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FLOOD HAZARD STUDIES IN THE MISSISSIPPI RIVER BASIN USING REMOTE SENSING

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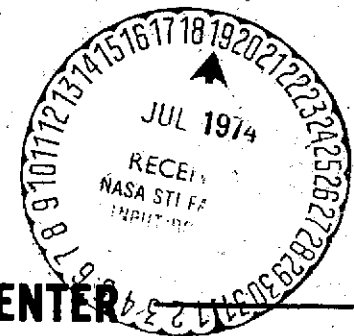
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ABSTRACT

The Spring 1973 Mississippi River flood was investigated using remotely sensed data from ERTS-1. Both manual and automatic analyses of the data indicate that ERTS-1 is extremely useful as a regional tool for flood management. Quantitative estimates of area flooded were made in St. Charles County, Missouri and Arkansas. Flood hazard mapping was conducted in three study areas along the Mississippi River using pre-flood ERTS-1 imagery enlarged to 1:250,000 and 1:100,000 scale. The flood prone areas delineated on these maps correspond to areas that would be inundated by significant flooding (approximately the 100 year flood). The flood prone area boundaries were generally in agreement with flood hazard maps produced by the U.S. Army Corps of Engineers and U.S. Geological Survey although the latter are somewhat more detailed because of their larger scale. Initial results indicate that ERTS-1 digital mapping of flood prone areas can be performed at 1:62,500 which is comparable to some conventional flood hazard map scales. (Key Terms: flooding, flood prone areas, remote sensing, ERTS-1)

FLOOD HAZARD STUDIES IN THE MISSISSIPPI RIVER BASIN
USING REMOTE SENSING

Albert Rango and Arthur T. Anderson*

INTRODUCTION

Floods, both rare and frequently occurring, have caused large amounts of damage to man's interests in floodplain areas throughout history, and he has constantly attempted to reduce this damage through the use of various types of flood prevention techniques. Annual flood losses in the United States frequently exceed $1,500,000,000. Projections indicate that annual flood damage will continue to increase markedly until the year 2000 and beyond despite large expenditures on downstream flood control measures (Todd, 1970). This projected annual increase is due to the continued encroachment and development by man on the floodplain in areas susceptible to flooding. In the United States, it has been estimated that at least 12% of the population lives in areas subject to periodic flooding (White, et. al., 1958). Floodplain occupance seems to be increasing at a more rapid rate than the overall population growth rate (Sewell, 1969). Because of economic pressures for development, better means for logically restricting growth in high flood hazard areas and for assessing flood damage where it occurs are needed.

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Satellites such as the first Earth Resources Technology Satellite (ERTS-1), with high resolution sensors and repetitive coverage capability, provide promising ways to solve some of the problems associated with mapping the areal extent of flooding and determining general flood susceptibility. ERTS-1 was launched July 23, 1972 into a near polar, 900 km circular orbit. The orbital characteristics of this satellite and the capabilities of the on-board sensors combine to provide a system which is capable of taking remotely-sensed observations over any given point on the earth once every 18 days. Since the launch of ERTS-1, the vast majority of observations have been taken by the Multispectral Scanner Subsystem (MSS) in the visible and near infrared wavelengths. The MSS takes observations in the 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 μm portions of the electromagnetic spectrum. The ability of the MSS to resolve objects on the earth's surface varies depending upon the geometric characteristics of a given object and its contrast with surrounding features, but generally a spatial resolution capability near 80 meters is available. In the 0.8-1.1 μm spectral region water and/or moist surfaces contrast most sharply with dry soil or vegetated surfaces. Therefore, for mapping of surface water and flood inundated areas, or areas with relatively high soil moisture content, the 0.8-1.1 μm spectral interval is the best of the ERTS-1 wavelength bands (Rango and Salomonson, 1974).

ERTS-1 has recently been used to map major floods on the Nishnabotna Rivers in Iowa (Hallberg, Hoyer, and Rango, 1973) and the Gila River in Arizona

(Morrison and Cooley, 1973). In both cases correspondence of ERTS-1 derived flood boundaries to boundaries obtained from low altitude photography was excellent. Additionally, more commonly occurring floods have been mapped using ERTS-1 on the James, Appomattox, and Nottoway Rivers in Virginia (Rango and Salomonson, 1974). Flooding in the Mississippi River Basin in 1973 provided an excellent test case for the ability of ERTS-1 to contribute to effective flood management on a major river system.

FLOOD MAPPING

Mapping of areas inundated, using ERTS-1, has been attempted in Iowa, Arizona, and Virginia and proven successful. In general, flood area mapping with the 0.8-$1.1\,\mu$m band was rapidly accomplished because of the ease with which the flooding effects were evident. For flood areas on the order of $100\,\text{km}^2$ or larger, the estimated procedural error in obtaining flood area measurements using ERTS-1 is conservatively evaluated to be less than five percent (Rango and Salomonson, 1974). It is felt that flood area mapping on a regional basis using ERTS-1 near infrared data is relatively straight forward and should be accomplished with ease for most watersheds. Both the U.S. Army Corps of Engineers (USACE) and the U.S. Geological Survey (USGS) have concentrated on flood mapping in the Mississippi River Basin for this particular flood. For this reason NASA investigators only studied the feasibility of flood mapping in a few test areas along the Mississippi River.

As an example, on March 31, 1973 ERTS-1 imaged eastern Arkansas and detected flood effects on the Mississippi River and some of its tributaries (e.g., the White, Black, St. Francis, and Ouachita Rivers). Several composites of the region were made (see Fig. 1), and the area affected by flooding in Arkansas was estimated at $7285\,km^2$, with only $628\,km^2$ flooded along the Mississippi River mainstem. The rest of the flooding occurred along the tributaries. Apparently the levee system along the Mississippi River was providing adequate protection, whereas flood areas on the tributaries pointed out locations where new or additional flood works might be necessary. Such an evaluation was impossible before the comprehensive, regional coverage from ERTS-1 became available.

A smaller area of Figure 1, centered on the lower White River, was studied using ERTS-1 computer compatible tapes. The MSS $0.8-1.1\,\mu m$ band data from October 2, 1972 (normal flow) and March 31, 1973 (flood flow) were superimposed on a digital image display and manipulation system (IDAMS) developed at Goddard Space Flight Center. This approach enabled quantitative change detection analysis. Of the total $14,680\,km^2$ in the study area, $188\,km^2$ were determined (through a digital pixel count) to be under water in both October and March—the normal flow surface water area. Areas flooded (possessing water only in March) were determined to total $1248\,km^2$. Areas that had decreased markedly in reflectance from October to March, but were apparently not under water, were observed

along various river floodplains and were most likely a result of increases in soil moisture. These areas, potentially susceptible to flooding as moisture continues to accumulate, were calculated to be 2275 km^2. Such kinds of change detection analysis prove very valuable for flood mapping.

Another automatic data analysis system—the General Electric Multispectral Information Extraction System (GEMS)—was used to classify and measure water areas according to differences in reflectivity. A portion of the St. Charles County, Missouri area under flood was analyzed using the ERTS-1 overpass on March 31, 1973. Five separate reflectivity classes for water were obtained in the analysis. Table 1 presents the results of the calculations of amount of area flooded by different water classes in the St. Charles County test site. The total study area is 1225 km^2 and the total area flooded is 265.2 km^2. The various classes of water are a result of physical differences in depth and/or sediment load.

The various effects of flooding along the entire Mississippi Valley can easily be seen from ERTS-1, with changes in surface water area the most striking. In addition, abnormal soil moisture levels can be observed as areas of very low near infrared reflectivity. Figure 2 is an ERTS-1 mosaic of the Mississippi Valley before flooding made from October 1-2, 1972 imagery taken in the 0.8-1.1 μm wavelength band. Figure 3 in comparison is an ERTS-1 mosaic of the same area constructed during and after flooding. This flood mosaic was

Table 1

Total and Sub-class Flooded Areas Extracted from the March 31, 1973

ERTS-1 Scene Using GEMS (St. Charles County, Missouri)

Classification	Percentage of Total Area (%)	Area in km^2
Total study area	100.00	1225.0
Water Class I	3.14	38.4
Water Class II	5.17	63.4
Water Class III	6.48	79.4
Water Class IV	4.10	50.3
Water Class V	2.75	33.7
Total Flooded Area	21.64	265.2

constructed using 0.8-$1.1\mu m$ imagery taken in March and May of 1973. Areas

of flooding can be seen as very dark tones, whereas excessive soil moisture is

shown as the darker gray tones in the floodplain. The upland areas not affected

by excess moisture have a much higher reflectivity. An example of this differ-

ential in soil moisture is observed just above center in Figure 3. Crowley's

Ridge, an elongated upland area running from north to south just west of the

Mississippi River on the floodplain, is highly reflective and much drier than the

surrounding, saturated lowland soils which appear dark. These relative differ-

ences in soil moisture can be observed to change before flooding, during the

flood period, and after the recession of flood waters. The monitoring of antecedent soil moisture in this manner provides promise for improving flood forecasting if quantitative values can eventually be attached to these soil moisture related reflectivity changes.

FLOODPLAIN DELINEATION

Floodplain development cannot be curtailed entirely, but with flood susceptibility inputs for specific areas, zoning can be established so as to considerably reduce losses from floods. Many states already have or are moving toward incorporating into state law some restrictions on floodplain development that are related to the expected areal extent of an arbitrary rare flood. The need for flood susceptibility information has also increased because of Federal legislation such as The National Flood Insurance Act of 1968 (Public Law 90-448) and the Flood Disaster Protection Act of 1973 (Public Law 93-234). It has been agreed, for example, that the area inundated by the 100 year return period flood should define the regulatory area under The Flood Insurance Act (Sheaffer, Ellis, and Spieker, 1970). Unfortunately, very few communities have been able to have flood hazard reports prepared for their local area and thus be eligible for Federal Flood Insurance. Conventional floodplain mapping is both time consuming and expensive (about $250-$4000 per km according to Wolman [1971]). It appears necessary to develop new methods that are faster and less expensive that could at the minimum be used as supplementary information for extending

existing detailed floodplain maps to nearby areas, and possibly be used to provide preliminary floodplain information in areas not previously surveyed. In some areas where requests for floodplain surveys are numerous and a backlog exists, the floodplain mapping agency (e.g., USACE) may be able to use ERTS type satellites as a means for initially screening the areas that have requested surveys. In doing so the floodplain mapping agency might be able to determine from the remotely sensed data whether a particular area is anywhere near a flood hazard region, and if it is not, then the need for a detailed, time-consuming engineering survey would be eliminated. This approach would reduce the backlog of requests and allow the agency to more expeditiously concentrate on the most critical areas.

The ERTS-1 mapping of the areal extent of flood inundation as already described in this paper establishes flood hazard zones along a stream associated with a particular recurrence interval. Although the mapping of an occasional flood is an effective way to delineate areas of flood susceptibility on the floodplain, it would take a considerable length of time to construct an adequate nationwide data base if the 100 year flood was the only return period of interest. Observations of floods of lesser magnitudes can be made much more frequently and can be used by floodplain mapping agencies to increase their understanding of how a particular section of stream reacts to flood producing conditions. Combining this type of information, e.g., satellite observations of the 25 year

flood, with the user's experience with flood profiles (and perhaps natural flood susceptibility indicators which will be discussed later), it is possible that a more efficient determination of the 100 year flood boundaries can be obtained.

A second approach would be to use the comprehensive coverage available from satellites to map features on the floodplain (before a flood actually occurs) that may correspond to the limits of major floods. This approach has been attempted with some success using aerial remote sensing by Lee, Parker, and Milfred (1972) in Wisconsin. Burgess (1967) has delineated a number of flood susceptibility indicators that should be useful in airphoto interpretation. Considering the resolution of ERTS-1 and the type of features visible in the imagery, a certain number of these flood susceptibility indicators should also be observable from space. The following is an extracted list of those indicators cited by Burgess (1967) that would likely be useful for floodplain delineation by ERTS-1.

1. Upland Physiography

2. Watershed Characteristics (such as shape, drainage density, etc.)

3. Degree of Abandonment of Natural Levees

4. Occurence of Stabilized Sand Dunes on River Terraces

5. Channel Configuration and Fluvial Geomorphic Characteristics

6. Backswamp Areas

7. Soil Moisture Availability (this could also be a short term indicator of flood susceptibility)

8. Soil Differences

9. Vegetation Differences

10. Land Use Boundaries

11. Agricultural Development

12. Flood Alleviation Measures on the Floodplain

The importance of the development of floodplain mapping using satellite data is many faceted. First of all, this type of mapping would be considerably less expensive than current ground survey techniques. Secondly, because of the comprehensive coverage available from ERTS-1 type satellites, many more areas could be mapped in a short period of time. Finally, as a result of ERTS-1 repetitive coverage, floodplain maps could be continually updated to reflect changing land use and cover types. If satellite flood mapping proves feasible, a major step would be made in reducing flood damage losses. As a result of the potential importance and economic saving to be realized, this aspect of floodplain management was studied by NASA personnel.

The Spring 1973 floods in the Mississippi Valley came at an opportune time in regard to satellite coverage. Several high resolution satellites were able to observe the effects of the flood: ERTS-1, NOAA-2, and the U.S. Air Force DAPP satellite (Data Acquisition and Processing Program). Because of its higher resolution and greater number of spectral intervals only ERTS-1 was suitable for floodplain feature delineation. The Mississippi River flood was

used as a study case for a number of reasons. It was a flood on a major U.S. river and as a result the effects were easily visible over an extremely large area. Secondly, without a pre-planned ground truth program, very little ground information is usually available in such a satellite study. It was felt that the availability of ground observations without pre-planning was maximized on the Mississippi River. Many other federal and state agencies would be involved in flood related studies that could be used as a source of information. Additionally, most river regimes and floodplain indicators found in other sections of the country would probably be found represented along the Mississippi River system. In general it was a very topical test case. There are some disadvantages, however, that should also be mentioned. Most useful floodplain mapping will be done on streams smaller than the Mississippi. Secondly, because of the comprehensive flood control network along the Mississippi River, the channel is really not free to respond to flood events in a natural way. Because of this confinement, some of the previously listed floodplain indicators may not be pertinent. Also, there may be features unique to the Mississippi Valley, such as highly developed natural levees, that will not be valid indicators in all areas. Finally, there is no guarantee that a set of indicators will exist in different areas that will be related to the boundaries of the 100 year flood (as opposed to some other return period event).

Approach

ERTS-1 imagery of the flood was available on a number of dates including March 31, 1973 (western half of valley) and May 5, 1973 (eastern half). Using these data as a base, several areas were selected where significant flooding was known to have occurred. Pre-flood images for these same areas were then examined, in many cases independently, to determine if there were indicators on the floodplain that delineated the areas susceptible to flooding. Different regions were tested to determine if there is some sort of consistency that would allow the identification of a general set of indicators.

In addition to comparing flood prone areas obtained from analysis of the pre-flood imagery with the actual flooded areas, flood hazard maps were also available for various areas along the Mississippi River. These maps constructed by the USACE or the USGS delineate the areas that would be inundated by a 100 year return period flood (and sometimes the standard project flood which may be expected to result from the most severe combination of meteorological and hydrological conditions). Although these boundaries may not always be accurate, they provide good large scale data for comparison with the ERTS-1 pre-flood imagery.

The areas selected for study along the Mississippi River on the basis of clear ERTS-1 imagery (both before and after flooding) and available flood hazard maps were (1) Greenville-Vicksburg-Natchez, Mississippi area, (2) Cairo,

Illinois to Memphis, Tennessee area, and (3) St. Charles County, Missouri area. These study areas are outlined in Figure 2. In study areas 1 and 2 various sub areas were used for training purposes, i.e., all available data were used to determine the floodplain indicators that best corresponded to the limits of flooding according to the ERTS-1 imagery and to the 100 year flood boundaries taken from the flood hazard maps. Other sub areas were used as controls, i.e., only the pre-flood imagery was examined and flood hazard mapping performed from it alone. These ERTS-1 flood hazard maps were then subsequently compared to the USACE and USGS flood hazard maps and the ERTS-1 flood imagery. In study area 3, flood hazard mapping was conducted for the entire St. Charles County area from the pre-flood imagery alone and compared to existing flood hazard maps and flood imagery. These mapping efforts were conducted initially at an original scale of 1:1,000,000. In study areas 2 and 3, however, some of the ERTS-1 imagery was first enlarged to scales of 1:250,000 and 1:100,000 and the mapping then performed.

Results and Discussion

Study area 1 was examined first to explore the general feasibility of using floodplain features visible from space to identify the relative flood susceptibility of a particular area. Using ERTS-1 imagery obtained on September 13, 1972 (ID 1052-16064) it was apparent that the Mississippi delta region north of Vicksburg would be an interesting test case. Using a color composite of this ERTS-1 scene (shown in Figure 4 in black and white) several areas of interest

were identified. The light tones in the left half of the scene that tend to be located along the smaller rivers in the delta region have been identified as natural levee systems. These structures result when a sediment-laden stream floods and the sediment is allowed to settle. The coarsest material is deposited near the stream whereas the fine material remains in suspension longer and finally falls out on the floodplain proper. The coarse material builds up steadily and tends to make the areas along the stream channels 5-10 feet higher than the adjacent, lower-lying bottomlands. The light tones were confirmed as natural levees by comparison with a general soils map of Northwest Mississippi (U. S. Soil Conservation Service, 1972) and through conversations with the personnel of the Vicksburg office of the USACE. These natural levee areas were mapped and appear on the right side of Figure 4. Additionally, the relatively sharp boundary between dark and light tones running north to south near the center of the ERTS image is actually the division between older upland geologic structures on the right and younger unconsolidated floodplain materials on the left. This upland boundary with a relative relief of a few hundred feet is very evident because of a sharp vegetation change associated with it. As such it marks a zone of transition between areas of low and high flood susceptibility and consequently was mapped in Figure 4.

Two other flood related significant features were observed in Figure 4. The first is the artificial levee system extending along the Mississippi River and

some of its tributaries. These levees are easily observed as light lines or areas of sharp vegetation changes and were mapped in Figure 4. Secondary levees along some of the tributaries were not easily observed in the September 13 image and as a result were not mapped. The other feature is the Vicksburg Industrial Park which is seen as a crescent-shaped, highly reflective region located northwest of Vicksburg. This area has been flood proofed and as such is not very susceptible to flooding.

Observing the same area during flood in Figure 5, which is a $0.8-1.1 \mu m$ image, allows evaluation of the areas designated as non-flood prone in Figure 4. It is initially apparent that the upland boundary provides an effective separation between flood prone and non-flood prone lands. Secondly, most of the natural levee system delineated in Figure 4 remains above water whereas the adjacent lowlands are flooded. The exception to this is the area just north of Vicksburg where some of the natural levees have been inundated. This is due to the fact that the backwater was usually deep here—on the order of 20 feet. Although the artificial levees have generally contained the Mississippi's flow, their effectiveness has been minimized by the backwater encroaching upon them from the rear in many areas. Finally, the Vicksburg Industrial Park in Figure 5 stands out in contrast to the surrounding floodwater as predicted. This simple comparison was encouraging with regard to the ability of remotely sensed floodplain features to be useful indicators of flood susceptibility, although it was recognized that these indicators might apply only to this area.

With the general success of this approach to mapping floodplain features in mind, attempts were made in each of the study areas outlined in Figure 2 to map features that would serve as indicators of the 100 year flood boundaries. Because study area 2 had a relatively complete set of conventional flood hazard maps along the Mississippi River from Cairo, Illinois to Memphis, Tennessee, it was used initially to evaluate the ability of ERTS-1 to delineate the floodplain areas subject to major inundation. Using flood hazard information reports prepared by the USACE at 1:62,500 map scale for the Missouri Water Resources Board from Cairo, Illinois to Midway, Tennessee and USGS flood prone area maps at 1:24,000 and 1:62,500 map scales from Midway, Tennessee to Memphis, a number of specific small study areas were chosen. The following sub areas were chosen for training purposes: Cairo, Illinois to Portageville, Missouri; Caruthersville, Missouri to Randolph, Tennessee; and the Memphis, Tennessee area. Two sub areas were chosen for control efforts, i.e., mapping of the flood hazard areas using only the pre-flood ERTS-1 imagery. These two control sub areas extend from Portageville, Missouri to north of Caruthersville, Missouri and from Randolph, Tennessee to north of Memphis.

Figure 6 presents the actual mapping done in both the training and control sub areas of study area 2. In the training areas the solid lines on either side of the Mississippi River represent the significant flood boundaries (approximately the 100 year flood) constructed using the October 1, 1972 ERTS-1 data in co-ordination with the May 5, 1973 ERTS-1 flood data and the USACE and USGS

flood hazard maps. The training areas were mapped first and surprisingly

little difficulty was encountered photographically correlating floodplain features

to the expected limits of the 100 year flood. Using the knowledge gained in these

training exercises the control area flood hazard mapping was attempted using

only the October 1 imagery at 1:1,000,000 map scale. The dashed lines indi-

cate the significant flood boundaries (again approximately the 100 year flood)

constructed in the control areas. There was no problem in joining these flood

hazard boundaries to the connecting training areas. Further, when these control

area flood hazard boundaries were compared to the USACE and USGS flood

hazard maps, the location of the boundaries were very close with only a few

deviations.

As an example of this comparison, Figure 7 presents both the Portageville

control area flood hazard mapping using ERTS-1 data at 1:1,000,000 scale and

the USACE 1:62,500 scale flood hazard map of the same area. The square box

in the upper left hand section of the ERTS-1 derived flood hazard map corresponds

to the same area as shown in the USACE map on the right. It is apparent that

the USACE flood hazard boundaries are much more detailed than the ERTS-1

boundaries because of the difference in scale. Both boundaries, however, are

in close agreement generally, and it appears that the ERTS-1 flood hazard

boundaries provide a reasonable approximation of the more detailed and expen-

sive USACE product. There appears to be a minor boundary difference in the

vicinity of the Reelfoot National Wildlife Refuge. This is probably due to a lack

of enough ERTS-1 floodplain information in this gently sloping area, although

there is the possibility of some discrepancy in the USACE map. Because the

USACE surveys are costly, they are mostly confined to the main channel of the

Mississippi. The ERTS-1 image used for mapping, however, revealed that

because of the entry of a major tributary south of the town of Ridgely, Tennessee

combined with a solid line of Mississippi River mainline levees to the west and

the upland boundary to the east, the potential for backwater flooding was high.

This was not indicated on the USACE map. When the ERTS-1 May 5 flood

imagery was examined in this particular area, flooded backwater areas existed.

This demonstrates a way in which remotely sensed data can be used to update

or improve existing flood hazard maps. The areas where backwater flooding

is likely have been indicated in Figure 6.

What are the floodplain features visible from ERTS-1 that permit the posi-

tioning of these flood hazard boundaries? Generally they are features that have

resulted from the occurrence of past floods in a particular area, or from flood

protection that a particular region may experience. Specifically they are as

follows:

1. Natural levee systems can be distinguished on the Mississippi River

   floodplain as light tones probably a result of soil and vegetation

   differences.

2. Soil differences can be observed from ERTS-1 and can be used as indicators. Lowland soils indicate areas of flood susceptibility.

3. Upland boundaries in the Mississippi Valley are very prominent and can be easily distinguished by strong vegetation contrasts. Vegetation pattern differences are noticeable as is the more lush growth associated with the upland area.

4. Agricultural pattern differences are readily apparent and are generally a result of the decreased likelihood of flooding behind levee systems. Well organized field patterns indicate areas not likely to flood whereas less organization, larger haphazard fields, more wild areas, and heavy vegetation growth indicate the flood prone areas.

5. Artificial levee systems indicate where there is less of a chance of flooding. The public has responded to these improvements by moving in behind the levees with towns and agriculture. The strong contrast between the organized fields and the non-organized areas tends to enhance the observation of the levee system.

6. Special flood alleviation measures in urban areas such as flood proofing of industrial parks are readily apparent as highly reflective areas.

7.   <u>Channel configuration and possible backwater areas</u> can be observed

where major tributaries enter the floodplain of the Mississippi River,

expecially where the Mississippi is well surrounded by levees.

Study area 1 was also examined using training and control mapping and the

results verified that these same indicators developed in study area 2 were

pertinent.

Study area 3 included all of St. Charles County, Missouri. Because of the

promising results obtained in study areas 1 and 2, it was decided to construct

an ERTS-1 flood hazard map for the entire study area using only October 2,

1972 imagery and then compare it with USGS flood prone area maps and ERTS-1

flood imagery. In addition, to help determine the scale at which the mapping

could be done, both 1:250,000 and 1:100,000 scale enlargements were used.

It was decided to restrict the floodplain mapping to the areas along the Mississippi,

Missouri, and Illinois Rivers. Initially it was apparent that a considerable

amount of detail was present on both the 1:250,000 and 1:100,000 scale color

composites. More detailed mapping was possible as one progressed from

1:1,000,000 down to 1:100,000 scale images. Figure 8 presents the results

of the ERTS-1 flood hazard mapping for St. Charles County at 1:100,000 scale

from a color composite print (shown in black and white). For comparison ex-

amine Figure 9 which is a composite of ten USGS flood prone area maps at

1:24,000 scale showing 100 year flood boundaries for most of the same area.

A generally good correlation exists between the ERTS-1 derived map and the products of the USGS. As indicated in Figure 8 there are a few areas of different interpretations in the positioning of the significant flood boundaries. There are five places where there is a possible error. One of these is a region where a secondary levee system exists which makes the area appear non-flood prone. Under significant flooding such as the 100 year return period flood it may in fact become inundated. Because the flooding observed by ERTS-1 near St. Charles County did not approach the 100 year frequency, it was not possible to check this out. The other four areas of possible error are most likely just interpretation differences. At this time, it is probably best to assume that the errors result from a lack of detail in the ERTS-1 imagery, however, it may be possible that some error exists in the USGS map product.

In order to arrive at a quantitative comparison of the flood prone area boundaries derived from ERTS-1 with those shown on the USGS maps, an attempt was made to measure the relative divergence of these boundaries and the correspondence of flood prone area in the St. Charles, Missouri Quadrangle. The St. Charles Quadrangle was chosen because a significant difference in interpretation of flood prone area was known to exist here. The 1:24,000 quadrangle map was reduced to 1:100,000 scale and overlaid on the comparable ERTS-1 enlargement of the area. Fifty points were picked at random along the USGS flood prone area boundary, and then the horizontal distance between the USGS

boundary and the ERTS-1 boundary was calculated. Additionally, the area prone to flooding in the Quadrangle was planimetered and compared on the USGS and ERTS versions.

The average horizontal distance difference between the two boundaries was approximately 340 meters, but the difference ranged from 0 to 1900 meters (in the region of significant interpretation disagreement). The total flood prone area on the USGS map and the ERTS-1 map was $116.8 \, km^2$ and $117.3 \, km^2$, respectively. Even when the large interpretation difference in the one area is considered, the correspondence of the two boundaries is generally good. The use of the more detailed ERTS-1 digital data may be able to reduce this difference considerably. It is interesting to note that topographic maps of sufficient accuracy for flood-plain mapping are very often not available. The best USGS map represents the contours of the terrain to a 5 foot (1.5 meter) interval (10 feet for the St. Charles Quadrangle). Most floodplains are substantially flat, with slopes less than 0.5%. On such a slope, a 1.5 meter uncertainty in height leads to an uncertainty of 300 meters in horizontal flood spread.

From our experience on the Mississippi River floodplain, it appears that most effective mapping can be done only after the dormant season arrives in Autumn. Summer vegetation growth in these areas is so lush that the ERTS-1 imagery does not allow much discrimination among surface features. Autumn imagery allows you to map floodplain surface features much more easily. In

this regard the October 1 and 2, 1972 ERTS-1 passes over the Mississippi Valley were outstanding. The September 13, 1972 ERTS-1 imagery was also excellent for mapping the natural levee systems in the Mississippi delta region. August 1972 imagery over the Mississippi Valley was clear, however, ability to detect surface features was poor. In general Spring imagery after agricultural fields have been plowed should be best for showing soil differences. The flooding during Spring 1973, however, did not allow confirmation of this hypothesis.

APPLICATIONS

By possessing the ability to rapidly survey the extent of flooding from space with ERTS-1, a new regional flood assessment tool is available. Never before has such a complete picture of flooding on a major stream been observed as was the case with ERTS-1 observations of the Spring 1973 Mississippi River flood.

The value of this new tool for flood management is multi-faceted. First, by having a comprehensive picture of flooding over the whole river valley, the areas of maximum flooding extent can be determined, thus focusing initial relief efforts on these hardest-hit areas. This application would be most pertinent in a hydrologically data-sparse, developing country. In the United States, however, value rests in the fact that the areas of extensive flooding point out locations where additional flood control works may be necessary, e.g., ERTS-1 showed flooding to be more extensive on the Mississippi River tributaries than on the mainstem.

Several Federal agencies (USACE and USGS) have as part of their tasks the job of flood assessment. Using ERTS-1 data they have been able to regionally assess the extent of the Mississippi River flood (e.g., see Deutsch, et. al., 1973). Although the regional approach using ERTS-1 will not answer questions about the flooding of specific fields and the exact location of flood boundaries, the results are extremely useful for aiding in the planning of flood recovery efforts. In fact it is possible that knowing the general areas where flooding took place will reduce the number of erroneous flood damage claims. It appears that there will still be a need for ground-based high water surveys in specific areas of interest, but even here ERTS-1 has a role to play. ERTS-1 flood imagery may reduce the need for numerous aircraft flights that are usually employed by the USACE to select the areas for ground surveys of major flood events.

Although flood mapping at 1:1,000,000 or 1:250,000 scale performs a useful regional function, it is not sufficient to enable insurance companies to settle claims. The use of the ERTS-1 digital data may help to solve this problem. Our initial early results indicate that digital mapping is possible at the 1:62,500 scale at a minimum (and perhaps even at the 1:24,000 scale). This type of mapping would indeed be approaching a scale commensurate with claim settlements. Improvements to be expected on future earth resources satellites such as higher resolution and increased frequency of coverage will help solve this problem of insurance settlements, improve general flood mapping, and allow more accurate positioning of flood crests in different parts of a river basin.

Satellite remote sensing such as that available from ERTS-1 can be used

as a regional floodplain mapping and planning tool that, in the long-term, will

help reduce flood damages. Although some sections of the major floodplains in

the U.S. have been surveyed for flood susceptibility, many areas have not and

will not be surveyed in the near future. Photographically, ERTS-1 can be used

at a scale as large as 1:100,000 to delineate flood susceptible areas on flood-

plains. At this scale ERTS-1 can be used on a regional basis as an input to

floodplain planning. ERTS-1 can locate the areas susceptible to flooding and their

relationship to "safe" areas. As such ERTS-1 mapping can be used to guide

development, e.g., ERTS-1 could be used to locate the sites of new planned

cities like Columbia, Maryland. In areas where towns already exist, further

expansion could be more logically regulated. If the desirability of development

of a specific area was still in question after an ERTS-type analysis, then ground

surveys or low altitude aircraft flights could be made. ERTS-1, however, could

eliminate the need for many of these surveys. Currently performed by the USACE

or USGS, floodplain ground surveys cost from $250-$4000 per km depending

on the area. Similar surveys from ERTS-1 total only the cost of about one man

hour. Floodplain mapping agencies may be able to better schedule their flood-

plain activities by using ERTS-1's regional analysis to rapidly determine whether

a specific request is from a critical or non-critical area.

In areas where some detailed ground information on the floodplain has been

compiled, ERTS-1 data can be used to extend this information into unmapped

regions and thus provide preliminary information to help guide development. This would both reduce the cost of surveys and also provide a sensible way to regulate man's ever increasing encroachment on the floodplain. A variation of this approach would be to use gound surveyed areas available from the USACE or USGS as a form of ground truth. Computer programs utilizing ERTS-1 digital data could use these areas as training sites and then extend the analysis into the surrounding region at the 1:62,500 map scale. This would provide an objective and very cost effective way to use remote sensing as a viable input for floodplain management.

Because boundaries derived from a set of natural and cultural floodplain indicators cannot be expected to correspond exactly with engineering boundaries derived from elevations, ERTS-1 probably cannot be used at this time to assist in performing surveys necessary for communities to qualify for the Federal Flood Insurance program. It is remarkable, however, that in the study areas chosen here, the two types of boundaries are very closely aligned. Attempting to measure their relative divergence is difficult when comparing small scales (1:250,000 or 1:100,000) with larger scales (1:24,000). In the one such attempt in St. Charles County (St. Charles Quadrangle), the average deviation of the boundaries was 340 meters, which is reasonably good. At this stage it is sufficient to say that the general boundary agreement is promising. In order to definitively measure the correspondence of these floodplain limits, a project

is underway to measure the divergence of boundaries derived from engineering, low altitude aircraft, and satellite surveys at 1:24,000 scale on the West Branch of the Susquehanna River.

SUMMARY

The Spring 1973 Mississippi River flood was investigated using remotely sensed data obtained from ERTS-1. It appears that regional flood extent mapping can be performed photographically at a scale of 1:100,000 and should be useful to agencies interested in obtaining a rapid, comprehensive assessment of flooded area. Using image analysis and information extraction systems, automatic and fast determinations of the percentage of area flooded in St. Charles County, Missouri and in eastern Arkansas were possible. The observation of flood extent allowed a general evaluation to be made of the effectiveness of flood control works on the Mississippi River and its tributaries in Arkansas.

The delineation of areas susceptible to flooding along the Mississippi River was performed using pre-flood imagery in three separate study areas. The areas subject to inundation by major flooding (approximately the 100 year return period flood) were identified by observation of various floodplain indicators such as natural and artificial levee systems, soil differences, agricultural pattern and vegetation differences, upland boundaries, backwater areas, and special flood alleviation measures in urban areas. The flood prone areas delineated using ERTS-1 were compared to conventional flood hazard maps prepared by the

USACE and USGS. The comparison indicated close agreement between the two types of maps with only a few areas of interpretation differences. Most ERTS-1 flood hazard mapping was done photographically at the 1:1,000,000 scale, however, flood susceptibility determinations in St. Charles County, Missouri using ERTS-1 were satisfactorily performed with more detail at scales of 1:250,000 and 1:100,000. Preliminary work with ERTS-1 digital data indicates that floodplain delineation can be conducted at a scale of 1:62,500. ERTS-1, because of its comprehensive view, can be used on a regional basis as an input to floodplain zoning. In areas where some ground surveys of flood susceptibility have been performed, ERTS-1 data may be used to extend this information into unmapped regions and thus provide preliminary information to guide development. In general ERTS-1 should provide a much needed, cost effective tool for increasing our knowledge about the flood susceptibility of floodplain areas.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1.   ERTS-1 views Arkansas flooding.
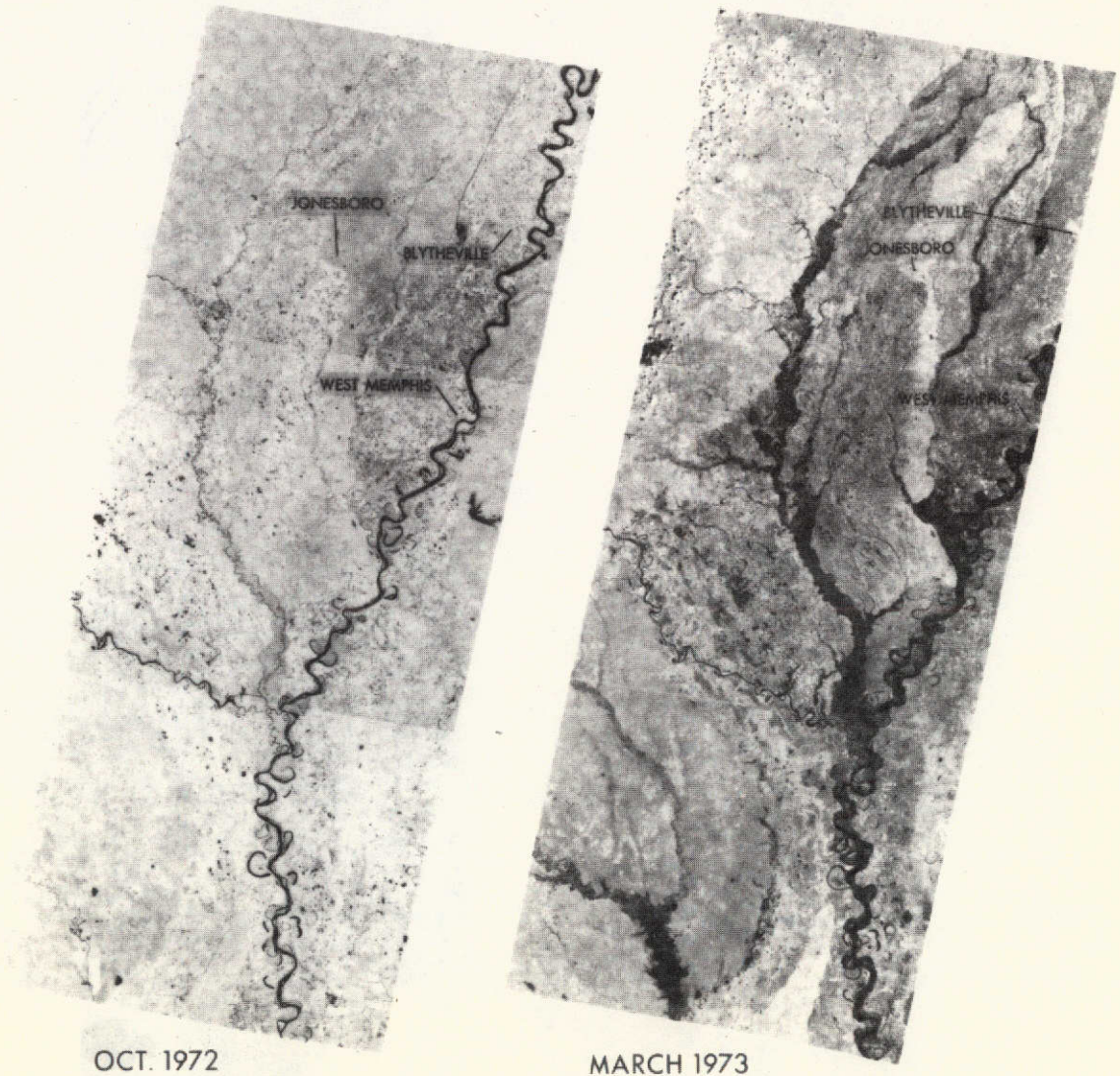
Figure 2.   ERTS-1 mosaic of the Mississippi River from St. Louis to New

Orleans, October 1 and 2, 1972 (0.8-1.1 μm).   Three separate
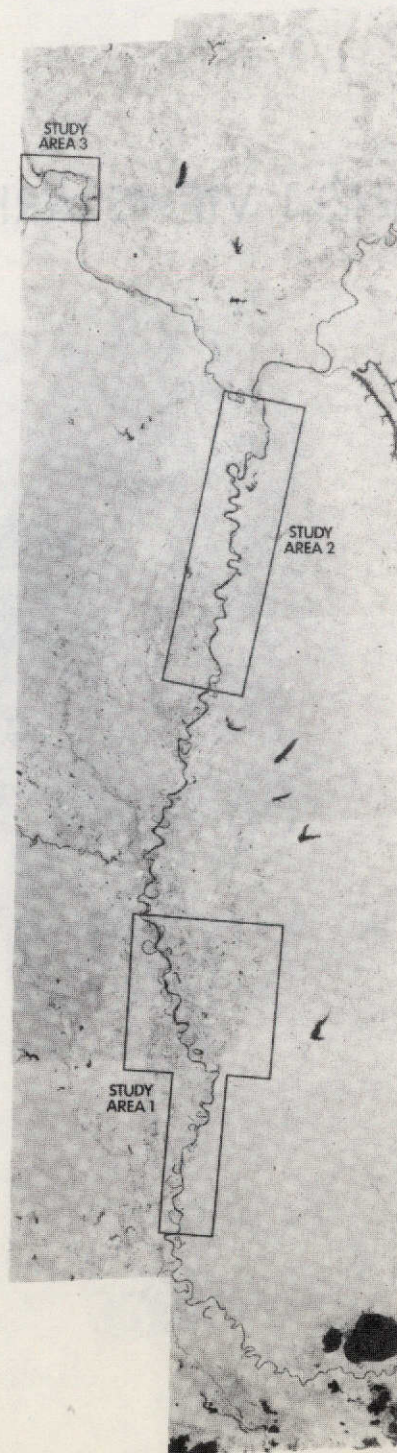
floodplain study areas are indicated.

Figure 3.   ERTS-1 mosaic of the Mississippi River in flood from St. Louis

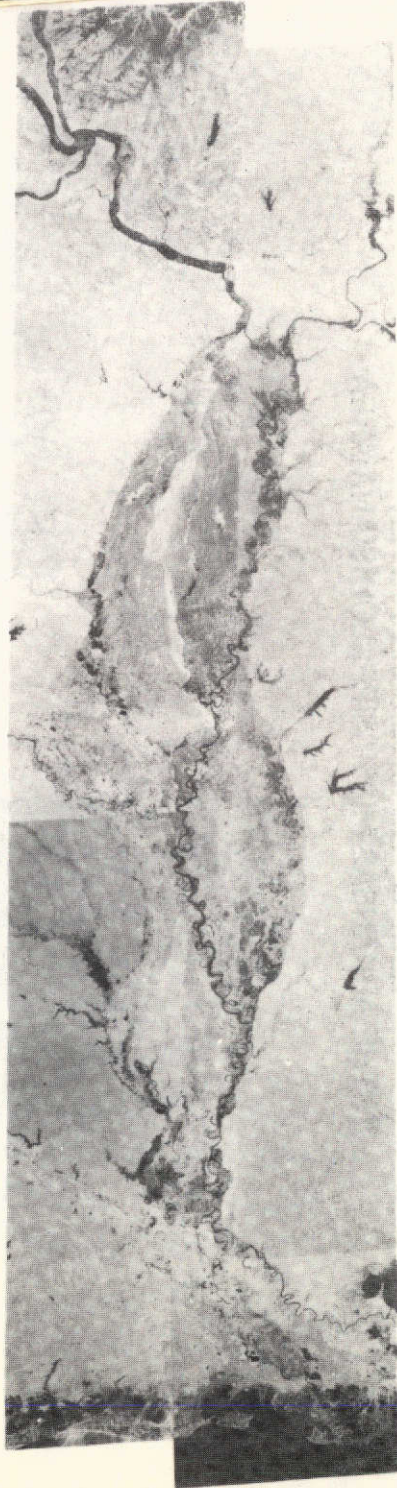to New Orleans—March 31, May 5, and March 24, 1973 images

(0.8-1.1 μm).

Figure 4.   ERTS-1 floodplain mapping along the Mississippi River in the

Arkansas-Mississippi-Louisiana area.

Figure 5.   ERTS-1 observations of Spring 1973 flooding on the Mississippi

River floodplain in the Arkansas-Mississippi-Louisiana area.

Figure 6.   ERTS-1 regional flood hazard mapping at 1:1,000,000 scale from

Cairo, Illinois to Memphis, Tennessee.

Figure 7.   ERTS-1 derived expected limits of significant flooding (approxi-

mately the 100 year flood) along the Mississippi River near

Portageville, Missouri.

Figure 8. ERTS-1 Flood hazard mapping in St. Charles County, Missouri at a scale of 1:100,000. The areas delineated as flood prone will be inundated by a significant flood (approximately the 100 year flood).

Figure 9. Composite of ten U.S. Geological Survey maps of flood prone areas in St. Charles County, Missouri at an original map scale of 1:24,000.

ERTS-1 VIEWS ARKANSAS FLOODING

OCT. 1972   MARCH 1973

Figure 1.

ERTS-1 MOSAIC OF THE MISSISSIPPI RIVER
FROM ST. LOUIS TO NEW ORLEANS,
OCTOBER 1 AND 2, 1972 (0.8-1.1 μm).
THREE SEPARATE FLOODPLAIN STUDY
AREAS ARE INDICATED.

STUDY
AREA 3

STUDY
AREA 2

STUDY
AREA 1

Figure 2.

ERTS-1 MOSAIC OF THE MISSISSIPPI RIVER
IN FLOOD FROM ST. LOUIS TO
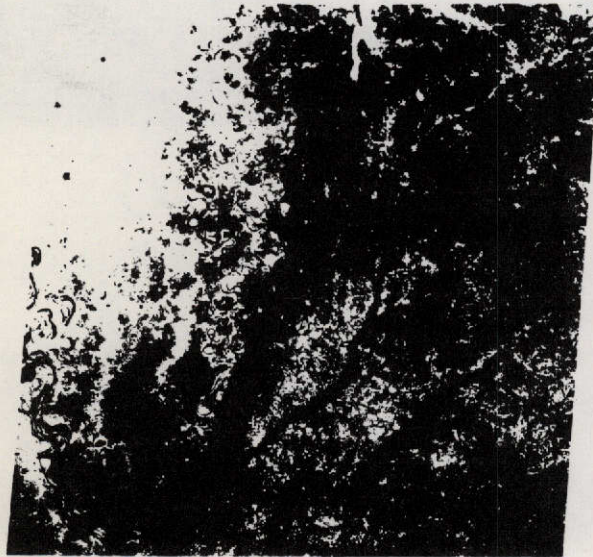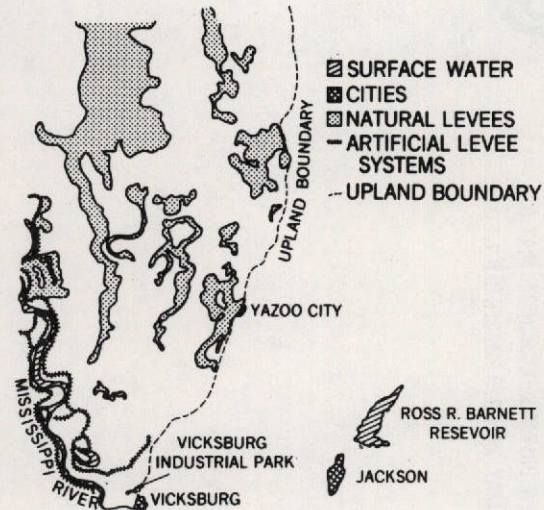NEW ORLEANS—MARCH 31, MAY 5,
AND MAY 24, 1973 IMAGES (0.8-1.1 μm).

Figure 3.

ERTS-1 FLOODPLAIN MAPPING
ALONG THE MISSISSIPPI RIVER
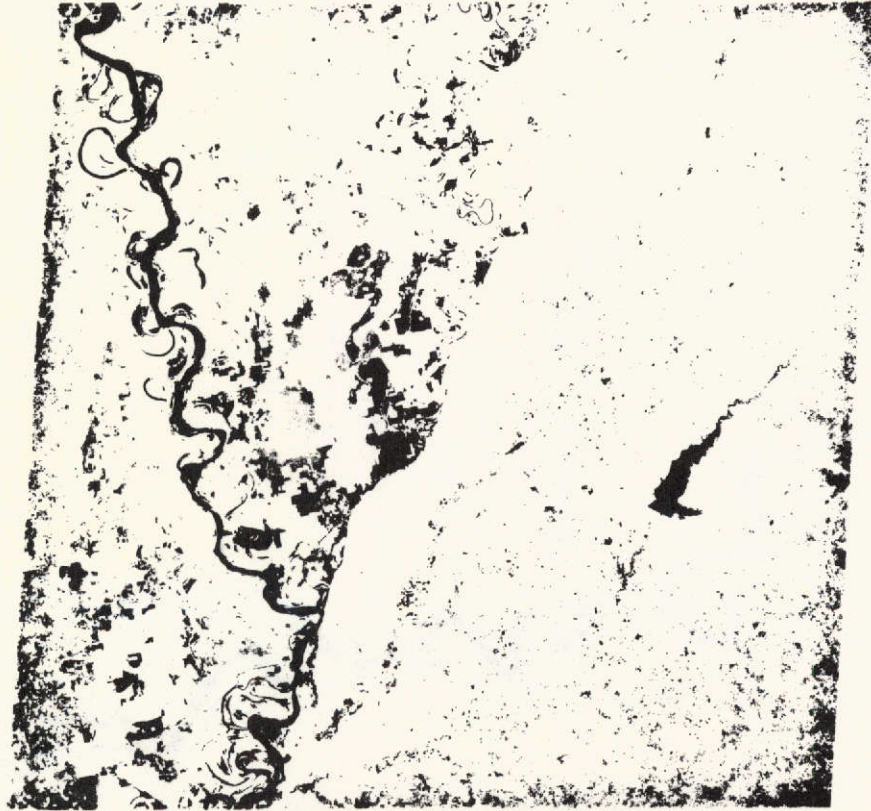## IN THE ARKANSAS-MISSISSIPPI-LOUISIANA AREA

SEPTEMBER 13, 1972

OVERLAY SHOWING FLOODPLAIN
FEATURES EXTRACTED FROM THE
SEPTEMBER 13, 1972 ERTS-1 COLOR
COMPOSITE (1052-16064)

Figure 4.

ERTS-1 OBSERVATIONS OF SPRING 1973 FLOODING
ON THE MISSISSIPPI RIVER FLOODPLAIN IN THE
ARKANSAS-MISSISSIPPI-LOUISIANA AREA

Figure 5.

MAY 5, 1973

0.8-1.1μm

ERTS-1 REGIONAL FLOOD HAZARD
MAPPING AT 1:1,000,000 SCALE
FROM CARIO, ILLINOIS TO
MEMPHIS, TENNESSEE

CAIRO

POSSIBLE BACKWATER
FLOODING AREA

BACKWATER FLOODING

SIGNIFICANT FLOOD BOUNDARIES (APPROXIMATELY
THE 100 YEAR FLOOD) CONSTRUCTED USING
OCTOBER 1,1972 ERTS-1 IMAGERY

SIGNIFICANT FLOOD BOUNDARIES (APPROXIMATELY
THE 100 YEAR FLOOD) CONSTRUCTED USING
OCTOBER 1,1972 ERTS-1 IMAGERY WITH THE
AID OF MAY 5,1973 ERTS-1 IMAGERY AND USACE
AND USGS FLOOD HAZARD MAPS

POSSIBLE
BACKWATER
FLOODING   MEMPHIS
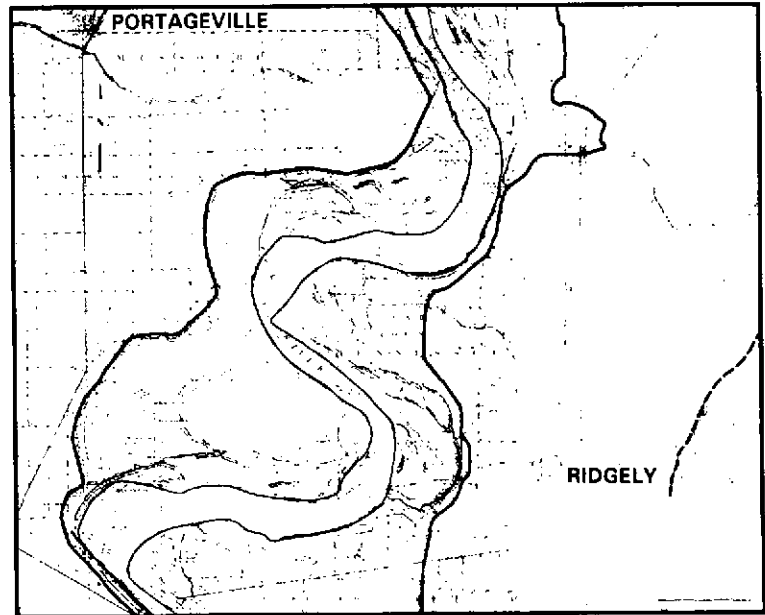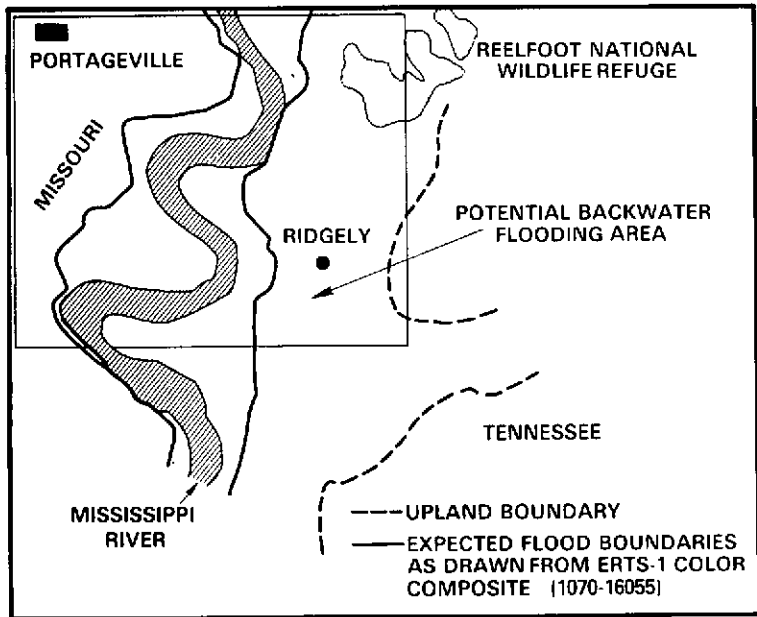
INDUSTRIAL AREA

MISSISSIPPI RIVER
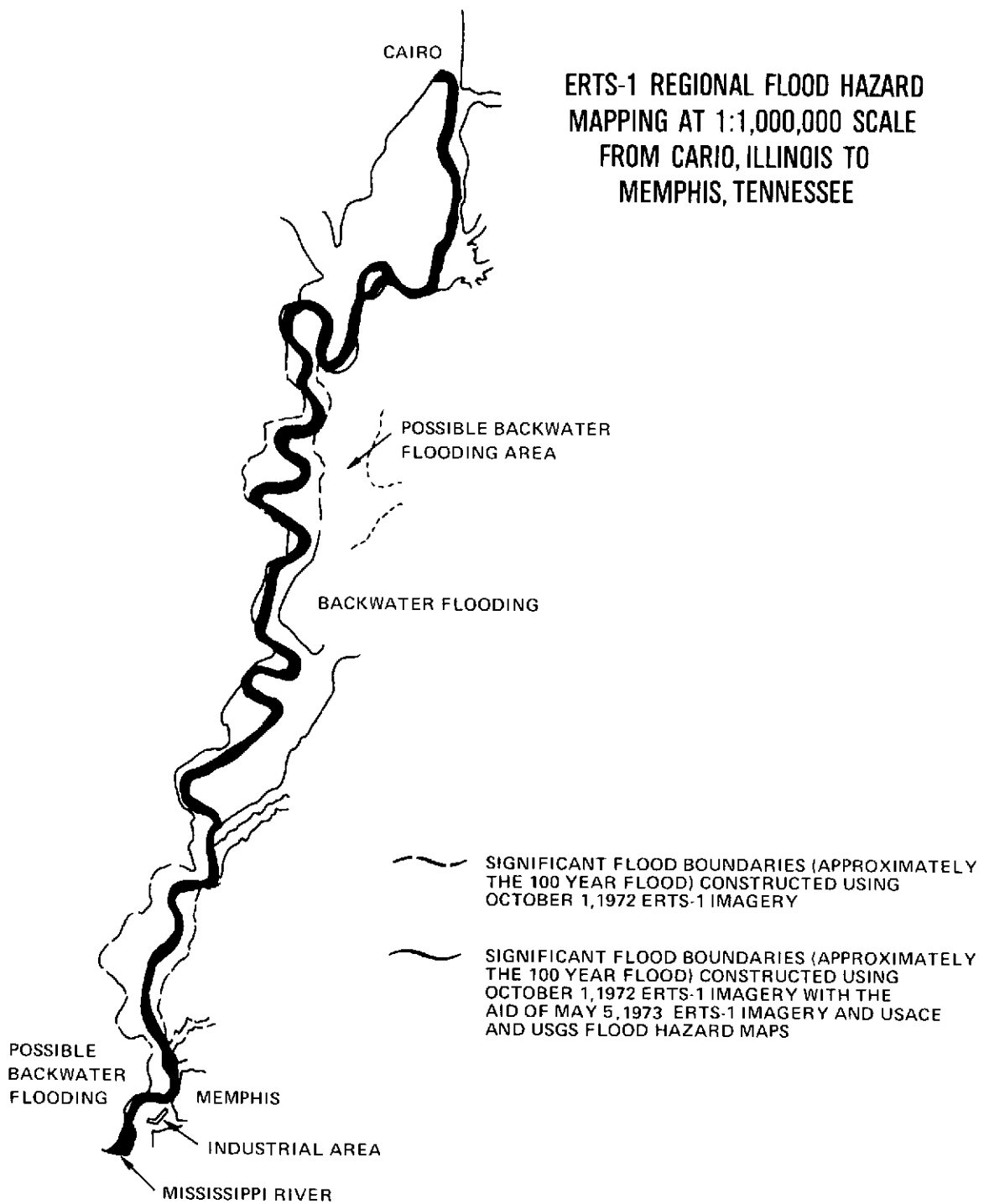
Figure 6.

Figure 7.

ERTS-1 DERIVED EXPECTED LIMITS OF
SIGNIFICANT FLOODING (APPROXI-
MATELY THE 100 YEAR FLOOD) ALONG
THE MISSISSIPPI RIVER.
ORIGINAL SCALE 1:1,000,000

U.S. ARMY CORPS OF ENGINEERS
100 YEAR FLOOD BOUNDARIES.
ORIGINAL SCALE 1:62,500

PORTAGEVILLE

MISSOURI

RIDGELY

REELFOOT NATIONAL
WILDLIFE REFUGE

POTENTIAL BACKWATER
FLOODING AREA

TENNESSEE

MISSISSIPPI
RIVER

----UPLAND BOUNDARY
——EXPECTED FLOOD BOUNDARIES
AS DRAWN FROM ERTS-1 COLOR
COMPOSITE (1070-16055)

ERTS-1 FLOOD HAZARD MAPPING IN ST. CHARLES COUNTY, MISSOURI AT A SCALE OF 1:100,000
THE AREAS DELINEATED AS FLOOD PRONE WILL BE INUNDATED BY A SIGNIFICANT FLOOD (APPROXIMATELY THE 100 YEAR FLOOD)
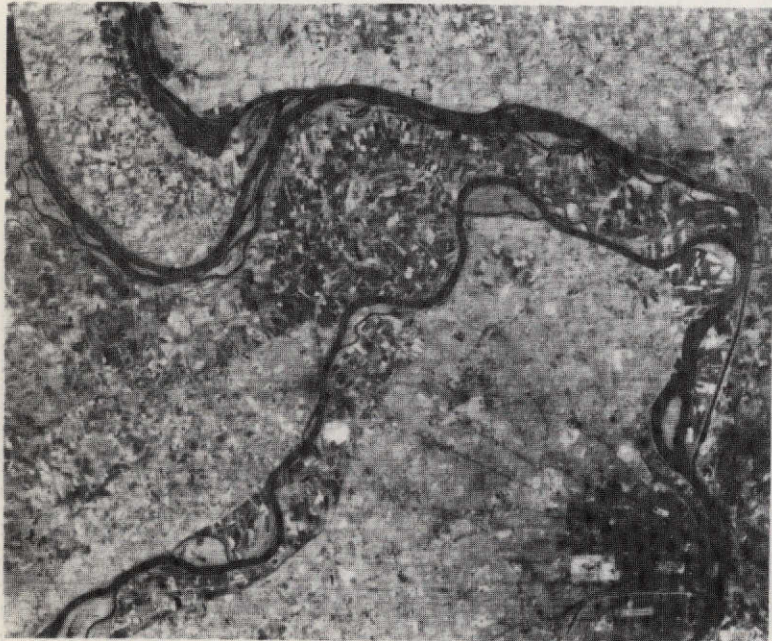
PORTION OF A 1:100,000 SCALE ERTS-1 IMAGE TAKEN ON OCTOBER 2, 1972 (0.8-1.1 μm)
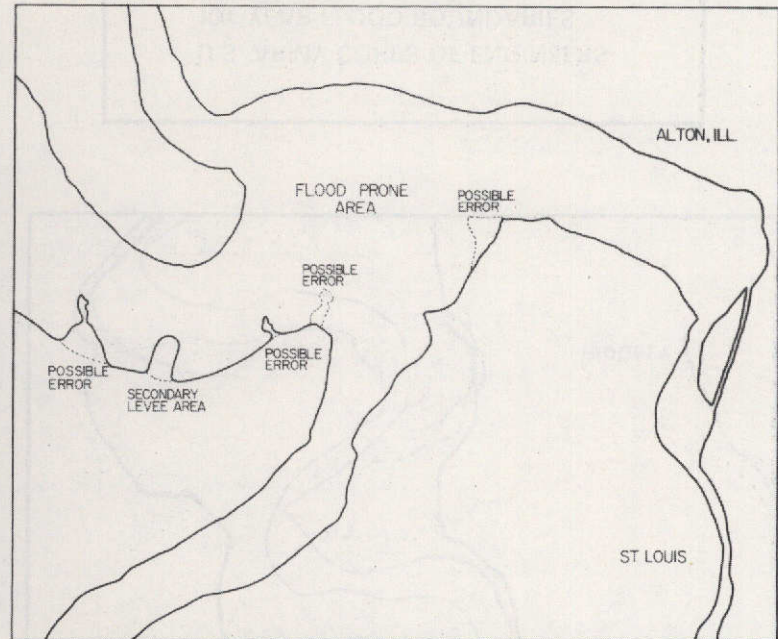
ERTS-1 DERIVED MAP OF FLOOD PRONE AREAS TAKEN FROM OCTOBER 2, 1972, 1:100,000 SCALE COLOR COMPOSITE

Figure 8.

COMPOSITE OF TEN U.S. GEOLOGICAL SURVEY MAPS OF FLOOD PRONE AREAS
IN ST. CHARLES COUNTY, MISSOURI AT AN ORIGINAL MAP SCALE OF 1:24,000

FLOOD PRONE AREAS HAVE A 1 IN A 100 CHANCE ON THE AVERAGE OF BEING INUNDATED IN ANY GIVEN YEAR.

Figure 9.