig. 1). The highly variable runoff from the Salt and Verde Rivers is regulated by six reservoirs that have a combined storage capacity of approximately 2 million acre-feet (2.5 cubic kilometres) (fig. 2). These reservoirs are operated by the Salt River Project to furnish hydroelectric power and municipal, industrial, and irrigation water to more than 1 million people and 250,000 acres (1,200 hectares) of land in the Salt River Valley near Phoenix, Arizona (fig. 1).

OBJECTIVES

The Arizona Test Site is one of four test sites included in the NASA Applications Systems Verification Test (ASVT) on Snow mapping. The principal objectives of this investigation are (1) to evaluate repetitive satellite imagery together with aerial surveys in an attempt to develop an operational capability in Arizona for using satellite imagery for mapping snowcover distributions, (2) to develop techniques and procedures for systematic monitoring of snowcover and moisture conditions using remote-sensor methods including repetitive satellite and aerial observations together with the use of the LANDSAT Data Collection System to relay ground-truth data, and (3) to develop or modify methods that will allow incorporation of satellite observations of snowpack into operational procedures used by the Salt River Project for predicting both short-term and seasonal snowmelt-derived runoff.

AERIAL OBSERVATIONS

Snowcover Distributions

Aerial observation of snowcover distributions can provide valuable information during periods of cloud cover that preclude satellite snowcover observations.

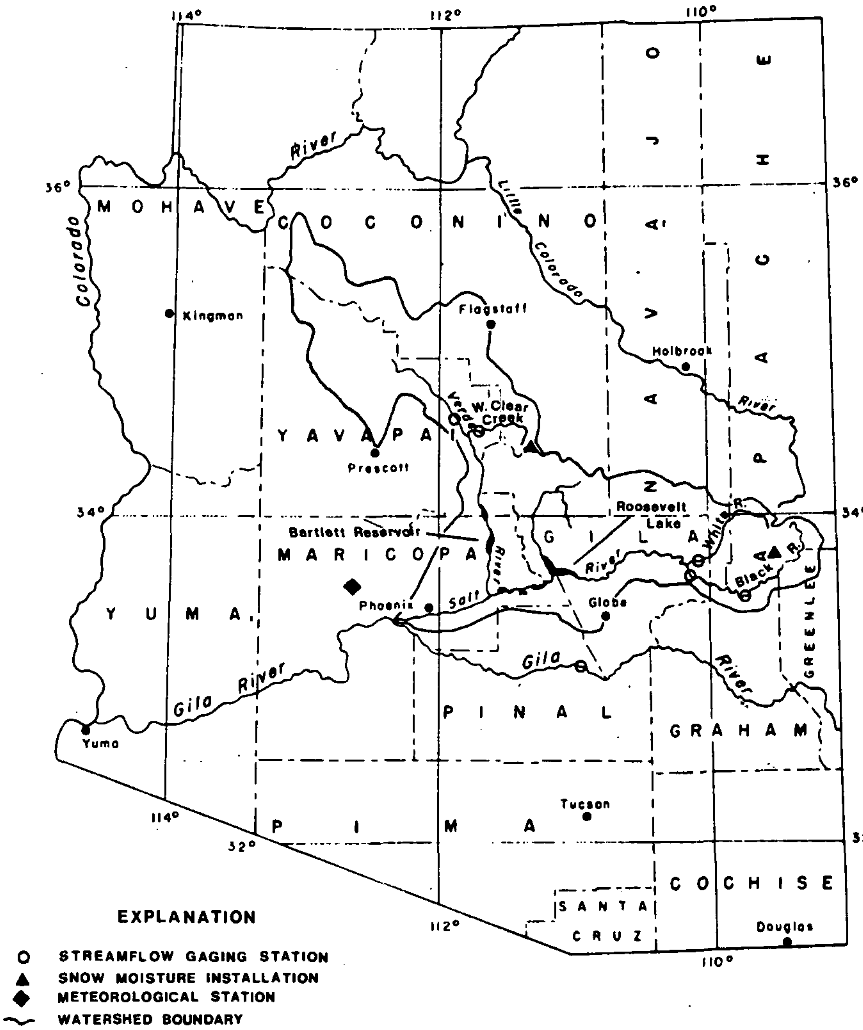


Fig. 1-Location of LANDSAT Data Collection Platforms and Salt and Verde watersheds, Arizona

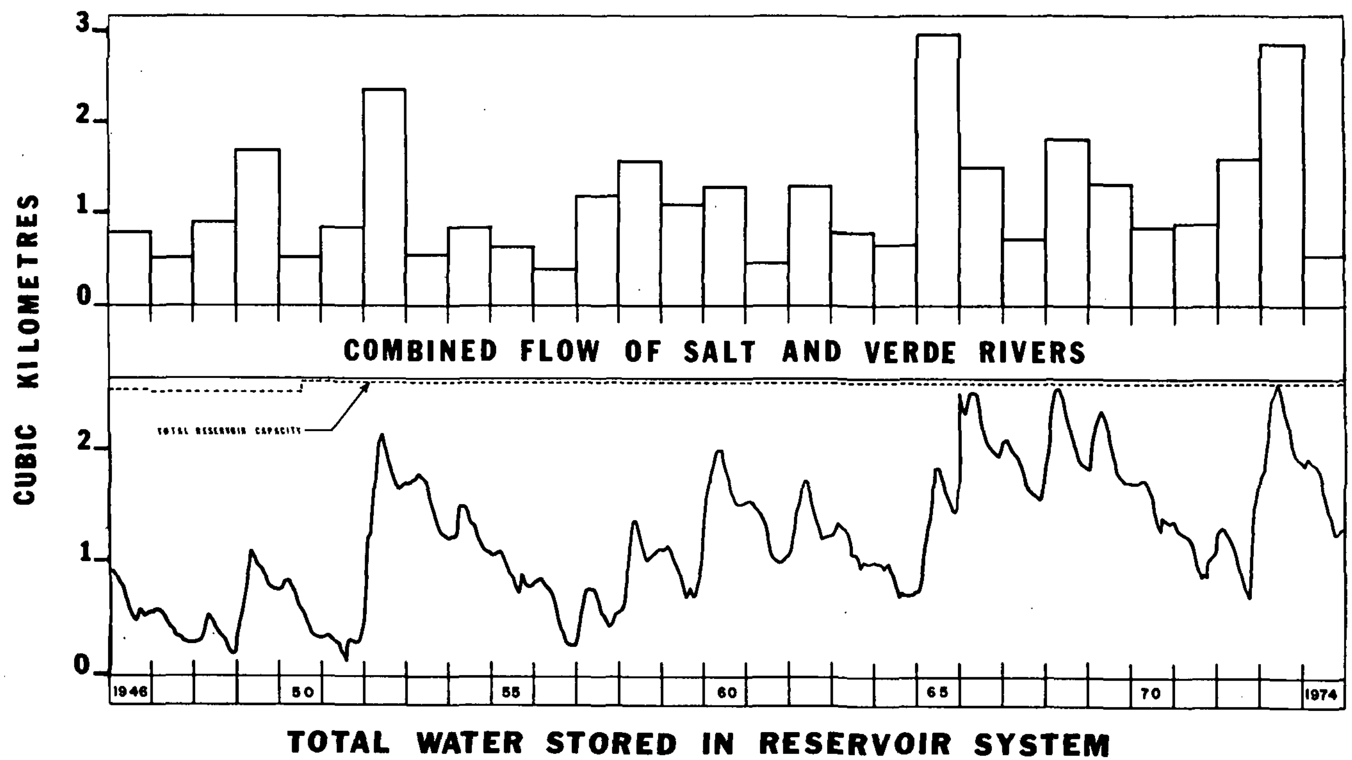


Fig. 2-Combined flow of Salt and Verde Rivers and total water stored in reservoir system

During the spring of 1975 eight aerial reconnaissance flights, averaging 4 to 6 hours in duration, were flown over the Salt-Verde watershed to collect information on the depth and distribution of snowcover and to train additional aerial observers. Maps of snowcover distributions were prepared during these flights using visual mapping techniques and a 1:1,000,000-scale LANDSAT-I image map of Arizona (fig. 3).

Snowcover distributions, as mapped by inexperienced aerial observers, were more generalized and tended to show lesser amounts of snowcover than snowcover distributions observed on LANDSAT imagery. However, snowcover distributions mapped by experienced observers were in close agreement with the snowcover distributions shown on the LANDSAT imagery. Similar results were observed when Barnes compared snowcover distributions observed on 1972-73 LANDSAT-I imagery with snowcover distributions on the Salt-Verde watershed mapped by the Salt River Project using visual mapping techniques (1). Barnes found an average difference of 7 percent between the two mapping techniques (table 1). However, when the aerial observations were made on or within 1 day of the data of the LANDSAT-I imagery, differences as small as 2 percent were observed.

Rapid snowmelt at elevations below 7,000 feet (2,100 metres) above mean sea level cause large and rapid changes in the snowcover on the Salt-Verde watershed. The snowcover on the Upper Tonto Creek watershed decreased from 70 percent to 5 percent between February 18 and 27, 1975, as shown on LANDSAT imagery (fig. 5).

Aerial Observations of Snow Depths

Surface wind speeds, estimated to be as great as 50 knots per hour, over the mountains of central Arizona produced rough air conditions during the spring of 1975 that often prevented low-level observation of snow markers and natural features such as logs and fences used to estimate snow depths. Oblique aerial photography of aerial snow markers on the upper Salt River watershed was attempted to obtain the desired snow-depth information.

After considerable experimentation, a technique was developed for obtaining economical, high resolution, aerial photography of the snow markers from safe altitudes above the

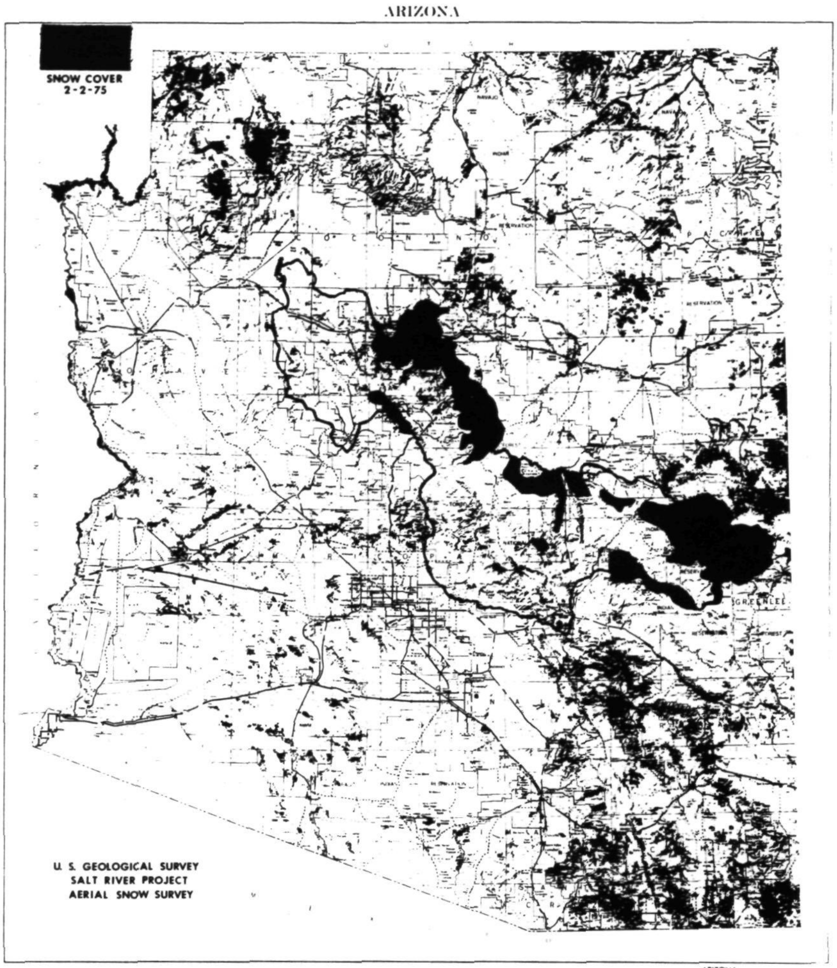


Fig. 3-Snow cover on Salt-Verde Watershed, Arizona

Table 1.--Comparison between snowcover mapped from ERTS imagery and aerial snow surveys for Salt-Verde watershed, Arizona 1972-73

Case	Date of ERTS imagery	Date of aerial snow survey	Interval between ERTS and aerial observations (days)	Percent of area snow covered		
				ERTS	Aerial	Difference
1	21 Nov.	14 Nov.	7	19	33	14
2	11 Jan.	12 Jan.	2	19	26	7
3	01 Feb.	02 Feb.	1	22	29	7
4	18-19 Feb.	15 Feb.	3-4	39	48	9
5	26 Mar.	26 Mar.	0	51	53	2
6	13 April	12 April	1	25	27	2
7	02 May	27 April	5	25	36	11
MEAN DIFFERENCE FOR ALL 7 CASES						7

Data from Barnes, Bowley and Simmes, 1974 terrain (500 feet or 150 metres). Several types of cameras and telephoto lenses of various focal lengths were evaluated. The combination of a motorized 35-mm camera fitted with a 500-mm focal-length lens, and Kodak High Speed Ektachrome color film was found to consistently provide the scale and quality of photography required. The use of a motorized camera allowed the acquisition of multiple images of the snow markers during a single imaging pass by the aircraft.

The processed film was mounted in slide mounts for interpretation using standard 35-mm film projection equipment. Knowing the dimensions of the aerial snow markers (including the total height, width of the bars, and the spacing between adjacent bars) it was possible to easily and quickly determine the snow depth with an estimated accuracy of ± 3 inches (± 7.5 mm) from photography taken at as much as 1, 000 feet (305 metres) above the terrain.

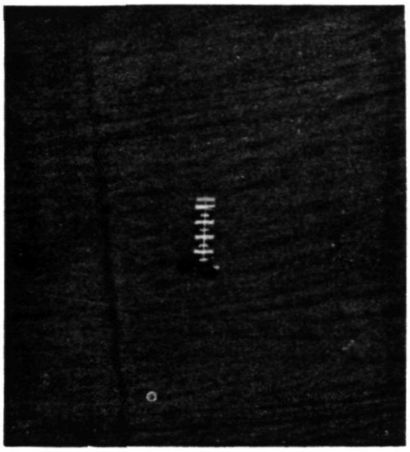
The use of high-speed color film was found to significantly facilitate the interpretation of aerial snow markers photographed under cloudy or overcast conditions. Examples of oblique aerial photography of a 9-foot (2.7 metre) simulated aerial snow marker, using the previously described camera system, are shown in figure 4. The shadow of the aerial snow marker is often more easily evaluated than the vertical marker itself. The shadow of the marker can be observed with the least distortion when photographed directly toward the sun (fig. 4B).

One major advantage of this technique for determination of snow depths is that it utilizes only standard and readily available photographic and projection equipment. Another advantage is that it provides a low-cost permanent photographic record of the snow markers that can be evaluated in the office as opposed to attempting to read the snow markers visually from low-flying light aircraft over mountainous terrain — often under less than ideal flying conditions.

SATELLITE OBSERVATIONS

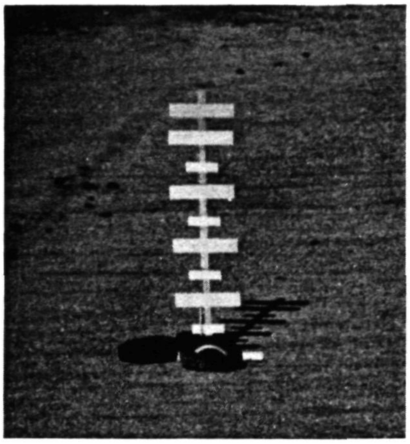
LANDSAT Imagery

Film positive copies of 1:1, 000, 000-scale LANDSAT Band 5 (0.6-0.7 um) imagery are essentially orthographic and provide sufficient detail for operational mapping of snowcover



A. from 1000 feet

B. from 500 feet



C. from 200 feet

Fig. 4-Oblique aerial photography of simulated aerial snow marker

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distributions and changes in snowcover distributions on the Salt-Verde watershed of central Arizona (fig. 5). Using visual interpretation techniques, an experienced analyst can accurately map snowcover distributions over the entire 13,000 square miles (34,000 square kilometres) of the Salt-Verde watershed from the LANDSAT imagery in less than 2 hours. Approximately 5 hours of flight time and 1 to 2 hours of map preparation are required to map the same area using aerial reconnaissance techniques.

The use of density-slicing techniques, together with appropriate watershed masks, allows rapid determination of the percentage of snowcover on individual watersheds and subwatersheds of particular interest for runoff forecasts. Color additive viewing of the multispectral LANDSAT imagery greatly facilitates the determination of snowcover distributions on the small, but densely forested, upper parts of the Salt-Verde watershed.

The single factor that has precluded operational utilization of LANDSAT imagery for snowcover mapping in central Arizona is the 4-week processing and shipping delay between the time of acquisition of the imagery by the satellite and its receipt in Arizona. Satellite imagery, to be used for operational prediction of short-term, snowmelt-derived runoff in central Arizona, must be received in Arizona within 48-72 hours after acquisition by the satellite.

Meteorological Satellite Imagery

Sample copies of the NOAA Very High Resolution Radiometer (VHRR) visible band (0.6-0.7 um) and SMS/GOES (0.55-0.75 um) satellite imagery over Arizona were received from the NOAA National Environmental Satellite Field Services Station in Redwood City, California, during the spring of 1975.

The high-polar-orbital NOAA satellite imagery and, to a lesser degree, the geostationary SMS/GOES imagery contain considerable distortion and are much more difficult to fit to planimetric maps than the nearly orthographic LANDSAT imagery. The resolution of both types of meteorological satellite imagery is reported to be 1 kilometre at nadir and is much lower than that of the LANDSAT imagery. However, the meteorological satellite imagery does cover very large areas — the entire Salt-Verde watershed and adjacent areas

LANDSAT II 2027-17213-5 February 18, 1975

LANDSAT I 1949-17170-5 February 27, 1975

Fig. 5-Snow cover changes on Upper Tonto Creek watershed

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are covered on a single image. Because meteorological satellite imagery is available on a daily basis, it is potentially of significant value for operational monitoring of snowcover over the Salt-Verde watershed where large changes in snow-cover occur within very short periods. Wiesnet and McGinnis (1973) described the successful use of NOAA VHRR together with LANDSAT-I imagery for snow mapping in the American River Basin, California (3).

LANDSAT DATA COLLECTION SYSTEM OPERATIONS

The LANDSAT Data Collection System (DCS) is being used to relay streamflow and snow-water equivalent information from six remote sites in central Arizona in support of the operational snowcover mapping on the Salt-Verde watershed (fig. 1). The LANDSAT-DCS provides the capability to collect data transmitted from earth-based environmental sensors by means of Data Collection Platforms (DCP's) and to relay these data to ground-receiving sites located at Goldstone, California, and at Greenbelt, Maryland.

The DCP's will accept inputs from as many as eight different environmental sensors in analog, serial digital, or parallel digital form. Eight channels of analog data, or eight 8-bit parallel digital words, or 64 serial digital bits can be input to a single DCP. Each analog input requires the use of one 8-bit word and the analog input voltage range is 0 to +5 volts DC. Any combination of analog inputs and parallel digital inputs, resulting in a total of 64 bits, can be accepted.

The DCP's operate continuously and transmit a 38-millisecond burst of data, each 90 or 180 seconds, containing the platform identification number and the encoded 64 bits of data from the eight sensor channels. When the LANDSAT satellite is in mutual view of a transmitting DCP and one of the ground-receiving sites the satellite relays the DCP transmission to the ground-receive site through an on-board receiver/transmitter. The LANDSAT satellite has no on-board DCS data storage capability and acts as a real-time relay. According to the system design the satellite should be in mutual view of at least one ground-receiving site and a DCP located almost anywhere in North America during at least two orbits per day. In Arizona DCS data have been received during two to six orbits per day depending on local site conditions. The DCS data handling and data products are described in detail in the

NASA ERTS Data Users Handbook (4).

The data flow from the ground sensor through the DCS and back to the Arizona user is shown diagrammatically in figure 6. DCP-equipped streamflow gages and a snow-water equivalent measurement site are shown in figures 7 and 8, respectively.

During the spring of 1973, the Salt River Project used near-real time hydrologic data furnished by microwave and LANDSAT-DCS telemetry to successfully predict the volume of runoff into their reservoir system and by prudent water management prevented flooding in the Phoenix metropolitan area. This was accomplished although the record snowfalls on the watersheds of central Arizona produced the greatest volumes of runoff recorded in recent years (2).

The data collection system associated with the operational SMS/GOES geostationary satellites offers increased data transmission capacity and will operate in either a self-timed or in an interrogate mode. Several new convertible data collection platforms, capable of transmitting to either LANDSAT or SMS/GOES satellites, have been purchased. Field testing of these units in central Arizona is scheduled for the fall of 1975.

SUMMARY AND CONCLUSIONS

Aerial observation of snowcover distributions has the significant advantage of providing the required information during periods of cloud cover that preclude satellite snowcover observations. Aerial reconnaissance flights also allow visual and photographic estimates of snow depths. For these reasons, aerial reconnaissance flights will continue to provide a valuable hydrologic tool and will provide complimentary data to satellite snowcover observations on the Salt-Verde watershed.

The feasibility of using satellite telemetry to furnish near-real time hydrologic data for use by water-management agencies in Arizona has been successfully demonstrated by the LANDSAT data collection system. The SMS/GOES data collection system offers an increased data handling capacity and will soon be field tested in Arizona.

The LANDSAT imagery at a scale of 1:1,000,000 is

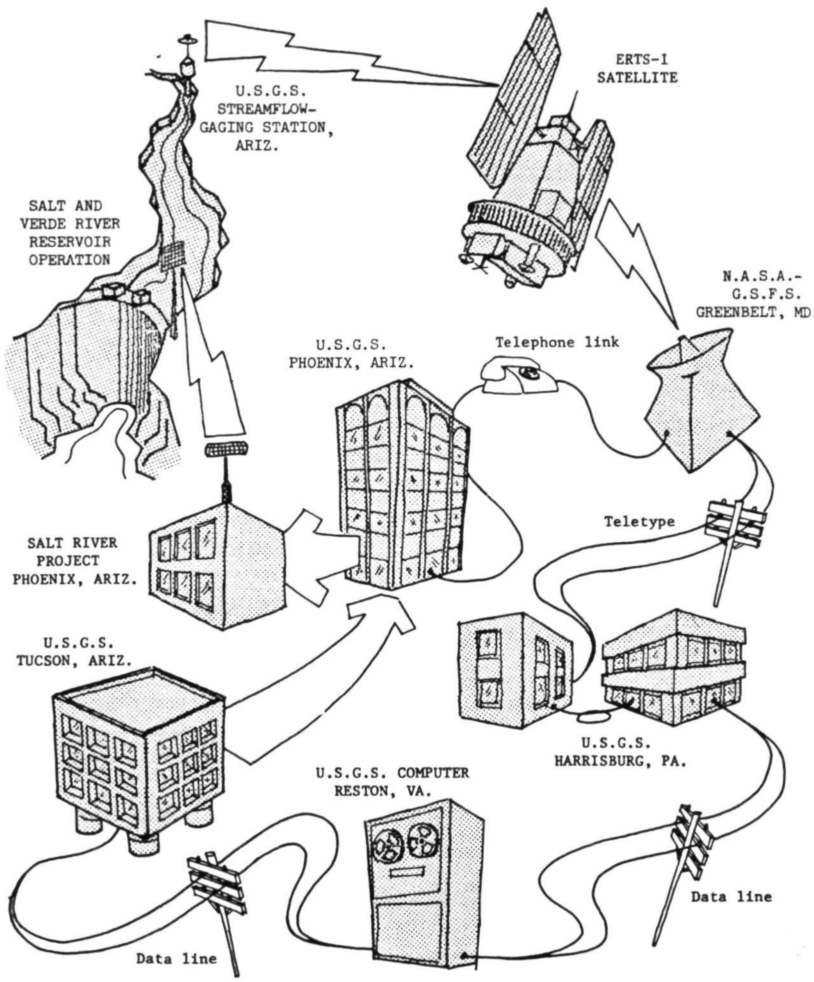

Fig. 6-LANDSAT Data Collection System operations in Arizona

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Fig. 7-White River streamflow gage near Ft. Apache, Arizona equipped with LANDSAT Data Collection Platform

Fig. 8-Snow-water equivalent measurement site at Baker Butte, Arizona equipped with LANDSAT Data Collection Platform

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relatively free of image distortion and provides sufficient resolution for operational snowcover mapping in central Arizona. However, the development of new procedures for rapid processing and delivery of the imagery, within 48-72 hours after acquisition by the satellite, will be required to allow operational utilization of the LANDSAT imagery for snowcover mapping.

The small irregular scale and relatively low resolution of NOAA VHRR and SMS/GOES meteorological satellite imagery cause it to be much more difficult to use than LANDSAT imagery for operational snowcover mapping in Arizona. However, because the meteorologic satellite imagery is available on a daily basis, it may be of significant value for monitoring the rapid changes in snowcover observed in central Arizona.

REFERENCES

1. Barnes, J. C., Bowley, C. J., and Simmes, D. A., 1974, The Application of ERTS Imagery to Mapping Snowcover in the Western United States, Final Report under Contract NAS 5-21803, Environmental Research and Technology, Inc., Concord, MA, 77 pp.

2. Schumann, Herbert H., 1974, Hydrologic Applications of ERTS-1 Data Collection System in central Arizona: in Proceedings of Third Earth Resources Technology Satellite-1 Symposium, NASA, vol. 1, sec. B, p. 1213-1223.

3. Wiesnet, D. R., and McGinnis, D. F., Jr., 1974, Snow-Extent Mapping and Lake Ice Using ERTS-1 MSS Together with NOAA-2 VHRR: in Proceedings of Third Earth Resources Technology Satellite-1 Symposium, NASA, vol. 1, sec. B, p. 995-1008.

4. General Electric Co. Space Division, 1972, ERTS Data Users Handbook: Beltsville, Penn., prepared under NASA Contract No. NAS 5-11320.