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A FEASIBILITY STUDY OF USING REMOTELY SENSED DATA FOR WATER RESOURCE MODELS

By James F. Ruff
Colorado State University
Fort Collins, Colorado 80521

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16. ABSTRACT

Remotely sensed data was collected to demonstrate the feasibility of applying the results to water resource problems. Photographs of the Wolf Creek watershed in southwestern Colorado were collected over a one year period. Cloud top temperatures were measured using a radiometer. Thermal imagery of the Wolf Creek Pass area was obtained during one pre-dawn flight. Remote sensing studies of water resource problems for user agencies were also conducted. The results of this study indicated that remote sensing techniques could be used to assist in the solution of water resource problems. Photogrammetric determination of snow depths is feasible. Changes in turbidity or suspended material concentration can be observed. Surface turbulence can be related to bed scour. Thermal effluents into rivers can be monitored.

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FOREWORD

This study was undertaken by the Civil Engineering Department of Colorado State University. The program was sponsored by the National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama and was administered under the direction of the Flight Data Statistics Office with Dr. F. R. Krause as project monitor.

The study was directed toward evaluating the feasibility of using remotely sensed data as input for a mathematical model and as information to check cloud seeding. The model would be used to estimate the net water available from the snowpack accumulated on a high mountain watershed. Cloud top temperature measurements were taken to check the hypothesis that cloud top temperatures are the strongest indicator of cloud seeding potential.

Appreciation is expressed to members of the Colorado State University faculty who assisted in the project. Dr. M. M. Skinner assisted in the original planning of the project and in the photographic mission planning and operations. Dr. A. H. Barnes directed the survey crew and the photogrammetric analysis. Grateful acknowledgement is expressed to the NASA personnel of the Flight Data Statistics Office who contributed their time and effort to this project.

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INTRODUCTION

The Colorado Rockies are the source for a number of the major river systems of the western United States. Headwaters of the North and South Platte, the Rio Grande and the Arkansas, the Colorado River and its tributaries such as the Yampa and San Juan Rivers all are fed by the snow melt which accumulates throughout the winter season in the high Colorado Rockies. These rivers provide water resources for California, Nevada, Arizona, New Mexico, Colorado, Wyoming, Nebraska, Kansas, Oklahoma, and Texas. To provide adequate management of the water resources it is necessary to start at the source of the water and that source is the available snow pack which provides the spring run-off and a major portion of the subsequent yearly flow in these river systems. The main source of the water supply in Colorado is snow. Recognizing this fact the United States Bureau of Reclamation has started a pilot project called the Skywater Program in which they have attempted to increase the snow pack in the high mountains by weather modification. Ground based cloud seeding generators are used and the program is now in the fourth year. The location of the Skywater Project test area is shown in Fig. 1. This test area covers primarily the headwaters of the San Juan and San Miguel rivers which are tributaries of the Colorado River.

Proper water resource management and prediction of run-off require knowledge of the quantity and distribution of the snow pack. This information combined with estimates of the water content in the snow should provide for better prediction of the run-off and the net water yield from the mountain basins. Due to the great variability of snow depth, areal distribution, rate of snow melt, and accessibility to the mountain sites during the winter season, the information necessary to provide adequate prediction is extremely difficult to obtain.

In 1934, Ralph Parshall of Colorado State University, surveyed and installed the first snow courses in the Colorado Rocky Mountains. Thirty-two sites were selected in the South and Middle Park areas of Colorado. These sites provided the first input data which attempted to relate snow pack to stream run-off. From that meager beginning the Snow Survey Division of the Soil Conservation Service, United States Department of Agriculture, has installed hundreds of such snow courses throughout the Rocky Mountains. These snow courses are the primary source of information to predict the water available from the run-off for a number of the rivers in the western United States. One phase of the remote sensing program was to attempt to supplement snow course readings using remote sensing techniques.

Additional samples should provide better reliability for the prediction of the net water available to downstream users. For example, the state engineer of Colorado presently is required to estimate the discharge in the Rio Grande River in order to meet the downstream water requirements of New Mexico and Texas as called for in the Rio Grande River Compact. This estimate must be made in April based upon the snow course measurements obtained during the preceding winter. Similarly, estimates of the water yield must be made to provide information for decisions regarding reservoir operations on the Colorado River and its tributaries. Adequate estimates of the water yield are needed to determine releases for power and irrigation, and to satisfy the discharge requirements at the Mexico - United

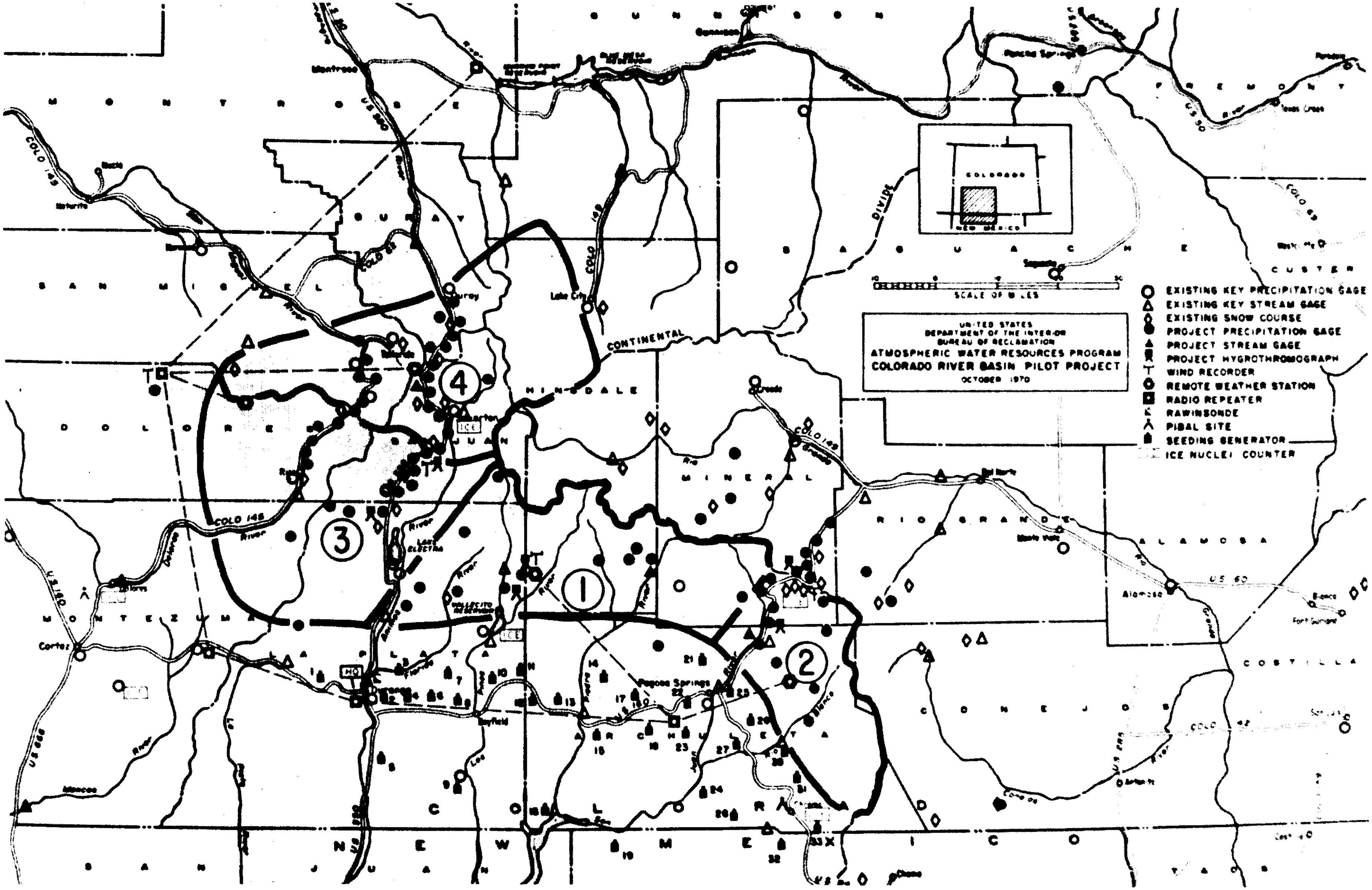

Fig. 1 - Skywater Study Area in Southwestern Colorado

States border as specified in the Colorado River Compact, an international water agreement between the two countries. The percent of the national economy that is related to forecasts based upon snow course measurements is unknown. But, it can be inferred that an inadequate estimate could affect greatly the economy of the western states. Therefore, in an effort to provide a practical method of obtaining additional samples to supplement snow course measurements, the snow depth determination phase of this study was initiated.

A small watershed in the Skywater Project test area was chosen as the site in which to perform the tests for this pilot program of snow depth determination. The West Fork of Wolf Creek located near the summit of Wolf Creek Pass was chosen because of the accessability, the number of snow courses in the watershed and the additional data that was collected in conjunction with the Skywater program. By utilizing photogrammetric techniques it should be possible to obtain a much larger number of snow depth samples. These samples would then provide an input to a hydrologic model to assist in predicting the water yield from a given watershed.

It was not the objective of this study to develop a new hydrologic simulation model. Therefore, the Stanford Watershed Model was chosen as the model to use initially. This model was known to be operational, however, it was not designed for remote sensing inputs but does contain a snow melt routine which possibly might be modified to accept the remotely obtained data inputs. Efforts to modify the Stanford Model are described by Winn (4) and were carried out in conjunction with the work reported here.

In conjunction with the photogrammetric determination of snow depth it was anticipated that multispectral scanner information would be an input to assist in determining the water yield also. The scanner was to be operated simultaneously with the photographic data collection effort in order to correlate the information obtained and reduce the amount of flight time. Development of classification algorithms and boundary detection algorithms were developed at Colorado State University in anticipation of the scanner data. These algorithms are described by Duong and Winn (4).

The scanner also was to be used to establish cloud top temperature measurements. The Bureau of Reclamation uses temperatures at cloud top height obtained with a radiosonde as input data to decide whether or not to seed a particular storm. It is conceivable that satellite mounted radiometers may be used to scan cloud top temperatures as input for operational weather modification programs. Therefore, a more detailed study of the cloud tops is needed and one phase of these project was directed at obtaining information relative to cloud top temperatures and increasing the efficiency of weather modification control procedures. Data were collected using a Barnes PRT-5 radiometer to estimate the variability of cloud top temperatures.

This feasibility study of scanner information tied in closely with work performed for user agencies such as the Corps of Engineers. Single channel scanner data was obtained over the Mississippi River and the Missouri River to identify characteristics of the river system. Photographic data were obtained over these sites also. This report describes the various facets of this project.

OBJECTIVES OF STUDY

The main purpose of this study was to determine the feasibility of utilizing remotely sensed data. Boundaries of the snow pack would be located using the thermal scanner information to determine the areal extent of available snow pack. Long range objectives were to extrapolate this data to satellite information which would provide greater coverage and more timely information for weather modification operations and water systems operation. Areal extent of the snow pack was only one aspect of the study. Determination of snow depth from photogrammetric measurements was another aspect. Determination of snow depths in inaccessable regions used in conjunction with snow depths determined from existing snow courses would increase the capability of estimating the net available water for runoff.

Evaluation of the feasibility of the three channel scanner for making measurements of cloud top temperatures was another phase of this project. The objective of the weather portion of this research was to map thermal characteristics of the tops of the orthographic cloud systems over the San Juan Mountains during the cloud seeding program of the Bureau of Reclamation. This information was to be used to check the hypothesis of cloud top temperature as the strongest indicator of cloud seeding potential.

WOLF CREEK PASS TEST SITE

General Description.- The Wolf Creek Drainage Basin is located in southwestern Colorado in the Bureau of Reclamation Skywater project test area. The mean elevation within the watershed of the West Fork of Wolf Creek is approximately 9,500 ft with the highest point at the summit of Sheep Mountain being 12,369 ft and the lowest point approximately 8,000 ft. U. S. Highway 160 traverses the region from east to west and crosses the continental divide at Wolf Creek Pass at an elevation of 10,857 ft. The continental divide borders the watershed on the east and north and the major portion of the watershed lies within the San Juan National Forest. Boundaries of the watershed are shown in Fig. 2 along with the location of snow gages within or near the watershed.

Data Collection.- All flights over the Wolf Creek Pass test site were made with the CSU Aero Commander 500-B research aircraft. The aircraft was modified specifically for this project. Two 17 inch ports with hydraulically operated doors were installed in the bottom of the airplane. Larger capacity alternators were also installed in the aircraft in anticipation of the three channel scanner power requirements.

Photography.- Photographic flights were performed over Wolf Creek Pass from November 1970 to September 1971. Table I lists the flight times, altitudes, and film type, used on each mission. The first years flight were primarily

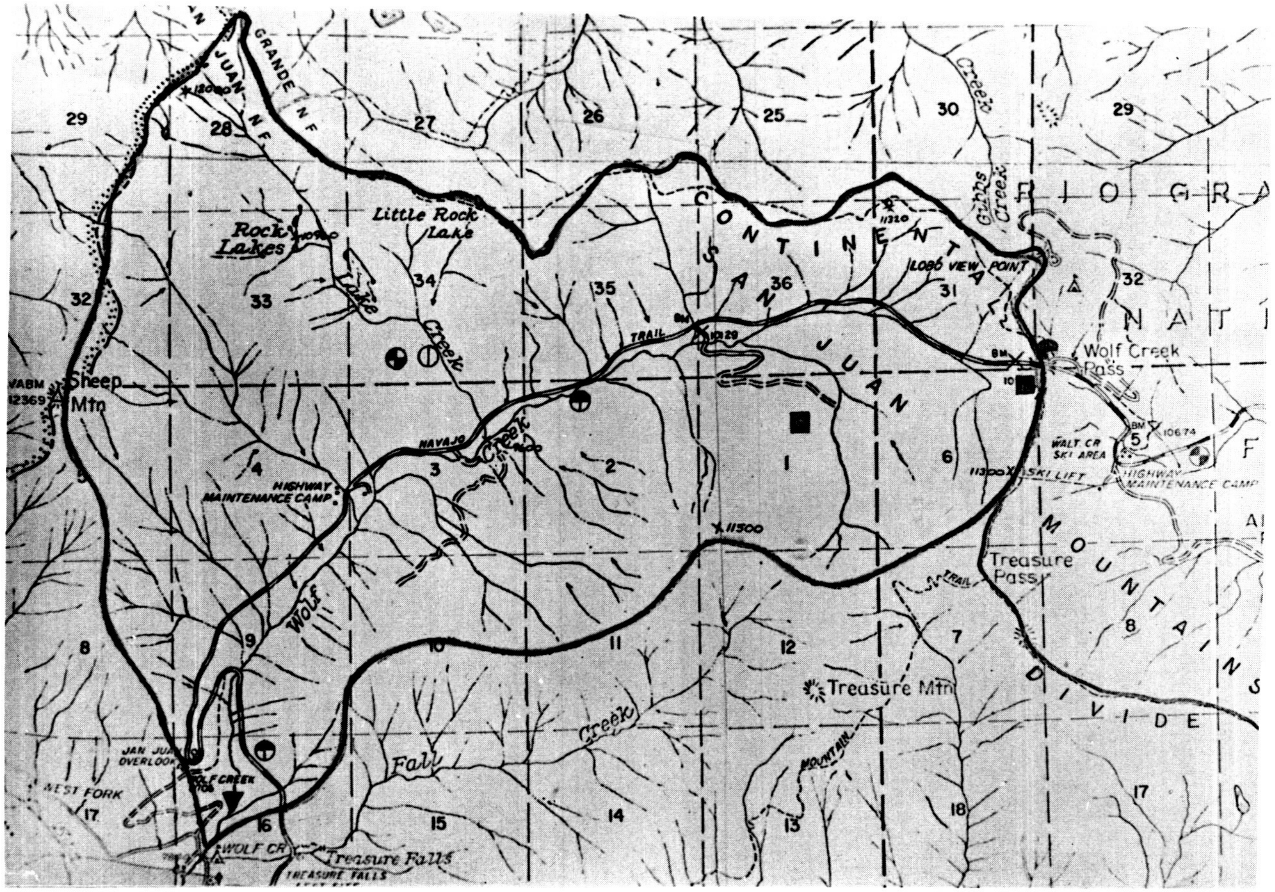

Fig. 2 - West Fork Wolf Creek Watershed

TABLE I - PHOTOGRAPHY COVERAGE FOR WOLF CREEK PROJECT

Date Flown	Area	Type of Film	Altitude (Ft MSL)	Type of Camera Used*
November 11, 1970	West Fork Wolf Creek	Color Infrared Kodak 2443 Aerochrome	18,000	1
November 11, 1970	West Fork Wolf Creek	Color Neg. 2445 Aerocolor	18,000	1
January 24, 1971	West Fork Wolf Creek Temporary Targets	Color Neg. 2445 Aerocolor	18,000 30,000	1
February 23, 1971	West Fork Wolf Creek	Color Neg. 2445 Aerocolor	18,000	1
March 13, 1971	Clouds North of Wolf Creek Pass	Color Neg. 2445 Aerocolor	19,000	1
March 19, 1971	West Fork Wolf Creek	Color Neg. 2445 Aerocolor	14,000 18,000	1
April 5, 1971	West Fork Wolf Creek	Color Neg. 2445 Aerocolor	18,000	1
April 9, 1971	PRT-5 Radiometer Calibration Flight	Color Neg. 2445 Aerocolor		1
	Red Feather Lakes & Clouds		18,650	
	Long Draw Res. Snow Fields		19,250	
	Horsetooth Res. Water		12,000	
May 1, 1971	West Fork Wolf Creek	Color Neg. 2445 Aerocolor	18,000	1
May 1, 1971	West Fork Wolf Creek	Multiband 2424 Kodak Infrared-B&W Aerographic	18,000	2

*
1 Wild RC-8 Precision Mapping Camera

2 International Imaging (I^2S) Multiband Camera

TABLE I - PHOTOGRAPHY COVERAGE FOR WOLF CREEK PROJECT (con't)

Date Flown	Area	Type of Film	Altitude (Ft MSL)	Type of Camera Used*
May 27, 1971	West Fork Wolf Creek	Color Neg. 2445 Aerocolor	18,000	1
June 8, 1971	West Fork Wolf Creek	Color Neg. 2445 Aerocolor	18,000	1
June 8, 1971	West Fork Wolf Creek	Multiband 2424 Kodak Infrared-B&W Aerographic	18,000	2
June 19, 1971	West Fork Wolf Creek	Color Neg. 2445 Aerocolor	18,000	1
July 13, 1971	West Fork Wolf Creek	Color Neg. 2445 Aerocolor	18,000	1
August 25, 1971	West Fork Wolf Creek	Color Infrared 2443 Kodak Aerochrome	14,300 18,000	1
September 6, 1971	Wolf Creek Pass Targets	Color Neg. 2445 Aerocolor	14,300 18,000	1
December 10, 1972	West Fork Wolf Creek San Luis Valley near Moffat, Colo.	Thermal Infrared Imagery 3-4.1 Micrometer 8-11 Micrometer	18,000 14,300	3

*

1 Wild RC-8 Precision Mapping Camera

2 International Imaging (I^2S) Multiband Camera

3 Modified Texas Instruments RS-7 Thermal Infrared Scanner

reconnaissance to identify areas blown free of snow and to determine if color or color infrared photographs would detect and provide the contrast necessary in the snow to place the floating dot of the Wild STK-1 Stereocomparator on the snow surface.

It was determined early in the program that precisely established ground control was necessary to make accurate measurements of snow depth. The project initially had begun after the first snows had accumulated on the watershed. For two reasons it was not feasible that winter to establish semi-permanent targets. The first was not being familar with the terrain and not knowing the locations of wind-blown, snow-free, clear areas in the watershed. Second was the difficulty of assembling and placing such targets during the winter. However, an attempt was made to provide targets within the area to check the procedures and see if such an approach was feasible. Temporary targets made from sheets of polyvinyl plastic were placed on the snow prior to the January 24, 1971 flight. The distances between the targets and the approximate relative elevations of the targets were determined from a ground survey using a theodolite and subtense bar. Photographs were taken at altitudes of approximately 30,000 ft, 18,000 ft mean sea level (MSL). Seven targets were located near the summit of Wolf Creek Pass of which five were surveyed to provide a temporary base line. The base line extended for a distance of approximately 4,000 ft and it had a change in elevation of approximately 1200 ft. Fig. 3 shows six of the temporary targets placed on the ground January 24, 1971. Near target 3 is the snow marker shown in Fig. 4. Snow depth near the marker was determined from the photographs using the Wild STK-1 Stereocomparator and compared with the measurement observed on the snow marker. The snow marker indicated a depth of 3.5 ft. The depth calculated from the Stereocomparator measurements was determined to be 4.43 ft $\pm$ 0.73 ft. There are three snow courses in the general vicinity of the snow marker at the top of Wolf Creek Pass and they are called Upper San Juan, Wolf Creek Pass, and Wolf Creek Summit (1). The courses were measured on January 18 and January 28. The snow depths at these three snow gages was relatively uniform for these dates and indicated an average depth of approximately 53 inches (4.42 ft). Table II gives the snow depths for these three snow courses measured on January 18 and January 28. Water content was determined by melting samples of snow.

An attempt was made to extrapolate points marked on the January 24 photos to those on March 19, 1971. This was not successful. It was determined that the temporary targets placed on January 24 were inadequate as the ground control necessary for photogrammetrically determining snow elevations from other photographs. Thus, further analysis of the photography obtained on January 24 was not warranted. The photographs obtained on overflights over the rest of the winter were analysed only to determine the best locations for semi-permanent targets which were to be located in windswept, snow free areas which could be seen throughout most of the year. The data utilizing the temporary targets indicated that it was practical to make snow depth measurements directly from stereo pairs of photographs provided that adequate ground control targeted points were available in the pictures. Therefore a sample area near the summit of Wolf Creek Pass was chosen and permanent targets were placed in the summer of 1971. A survey crew was sent to Wolf Creek Pass in August and placed

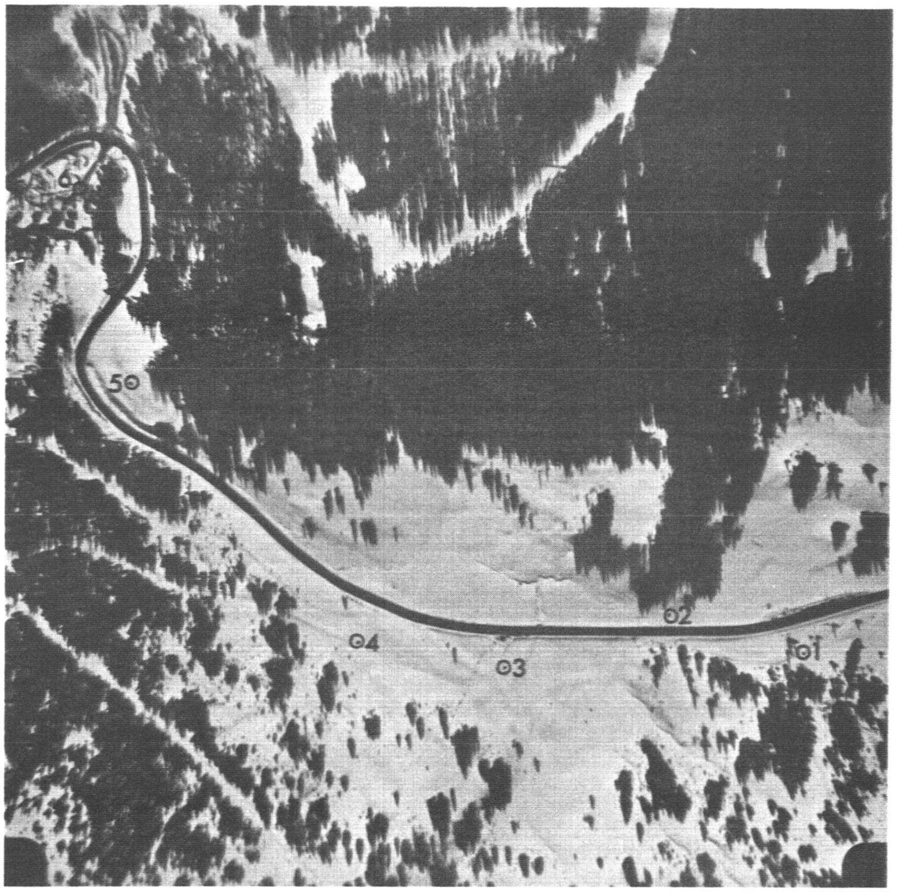

Fig. 3 - Temporary Aerial Targets near the Summit of Wolf Creek Pass

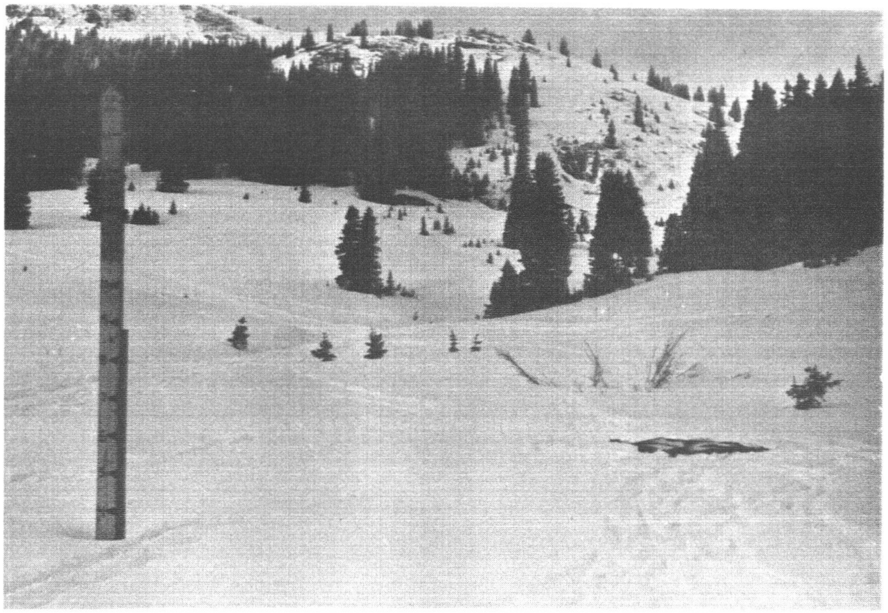

Fig. 4 - Snow Marker at Summit of Wolf Creek Pass and Temporary Aerial Target

TABLE II - SNOW DEPTHS NEAR WOLF CREEK PASS SUMMIT

Snow Course	Upper San Juan	
Date	Snow Depth (Inches)	Water Content (Inches)
1/18/71	55	17.3
1/28/71	54	17.8

Snow Course	Wolf Creek Pass	
Date	Snow Depth (Inches)	Water Content (Inches)
1/18/71	52	16.3
1/28/71	51	16.1

Snow Course	Wolf Creek Summit	
Date	Snow Depth (Inches)	Water Content (Inches)
1/18/71	55	16.8
1/28/71	54	17.3

fourteen targets at points determined from photographs of the previous year. Fig. 5 shows several locations (circled) of the targets placed by the survey crew on the road and on the ridge north and west of the Wolf Creek maintenance camp. The targets on the road were painted with road stripping paint. The targets on the hillsides and on top of the AT&T microwave station were perforated metal plates painted black. No photographic missions over the Wolf Creek Pass area were authorized after September, 1971.

Imagery.- Data were collected on several snow fields of the Montana Mountains in November, 1970 using a thermal infrared line scanner operated by the U. S. Forest Service. The Forest Service scanner is a modified Texas Instrument RS-7. The imagery format is on 5 inch film. The image is 3-1/2 inches wide and the 1-1/2 inch border provides space for annotation of the film. The scanner output was recorded on magnetic tape. These data were submitted to the Flight Data Statistics Office at NASA/MSFC for digitization. The data were to be used to develop the method of data reduction and analysis by NASA/MSFC prior to the acquisition of the three channel scanner.

The first thermal scanner imagery and data of Wolf Creek Pass were obtained on December 12, 1972. The U. S. Forest Service Aerial Fire Depot at Missoula, Montana, was subcontracted to obtain the data on Wolf Creek Pass. Two flights over the site originally were scheduled. One flight was to be near dawn and one approximately near midday. An attempt was made to scan Wolf Creek Pass on December 4, 1972, but it was aborted because of a local storm and intense cloud cover over the target area. On December 10, 1972, eight scanner runs were made over Wolf Creek Pass near dawn. Three runs were obtained at 18,000 ft and five at 14,300 ft MSL. The output from the scanner was recorded on a Sangamo Sabre III Magnetic Tape Recorder. Data was recorded in the 3 to 4.1 micrometer band and 8.5 to 11 micrometer band. Photographic coverage of the Wolf Creek Pass area taken on January 24, 1971 is shown in Fig. 6. The imagery from one pass over Wolf Creek test site at 14,300 ft is shown in Fig. 7. The lighter areas indicating a warmer temperature in the thermal imagery are the trees in the area, the darker spots are the ski area and clear cut timber areas in which snow has accumulated and can be seen without tree cover.

The analog data were digitized in the CSU computer center. The first effort at analysis of the data was a voltage level slicing which was an attempt to reconstruct a grey level map which could be compared to the original imagery. The computer developed grey level map corresponding to Fig. 7 is shown in Fig. 8. The noon flight on December 10, 1972 was cancelled because of clouds.

Cloud Top Temperatures.- Detailed measurements of cloud top temperatures were made for a cold orographic cloud near Wolf Creek Pass on March 13, 1971. The measurements were made using an airborne radiometer with a 2° field of view. Eleven passes over the cloud which covered a total of 5 hours were made during a one day period. The data was analysed by Rasmussen and Balick (4) and their results showed that the cloud tops are highly variant in space and time and give the appearance of cumulus cells embedded within the cloud. They correlated cloud top temperatures with

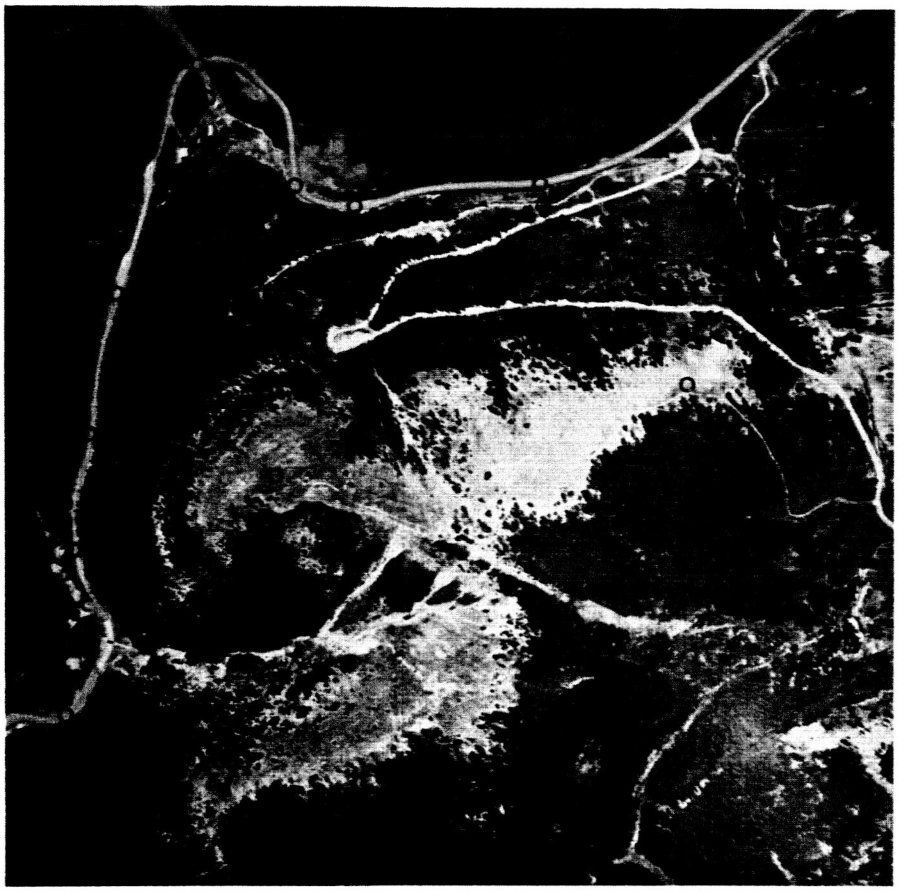

Fig. 5 - Location of Semi Permanent Targets near
Summit of Wolf Creek Pass

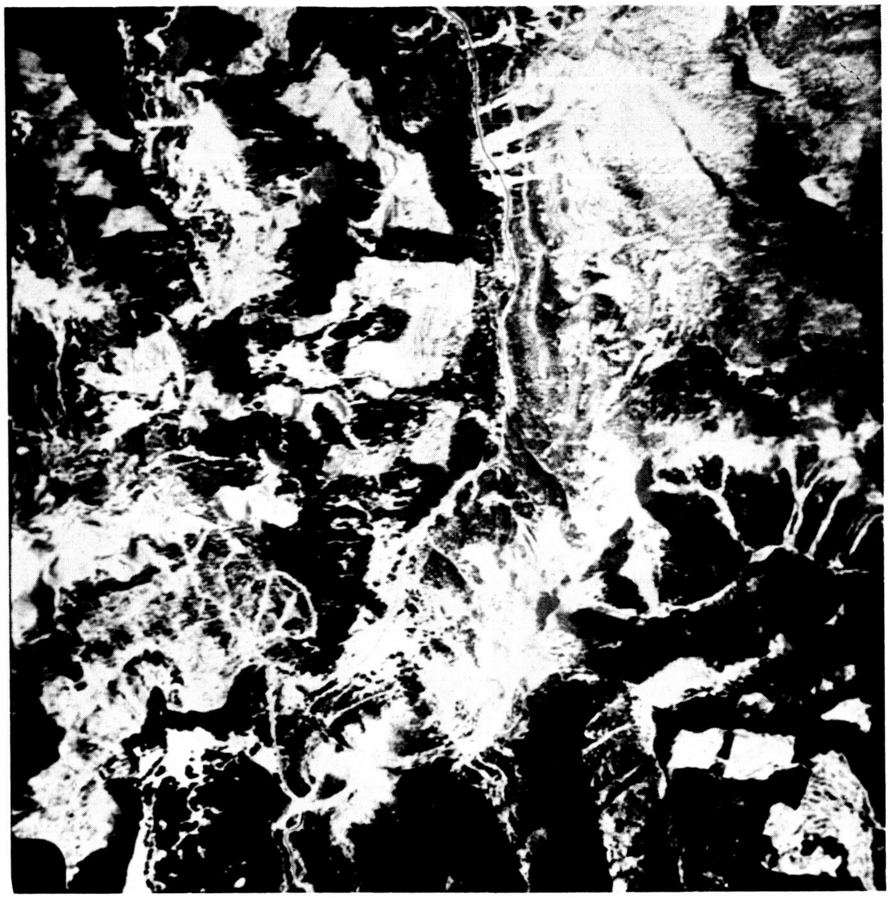

Fig. 6 - Aerial Photograph of Wolf Creek Pass area taken at approximately 30,000 ft MSL on January 24, 1971

Fig. 7 - Thermal Infrared Imagery of Wolf Creek
Pass Area (8.1-11 micrometers)

Fig. 8 - Computer printout reconstruction of grey levels from digitized Thermal Infrared Scanner Output of Wolf Creek Pass

rawinsonde data obtained on the same day and found that the remotely sensed temperature corresponded with the rawinsonde data but the variability of cloud top temperatures was so great that for weather modification control purposes the point radiosonde measurements do not adequately describe the cloud top.

In addition to the measurements over the Wolf Creek Pass clouds, a calibration flight was performed to correlate the radiometric data with photographs and graphic data recorded simultaneously on film and on a Moseley strip chart recorder. A number of small clouds were overflown in an area over the mountains northwest of Ft. Collins, Colorado. Radiometric temperature was recorded and digitized to provide temperatures at one second intervals. Photographs of the clouds were taken at approximately five second intervals. Radiometric temperatures are superimposed on top of the cloud and topography in the photograph of Fig. 9. The temperature plot is in terms of time and does not correlate exactly with the photograph which is an instantaneous picture. Only a small portion of the photograph near the center can be related to the radiometer data with any reliability because of the movement of the aircraft, the movement of the cloud, and the ground topography. The time interval between exposures of two successive photographs established the scale between center points of the successive photographs. This scale was used in correlating times and, therefore, temperatures on the photographs.

RELATED PROJECTS - MISSISSIPPI RIVER - MISSOURI RIVER

Colorado State conducted remote sensing feasibility studies for the Corps of Engineers on the Mississippi River and the Missouri River. The two studies were related to problems of sedimentation and to monitoring of effluent into the rivers. Remote sensing data collected over the site included both photographic coverage and thermal infrared scanner imagery. The Corps of Engineers studies, although not directly related to the NASA study, provided scanner information and familiarity with scanner data. The experience gained on these studies was expected to assist in the data collection, interpretation, analysis of the three channel scanner data and aerial photography. From the Mississippi River test (3) it was found that color infrared photography enhanced the flow pattern in the river because of the differences in suspended material concentrations. The enhanced flow patterns were observed as turbulence on the water surface, shear zones, mixing zones and regions of high velocity flow. Visualization of these flow patterns had not been accomplished before. This new information, in conjunction with ground truth data collected by survey teams on the river at the time of the overflights, was used to identify areas of high and low suspended sediment concentrations, to local areas of scour, to evaluate the relative depth of water immediately adjacent to banks or bars, and, in some cases, to identify the main thalweg of the river.

Fig. 10A shows the area near Range 413.2 above Head of Passes (AHP) on the Mississippi River. This is a black and white reproduction of a color infrared photograph and shows the eddy pattern generated by a chute flow and a bend way flow recombining downstream from a small island. The

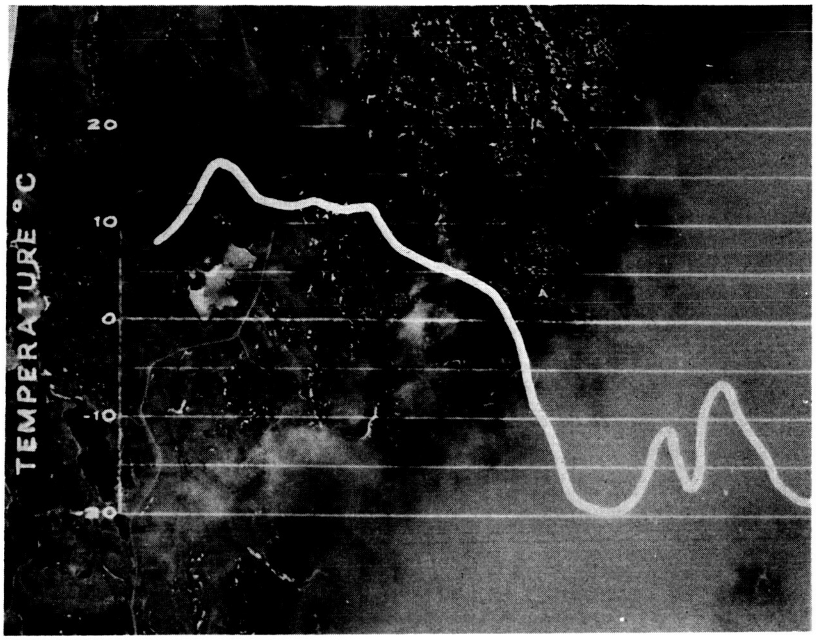

Fig. 9 - Radiometric temperature superimposed on an aerial photograph of cloud

Fig. 10a - Eddy Pattern near Range 413.2 (AHP)
on the Mississippi River

Fig. 10b - River Bed Contours at Range 413.2 (AHP) on
the Mississippi River

diameters of the eddies vary between approximately 200 ft and 500 ft as they move downstream. This eddy pattern is the result of turbulence generated by the recombining flows and is expected to cause scour immediately under the eddy as can be ascertained by the bed contours for this area which are superimposed on the photograph shown in Fig. 10B. Similar flow patterns can be observed around man-made structures. Fig. 11A shows a black and white reproduction of a color infrared photograph in the vicinity of Range 486.4. The dikes observed in this photograph are the Ben Lomond Dikes and are located near Lake Providence, Lousiana. Turbulence can be observed at the water surface near the upstream and downstream end of each dike. The turbulence generated by the dikes assists the observation of the flow pattern through this dike field. Scour can be expected to occur in the vicinity of the observed turbulence and is demonstrated by the hydrographic surveys shown by the superimposed contour lines shown on Fig. 11B. Turbulence near the left bank is observed also, and the accompanying scour is verified by the hydrographic survey. The thermal imagery for this same area is shown on Fig. 12. The imagery shows a relatively uniform grey level across this range indicating uniform temperatures. This observation is confirmed by measurements made by the survey crews which indicated the maximum temperature difference of 0.5°C.

Water surface temperature patterns were not observed on the Mississippi River due to the extremely uniform temperatures encountered and measured by the survey crews. However, scanner information can be used to find relative depths of water immediately adjacent to bank or bar from an estimate of the width of the cool band of wet sand near the edge of the deposit: the wider the cool band of moist soil; the shallower the water adjacent to the bar.

Thermal infrared imagery is extremely useful for monitoring thermal effluent into a river. Fig. 13 shows a black and white reproduction of a color infrared photograph of a power plant on the Missouri River near Omaha, Nebraska (2). No apparent effluent from the plant can be seen in the river, on the photograph. However, the thermal infrared imagery of this same plant, shown in Fig. 14 which was taken at a later date, shows the effluent from the plant entering the river from the right bank. A difference in temperature between the effluent and the river at the point approximately 100 to 200 ft downstream from the outfall is approximately 5°F with the river temperature at 67° and effluent at 72°F.

THREE CHANNEL SCANNER

The examples cited above show applications for which the three channel scanner might be utilized. Practical applications for the three channel and cooperation with user agencies was encouraged throughout the program.

One phase of the overall NASA/MSFC project was to use a thermal infrared line scanner for detection of selected ground features. It was anticipated that initially, through the use of classification algorithms, four features could be identified and the boundaries between the features

Fig. 11a - Flow Patterns identified from surface turbulence near Range 486.4 (AHP) on the Mississippi River

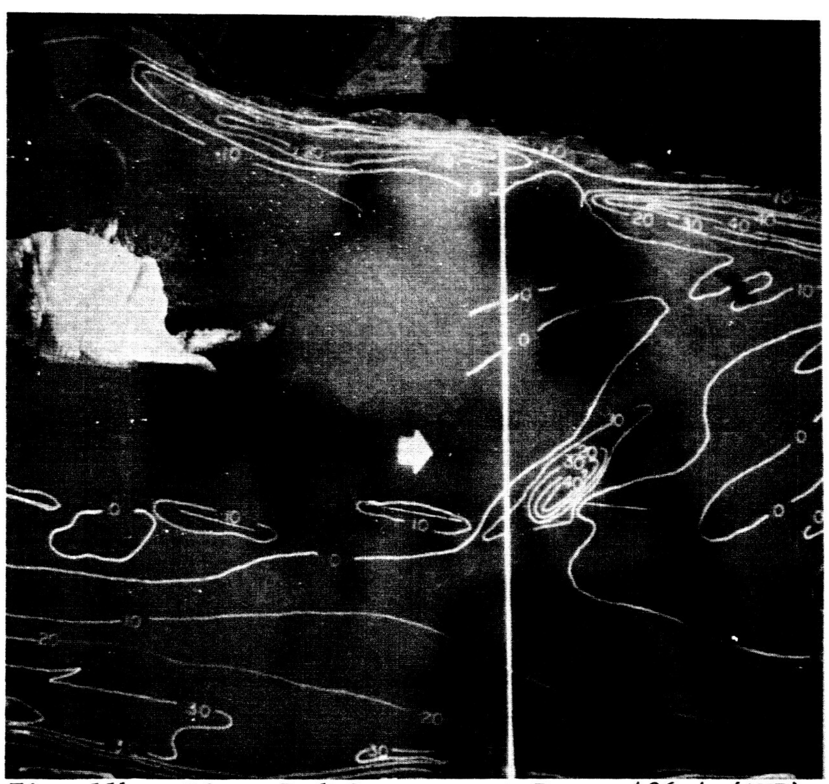

Fig. 11b - River Bed Contours at Range 486.4 (AHP) on the Mississippi River

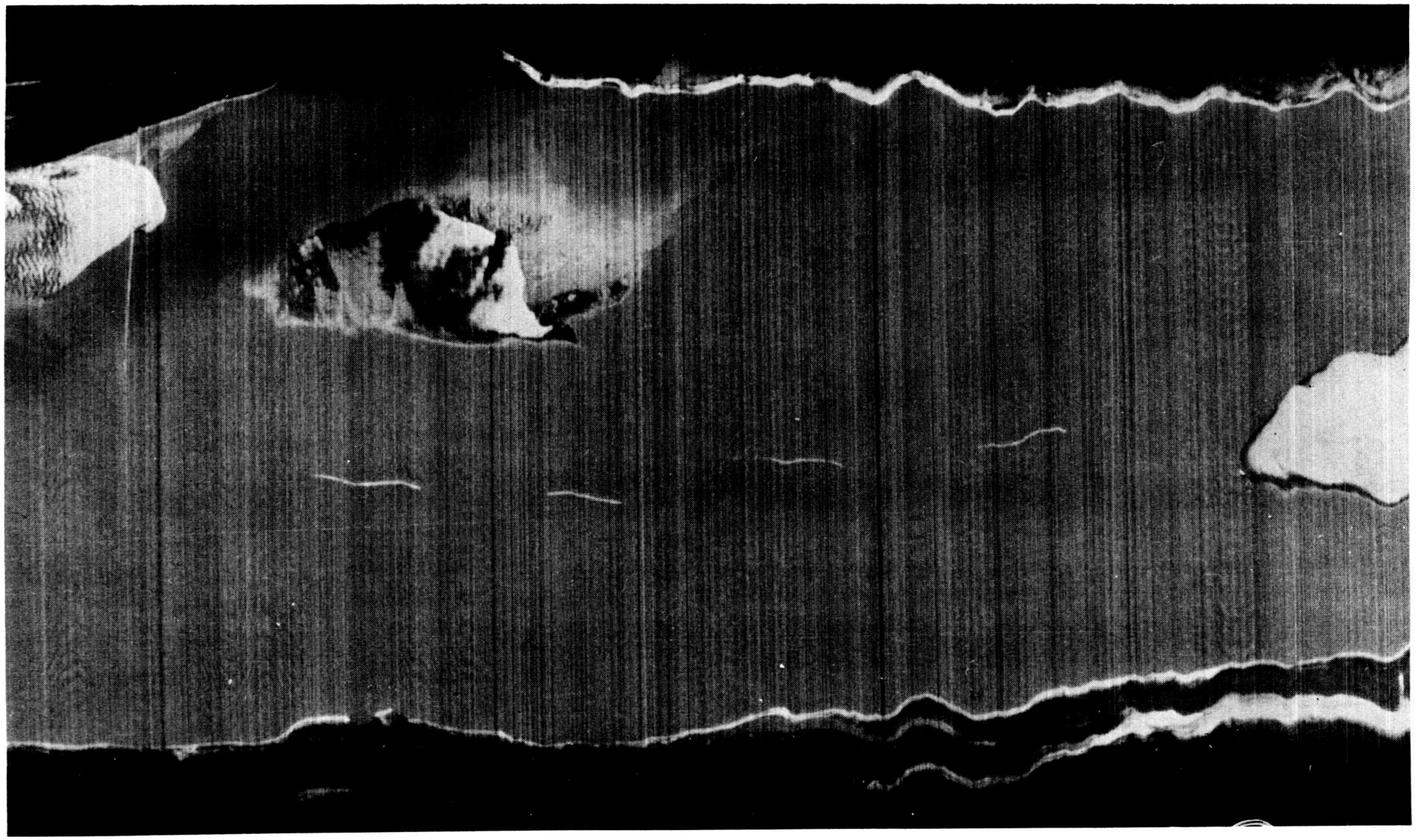

Fig. 12 - Thermal Infrared Imagery at Range 486.4 (AHP)
on the Missisippi River

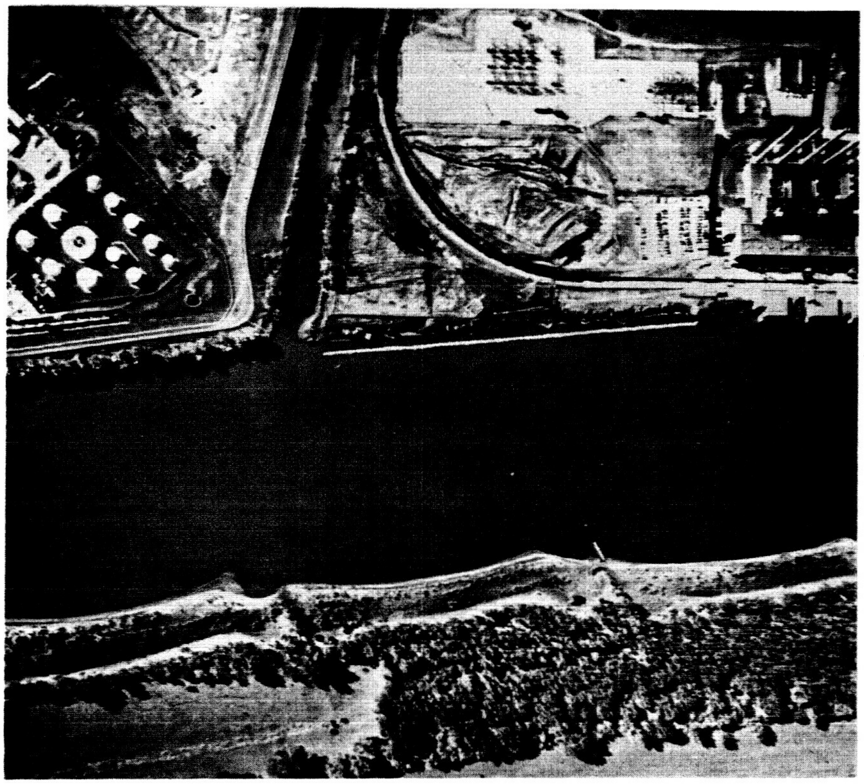

Fig. 13 - Omaha Public Power Department Power Plant on the Missouri River near Omaha, Nebraska. (NOTE: effluent can not be observed)

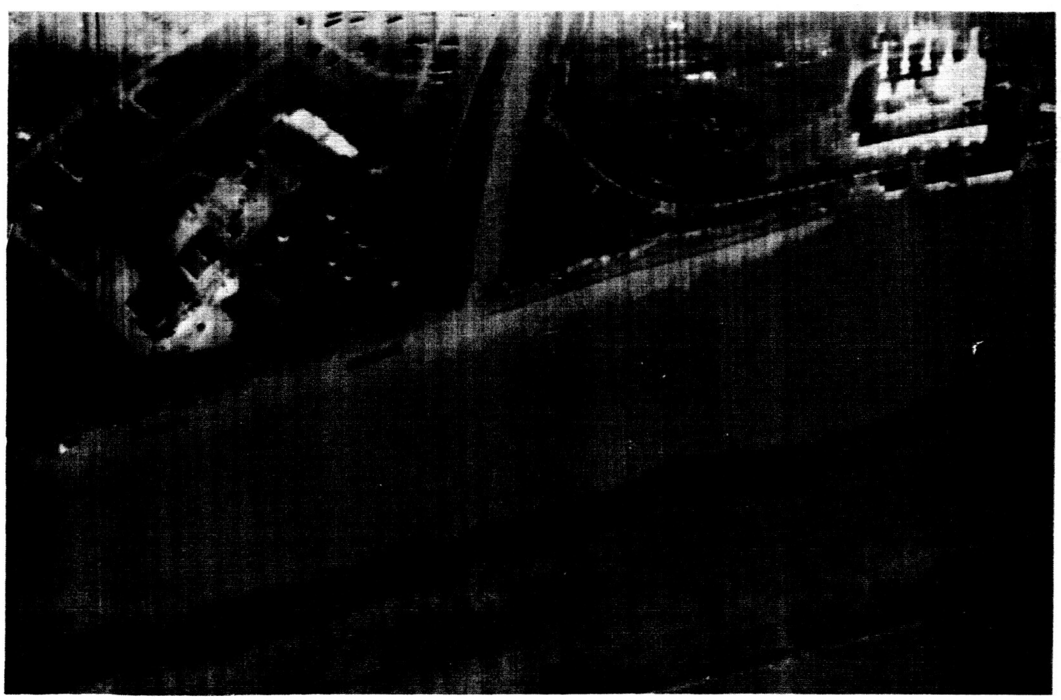

Fig. 14 - Thermal Infrared Imagery of O.P.P.D. Power Plant on Missouri River near Omaha, Nebraska (NOTE: effluent along right bank)

could be detected. The four features were bare ground, snow, water, and trees. Everything else would be lumped into a fifth classification which would not be identified specifically. Since this objective of this study was never realized, perhaps a short chronology of the scanner development, short term objectives and long term objectives of three channel scanner operation may be in order.

The three channel scanner was to be furnished by NASA Marshall Space Flight Center, to Colorado State University for use on this project. Initially it was expected that the scanner would be used to measure cloud top temperatures, to identify snow fields boundaries as the snow fields receded in the spring time, and to estimate water vapor mass in the atmosphere. The boundary location would be used to provide an estimate of the areal extent of the snow pack on a given watershed..

Ultimately, the results from this study would be extrapolated to satallite recorded data to determine cloud top temperatures, snow boundaries and water vapor mass in the atmosphere. From the Wolf Creek Pass photographs, it was observed that color infrared photographs of the snow fields provided better contrast in the snow than normal color or black and white photographs. The color infrared film is sensitive to wavelengths from 0.4 to 0.9 micrometers and is filtered to eliminate wavelengths less than 0.5 micrometers when exposed. Normal aerial color film is sensitive to wavelengths from 0.4 to 0.7 micrometers. It was felt additional information could be gained from the scanner system if this portion of the spectrum was included and correlations were made between the different portions of the spectrum. Originally a single channel scanner was anticipated. In light of additional developments it was felt that a two or three channel scanner or a multi channel scanner might be more advantageous for the classification algorithms to define snow, water, vegetation, and the earth, soil, and rocks. Therefore, NASA recommended that a three channel scanner be furnished to Colorado State University. Bendix Corporation of Ann Arbor, Michigan, was awarded the contract to build such a scanner.

In order to increase the efficiency of data processing and the flow of information from the scanner to the user, additional modification of the scanner was made to provide for direct digital recording of the data. The electronic interfacing package was to be compatable with the computer facilities at Marshall Space Flight Center. The design and construction of the modified thermal infrared scanner and peripheral analog digital electronics were completed in September, 1971 and delivered to Marshall Space Flight Center.

The CSU Aero Commander was dispatched to Huntsville for installation of the scanner in late October, 1971. The scanner was installed in the aircraft on October 29, 1971. Power for the scanners was supplied by nickel cadmium batteries. A test flight was made with the objective of obtaining a magnetic tape and a thermal infrared image on film of the Brown's Ferry Nuclear Power Site. In the initial run a film strip was obtained and a portion of that film strip showing the Brown's Ferry Nuclear Power Plant Site is shown in Fig. 15. The magnetic tape recorder did not operate properly. The power drain on the batteries was to great and the

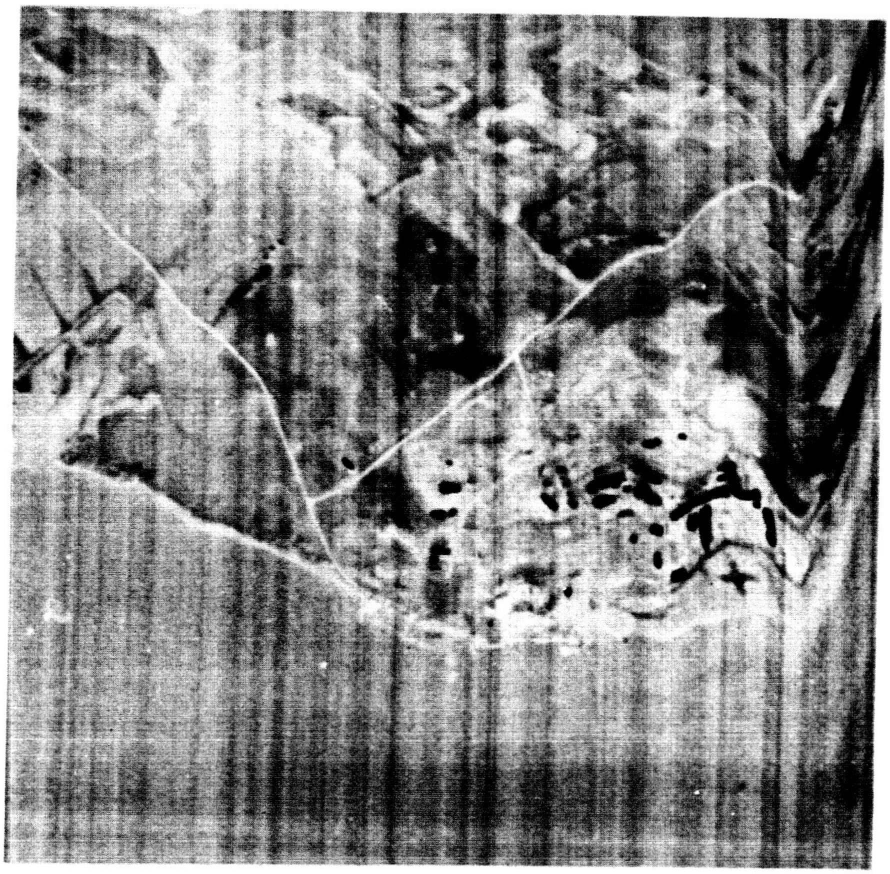

Fig. 15 - Thermal Infrared Imagery (8-14 micrometer band) on Wheeler Lake of Browns Ferry Nuclear Power Plant Site obtained with the NASA/MSFC three channel scanner.

recorder would not lock in the record mode when activated. After examining the processed imagery obtained on the initial flight it was apparent that the gain settings on the scanner needed to be increased. (NOTE: No manual had been supplied with the scanner at this time.) Freshly charged batteries were installed in the aircraft and an attempt was made to avoid such a rapid power drain on the batteries as had occured on the previous flight. The scanner system was hooked up primarily to the aircraft power. A ground test of the system was made but the aircraft breakers were thrown since the generators could not handle the current required by the scanner. The configuration used on the previous attempt again was made. After take off, the units were turned on and before starting the tape recorder, the voltage of the batteries was checked. Over approximately a five minute period the voltage dropped from 31.6 volts at no load to approximately 6.5 volts under full load of the scanner system. At this point it was decided to terminate the tests and return to the airport. The scanner was removed from the aircraft and returned to Marshall Space Flight Center. These tests demonstrated that the existing aircraft power was not sufficient for scanner operations. Therefore, it was decided to install larger capacity alternators in the CSU aircraft to handle the power requirements of the three channel scanner.

In view of the aircraft flights with the scanner in operation the objectives of the study were reevaluated and are reiterated here. The three channel scanner was to be assessed by CSU to evaluate its potential as an atmospheric water vapor measurement device and as a tool for detecting and establishing changing snow field boundaries. It also would be used as a device for providing raw data for the determination of physical characteristics of the watersheds through the use of recognition algorithms developed at the Flight Data Statistics Office NASA/MSFC. It was anticipated that these objectives could be accomplished by correlating the three bands and by specifically observing the opacity of air masses to reflected energy in the atmospheric transmission window at 0.85 microns and in the minor water vapor absorption band at 0.93 microns. In addition to the short term objective listed above it was expected that the results could be applied to long term objectives. There were two long term objectives: to detect the amount of water vapor transmitted to the atmosphere from the snow mass and from vegetation through evapotranspiration; to evaluate the amount of water vapor in a column between the earth and the sensor. Monitoring of the volume of snow pack also was anticipated. This would be accomplished by determining the areal extent from scanner data and to establish depths photogrammetrically from aerial photographs. This snow volume would provide the input for a hydrologic simulation model.

On July 25, 1972, representatives from CSU traveled to Huntsville to observe ground tests of the three channel thermal scanner. The ground tests were to be performed to insure that the scanner was operational before the aircraft was returned again to Marshall Space Flight Center for installation of the scanner. These ground tests were made also to provide data to check the data processing loop to determine time requirements for data processing and analysis. Fluctuations in the voltage level of the power supply to the scanner created numerous problems during these ground tests. The test series was delayed because several circuits were damaged by the fluctuating voltage level. Additional tests were performed a few weeks later from the ground test stand to evaluate the scanner. Data from the scanner were recorded and the data processing loop was being checked when the project was terminated. The key to this portion of the entire project was the three channel thermal scanner. Upon receipt of the termination notice, graduate students were reassigned to other projects and all operations of this project were phased out. All photographic records for the Wolf Creek flights were cataloged and filed.

SUMMARY

The principal goal in this program was to determine the feasibility of applying remote sensing techniques to the management of water resources. This goal was to be accomplished by assessing the potential of the three channel thermal scanner as an atmospheric water vapor measurement device, as a tool for detecing and establishing changing snow field boundaries, and as a device for providing raw data for the determination of physical characteristics of watersheds through the use of recognition algorithms developed at the Flight Data Statistics Office NASA/MSFC. These objectives were never fully realized. It was determined that it was feasbile to measure snow depths using photogrammetric techniques within the watershed. Temporary targets, placed prior to the over flight of January 24, 1971, were not adequate to assess the snow depth within the watershed. Semi-permanent targets were surveyed in place in August, 1971. Photographs of Wolf Creek Pass throughout the snow season after placement of these targets were not obtained because of lack of authorization for photographic flights over the Wolf Creek watershed after August, 1971.

Assessment of cloud top temperatures was made using a Barnes PRT-5 radiometer over the Wolf Creek Pass area. This was a prelude to cloud top temperature measurements using the three channel thermal infrared line scanner. The results of this study showed cloud top temperatures are highly varient in space and time and in this particular cloud study gave the appearance of cumulus cells imbedded within the cloud.

Dual channel thermal infrared scanner data were obtained over Wolf Creek Pass in December, 1972. These raw data will be used to verify algorithms which were developed at CSU by Duong and Winn to identify boundaries of snow, trees, and earth. Similar data had been collected earlier over snow fields in Montana and transmitted to Marshall Space Flight Center in order for them to develop the data processing procedures and algorithms for classification of ground features such as snow, bare ground, vegetation, and water.

Studies in conjunction with user agencies were encouraged by NASA/MSFC. Two studies were undertaken in cooperation with the Corps of Engineers. Remote sensing techniques were used over test sites on the Mississippi River near Vicksburg, Mississippi, and on the Missouri River near Omaha, Nebraska. Flow patterns were greatly enhanced on color infrared film and indicated areas of scour caused by turbulence generated by high velocity flow or by shear zones of recombining flows. Relative flow depths near sand bars could be assessed from the shape of sand bar edges and from the width of cool sand adjacent to the water line on sand bars. Thermal effluents, which could not be detected with normal or color infrared photography, could be monitored using the thermal infrared line scanner.

The three channel thermal scanner was never fully operational during this study. It was installed in the CSU aircraft for one preliminary test flight and thermal infrared imagery of the Brown's Ferry Nuclear Power Plant site was obtained.

REFERENCES

1. Snow Survey Phase of Park Range and Colorado River Basin Pilot Project, Atmospheric Water Resources Programs of the Bureau of Reclamation, United States Department of the Interior, Prepared by Soil Conservation Service, Denver, Colorado, 1971.

2. Skinner, M. M. and Ruff, J. F., Color Infrared Photography and Thermal Infrared Imagery of Selected Locations Along the Missouri River Between Omaha and Blair, Nebraska. Report prepared for the Corps of Engineers, Omaha District, June, 1972. CER71-72MMS-JFR49.

3. Skinner, M. M., Ruff, J. F., and Barnes, A. H., The Use of Remote Sensing to Obtain Data for Describing the Large River. Report prepared for the Corps of Engineers, Vicksburg District, Vicksburg, Mississippi, November, 1972. CEP72-73MMS-JFR-AHB20.

4. Winn, C. Byron, Johnson, Gearold R., Ruff, James F., and Rasumessen, J. L., Snopset-NASA NAS8-21049, June, 1972. ME72-2.