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# Landsat Digital Analysis of the Initial Recovery of the Kokolik River Tundra Fire Area, Alaska

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ABSTRACT

During late July and early August 1977, a wildfire burned a 48 square kilometer area in the tundra of northwestern Alaska near the Kokolik River. The environmental effects of the fire were studied in the field and from aircraft and Landsat data. Three categories of burn severity were delineated using an August 1977 Landsat scene acquired shortly after the fire stopped. Measurable reflectance increases occurred in all three categories of burn severity by the following year as determined from a Landsat image acquired in August 1978. Regrowth of vegetation in the one year period following the fire was measured using Landsat digital data and compared with field measurements from selected portions within the burned area. Live ground cover increased 50 percent in the severely burned portions of the burned area and 50 – 75 percent in the lightly burned portions as determined from field measurements. Landsat-derived measurements showed an increase of 62.5 percent in reflectance for the severely burned areas, and 53 percent for the light burned areas, which is attributed to regrowth of vegetation. The most severely burned portion of the burned area decreased by 9.6 square kilometers in area in approximately one year according to measurements made using Landsat data. Within the lightly burned portion, 5.9 square kilometers had completely recovered based on spectral response. Prefire terrain and vegetation conditions were also found to influence burn severity. Field measurements showed that high relief areas generally burned more completely than lower lying areas. Satellite data before and after the fire confirmed this for much of the burned area.

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# LANDSAT DIGITAL ANALYSIS OF THE INITIAL RECOVERY OF THE KOKOLIK RIVER TUNDRA FIRE AREA, ALASKA

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## INTRODUCTION

Numerous tundra and forest fires occurred in northwestern Alaska during July and August of 1977 due to drought-like conditions which prevailed during that summer (Ernst and Matson, 1977). One such fire, started by lightening, burned several kilometers southwest of the Kokolik River in the tundra of northwestern Alaska at 69°30′N, 151°59′W, and spread to a maximum extent of 48 square kilometers. The Kokolik River fire burned from approximately July 26 to August 7, 1977, and was fought by Bureau of Land Management (BLM) fire fighters between July 27 and July 31, after which it was contained by drainage relief (Hall et al., 1978a).

Understanding the effects of disturbances, such as wildfire, to the tundra surface is becoming increasingly important because of activities related to present, planned or projected oil and mineral exploration and extraction in northern Alaska. Analysis of the short- and long-term impacts of surface disturbances is critical to an understanding of the physical processes operating in permafrost regions. Fire may significantly alter the tundra by increasing the thickness of the active layer of permafrost, or it may produce no appreciable effect. The active layer is defined as the seasonally thawed portion of the surface overlying permafrost and has a thickness of up to 0.5 m on the Arctic Slope of Alaska. The increase in the thickness of the active layer may last for decades depending upon the behavior of the fire and the type and proximity of ground ice to the surface. The long-term effects of fire in permafrost regions remain to be evaluated (Brown and Grave, 1979; Viereck, 1973).

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The purpose of this paper is to provide results demonstrating that first-year recovery of vegetation in the Kokolik River burned area was considerable, and that Landsat data can be used to delineate and monitor recovery of different severities of burn. Indications of the recovery process, as expressed in the relative regrowth of vegetation, were measured using digital Landsat data.

## GROUND AND AIRCRAFT OBSERVATIONS

### Ground Observations

After the fire ceased burning in August 1977, a field party including one of the authors (L. Johnson) landed within the burned area to make ecological observations. From the observations it was estimated that 80–90% of the tussock vegetation, Eriophorum vaginatum, was consumed in the fire with less than 10% live vascular cover remaining in high relief areas and 30% live vascular cover remaining in areas of wet, low relief (Hall et al., 1978a). The depth of thaw averaged 26.6 cm in unburned areas compared to 35.4 cm within the severely burned areas.

Locations of field observations taken again approximately one year later, in August 1978, are summarized in Figure 1. A ground transect crossed lightly, moderately and severely burned portions of the burned area. The 1977 transect extended from the center of the southern part of the burned area eastward to the edge of the burned area with an unburned control plot to the east (control area 1, C1, on Figure 1). Additional study areas, established in 1978, were located on a small drainage area or swale just east of the large lake, on the eastern edge of the burned area, and in an unburned area due east of the large lake (control area 2, C2, on Figure 1). Other areas observed included small unburned areas of the ridgetop with rocky outcrops and different vegetation types on the eastern half of the fire and between the two lakes.

The severity of the burn varied greatly among the observed areas as did the vegetation types. Similarly, there is a great deal of heterogeneity in tundra vegetation due to variations in microtopography. This greatly complicates patterns of burn severity and vegetation recovery on the tundra. Hence the following observations are general.

Cottongrass tussocks (Eriophorum vaginatum) dominated the two control areas along the eastern border of the burn although associated shrubs and herbs much like those described by Johnson et al. (1966) were also observed. There were no control areas for the swale and the high-centered polygons. (High-centered polygons are interconnected ice wedges with raised centers, the 0.5 – 2.0 m positive relief resulting from formation of ice wedges in the surrounding troughs.) The severity of burning was so light in the swale that the vegetation was clearly discerned as a wet meadow community (Eriophorum augustifolium - Carex aquatilus) (Johnson et al., 1966). However, the original vegetation type of the high-centered polygon area is not discernable due to the severity of burning although some burned willow stems remained. The high-centered polygons are located just above and to the east of the large lake. The swale is adjacent to the large lake and just north of the polygons.

Table 1 presents the estimates for live vegetation cover from the 1977 and 1978 ground observations of the burned areas. The field observations showed significant recovery of live ground cover in most categories of burn severity between August 1977 and August 1978. For example, in control area 1, C1, there was 80% vascular plant cover and 50% lichen and moss cover and in a nearby low relief burned area only 5% lichen and moss cover was present in 1977 increasing to 10% in 1978. Forms of recovery were generally by resprouting, especially in the case of the cottongrass, by reinvasion of mosses, and by limited establishment of seedlings. Although no 1977 observations were available for the high-centered polygon area, the August 1978 ground cover measurements indicate dramatic recovery especially by the liverwort, Marchartia polymorpha, and the moss, Certodon purpureus. Recovery of vascular plant cover was less than 10%.

## Satellite and Aircraft Observations

In conjunction with other measurements in northern Alaska, the NASA Convair 990 instrumented aircraft was flown over the site of the Kokolik River fire area on July 12, 1978. A false color infrared image was obtained during that flight and is the base map shown in Figure 1.

Landsat images obtained before, during and after the fire in 1977, and also during August of 1978 were analyzed. The Multispectral Scanner Subsystem (MSS) on the Landsat satellite provides 80 m resolution images in four wavelength bands: visible (Band 4: 0.5 - 0.6 $\mu$m and Band 5: 0.6 - 0.7 $\mu$m) and near-infrared (Band 6: 0.7 - 0.8 $\mu$m and Band 7: 0.8 - 1.1 $\mu$m). Band 5 was found to be best suited for the determination of atmospheric contamination such as smoke, haze and clouds. The wind direction can be inferred from blowing smoke and hence the direction that the fire was moving could be determined. Band 7 was found to be best suited for determination of the areal extent of the fire due to the sharp contrast between vegetated and burned areas (Hall et al., 1978b).

## LANDSAT DIGITAL DATA ANALYSIS TECHNIQUES

Landsat scenes obtained before the fire (July 16, 1977), shortly after the fire had stopped (August 21, 1977), and approximately one year after the fire (August 14, 1978) were selected for digital analysis on the Atmospheric and Oceanographic Image Processing System (AOIPS) at Goddard Space Flight Center. The system provides a capability to classify a 512 x 512 pixel (picture or resolution element) subscene by using various routines which employ one to four MSS bands. The single channel density slice was found to be most useful for the present analysis.

Before the classification, a subscene of the burned area was extracted from each of the three scenes and saved on tape. A four times enlargement was made by requesting a 256 x 256 pixel portion of the raw data and inputting it to the 512 x 512 pixel size television screen on the AOIPS. This provided good visual definition of the surface features.

The prefire scene, July 16, 1977, and the August 21, 1977 scene were taken 36 days apart, a multiple of the 18-day Landsat repeat cycle. These two scenes were easily registered on the AOIPS screen using an X and Y translation. However, the scene acquired on August 14, 1978 was not on the same subsatellite track. Consequently, registration of that scene to the other scenes was more difficult and involved the use of an affine or linear transform routine which is available on the AOIPS. Features common to both the 1977 and 1978 scenes, such as the thaw lakes surrounding the burned area, were used to define common points within the subscenes. Printouts of the land/water interfaces in all scenes showed that the fit or registration was within one or two pixels.

Band 7 was used for the single channel density slice classification. There exists maximum reflection from vegetation and maximum absorption by water in Band 7. This provides the best contrast compared to the other MSS bands between water and vegetation, and between vegetated and burned areas.

Initially the computer was instructed to divide the gray levels within the scene and display the results on the eight theme tracks. All eight theme tracks were not required for the classification of the subscene of the burned area due to relative uniformity of ground conditions. Reflectance values for each theme (within each subscene) are presented in Tables 2 and 3 and range from 0 to 111 out of a possible 256 digital counts. For example, moderately burned areas ranged from 13 – 24 in 1977 and 32 – 51 digital counts in 1978.

On the prefire scene (July 16, 1977), the initial density slice of Band 7 resulted in good definition of water areas, drained lake basins, stream channels, wet meadows characteristic of swales, and tussock covered higher ground. A second density slice using a smaller range of gray levels was performed resulting in better definition of water and drained lake basin themes. The better results from these two density slices were then combined and retained.

The prefire scene was analyzed in order to determine the spectral response of the unburned tundra and to assess ground cover with differing propensities for burning. Drained lake basins show up clearly in the prefire scene (Figure 2) because they represent moist surface conditions. These conditions occur predominately in lower areas and near streams. Ground cover intermediate in moisture is referred to as vegetation type 1 in Figure 2. The rest of the scene represents the better drained areas which clearly predominate in the prefire subscene. This is referred to as vegetation type 2 in Figure 2. Comparisons of the prefire subscene with the two post-fire subscenes (Figures 3 and 4) reveals that the most severe burning generally occurred in the better drained areas where the vegetation and mossy substrate was undoubtedly drier. Vegetation in or near drainages (including drained lake basins and swales) was generally lightly burned and showed significant recovery between August of 1977 and August of 1978. This information correlates with the field observations which show that the most complete vegetation regrowth occurred in the lightly burned areas. However, vegetation regrowth in severely burned areas also showed significant increases from August 1977 to August 1978.

Figure 3 shows three burn severity categories derived from the August 21, 1977 subscene, labeled severely, moderately and lightly burned. Figure 4 illustrates the recovery attributed to vegetation regrowth within portions of the burned area from the August 14, 1978 Landsat digital data. The reflectance values within the severely burned portion showed significant increases by August 1978 where the mean reflectance ($\bar{x}$), as expressed in digital counts, of the severely burned area increased 62.5% as shown in Table 5. The reflectance values within the severely burned portion changed markedly. A 9.6 $km^2$ area within the severely burned region showed only minimal recovery compared with the previous year. This was inferred because that area (shown in Figure 4) had a lower spectral response than the rest of the severely burned area. Within the lightly burned region, an area of 5.9 $km^2$ had the same spectral response as the unburned areas and was considered fully recovered.

## Recovery of the Burned Area

By August 14, 1978, the boundaries of the southwestern central part of the burned area had become indistinct due to rapid regrowth of vegetation in the lightly burned areas. The boundaries in the severely burned areas in the northeastern and southeastern portions of the burned area remain distinct. Their spectral reflectance values are higher than the previous year as a result of some regrowth of vegetation and lower moisture conditions. The mean reflectance of the entire scene in 1978 is higher by 16 digital counts than in 1977. Therefore, the value of 16 was subtracted from the 1978 mean spectral reflectance for all three burn severity categories as well as in the non-burned areas. This allowed for a better comparison between the two scenes.

The lower overall spectral response in the August 21, 1977 data primarily results from rainfall (Table 4) prior to the date on which the scene was acquired. During the month of August 1977, 14.7 mm of precipitation were recorded at Barrow 10 days prior to the Landsat pass as compared to 0.5 mm of precipitation in August of 1978 10 days prior to the Landsat pass. The additional moisture available to the green plants and soil altered the spectral reflectance in the near-infrared and accounts for the lower reflectance during the wetter conditions in 1977. A similar phenomenon was noted by Stauffer and McKinney (1978).

Even after the 16 counts were subtracted from the 1978 data a significant difference in gray level values (as expressed in digital counts) was present within each of the three burn severity categories between the two years. The increase in reflectance in each burn category (a measure of vegetation regrowth) was compared with the percent increase in live ground cover in the general areas surveyed on the ground in 1978. This comparison is shown in Table 5. On the ground, a 50% increase in live ground cover was reported in the severely burned areas surveyed, and a corresponding 62.5% increase was inferred from Landsat measurements.

## DISCUSSION

Through analysis of Landsat imagery obtained during the fire on August 1 and 2, 1977, and false-color images obtained after the fire, it was inferred that the severity of burning in various portions of the affected region was influenced by the prefire terrain and vegetation conditions, and also by the wind conditions during the burning (Hall et al., 1978b). Landsat images showing the burning and wind direction as inferred from the smoke were previously presented (Hall et al., 1978b) and showed preferential burning of the northeastern and southeastern portions of the burned area. These areas experienced the most severe burning even though other areas had similar terrain conditions as determined from the Landsat prefire computer-derived subscene.

The aerial photograph (Figure 1) was acquired about one month prior to the August 14, 1978 Landsat image. In general, the severely burned areas on the aerial photograph are dark in tone, as seen in the southern portion of the burned area. The field measurements support the Landsat and aerial photograph interpretations regarding recovery. The aerial photography was also found to be useful for locating study sites in the field.

The use of Landsat data for analysis of recovery of vegetation is advantageous because the recovery process can be monitored over a period of time following the fire. Landsat provides a multispectral and multitemporal record of the recovery process. Landsat can be successfully used to augment aircraft and field measurements which are taken only at discrete times and at greater logistic expense.

## CONCLUSIONS

Considerable regrowth of vegetation was observed between August 1977 and August 1978, both in the field and through analysis of Landsat near-infrared digital data. The spectral reflectances in the burned areas were found to increase with the age of the burn in a one year period due to vegetation regrowth. Regrowth was particularly evident in the lightly burned portions of the burned area. Image analysis techniques using the AOIPS system enable one to delineate burn severity categories. The condition and type of ground cover prior to the fire influenced the severity of burning, as did the direction of the winds while the fire was in progress as determined from field and Landsat observations. Winds induced more severe burning in the northeastern and southeastern portions of the burned area as observed on both Landsat and aerial photographs.

## ACKNOWLEDGEMENTS

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Table 1

Percent of Live Ground Cover in the Kokolik River Burned Area and

Control Areas as Determined from Field Measurements

| Area | Percent Total Vascular Plant Cover | Percent Total Lichen and Moss Cover |
|---|---|---|
| 1977 C1 (control) | 80 | 50 |
| High Relief | 10 | 0 |
| Low Relief | 30 | 5 |
| 1978 C1 (control) | 80 | 50 |
| C2 (control) | 10 | 30 |
| High Relief | 10 | 10 |
| Low Relief | 40 | 10 |
| High-centered polygon | 5 | 70 |
| Swale | 70 | 10 |

Table 2

Spectral Limits of the July 16, 1977 Subscene Prior to the Fire from a

Band 7 Density Slice

| Theme | Name | Spectral Limits |
|---|---|---|
| 1 | water | 0 - 39 |
| 2 | drained lake basins (wettest areas) | 40 - 69 |
| 3 | vegetation type 1 (intermediate areas) | 70 - 87 |
| 4 | vegetation type 2 (driest areas) | 88 - 111 |

Table 3

Spectral Limits of the August 21, 1977 and August 14, 1978 Subscenes of the Burned Area from Band 7 Density Slices

| Theme | Name | Spectral Limits | |
|---|---|---|---|
| | | August 21, 1977 | August 14, 1978 |
| 1 | water | 0 - 3 | 0 - 8 |
| 2 | severely burned and smaller lake | 4 - 12 | 9 - 31 |
| 3 | moderately burned | 13 - 24 | 32 - 51 |
| 4 | lightly burned | 25 - 44 | 52 - 64 |

Table 4

Amount of Precipitation (mm) Ten Days Prior to the Acquisition of the August 21, 1977 and August 14, 1978 Landsat Scenes

| Year | Station | Precipitation (mm) |
|---|---|---|
| 1977 | Barrow | 14.7 |
| | Cape Lisburne | 15.2 |
| 1978 | Barrow | 0.5 |
| | Cape Lisburne | no data available |

Table 5

Percent Change in Live Ground Cover between August 1977 and August 1978

Inferred from Ground and Satellite Data

| | Landsat Measurements (mean digital counts, $\bar{x}$) | | |
|---|---|---|---|
| | 1977 | 1978 | Percent Increase |
| Severe | 8 | 13 | 62.5 |
| Moderate | 21 | 30 | 43.0 |
| Light | 30 | 46 | 53.0 |
| | Ground Measurements (percent live ground cover) | | |
| | 1977 | 1978 | Percent Increase |
| Severe | 10 | 15 | 50 |
| Moderate | 30 | 40 | 33 |
| Light | 40 | 60 - 70 | 50 - 75 |

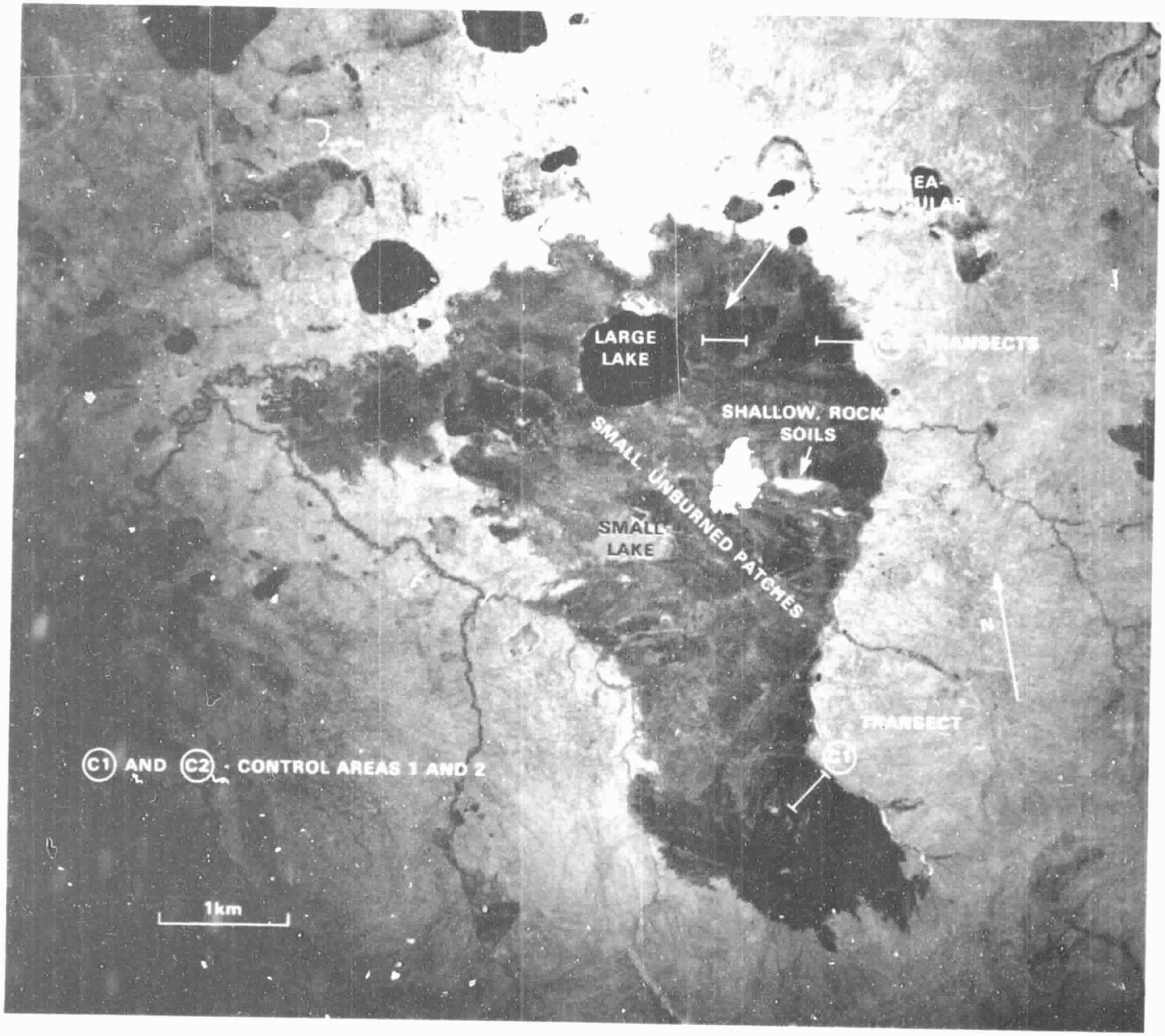


Figure 1. Air photo of the site of the Kokolik River tundra fire area taken on July 12, 1978, showing the August 1978 Field Transect.

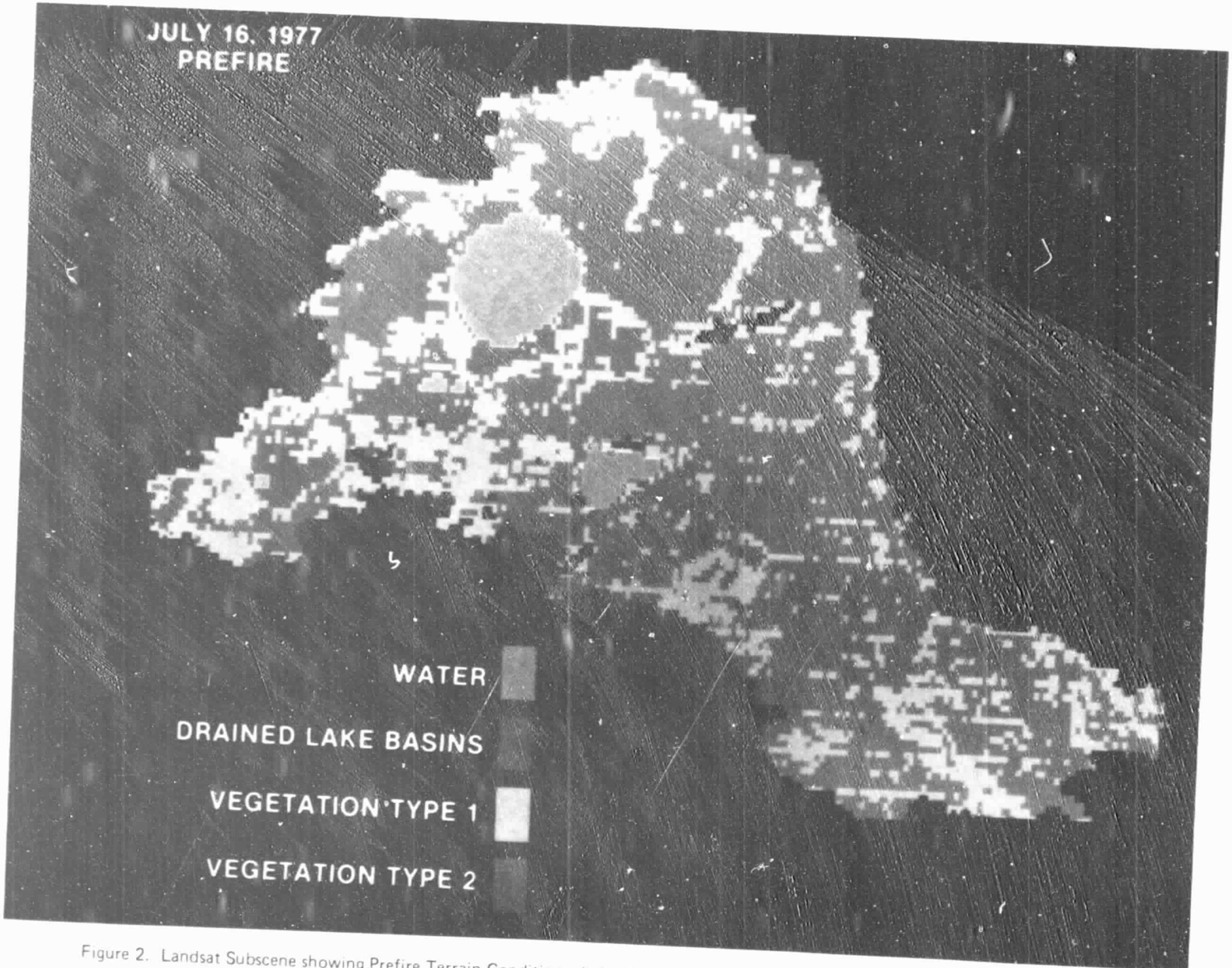


Figure 2. Landsat Subscene showing Prefire Terrain Conditions derived from July 16, 1977, digital data (scene I.D. #20906-21410).

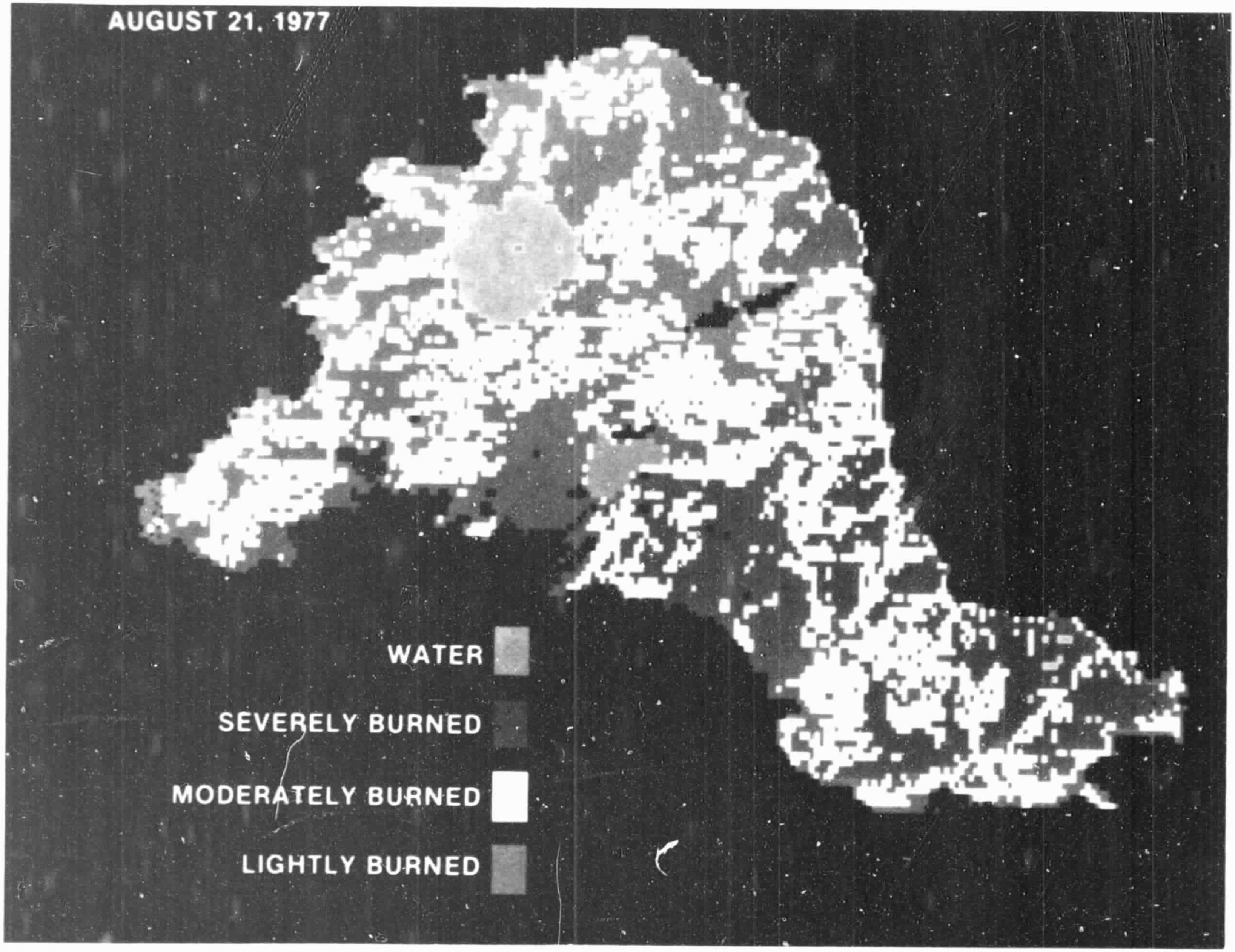


Figure 3. Landsat Subscene of three burn intensity categories derived from August 21, 1977, digital data (scene I.D. #20942-21390).

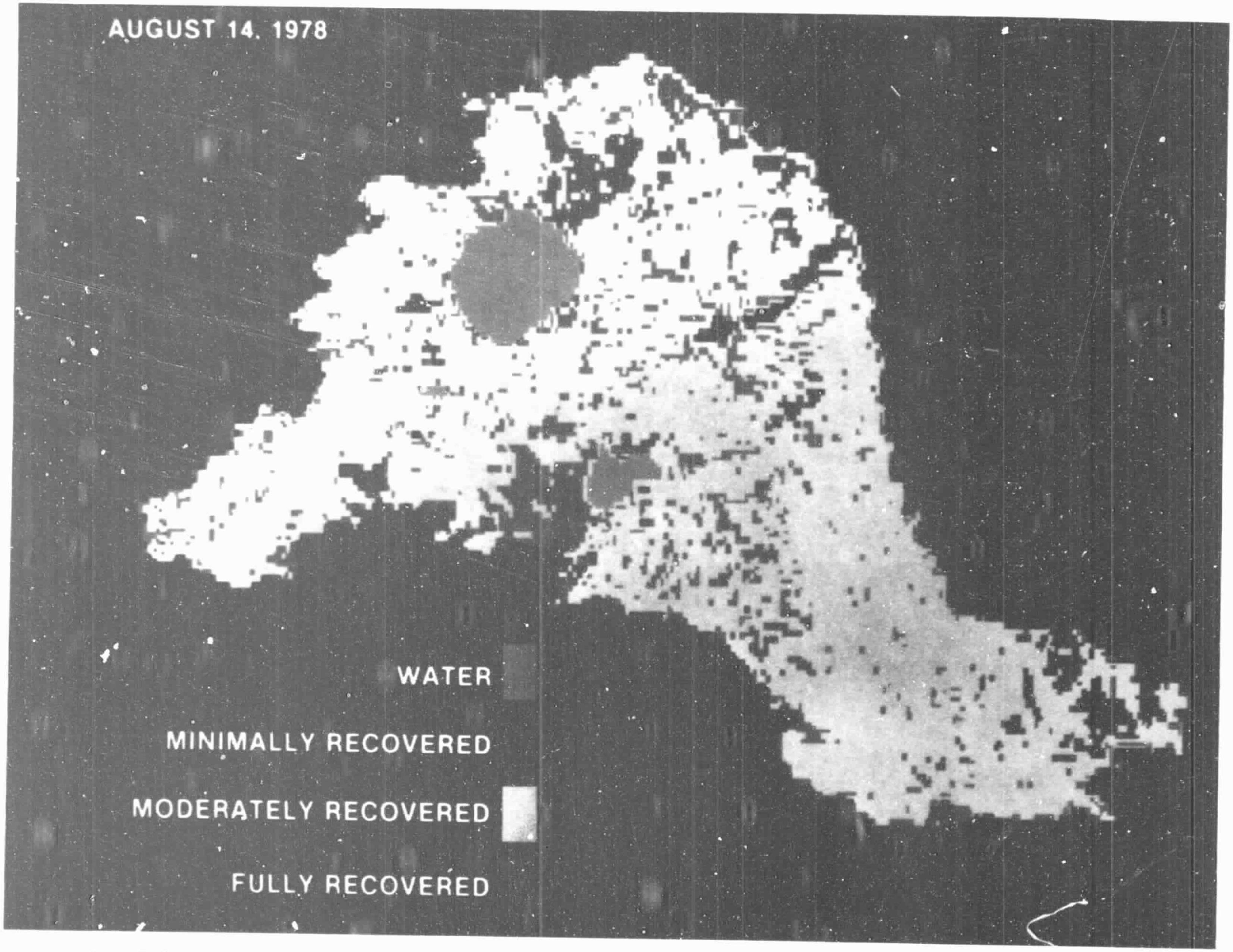


Figure 4. Landsat Subscene of Vegetative Recovery approximately one year after the fire, August 14, 1978 (scene I.D. #21300-21323).

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