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Manual versus Digital Landsat Analysis for Delineating River Flooding*

Visual interpretation of Landsat band 7 images gave results which were at least as accurate as those obtained through color-additive viewing or digital analysis.

Abstract: *The comparative value of manual versus digital image analysis for determining flood boundaries was examined in a study of the use of Landsat data for modeling flooding of the Black River, in northern New York. It was found that delineating flood-affected areas through visual interpretation of Landsat band 7 images gave results which were at least as accurate as those obtained through color-additive viewing or digital analysis.*

Introduction

Like many low gradient rivers, the Black River in northern New York floods regularly. Black River flood waters inundate farm land, breach roads, and cause annual damage which is estimated to exceed $500,000 (Mayhew, 1979). Ground surveys of Black River flooding may be incomplete, however, and together with the existing topographic maps, they are inadequate for estimating agricultural and other losses. In general, ground surveys of flooding are difficult and costly to perform. The recurring problem in the Black River and similar basins is to determine the true extent of flooding in order that flood losses may be reliably estimated.

Various investigators have found that Landsat satellite data can be used effectively for delineating flood boundaries (e.g., Hallberg *et al.*, 1973; Deutsch and Ruggles, 1974; Rohde *et al.*, 1976; Sollers *et al.*, 1978). McLeester and Philipson (1979) extended these findings to the Black River in an attempt to model river flooding. They showed that flood boundary information derived from Landsat images, acquired at different flood stages, could be used to develop an empirical model for estimating the extent of flooding on the basis of in situ measurements of river discharge.

In their study of Black River flooding, McLeester and Philipson (1979) derived all flood boundary information through visual interpretation of Landsat band 7 (0.8 to 1.1 μm) images. The work described here was undertaken to determine whether improved results might have been obtained through digital image analysis or by including other Landsat spectral bands. In essence, if Landsat data are to be used for deriving flood boundary information: (1) are Landsat band 7 data adequate or should other Landsat spectral bands be examined, and (2) can visual image analysis provide sufficiently detailed and accurate information or should more costly digital image analyses be implemented?

Methods and Materials

Study Area

The study area encompasses a highly flood-prone reach of the Black River in Lewis County, New York (Figure 1). It extends approximately 65

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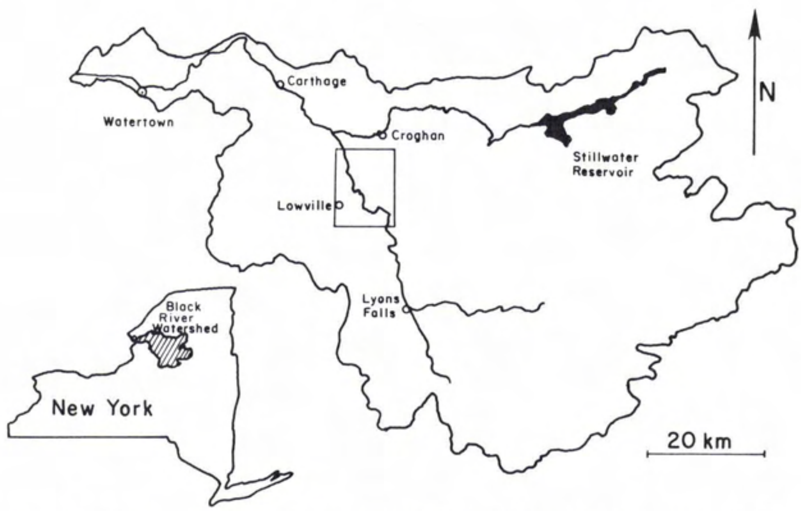

FIG. 1. Location of Black River watershed and Lowville Quadrangle in New York.

km from Lyons Falls to Carthage, being depicted on six 1:24,000 scale, U.S. Geological Survey topographic maps (Brantingham, 1976; Carthage, 1943; Croghan, 1966; Glenfield, 1966; Lowville, 1966; W. Lowville, 1954). This area is known locally as the "Black River Flats" because the net change in river elevation for the entire reach is only 3 metres. From Carthage to Lowville, the width of the river valley varies from 1 to 3 kilometres, with levees less than one metre above low river flow. Vegetation is absent or without foliage through most of the spring flood season, allowing generally unobstructed overhead monitoring of flood waters.

Flooding along a 35 km stretch of the Black River has been studied by the U.S. Army Corps of Engineers, Buffalo District (1974), using previous high water marks from a single flood as input to a computer program for determining water surface profiles. Plotting of these profiles was based on interpolation of elevations from the available 10 ft (3 m) contour maps.

REMOTELY SENSED DATA

Computer-compatible tapes and selected images of three Landsat scenes of the Black River were obtained for analysis. One scene had been acquired during a period of normal river flow (11 October 1972, scene #8108015180500); the other two scenes had been acquired during flood stages, when the flood waters extended laterally approximately 1 kilometre (15 April 1977, scene #8281414491500 and 28 April 1978, scene #8211921441400).

Aerial photographs of the portion of the Black River depicted on one U.S. Geological Survey topographic map, the Lowville Quadrangle (Figure 1), were also obtained for analysis. These stereoscopic, 1:19,000 scale, panchromatic, 23 cm transparencies had been flown by the U.S. Air Force, Rome Air Development Center during a flood period on 6 May 1971. Although the photography and Landsat scenes were not concurrent, the extent of flooding associated with the previous peak flows were comparable. The aerial photographs were acquired during a net river discharge of 16,930 cfs, following a peak discharge of 18,340 cfs by two days; the 1977 Landsat scene was acquired during a net river discharge of 13,970 cfs, following a peak discharge of 20,900 cfs by 14 days. (All discharge measurements were taken at Watertown, N.Y., and adjusted for flow from the Stillwater Reservoir and the time delay from Lowville.)

A 15 April 1977 meteorologic satellite image, acquired by the NOAA/ITOS VHRR-IR sensor, was also examined; however, the spatial resolution of this image was inadequate for assessing the relatively narrow flood waters of the Black River.

IMAGE ANALYSIS—BASES FOR COMPARISON

Two bases for comparison of flood boundary information were established in the form of acetate overlays to the Lowville, 1:24,000 scale, U.S. Geological Survey topographic map (Figure 1). The first was an overlay of visually interpreted flood boundaries derived through analysis of the 15 April 1977 Landsat band 7 image. This overlay, compiled for the earlier study by McLeester and Philipson (1979), was produced by enlarging the original 70-mm Landsat image to a 3 by 4 in. (7.6 by 10 cm) projection plate, which was subsequently projected to a scale of 1:84,000 on a rear-view projection screen. The interpreted flood boundaries were delineated on a sheet of matte acetate at this scale and later enlarged to the final 1:24,000 scale map overlay using a Zoom Transfer Scope.

The second base for comparison of flood boundary information was a 1:24,000 scale map overlay of flooding conditions, interpreted from the 6 May 1971 aerial photographs. Four mapping units—"water," "wet areas (previously flooded)," "wet areas with taller vegetation," and "areas unaffected by flooding"—were delineated using a light table, zoom stereoscope, and subsequently a Zoom Transfer Scope. The location of the river channel was also mapped through interpretation of tree lines, exposed levees, and other indicators.

IMAGE ANALYSIS—PRODUCTS FOR COMPARISON

The airphoto-derived map overlay and the map overlay derived through visual analysis of the 1977 Landsat band 7 image were compared to each other and to other flood boundary products derived from the 1977 Landsat scene. These other products were derived through color-additive viewing and through digital analysis.

For color-additive viewing, the positive, 70-mm transparencies of the 1977 (flood) Landsat bands 4, 5, and 7 images were projected along with the positive 70-mm transparency of the 1972 (no flood) Landsat band 7 image. Also analyzed were positive and negative transparencies of these images, photographically enlarged to three times their original scale. Various color filter-spectral band combinations were examined, including those recommended by other investigators (Deutsch and Ruggles, 1974). The combinations judged most informative were photographed directly from the screen of the color-additive viewer, and the resultant color slides were projected onto the 1:24,000 scale base map overlays.

The digital analysis was performed using the 1977 version of ORSER (Borden *et al.*, 1977), modified for operation on Cornell's IBM 370/168 computer. For the analysis, a 20 km stretch of the Black River, including that portion within the Lowville Quadrangle, was selected. The total lateral coverage of the subset study area varied from 3 to 5 kilometres.

The first analysis was restricted to the 1977 Landsat flood scene. Although the data were examined through spectral band ratioing and unsupervised classification (clustering), the most useful computer printout "flood maps" from the 1977 Landsat scene were derived through supervised classification.

In brief, brightness maps (NMAPS) of the subset area were produced (i.e., printouts with different symbols assigned to represent different increments of radiance); test sites (training areas) for "water," "wet areas (previously flooded)," and "wet areas with taller vegetation" were selected; statistics (STATS) characterizing the spectral response of the test sites were generated for each of Landsat's four spectral bands; and, using the test site statistics, a classification routine was implemented. The classifier (CLASS) categorizes pixels on the basis of their "nearness" to the statistical means established by the test site spectral values. Selection of additional test sites and refinements to test site boundaries produced improvements in the classification. Further, in order to address the study objectives, classifications were based separately on all spectral bands, bands 5 and 7, and band 7 only.

For the final analysis, the single scene classification was extended by digitally merging the 1977 and 1978 Landsat flood scenes with each other and with the 1972 (no flood) scene. The merged data were examined through supervised classification and temporal band ratioing.

RESULTS AND DISCUSSION

The location of the Black River in New York is shown in Figure 1, the 1972 (no flood) and 1977 (flood) Landsat band 7 images are shown in Figure 2, and the flood-affected area interpreted from the 1977 Landsat band 7 image is shown in Figure 3.

As described, two 1:24,000 scale map overlays depicting flood boundary information in the Lowville Quadrangle were produced, the first through visual analysis of the 1977 Landsat band 7 image and the second through interpretation of the 1971 aerial photographs. Based on the respective previous peak discharges and the time elapsed since the peaks, flood conditions on the two dates were judged to be similar. The information derived from the satellite and aircraft imagery was also found to be similar. Flood boundaries from the two map overlays generally differed by less than 100 metres on the ground, with flood-affected areas differing by only 3 percent.

Color-additive viewing of positive and negative spectral images of the 1977 (flood) Landsat scene, with and without the 1972 (no flood) Landsat scene, produced flood boundaries which were nearly identical to those derived through visual analysis of the Landsat band 7 images alone. Tonal differences within the flood-affected area could be observed with the different spectral images; however, ground or aircraft data, acquired concurrently with the Landsat data, would have been needed to determine the true cause of the tonal differences (e.g., turbidity patterns or flooding conditions).

The results of the digital analysis of the 1977 Landsat scene are summarized in Table 1. A total of 2,420 Landsat pixels were included within the flood boundaries derived from the aerial photographs, and 2,500 Landsat pixels were included

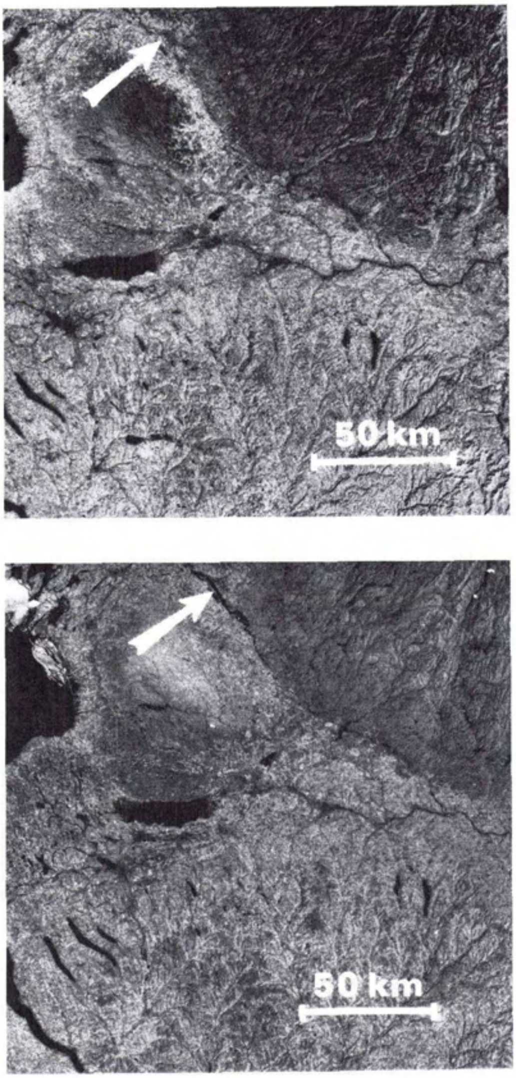

FIG. 2. Landsat band 7 images of Black River during normal flow (October 1972, top) and flood stage (April 1977, bottom).

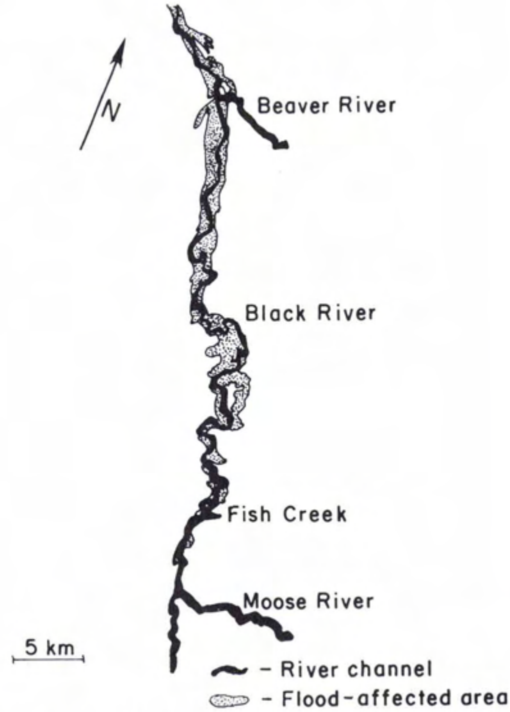

FIG. 3. Flood-affected areas interpreted from April 1977 Landsat band 7 image.

within the flood boundaries derived through visual analysis of the Landsat band 7 image. These numbers were determined by superimposing the flood boundary overlays on geometrically corrected Landsat printouts (e.g., Figure 4).

Percentages recorded in Table 1 relate to the number of Landsat pixels that were classified as flood-affected *within* the flood boundaries delineated on the map overlays. The percentages represent the number of "flood-classed" pixels relative to the total number of pixels within the map overlay flood boundaries (i.e., relative to

TABLE 1. COMPARATIVE ACCURACY OF CLASSIFYING FLOOD-AFFECTED AREAS USING A SUPERVISED CLASSIFIER WITH DIFFERENT LANDSAT SPECTRAL BANDS

Method of Delineating Flood Boundaries	Total Number Landsat Pixels Within Flood Boundaries	Percentage of Landsat Pixels Classified as Flood-Affected		
		All Bands	Bands 5 & 7	Band 7
Visual analysis of stereo air photos	2,420	68	94	93
Visual analysis of Landsat band 7 image	2,500	73	92	96

FIG. 4. Printouts of geometrically corrected Landsat classifications of a portion of the Black River, classified using all four spectral bands (top) and band 7 only (bottom). W-water; S-wet areas, previously flooded; V-wet areas with taller vegetation.

2,420 or 2,500). For example, when classification was based on data from all spectral bands, some 68 percent of the pixels within the flood boundaries derived from the aerial photographs were classified as flood-affected. The numbers of "flood-classed" pixels that were in error outside of the map overlay flood boundaries were negligible and are not reported.

Supervised classification using band 7 and bands 5 and 7 produced printouts of flood-affected areas which were in excellent agreement with each other as well as with the flood boundary overlays. In contrast, the results of classification using all four spectral bands were not in close agreement with either the flood boundary overlays or the other Landsat printouts.

Computer merging of the Landsat scenes was difficult to accomplish because of the lack of defined control points. Neither supervised classification nor simple band ratios of the merged data sets produced new information, and the results of both approaches were difficult to interpret. In contrast, one ratio was devised which served to normalize differences, and this ratio was effective in classifying the merged 1977 (flood) and 1972 (no flood) Landsat scenes. The form of the ratio was, as follows:

$$\frac{(\text{Band 7, No Flood}) - (\text{Band 7, Flood})}{(\text{Band 7, No Flood})}$$

If Landsat band 7 values approach 0, as would be expected with water, the calculated ratio should approach 1 for flooded areas and 0 for unflooded areas.

Although the capacity to place quantitative limits on flooding is a clear advantage over other approaches, the ratio failed when applied with the 1978 Landsat flood scene. In essence, flood-induced turbidity was such that band 7 values for water exceeded those for the corresponding unflooded areas.

SUMMARY AND CONCLUSIONS

In this study of Landsat data for delineating the extent of river flooding, it was found that

- visual analysis of aerial photographs and a Landsat band 7 image gave similar results,
- visual and digital analysis of Landsat band 7 data gave similar results, and
- digital analysis of Landsat band 7 data gave results which were at least as good as digital analysis of combinations of spectral bands.

Although these findings may be peculiar to the data or river basin studied (e.g., basins without concealing vegetation during flooding), it is concluded that visual analysis of Landsat band 7 images will produce results that are likely to be as accurate as any other approach which relies on Landsat data. If Landsat data are to be used for delineating flood boundaries, there seems little justification for applying more costly digital analysis if visual analysis of images from a single spectral band produces comparable or better results.

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