REMOTE SENSING
AND
WATER RESOURCES MANAGEMENT

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MAPPING OF THE 1973 MISSISSIPPI RIVER FLOODS
FROM THE EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS)¹

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ABSTRACT: On March 31, and May 4 and 5, 1973, the first Earth Resources Technology Satellite (ERTS-1) obtained multispectral scanner imagery over the Mississippi River below St. Louis, Missouri. The river was in flood, and the ERTS data provided the first opportunity for regional synoptic mapping of the extent of flooding at the time the imagery was obtained along a 1200 river-mile reach and some of its tributaries. The flood data were compared with imagery collected by ERTS on October 1 and 2, 1972, when the rivers were confined to their normal channels. The specially processed data were analyzed by additive-color techniques, and special enhancements were prepared to aid in interpretation of the data. The extent of flooding was delineated by additive-color, temporal composites of MSS band 7 infrared images. The temporal composites vividly depict, on a single scene, the flooded areas in relation to the normal channel. Color composites of the two near-infrared bands, which usually accentuate surface water, were enlarged to a scale of 1:250,000. Excellent registration was obtained between the image and transparencies of the 1:250,000 topographic maps used as overlays. The resulting image maps were then used as an interim product for preparation of maps showing the extent of flooding at the same scale.

(KEY TERMS: Mississippi River, Floods, Flood mapping, Multispectral scanner, Earth Resources Technology Satellite, Infrared imagery, Additive-color composites, Temporal composites, Remote sensing)

INTRODUCTION

During the spring of 1973, the Mississippi River Valley experienced some of the most disastrous flooding in recorded history. Tremendous areas of lowland were inundated along the Mississippi River main stem and along a number of major tributaries between St. Louis and the mouth of the river below New Orleans. At St. Louis, an all-time high flood crest of 43.3 feet was recorded on April 28, 1973, exceeding the previous record of 42 feet recorded in April 1785. It is unlikely that the maximum recorded discharge was exceeded, however. The high stage was probably due, in part, to constriction of the river

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Figure 1. These hydrographs show that the lower Mississippi River was above flood stage for prolonged periods during the spring of 1973.
Flood mapping, by conventional methods, the techniques of which are well established and understood, is a time-consuming and expensive procedure. Traditionally, either ground surveys or black and white panchromatic photography has been used as a basic tool in flood mapping. During the past several years, however, utilization of new techniques of remote sensing by aircraft- and spacecraft-borne sensors has been gaining increased attention. Myers, Waltz, and Smith (1972) delineated the area flooded by Rapid Creek at Rapid City, South Dakota, using color and color infrared aerial photography and thermal infrared aerial imagery. From some of the earliest data obtained by ERTS-1 (June 29, 1972) Benson and Waltz (1973) delineated and measured an area inundated by a severe local rainstorm near Aberdeen, South Dakota. Hallberg, Hoyer, and Rango (1973) reported on the mapping of the Nishnabotna River flood in Iowa, employing ERTS data collected a week after the flood. They also assessed the use of color infrared photography versus traditional black and white panchromatic photography for flood mapping purposes and found the former to be highly superior. Morrison and Cooley (1973) mapped inundation limits of the Gila River flood in Arizona from ERTS imagery and obtained good agreement with maps prepared from aircraft photography and ground surveys.

Early in March, in anticipation of flooding along the Mississippi River, the U.S. Geological Survey made a special request to the National Aeronautics and Space Administration for data from subsequent passes of the first Earth Resources Technology Satellite (ERTS-1) over the Mississippi River Valley. Basically, it was desired to be able to map the extent of inundation as quickly as possible, and with a minimum amount of conventional ground observations. It was surmised that specially processed ERTS data could provide hydrologists with a powerful new technique to supplement established methods of flood mapping, for the first time making it possible to accurately map the extent of flooding over very large areas, and to optically depict the flooded area.

On March 31, 1973, ERTS-1 provided the first synoptic view of extensive flooding of two large reaches of the Mississippi River, between St. Louis, Missouri, and New Orleans, Mississippi. On May 4 and 5, ERTS-1 sensors imaged a strip of the Mississippi River reaching from midway between St. Louis and Cairo, Illinois, to New Orleans and the Gulf of Mexico. The flood is depicted at its peak within the reach between Cairo and Memphis. The flood peaked at Cairo on May 4 at 14.7 feet above flood stage. Cloud cover over most of the Mississippi River Valley below St. Louis on March 30, April 17 and 18, and May 6, prevented consecutive-day coverage over the entire reach from St. Louis to the mouth of the river.

Objectives and Scope

Because the first Earth Resources Technology Satellite (ERTS-1) is operated by the National Aeronautics and Space Administration on an experimental basis, the flood-mapping activities described herein are considered to be part of an experiment which has the following objectives:

1. Determine the utility of ERTS data for:
   a. Mapping the regional extent of flooding at the time of the imagery at a scale of 1:250,000 (the entire United States is covered by topographic maps prepared at this scale.)
b. Measuring the areas flooded along the main stem as depicted on flood maps derived from the imagery.

c. Mapping the total area inundated by flood water, using post-flood data
d. Classifying the use of the flooded lands
e. Determining post-flood use and productivity of the flooded area.
f. Determining changes in the river channel resulting from the floods.

2. Develop optical enhancement techniques for ERFS data to facilitate flood mapping.

3. Develop procedures for preparation of cartographically accurate flood maps or flood image-maps.

4. Determine limitations of optically processed ERFS imagery for flood mapping.

The work described above was still in progress at the time of this writing. It represents the first attempt at quantitative flood mapping, employing space-acquired data. Since the flood was in progress on March 31 and May 5, the two dates on which cloud-free imagery was obtained by ERFS, the results described herein related only to the extent of the flooding at the time the imagery was obtained by the satellite.

On May 24, the date the Mississippi River receded to bankfull stage at St. Louis, excellent imagery was obtained over an area comparable to that obtained on March 31. Initial evaluation of the imagery indicates that changes in spectral characteristics of the area from which the flood waters have receded make it possible to map the total area inundated by flood waters.

Insufficient time was available to correlate land-use analyses with the flood maps described below, hence results on that objective are also not described herein. The use of digital data processing techniques, which probably could produce maps at a scale of 1:62,500 (1 inch equals 1 mile) or possibly even 1:24,000 (1 inch equals 2,000 feet) was beyond the scope of the initial experiment because of the time and cost factors involved in the use of computer compatible tapes. The present study was, therefore, limited to optical data-processing techniques. The initial flood mapping was limited to the main stem of the Mississippi River on eight 1:250,000 topographic sheets from 39° North latitude (north of St. Louis) to 35° North latitude (just beyond Memphis, Tennessee).

All of the ERFS data used for this study were obtained by the multispectral scanner (MSS) which images reflected solar radiation from the Earth’s surface in four bands of the visible and near-infrared portions of the electromagnetic spectrum, nominally as follows (NASA, 1971):

<table>
<thead>
<tr>
<th>MSS Band</th>
<th>Wavelength (Micrometers)</th>
<th>Nominal Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>.5 - .6</td>
<td>Green-yellow-orange</td>
</tr>
<tr>
<td>5</td>
<td>.6 - .7</td>
<td>red</td>
</tr>
<tr>
<td>6</td>
<td>.7 - .8</td>
<td>near-infrared</td>
</tr>
<tr>
<td>7</td>
<td>.8 - 1.1</td>
<td>near-infrared</td>
</tr>
</tbody>
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ERTS-1 DATA COVERAGE

Figure 2 is a mosaic prepared from ERFS-1, MSS band 7 images showing flood inundation over large reaches of the Mississippi River Valley from St. Louis to the Gulf of
Figure 2. On March 31 and May 4-5, 1973, ERTS-1 imaged the lower Mississippi River Valley in a total time of about seven minutes. This mosaic of band 7 near-infrared images provided the first overall view of flooding for the entire region.
Mexico. The imagery was obtained by the satellite on March 31 for the western swath including the St. Louis area, and on May 4 and 5 for the eastern swaths. The images were precisely enlarged to a scale of 1:1,000,000. The May 4 and 5 orbital swaths cover a 1,200 river miles of the Mississippi, from about half way between St. Louis and Cairo, Illinois, to the Gulf of Mexico. The flood is at its peak along the reach between Cairo and Memphis (see figure 1). Flooding along the lower Ohio River at its confluence with the Wabash River is also clearly shown. The seven May 5 scenes used in the mosaic were collected during an orbital interval of only 3 minutes. All of the flood data shown in figure 2 were collected in a total time of about 7 minutes.

In order to map the area inundated by any flood, obviously, it is necessary to have data on the area normally covered by water. For this critical analysis, data collected by ERTS-1 over the Mississippi River on October 1 and 2, 1972, were obtained from the Earth Resources Observation Systems (EROS) Data Center at Sioux Falls, South Dakota.

Figure 3 is a black and white mosaic of MSS band 7 images recorded by ERTS-1 sensors on October 1 and 2, 1972, which depicts “normal” conditions. The difference in water-covered or wet surface between October 1972 and the 1973 flood period is obvious. Especially noticeable also is the wet flood plain between St. Louis and Cairo, Illinois, and the lower White River above its confluence with the Arkansas River in the lower left image. For the purposes of the present study, covering the reach from about St. Louis to Memphis, data from only seven ERTS scenes in October and seven flood images were needed.

Data Reprocessing

The original data used for the analyses in this study were 70mm ERTS, MSS negatives. All of the data were reprocessed to balance the density range and minimum density in the black and white positives with respect to each other. This was done to achieve the greatest enhancement of specific areas of interest in additive-color projection of multispectral imagery.

In general, the areas of interest (in this case the flood plains) should be of an average density of approximately one, and the density range within the flood plane should be considerably greater than in a unity gamma reproduction. The 70mm film positives received from NASA are linear gamma one reproductions of the scene. For enhancement of flood-plain detail the minimum density is excessive and the density range too small to be suitable for additive color projection.

It was necessary to differentially print negatives in order to correct for such variables as:

1. the differential reflectance of the terrain in different spectral regions.
2. the effect of the atmospheric column, which tends to decrease the density range of the image (but not of the wedge recorded at the bottom of the ERTS chips) in the shorter wavelength regions.

The reprocessing procedures are explained in detail by Anderson and Yost (1973).

Color Enhancements

From analysis of the “standard” false-color composite of bands 4, 5, and 7 images
Figure 3. The ERTS flood data were compared with the band 7 near-infrared images used to construct this mosaic depicting "normal" conditions along the Mississippi Valley between St. Louis and the mouth of the Arkansas River on October 1-2, 1972.
covering the study areas produced by the NASA Data Processing Facility (NDPF) it appeared that the flooding was more extensive on the image than was actually the case. For that reason it was decided to specially prepare color enhancements so as to highlight conditions on the flood plains of the Mississippi River and its tributaries.

The Spectral Data Comparator Model-64 Additive Viewer was used for the analysis of the 70mm ERHS-1 MSS positive transparencies prepared from the reprocessed negatives.

From among the numerous additive-color combinations examined on the viewer screen the following were deemed to be best for detailed flood-plain analysis or mapping.

**Rendition “A”** (figure 4, upper left) - Band 5 is projected as blue; band 6 as green; and band 7, filtered to about 60 percent transmission, as red. This rendition was best suited

![Image of three color renditions](image)

*Figure 4.* Three specially filtered additive-color enhancements, along with the “standard” NASA Data Processing Facility color composite, were prepared from ERHS-1 multispectral scanner images to study detailed flood-plain conditions north of the confluence of the Mississippi, Arkansas, and White Rivers on March 31, 1973.
for interpreting the extent of flooded area in relation to rural land use. Morphologic and
gologic features are enhanced, and water detail is well preserved. Areas with standing
water appear as blue, and wet or saturated soils as brown.

Rendition “B” (upper right) - Band 6 is projected as red, filtered to about 60 percent
transmission and band 7 as green. This pictorial rendition prepared from the two near
infrared bands was considered to be the best for differentiating areas of varying degrees of
inundation and wetness. This rendition, therefore, was used as the basic source of
information from which the flood maps described below were prepared. Standing water
appears as red and the wet or saturated flood plain as green. An explanation for this
additive-color rendition is given below under “Temporal Depiction of Flooded Areas.”

Rendition “C” (lower right) - Band 4 is projected as blue; band 5 as green; and band 7,
filtered to about 40 percent transmission, as red. This pictorial rendition is best suited for
interpreting flooded areas in relation to urban patterns. While preserving water detail, it
enhances cultural detail. In this rendition, standing water is shown in shades of blue or
green, and areas of wet or saturated soil appear as brown.

Figure 5 is a rendition “C” color composite of the St. Louis area. The location of the
city is clearly seen on the west bank of the Mississippi, where the river is confined to its

![Figure 5](image-url)

Figure 5. This additive-color composite of ERTS-1 multispectral scanner data enhances urban
features in the St. Louis area as well as details in the flood plains of the Mississippi River and its
tributaries.
channel on March 31. The major road network is also brought out in this rendition. The extent of flooding along the valleys of Missouri and Illinois Rivers is clearly depicted where not obscured by clouds. The dark brown area along the Kaskaskia River below Carlyle Reservoir represents very wet or saturated conditions along the river valley.

Temporal Depiction of Flooded Areas

The extent of flooding can be clearly displayed by projecting a pre-flood image and one collected during the flood into a single composite image. Band 7 was used because there is little or no reflection of incident radiation from water in this spectral region, and thus the water appears dark in a positive print.

Figure 6 shows the Cairo, Illinois, area imaged by MSS band 7 on May 5, 1973, in green, and on October 1, 1972, in red. The temporal composite (bottom), prepared by additive projection of the two band 7 scenes, depicts the flooded area in red, as described below. The composite covers only the area of image overlap between the two dates. This image, therefore, shows excellent differentiation between dry soil, saturated soil, and standing water. In a properly processed positive, standing water is very dark, dry soil is relatively light, and saturated soil is intermediate in density. When a non-flood image is projected as red, in register with a flood image projected as green, the composite color image is composed of the following elements:

1. Where there is surface water present on both images, the composite image receives little or no light and is therefore essentially black. This depicts the area normally covered by the river and other surface-water bodies.

2. Where the ground is not covered with water in both scenes, the composite image receives relatively equal amounts of red and green light, and is therefore yellow. This depicts the area unaffected by flood waters.

3. Where there is surface water in the scene projected in green, and dry soil in the scene projected as red, the composite image receives only red light, and is therefore a highly saturated red color. This depicts the area of flood inundation.

4. Where there is water-saturated soil in the scene projected as green, and dry soil in the scene projected as red, the composite image received red light combined with a lesser amount of green light, and results in a color on a continuum between yellow and red.

This is, of course, a simplification of the factors affecting the color of the composite image. Some additional factors that can affect the image color but are not connected with the flood factors are:

1. If there are clouds present in one of the images, the areas of the terrain in the shadow of the clouds will be a highly saturated red or green.

2. If the atmospheric conditions are different, such as thin cirrus clouds in one image, the color of the dry terrain will be variable shades of yellow.
3. Seasonal changes, such as the presence or absence of vegetation, will also affect the "color" of the terrain.

It can be seen that the orbit of the satellite has shifted about 20 miles to west between October and May. Furthermore, the swaths were not framed at the same latitudes for the two dates; hence, the number of temporal composites needed to mosaic the reach of the Mississippi River was doubled.

Figure 7 is a flood image-map using the Cairo area temporal composite enlarged to a scale of 1:250,000 as an image base. Figure 8 is a mosaic of band 7 temporal composites for the entire study area. Except for cloud shadows, the presence of red depicts water on the surface during the flood period that was not present during "normal" conditions in October. There is major flooding along the Mississippi above St. Louis and at its

Figure 6. Band 7 images covering the flooded areas (green) were combined with images of the same area collected under "normal" conditions (red) to prepare temporal composites (bottom) such as the one shown here at the confluence of the Mississippi and Ohio Rivers. The extent of flooding is depicted in red; "normal" conditions in black.
confluence with the Missouri River. There is also flooding in the Cairo area, and the flood peak is depicted between Cairo and Memphis. In fact, there is widespread flooding.

Figure 7. Detailed distribution of flooding in the Cairo, Illinois, area is shown in red on this image map prepared from an enlargement to a scale of 1:250,000 of the temporal composite shown on figure 6.
Figure 8. This mosaic of temporal composites shows the extent of flooding in red along the Mississippi Valley between St. Louis and the mouth of the Arkansas River on March 31 and May 5, 1973. "Normal" river conditions and the areal extent of surface water on October 1 and 2, 1973, appear as black.
throughout the Mississippi River Valley in the study area. The Ohio River is in flood at its confluence with the Tennessee. The entire valleys of the Kaskaskia River in Illinois, and the White and St. Francis Rivers in Arkansas are very wet and locally in flood. In contrast, the Arkansas River (lower left) is confined to its banks. The change in area of surface storage in several reservoirs is clearly depicted by red extensions beyond their pre-flood shorelines.

INTERPRETATION AND FLOOD MAPPING PROCEDURES

Enlargements of optically processed ERTS imagery indicated that high contrast features such as land-water boundaries, could be effectively mapped at scales as large as 1:125,000 or even 1:100,000. Since topographic map coverage of the United States is available at a scale of 1:250,000, it was decided to perform the actual mapping at that scale, so as to accomplish the task in the least possible time and at minimum cost.

All of the Mississippi River renditions were pictured on the Spectral Data Model 64 Viewer at a scale of 1:1,000,000 by establishing a scale ratio from Aeronautical Chart CG-20 (scale 1:1,000,000 Lambert Conformal Conic Projection), and registering on prominent drainage features. An interim evaluation of the geographic registration between additive-color composites and the Aeronautical Chart showed near coincidence of most planimetric features to within 1/50 inch at map scale.

In mounting successive scenes to form mosaics at 1:1,000,000, it was noted that the integrity of close image registration to the aeronautical chart was retained over 4 successive scenes.

Rendition “B” composites of MSS bands 6 and 7, of seven scenes dated October 1-2, 1972, from four scenes dated March 31, 1973, and three scenes dated May 5, 1973, were enlarged to a scale of 1:250,000. For accurate scale ratios the planimetry of these enlargements were maintained by holding to drainage features depicted on stable base drainage overlays of the 1:250,000 scale map series for the area (UTM). An interim evaluation of image registration with map features at the same scale showed near coincidence within local areas of about 10 x 10 inches and offsets of ± 0.025 inch over distances of about 20 inches. It is anticipated that refinement of the enlarging ratio could improve the precision of overall registration between the image and the map.

The initial area selected for flood inundation map preparation was the ERTS image that covered Cairo, Illinois area at the confluence of the Mississippi and Ohio Rivers. The 1:250,000 scale drainage overlays of NJ16-7 (Paducah quadrangle) and NJ16-10 (Dyersburg quadrangle) were superimposed on the 1:250,000 rendition “B” multispectral enlargement, and the perimeters of the flooded area along the main stems of the Mississippi and Ohio Rivers were drafted (figure 9). Some areas of dense forest that were known to have been flooded on May 5, 1973 are not shown as flooded on figure 9 because the ERTS image shows the dense leaf canopy rather than the flood waters. It is safe to say that all areas shown as flooded on figure 9 are actually flooded, but additional information from topographic maps or ground observations is required to detect flooding in areas of dense trees.

Area measurements that differentiated normal river stage acreage from flooded inundation acreage were computed by subtraction. The wet areas were determined with a Dell-Foster 3-axis Digitizer-Quantitizer. This procedure was repeated to complete the analyses of the extent of flooding in the Mississippi River from St. Louis to the confluence with the Arkansas and White River (Guss and Ruggles, 1973).
Figure 9. This map showing the extent of flooding along the main stems of the Mississippi and Ohio Rivers near Cairo, Illinois, was based exclusively on band 6 and 7 near-infrared images collected by ERTS-1 on October 1, 1972, and May 5, 1973.
CONCLUSIONS

Optically processed imagery obtained by ERTS-1 provides hydrologists with powerful new technique for rapid flood inundation mapping and related studies:

- The areal extent of flood waters over very large reaches of a major river basin can be viewed synoptically for the first time.
- Areas in flood can be quantitatively determined by automatic data-processing techniques.
- ERTS imagery can be color enhanced by additive-color techniques to aid in the interpretation of flood conditions and their relation to geologic, physiographic, and urban settings.
- The extent of inundation versus "normal" conditions can be sharply delineated on a temporal basis on single color-composited images.
- The near-infrared bands (6 and 7) on ERTS can be used in combination for interpretation of flood conditions and delineation of flood-water boundaries.
- Bulk-processed ERTS imagery can be used as the basis for area-of-flood inundation mapping for a region at a scale of at least 1:250,000.
- Optical data-processing of ERTS MSS imagery provided for an extremely fast and inexpensive means of regionally delineating the Mississippi River floods of 1973, and measuring the areal extent of inundation during the course of the floods.

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LITERATURE CITED


The American Water Resources Association (AWRA) is a scientific organization, incorporated in 1964. A major factor in the establishment of AWRA was the need for an organization to encourage and foster interdisciplinary communication between professionals of diverse backgrounds working on all aspects of water resources problems.

Professional persons, groups, or corporations interested in any aspect of water resource activity or planning to take part in the national effort on environmental quality control can benefit greatly by joining AWRA and becoming active participants in its committees, meetings or by receiving its publications. AWRA meetings and publications help to coordinate and improve cooperation between those active in all areas of water resources science and technology.

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- the collection, organization and dissemination of ideas and information in the field of water resources science and technology.

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