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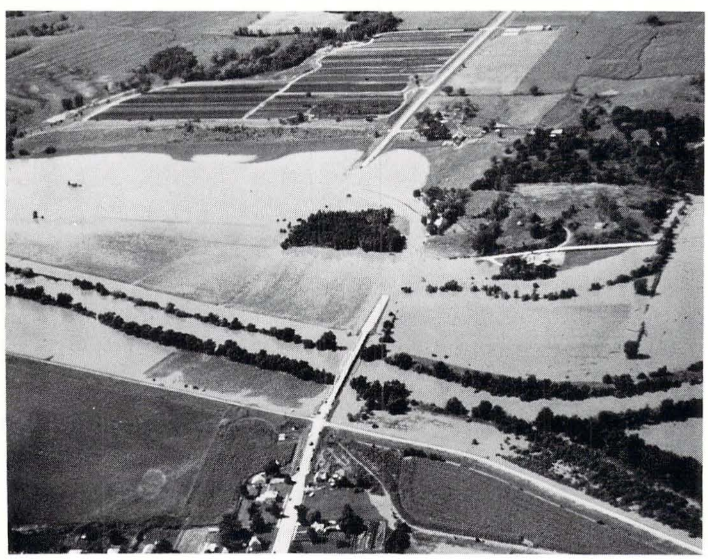
SUMMARY OF MULTISPECTRAL FLOOD INUNDATION MAPPING IN IOWA



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PREFACE

This Public Information Circular summarizes information related to flood inundation mapping in the Midwest. Most of this flood mapping research was conducted within the Iowa Geological Survey Remote Sensing Laboratory (IGSRSL). Applied research in remote sensing does not take place in a vacuum, however. Other individuals and organizations have provided suggestions and guidance which have made this effort successful.

The staff of the Remote Sensing Institute (RSI) of South Dakota suggested the research, based on their analysis of the June 9, 1972, Rapid City flood. This RSI study used color and color-infrared film to record the effects of flooding, and analysis of the imagery revealed that color-infrared film was most suitable for evaluating flood damage. On the first day of the Nishnabotna flood, staff from RSI alerted IGSRSL staff of the flooding and suggested a possible flood-mapping experiment. Lack of emergency flood mapping funds in Iowa prohibited RSI involvement in the subsequent study.

Funding for research and development is generally not easily obtained. Trying to obtain funding in a few hours during an emergency is especially difficult. The U. S. Geological Survey, Water Resources Division located in Iowa City graciously provided funds for this emergency flood study and has continued support for other flood studies. Without their support, this research would not have been possible.

The EROS Program of the U. S. Department of Interior assisted IGSRSL staff in the application of Earth Resources Technology Satellite (ERTS) data to Midwestern flood mapping. EROS Program personnel examined ERTS-1 imagery, produced seven days after the Nishnabotna flood, and they noted that flooded areas were apparent. The EROS Program office contacted IGSRSL and alerted the staff to the possibility of using multispectral satellite imagery for flood investigations. The EROS Program office has continued to encourage all aspects of this applied research in remote sensing.

The National Aeronautics and Space Administration, Goddard Space Flight Center also assisted the IGSRSL study. Personnel at Goddard independently mapped the flooded area on ERTS-1 imagery. When Goddard staff learned of the IGSRSL study they shared the results of their investigations with IGSRSL personnel and both organizations collaborated in presenting a paper at the March 1973, "Symposium on Significant Results Obtained from Earth Resources Technology Satellite."

Much appreciation is extended to others who have supported this research project. Especially important for their consultation and arrangement of financial support are Sulo Wiitala, Water Steinhilber, Ivan Burmeister, and Oscar Lara--all from the U. S. Geological Survey, Water Resources Division. Paul Allee, Aerial Services, Inc., has been very helpful by allowing the multiband camera to be installed in his aircraft, and by furnishing metric imagery and photogrammetric information. In addition, James Cooper, Iowa Natural Resources Council, has shown continued interest in developing these techniques. Charles Rucker, Corps of Engineers, provided radar imagery for this report.

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SUMMARY OF MULTISPECTRAL FLOOD INUNDATION MAPPING IN IOWA

ABSTRACT

Evaluation of multispectral imagery from three floods occurring at different times of year in Iowa has indicated methods of mapping flood inundation several days after flood waters have returned to the main channel of rivers. Cooperative studies by the Iowa Geological Survey, Remote Sensing Laboratory and the U. S. Geological Survey, Water Resources Division, suggests that color infrared film would provide flood inundation data having the highest multiplicity of possible uses for floodplain management-planning in Iowa.

Characteristics of infrared radiation; including the absorption of photographic infrared wavelengths by water, the reduced infrared reflectance of wet soils and stressed plants, and the different reflective properties of snow and ice at infrared wavelengths; account for the wide application of color infrared film for flood mapping in Iowa. Winter floods at higher latitudes may be mapped by identifying ice remaining after flood recession. Evaluation of multispectral imagery from mid-spring floods indicates that significant flooding may be mapped for at least five days following flood recession. Late summer floods may be mapped for at least seven days following flood crest using color-infrared imagery. Best flood inundation mapping was accomplished by multispectral color-additive viewing utilizing the blue and infrared bands. ERTS-1 satellite data supported the basic conclusions of the low-altitude studies and extended the time for acquisition of infrared imagery to possibly over several weeks in late summer. The satellite imagery also allowed rapid appraisal of the areal extent of flood inundation on a regional scale.

REMOTE SENSING STUDIES OF IOWA FLOODS

Floods are being mapped and analyzed by various state and federal agencies, especially the U. S. Geological Survey and the U. S. Army Corps of Engineers. Present methods include recording stream-gaging stations, special ground surveys to acquire ground control between stations, and computing flood stages based on stream and valley profiles. Sometimes aerial reconnaissance and aerial photography is also acquired. Usually this photography has been acquired utilizing panchromatic black-and-white film with a minus-blue filter on the aerial camera, and the mission was usually flown as close to flood crest as possible. Several problems have been identified with this traditional approach to flood mapping:

1. Inclement weather may prevent adequate photographic coverage during flood crest.
2. The movement of a flood crest downstream slowly through time requires repeated overflights.
3. The film-filter combinations commonly used for flood mapping are not optimal for this purpose.

Iowa Geological Survey, Remote Sensing Laboratory (IGSRSL) staff recognized that many of these problems could be alleviated if an aerial photographic technique could be developed that would permit optimal detection of flood inundation after flood crest. The surface cover of the Iowa landscape changes constantly with different seasons and it was recognized that the aerial flood mapping techniques developed must accommodate this variability.

The IGSRSL and the U. S. Geological Survey, Water Resources Division entered into a cooperative program to develop aerial methods for mapping midwestern flood inundation on a seasonal basis. This research evaluates flooding in Iowa that occurred during three seasons of the year (fig. 1). Results of these seasonal studies in Iowa may be extended to other areas by evaluation of the effects of flooding on various ground-cover types present. The multispectral characteristics of bare soils, vegetation, and snow and ice should be similar in other climatic regions. In general, color-infrared imagery with stereoscopic coverage provides the most suitable product for flood-inundation mapping in a variety of expected ground-cover situations.

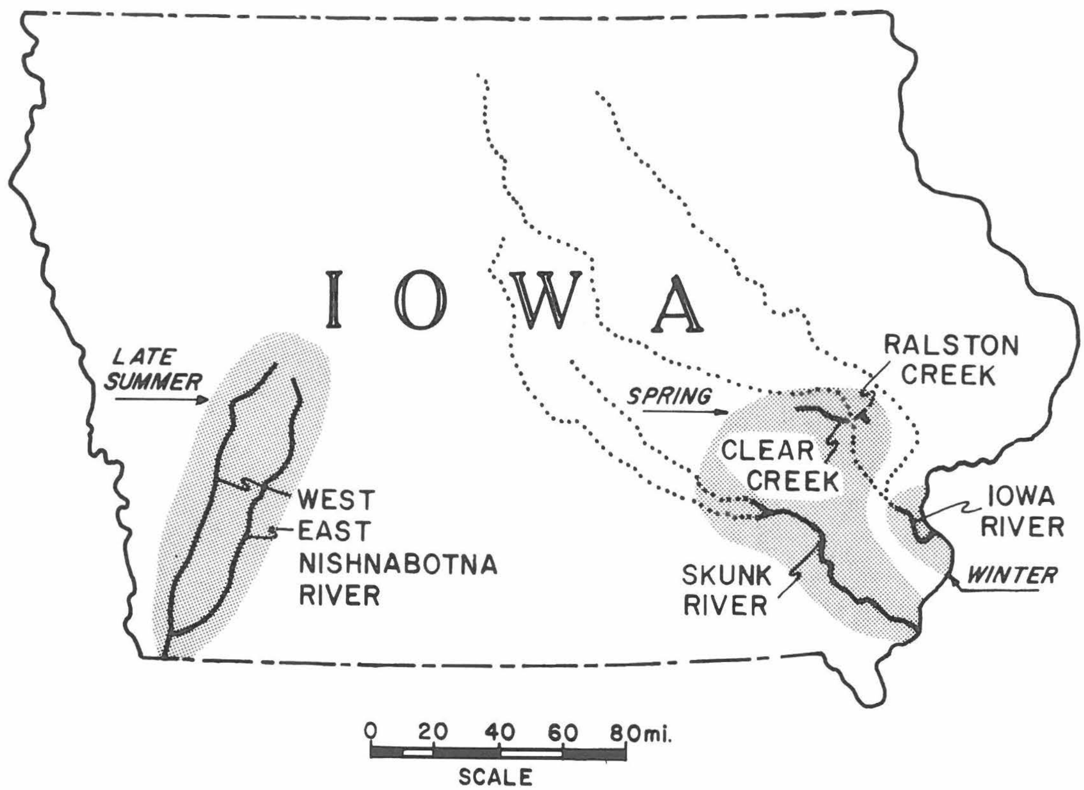
Nishnabotna Rivers Flood Study - September 1972

The IGSRSL program to develop a flood mapping technique began in September 1972, with a study of a flood on the East Nishnabotna River (Hoyer and Taranik, 1972). On September 10-12, 1972, a large storm system produced up to 20 inches of rain locally in west-central Iowa. Extensive overbank flooding occurred in the Nishnabotna River basin where record flow rates were recorded at two stations on the East Nishnabotna River, and one station on the West Nishnabotna River. These records indicated that the Nishnabotna flood was the one-hundred-year flood in many locations. The flood crest moved downstream from the northern portion of the study area to the mouth of the drainage basin and the Missouri River between September 12-15, 1972.

At the time this flood occurred crops were at maturity, soybeans were turning yellow-brown, corn was still green, the trees and underbrush were in full leaf, and the short grasses and weeds were still green. Uncut grasses along the waterways had matured and turned yellow.

Imagery was obtained on the East Nishnabotna River between Interstate 80 and Hamburg, Iowa. Simultaneous field investigations were conducted to document

FIGURE 1. Locations of streams studied for the development of seasonal flood mapping techniques.



the extent of inundation with ground data. On September 14, color (Kodak 2445) and black-and-white panchromatic (Kodak 2405) vertical, stereoscopic imagery was obtained from 8,000 feet above ground level (AGL) with a Wild RC-8 camera. The black-and-white imagery was acquired with a minus-blue filter (Wratten 12). Color-infrared imagery was not produced on a nine-inch format because color-infrared film was not available from any supplier on short notice. On September 15, multiband imagery was obtained from 8,000 feet AGL, using an International Imaging Systems (I^2S) multiband camera and black-and-white infrared film (Kodak 2424). In addition, 35 mm stereo, oblique imagery was obtained. The films used were Ektachrome and Ektachrome infrared because of their similarity to available aerial color and color-infrared films. The conventional imagery was analyzed visually with stereoscopic viewing equipment, and the multispectral imagery was analyzed using an I^2S color-additive multiband viewer. Imagery acquisition coincided with the flood crest in some areas, but was as much as three days after the crest in some upstream areas. Some of the black-and-white panchromatic imagery was taken prior to the flood crest in the southernmost portion of the river.

The ERTS-1 satellite imagery of this area was also obtained on September 18 and 19, 1972, up to seven days after the flood crest. This imagery was also utilized in this initial study (Hallberg, et al., 1973). Maps of the inundated area were prepared by interpretation of the various types of imagery. All known ground data agrees with this mapping (fig. 2). In short, the study produced a system capable of mapping Midwestern, late summer, flood inundation several days after flood crest.

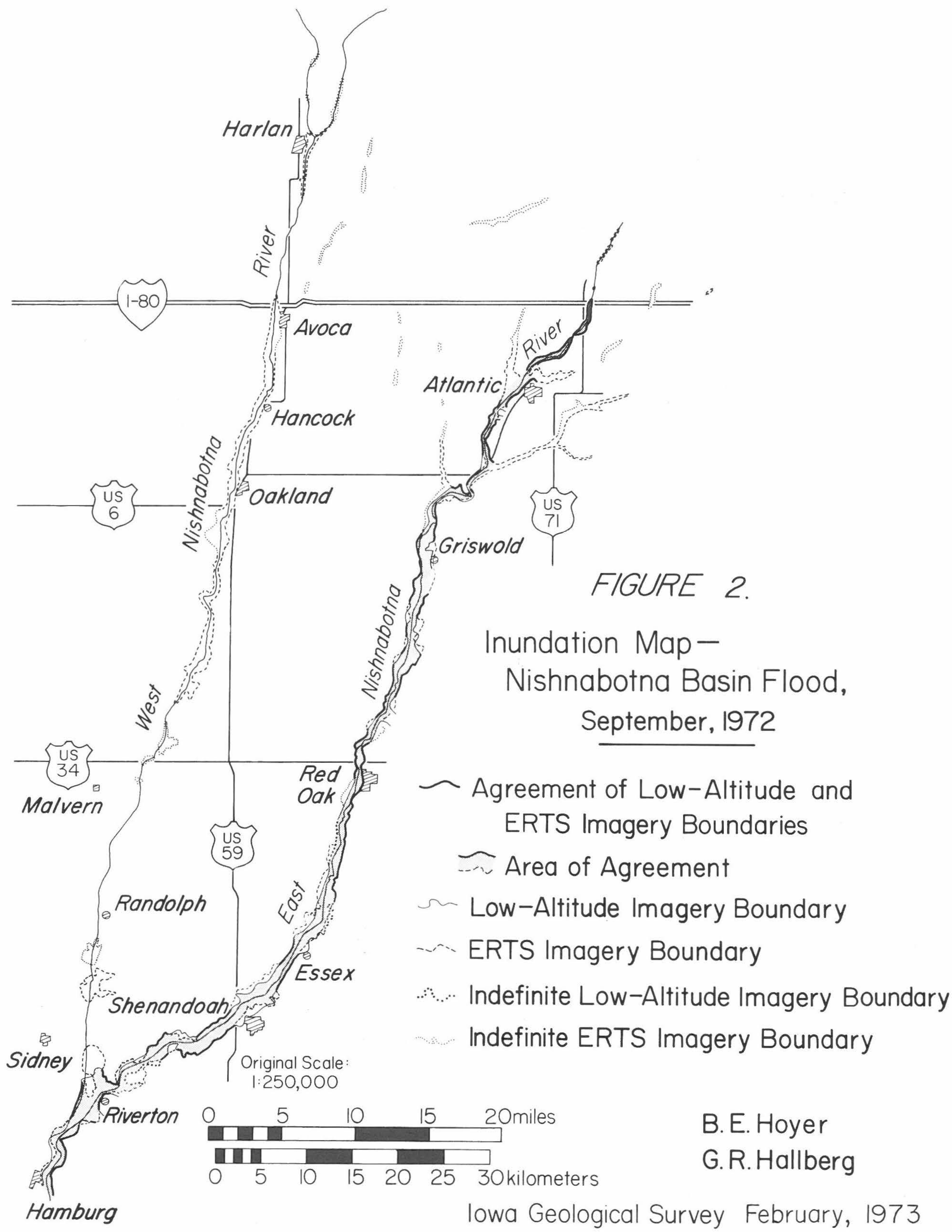


FIGURE 2.

Inundation Map—
Nishnabotna Basin Flood,
September, 1972

Table 1. Spectral band configuration of IGSRSL I^2S Multiband Camera and ERTS-I Multispectral Scanner.

IGSRSL Multiband Camera			ERTS-I Multispectral Scanner		
Band No.	Spectral Band	Wavelengths (nanometers)	Band No.	Spectral Band	Wavelengths (nanometers)
I	Blue	400 - 465	-----	-----	-----
2	Green	480 - 570	4	Green	500 - 600
3	Red	595 - 685	5	Red	600 - 700
4	Infrared	740 - 900	6	Infrared	700 - 800
-----	-----	-----	7	Infrared	800 - II00

Conclusions of the Nishnabotna Rivers Flood Study

1. Infrared radiation (700 to 1,100 nm) proved most important for flood-inundation mapping. Saturated soils and standing water resulting from flooding reflect less infrared radiation than adjacent nonflooded areas. Likewise, many plants stressed by the flood reflect less radiation in the infrared band than comparable plants that were not inundated. River bottom tree species, many of which are phreatophytes, did not show a decrease in infrared reflectance.

2. Blue radiation (400 to 465 nm) was reflected more strongly from flooded vegetated areas than from the surrounding areas. The green (480 to 570 nm) and red (595 to 685 nm) bands were found to be least definitive for delineating the flooded area. Thus, black-and-white panchromatic film, which is normally exposed through a minus-blue filter for haze penetration, contains the least information for mapping late summer flooding after flood crest.

3. Color imagery aided interpretation in the visible and near-visible infrared portions of the spectrum. The best delineation of the inundated area was provided by multispectral color-additive viewing utilizing the blue and infrared bands. However, for maximum utility the imagery should allow the production of topographic maps. Of commercially available films, color infrared (Kodak 2443) appears to be of greatest use for flood-inundation mapping (table 2).

4. Stereoscopic viewing was found to be very helpful for interpreting the flooded area. The ability to view surface relief is helpful for interpreting the flooded area, especially in very flat areas where the flood boundary may be very complex, and tone or colors are not completely definitive.

5. The low-altitude multiband imagery demonstrated that flood inundation can be accomplished in late summer for at least three days following flood crest. Analysis of ERTS-1 MSS imagery reinforced the above conclusions, and increased the time period critical for imagery acquisition to at least seven days after the flood crest.

6. The interpretation of ERTS-1 imagery was compared with the interpretations from the low-altitude imagery and ground data, and this comparison demonstrated the capability of ERTS-1 imagery to map flood inundation at 1:250,000 scale.

7. The synoptic view of the ERTS-1 imagery allows a rapid appraisal of flood inundation on a regional scale. In addition, reasonable measurements of flooded acreage seem possible for entire river

Table 2. Suitability of low-altitude multispectral photographic images for late summer flood mapping in the Midwestern Region.

Spectral Band (s)	Appearance of Flooded Areas Versus the Appearance of Unaffected Areas	Suitability for Flood Mapping
Blue	Lighter	Fair
Green	Lighter or Darker	Very Poor
Red	Lighter or Darker	Poor
Infrared	Darker	Good
Green, red, infra-red--false colored as blue, green, & red, respectively.	Darker Red, grading to Green, Blue, or Grey	Very Good
Blue, infrared--false colored as blue & red, respectively.	More Blue to Purple	Excellent

systems. The total flooded area mapped in the Nishnabotna basins was 78,000 acres and the flooded acreage in the West Nishnabotna basin (23,000 acres) was determined solely from ERTS-1 imagery. The use of satellite imagery to assess floods could be an important tool, particularly in poorly mapped, sparsely settled, or inaccessible areas, and for assessing floods along the larger interstate river systems.

8. The present ERTS-1 systems do not provide enough resolution or relief displacement for the detailed analysis necessary for legal and engineering purposes. However, the qualities of large, synoptic, regional coverage and rapid appraisal of flooded acreage could make analysis of ERTS-1 imagery useful to those agencies involved in flood control, disaster relief, agricultural predictions, and flood insurance.

This first flood study showed that time and money could be saved by using the remote sensing approach to map and evaluate flood inundation. A major advantage of this technique is the production of a map of the inundation, as opposed to the conventional plotting of a series of scattered datum points produced from expensive ground studies. The map of inundation is particularly helpful for planning and management along the floodplain. It remained the research task of expanding the technique so that flood-inundation mapping could be accomplished at different seasons of the year.

Skunk River Flood Study - April 1973

The Skunk River experienced the greatest flood on record on April 23, 1973. The Skunk flood was triggered by a regional rainstorm which dropped as much as 6.5 inches of rain in the Skunk basin at Mt. Pleasant, Iowa, on April 20, 21, and 22, 1973. This rain was added to meltwater from an unusually late snowstorm which, just one week before, produced as much as 11 inches of wet snow at Oskaloosa, Iowa. Gaging records indicate the peak flow (66,800 cfs) occurred at 1:30 a.m. on April 23, near the mouth of the river.

Vegetation at this time of year is changing rapidly. Ground cover on the southern-Iowa floodplains at this time consisted of growing grasses, alfalfa, sprouted oats, plowed and bare stubble covered fields, row crops, and budding trees and shrubs.

Multispectral imagery of the flooded area was obtained for about eighty-river miles between Burlington and the junction of the North and South Skunk Rivers. The imagery was obtained at 12,000 feet AGL, using an I^2S multiband camera and Kodak type 2424 infrared-sensitive film. In addition, 35 mm stereo-oblique imagery (utilizing black-and-white panchromatic, color, and color-infrared films) was obtained at selected locations from about 1,500 feet AGL. Imagery was obtained at peak flow conditions to serve as base data on flood-inundation limits. The river receded at least 0.5 feet at points above Augusta, when imagery was first obtained on the 23rd of April, and the river had receded about 15 feet, when imagery was acquired on the 28th of April.

Interpretation of the multiband imagery was accomplished utilizing an I^2S Mini-Addcol viewer (color-additive multiband viewer), and hand-held 35 mm imagery was analyzed utilizing lens type "pocket" stereoscopes. The variety of ground cover conditions present in late April resulted in somewhat different photographic records of flood inundation. The imagery produced near flood crest indicates that the infrared band is most important for flood-inundation mapping at flood crest. The absorption of infrared radiation at the water surface produces a sharply reduced reflectance, and thus great contrast, between the inundated area and both bare soils and green vegetation. At flood crest the red and green bands also can be utilized for flood mapping, although tonal contrast is low between the silt-laden floodwaters and adjacent nonflooded areas. The smooth appearance of the water becomes important as a recognition trait when utilizing the green and red bands. Interpretation, using these bands, is difficult or impossible in areas of forest vegetation. The blue band was not as usable for mapping flood inundation during this spring flood because high humidity very seriously reduced scene contrast by scattering blue wavelengths of light. Mapping flood inundation in some extremely flat areas during flood crest was difficult utilizing any band. The original rainfall, associated high water table and poor drainage, produced an irregular and poorly defined boundary adjacent to the area which was obviously inundated.

Five days after flood recession the infrared band again was found to be superior to either the green or red bands for mapping flood inundation. The imagery produced mapped limits of flooding correctly for all areas that were checked against imagery acquired at flood crest. Some extremely flat areas were difficult to map at flood crest because of the complex mosaic produced by flood inundation. Only those areas that definitely appeared inundated on flood-crest imagery appeared flooded after flood recession. All four bands were capable of producing reasonable interpretive results on bare soils, but only the infrared band provided flood inundation information in all vegetated areas. The blue band suitably mapped the flooded area where ground cover consisted of pasture and recently sprouted fields of grain, however, in brushy or densely forested areas, interpretation was difficult using this band alone. The green and red bands were not suited for interpretation in vegetated areas. The infrared spectral region proved again superior for aerial flood mapping, both concurrent with flood crest and five days after flood crest.

Color additive viewing aided the interpretation of spring-flood inundation, but was not greatly superior to using imagery produced only by the infrared band.

No ERTS-1 satellite data was acquired over the Skunk River flood site for at least 45 days following flood crest. Although clear skies were present several times during this time interval, these conditions did not coincide with the 18-day cyclical overpasses of the ERTS-1 satellite. In general, the 18-day cycle of ERTS-1 did not coincide with clear weather conditions during the spring and early summer months of 1973. Lack of frequent coverage is a major limitation of the use of satellite photography to flood monitoring in the Midwest.

Conclusions of the Skunk River Flood Study

1. In the Midwest, operational flood-inundation mapping during midspring can be best accomplished using the 700-1,100 nm (infrared) portion of the spectrum. Saturated soils and standing water absorb infrared radiation while less moist soils generally have a higher infrared reflectance. Likewise, many forms of early developing vegetative covers such as oats, alfalfa, and grasses exhibit marked reduced infrared reflectance from flooding.

2. The blue band (400 to 465 nm) was not tested well because of high-atmospheric humidity. This trait would be common in spring and the moisture reduces scene contrast. The green (480 to 570 nm) and red (575 to 685 nm) bands could be used in bare-soil areas for mapping flood inundation, both near flood crest and several days after flood recession. However, tonal contrast was low between silt-laden floodwaters and nonflooded areas using these bands. Vegetated areas are poorly mapped by the green and red bands.

3. Color film is better than black-and-white panchromatic film, however, black-and-white infrared film exposed through a minus-blue filter provides about the same amount of information as color film.

4. Black-and-white infrared film exposed through an 88A or 89B (minus visible) filter is superior to the combinations mentioned above. Color infrared film exposed through a minus-blue filter is slightly superior to black-and-white infrared film, filtered only for the near-visible (700 to 900 nm) portion of the spectrum.

Iowa River Flood Study - January 1973

In early January of 1973, an ice jam developed at the lower end of the Iowa River. Flow rates were not abnormally high, but the ice formed a temporary dam which artificially raised the river stage until the water flowed on to the adjacent floodplain. On January 12, 1973, 35 mm stereo-oblique photographs were acquired of the flooded area utilizing black-and-white panchromatic film, with yellow, green, and red filters; color film; and color infrared film with a Wratten 12 filter. Metric photography was obtained over the flooded area utilizing a Wild RC-8 camera, black-and-white infrared film (Kodak type 2424), and Wratten 12 filter. The metric photography was obtained at 12,000 AGL.

Ground cover at this time of year consisted mainly of dormant and dead plant materials and rowcrop fields with only stubble remaining. Underbrush was largely absent and trees were bare. Only patches of snow were present in some protected areas. The flooded area was readily apparent to the aerial observers because it had remained as smooth ice surrounded by rough ice, snow, and areas of dormant vegetation. Flood inundation could be interpreted from all of the imagery types. The black-and-white panchromatic images indicate the rough ice and snow as white, and the smooth ice as a gray tone that was generally lighter than the tones exhibited by dormant vegetation. Black-and-white imagery shows ice as a darker tone than the areas covered by snow. Color film indicates snow and rough ice as white, smooth ice as gray, and dormant vegetation as yellow-brown. Color-infrared imagery indicates snow and rough ice as white, smooth ice as blue, and the vegetative cover as green. The flood area was best mapped on color images.

The reflective charactersitics of water, snow, and ice suggest that an infrared emulsion would be most descriminative for winter flood mapping. The amount of light and near-visible energy that is reflected from water, snow, and ice is dependent upon the spectral distribution of incident energy, the angle of incidence of incoming radiation, the refractive index and surface characteristics of the material, and the ability of the material to absorb and transmit radiation. Reflection from water is largely a function of the angle of incidence and the spectral absorptivity of water. Specular (mirror-like) reflection is a function of the angle of incidence (sun angle) and the index of refraction of water, snow, and ice. Usually, high sun-angle photography is avoided to eliminate bright sun reflections when photographing these materials. The IGSRSL staff have found that in blue (400 to 480 nm), reflection from water is a maximum. In the interval from 470 to 550 nm (blue-green), maximum transmission occurs in clear water. Maximum absorption, hence lowest reflection, occurs at wavelengths beyond 700 nm (infrared). Thus water on the infrared band appears dark, while on the blue band it appears light. Snow behaves like an excellent diffuse reflector. It scatters blue, green, red, and infrared radiation equally by specular reflection from the surfaces of individual ice crystals. Thus, snow appears as white on color imagery and as light gray on black-and-white imagery. Ice has a higher reflectivity in blue, moderate reflectivity in green and red, and a lower reflectivity in infrared. Snow is easily discriminated from ice utilizing an infrared sensitive film, while the utility of color film can be considerably reduced if hazy conditions exist. On color-infrared film snow appears white, while ice-covered areas are blue-green. These observations on snow and ice were made by one of the authors, Taranik, while he was analyzing ice and snow fields in Alaska.

Winter flooding ground conditions could vary from a continuous blanket of snow to a completely thawed soil-water condition. Snow cover would necessitate a better discrimination of snow, ice, and water. If thawed conditions existed and no ice formed in the flooded zone, the ground condition may be somewhat analogous to the spring-flooding situation. While conditions of winter flooding may vary widely, and data from this study are in no way comprehensive for all of these conditions, a combination of evidence and rationale suggests that color-infrared film should satisfy the widest range of winter flooding conditions.

Nothing has been said concerning the time interval between flood crest and data acquisition. Winter should provide the greatest amount of time suitable for imagery acquisition. Should ice develop after flooding, imagery can be obtained any time until it thaws and/or sublimates, provided it is not covered with additional snow. In the winter study, imagery was acquired about one week following the flooding. If winter overland flooding occurs without ice forming, open saturated areas should remain at least as long as the time interval for spring flooding conditions, because evaporation is generally low under cool winter conditions.

Conclusions of Iowa River Flood Study

1. In the Midwest, operational flood-inundation mapping during winter months can be best accomplished using the 500 to 900 nm portion of the spectrum. Because snow is a good diffuse reflector it scatters green, red, and infrared wavelengths equally and appears white on all imagery. Ice,on the other hand,has a decreasing reflectance over the interval from 500 to 900 nm and it appears gray on black-and-white imagery, or it appears greenish-blue on color infrared imagery. Use of color film may be limited by high humidity and scattering of blue light due to winter low sun angles.

2. Color-infrared film should provide the best information for winter flood-inundation mapping.

MULTISPECTRAL ANALYSIS OF GROUND COVER AS IT RELATES TO FLOOD MAPPING

The previous discussion has included three specific seasonal studies in Iowa. However, seasons are not the most important variable for flood mapping. Rather, it is the physical character of the ground-cover surface that is most important. Seasonal characteristics vary significantly from one geographic location to another. However, the extraction of information about various ground-cover types derived from these seasonal studies may facilitate the utilization of remote sensing techniques in other geographic areas. Therefore, in order to make remote sensing techniques of flood-inundation mapping more useful in regions other than Iowa, the following discussion relates the remote sensing technique to the different ground-cover conditions. Included is information from studies outside of Iowa.

The surface-cover conditions are discussed separately. However, these conditions do not exist in nature separately, but rather in some combination. Thus, while a flooded river may flow through only bare, plowed fields in one small area, it probably flows through some combination of growing vegetation, dormant vegetation, or snow, as well as bare soils. Thus, to determine the best operational procedure for mapping flood inundation during any season in many geographic locations, the remote sensing technique utilized should be suitable for all the expected ground-cover types.

Flood Inundation Mapping with a Surface Cover of Bare Soil

Distinguishing flood waters from bare soil is most difficult in the visible portion of the spectrum. Generally, water is less reflective than adjacent soils in the blue (400-465 nm), green (500-600 nm), or red (600-700 nm) bands; water generally appears darker than soil on photographic imagery. This contrast may be greatly reduced at flood stage because the water is often carrying a large sediment load. Some backwater areas may present problems because of reflectance off bottom sediments in shallow-water areas. Additional complications arise from the problems of reflection off water surfaces at different sun angles. Frequently, image texture becomes more important than image tone for differentiating water from soil. The near-visible infrared band (700-1,100 nm) is superior to any of the visible wavelengths because almost all of the infrared wavelengths are absorbed at the water surface. Conversely, bare soil has a relatively high infrared reflectance. Thus, the tonal contrast exhibited in the infrared band is much greater than in any band in the visible spectral region. Sediment load increases the reflectance of water surfaces, even in the infrared band, but there remains more tonal contrast between the floodwater and soil in the infrared than in other bands (fig. 3). The long wavelengths in this spectral region (800-1,100 nm) provide even better contrast because they are more effectively absorbed by water.

After the flood recedes, the flood inundated area can still be mapped. The wet soils remaining after a flood show reduced reflectance in all visible and infrared bands. Again, the infrared band provides the most suitable information for mapping (fig. 4). The tonal contrast is greater on this band than others because the wet soils absorb much of the infrared radiation while dry soil materials have a higher reflectance. The red band also effectively delineates flood inundation several days after flood recession. As shown in the Skunk River study, the reduction in the infrared reflectance of soils remains pronounced for at least five days after flood recession. This reduced reflectance can be detected and the flooded area

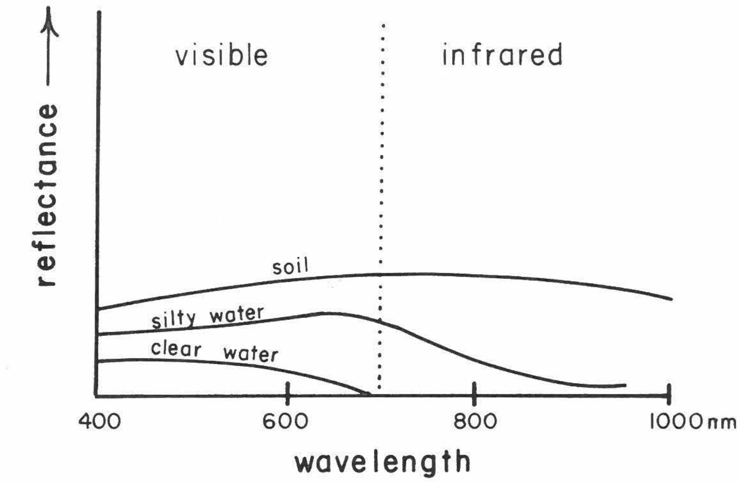


Figure 3. Relative Reflectance of Water and Sand at Flood Crest.

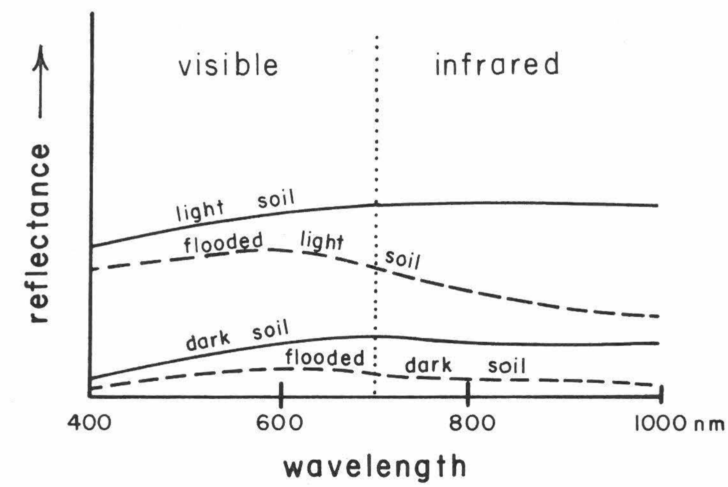


Figure 4. Relative Reflectance of Soil after Flood Recession.

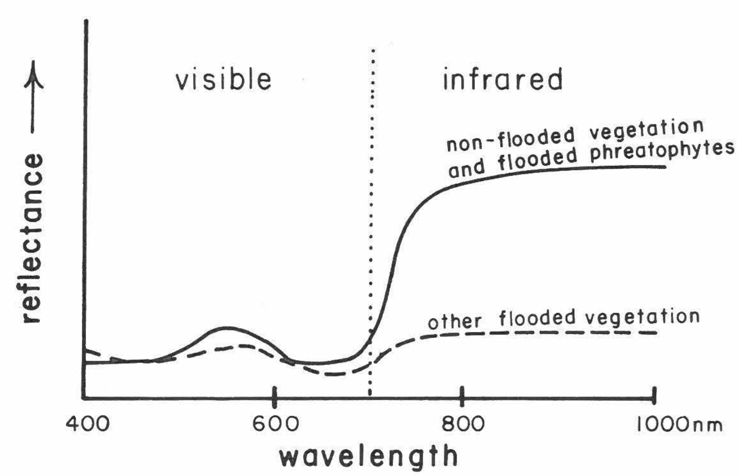


Figure 5. Relative Reflectance of Vegetation after Flood Recession.

accurately mapped, even under the high soil-moisture conditions that would normally occur in the Midwest during the spring (Hoyer, et al., 1974). Bare soils located in areas having a high potential for evaporation may show a decrease in reflectance for a shorter time interval, however, sufficient data has not been gathered on this problem.

Flood Inundation Mapping with a Vegetative Surface Cover

Multispectral analysis of flood inundation becomes more complicated when flooding occurs with a surface cover of green vegetation. At flood crest, the visible bands can be used; but again the contrast between flood water and vegetation is not great. A complex flood boundary may be particularly difficult to distinguish in agricultural areas when vegetation is present. The height of field crops may obscure the flood waters when the water is not covering the plants. Forested areas are also very difficult to interpret because the trees obscure the flooded area.

When dealing with vegetation, the infrared band is by far the most effective wavelength band for flood mapping (fig. 5). High contrast is produced between vegetation having a high infrared reflectance, and water having an extremely low reflectance. In addition, the flood waters stress many plants which reduce their infrared reflectance. Thus, vegetation can be used for mapping the flooded area even when the water is covered by a continuous canopy of vegetation. Some low-land tree species (predominantly phreatophytes) are not stressed by flooding, and they do not show decreased reflectance. These species are not affected by relatively short periods (less than one week) of flood inundation (Hallberg, et al., 1973). Forested areas including these lowland tree species are still mapped best with the infrared bands. Absorption of the infrared radiation by standing water and the associated decreased reflectance of undergrowth and soils makes the flooded area distinct in any clearings that exist. These areas are not as distinct when the visible bands were utilized.

Flood boundaries may be mapped in vegetated areas after flood recession because plants are stressed by the lasting effects of flooding and thus have decreased infrared reflectance. Vegetation stressed by flooding can be distinquished from unaffected vegetation for substantial periods of time if an infrared-sensitive sensor is used. This effect has been noted in both humid and arid climates at various times of the year. Hallberg, et al., (1973) reported that inundation mapping in vegetated areas like the Midwest, could be accomplished at least one week after flood recession in the late summer months. Some effects of flooding may be mapped for at least 25 days after the flood waters have returned to the main river channel. In October, in the arid Southwest, Morrison and Cooley (1973) noted the decreased reflectance of plants 12 days after flood recession; this effect may be mappable in this region for at least three weeks after flooding (H.H. Schumann, oral communication). April imagery in the Midwest demonstrated that spring vegetation maintains this decreased reflectance for a minimum of five days after flood recession.

The blue spectral band is also useful for mapping flood limits. Flood-stressed plants reflect more blue radiation than comparable nonflooded species. This effect has been noted for a time period of at least five days after flood recession. Unfortunately, haze may nullify some of the usefulness of this band because it often seriously reduces scene contrast and makes imagery interpretation more difficult.

Flood stress does not consistently affect the green and red reflectance of plants. These bands were found to be the least effective for delineating the inundated area after flood recession in vegetated areas (Hoyer and Taranik, 1973).

Some Midwestern winter and spring imagery indicates that a surface cover of dormant vegetation is more similar to the situation previously described for bare soils than the situation for green vegetation. Dormant plants are not highly reflective in the infrared band, consequently the flood waters cannot cause a stress which reduces plant infrared reflectance. Generally, the absorption of infrared radiation by excess soil moisture or standing water in these areas allows interpretation of flood limits.

<u>Flood Inundation Mapping with a Snow Surface Cover</u>

While major flood inundation normally occurs when the surface cover consists of live vegetation, bare soils, or some combination of the two, some floods can occur with other surface covers. Winter ice jams occurring in moderate and high latitudes can produce localized flooding on a ground cover of snow. This winter flooding can often be detected as smooth ice long after the flood has receded. The flood waters may strip off snow, or flow on top of the snow. After the flooding recedes, bare ground or ice is left behind exhibiting sharp contact lines, which differentiate the flooded areas from the snow. The differentiation either of water and snow, ice and snow, or ice and soils is made possible because of the different reflectances of these materials at different wavelengths.

Little study has been made of winter flooding, but results suggest that the visible and infrared bands could all be used for these ground cover situations. Longer wavelengths, especially the infrared, are superior to shorter visible wavelengths for the variety of flooding situations possible in winter.

MULTISPECTRAL ADDITIVE COLOR VIEWING AND REMOTE SENSING SYSTEMS

The previous multispectral analysis has discussed how the reflectance of individual surface cover types has been affected by flood waters. These ground-cover situations are generally not separate; rather they occur together in various combinations as previously described. In addition, the most common applied remote sensing technique is aerial photography, which generally records all spectral regions simultaneously, thus integrating any spectral uniqueness that has developed in response to flooding. For practical application, multispectral analysis must also consider combinations of spectral bands and surface covers along with the standard available film and filter combinations.

Visible wavelengths provide the least information on flooding for ground-cover situations consisting of mixed soils and vegetation. Black-and-white panchromatic films integrate the reflectance of all the visible wavelengths, and are therefore generally unacceptable for flood mapping. They can be utilized for mapping the flooded area on bare soils, but are not satisfactory in vegetated areas, either at flood crest or after flood recession.

Multispectral analysis has shown that near-infrared radiation (700-1, 100 nm) is by far the most important and useful spectral region for mapping floods either after flood cessation or concurrent with flood crest. The characteristics of infrared radiation, including the absorption of these wavelengths by water, the reduced infrared reflectance of wet soils and stressed plant species, and differences in reflectance of between snow and ice, make the infrared band the most useful for flood-inundation mapping.

Black-and-white infrared film is superior to the black-and-white panchromatic films. It is often exposed with a Wratten 12 (minus blue) filter because most aerial contractors do not have the Wratten 89B or 88A filters to fit their aerial camera, or because they want cultural features, like roads, to be well defined on the imagery. Use of the Wratten 12 filter allows green and red wavelengths to reach the film. This is not too serious where bare soils or unconsolidated materials are being imaged, but where vegetation is the surface cover, the reflected red and green radiation actually obscures the important information contained in the infrared portion of the spectrum. Even when imaging the flood crest itself, the infrared band generally defines the flood boundary better than the standard combination of green, red, and infrared wavelengths, because of the high reflectance of the sediment in the floodwaters.

Analysis of ERTS-1 multispectral-scanner imagery indicates that the 800 to 1,100 nm (MSS band 7) portion of the spectrum provides more contrast, and thus better discrimination of flooded areas than the 700 to 800 nm portion (Hallberg, et al., 1973). Available infrared films are only sensitive to approximately 900 nm. To utilize the enhanced contrast of the balance of the near-visible infrared (900 to 1,100 nm), would necessitate the use of an electronic scanning system. Other considerations of the flood-mapping mission, such as the production of topographic maps from the imagery for engineering purposes, may make the use of a scanner system impractical. The use of the conventional black-and-white infrared films that utilize the 700 to 900 nm portion of the spectrum is not a serious limitation.

The addition of color aids the interpretation in both the visible and near-infrared wavelengths. In the visible portion of the spectrum, color films are better than black-and-white panchromatic, both during and after a flood (Hoyer, et al., 1973). While the visible bands are not as useful as the infrared band for flood-inundation mapping, the addition of color aids in delineating the flooded area. During flood stages, the color of water, even silt laden water, is different from soil. The same is true for color infrared and black-and-white infrared films. Unlike black-and-white infrared film, the inclusion of the green and red visible wavelengths on color-infrared imagery does not deteriorate the flood imagery. The addition of color facilitates interpretation of flooding. Color infrared film (Kodak 2443) appears to be the best available film for inundation mapping, particularly where dense vegetation is present.

Various false-color techniques may be useful as well. Deutsch and Ruggles (1973) utilized several false-color techniques to enhance ERTS-1 scanner imagery for mapping spring flooding on the Mississippi River. The Nishnabotna Rivers study in Iowa showed that the best delineation of the inundated areas under dense vegetation was provided by color-additive viewing utilizing the blue and infrared bands. As previously described, the vegetation in the area inundated generally has an increase in blue reflectance, but a decrease in infrared reflectance. Thus, if the blue band were false-colored blue, and the infrared band were false-colored red, the most blue area would generally correspond to the flooded area and the most red area would correspond to the nonflooded area. However, the complexity of color additive and multispectral systems and the additional information needs of agencies involved in floodplain management, generally may make multiband imagery less desirable than color-infrared imagery acquired in a large format aerial camera.

OPERATIONAL CONSIDERATIONS--MISSION DESIGN

The remote sensing techniques and research discussed above have demonstrated the capability to map flood inundation after the recession of flood water. This is a new and very valuable aspect of flood mapping using remote sensing techniques. In the past the use of aerial imagery for flood mapping has generally been limited to imagery acquisition concurrent with the actual crest of the flood. However, a flood crest takes time to move downstream. A flood crest on a large river may take from a few days to possibly weeks to move downstream before the river begins to return to its banks. Imagery acquired during flood stage will show the river at flood crest at one location, receding at another location, and within its banks at locations downstream of the flood crest. In addition, inclement weather often associated with flooding can make it impossible to acquire imagery during the crest. Thus, the ability to determine flood inundation at some time after the flood has receded can alleviate these operational problems and produce more useful imagery. Infrared photographic imagery can be acquired for at least five days after the flood has receded from any surface-cover type. Vegetative cover allows interpretation of flood inundation on color-infrared film for at least 12 days following flood crest. Preliminary results from the analysis of ERTS-1 imagery of floods on the Mississippi River near St. Louis indicate that false-colored infrared imagery may be useful for up to 26 days after flood recession during April and May, a time when both soil and vegetation covers are present (Deutsch and Ruggles, 1973).

The accurate delineation of the maximum flood boundaries, from infrared imagery, can eliminate much of the expensive ground work that has been used in the past to set high watermarks during floods. Also, field placement of high watermarks results in a series of point datum from which flood boundaries must be extrapolated by use of available topographic maps.

Topographic maps are available in few areas with sufficient detail to map subtle topographic differences present on most floodplains. These subtle topographic variations can make great differences in the boundaries of the flood. The remote sensing apprach provides an image of the inundated area with the boundary of flooding delineated.

Scale of the imagery acquired is an important consideration for a flood-mapping mission. A complete overview of the flooded area with the adjacent nonflooded areas provide contrast which aids interpretation. This allows the comparison of the reflectance properties in areas where the limits of inundation may be difficult to define. Thus, synoptic coverage is desirable.

Stereoscopic viewing aids flood mapping, especially in areas in which interpretation based on color or tone is difficult. Proper overlap should be provided to allow stereoscopic viewing and to allow photogrammetric operations such as topographic map production. Normally a 60 percent overlap and 30 percent side lap of images is desired. Careful design of a mission to map inundation after flood recession may include some low-altitude coverage of selected areas to provide detailed topographic maps (e.g., maps with one-foot contour intervals) to facilitate hydrologic analyses and other floodplain planning and management activities.

Color-infrared photography, black-and-white infrared imagery, and multiband imagery combined with false coloring techniques, were outlined previously as being the most suitable remote sensing techniques for flood mapping (table 3). Other considerations of a multipurpose operational mission, discussed above, narrow this choice of suitable sensors. Scanners and multiband cameras are not readily available from aerial contractors, and they are not suitable for stereoscopic analysis or photogrammetric plotting. These systems usually require special viewing equipment for interpretation of their imagery products. Black-and-white infrared band photography in the 700 to 900 nm portion of the spectrum is often not possible because of the lack of 89B and 88A filters. Only color-infrared film combines all the necessary attributes to be the most generally acceptable imagery system for flood mapping. The best operational procedure would be to employ color-infrared film in a large format camera (9 x 9-inch format) as soon as possible after flood recession. Significantly, the film is widely usable by aerial contractors. Wratten 12 filters, required when color-infrared film is employed, are generally used by contractors. Color-infrared film can be utilized in metric cameras and imagery can be obtained from both stereoscopic viewing and photogrammetric purposes. Thus, interpretation can be enhanced and the imagery can be used to produce topographic maps.

Table 3. Summary of Remote Sensing Flood Inundation Mapping Techniques*

Imagery System	Suitability Soil	Suitability Vegetation	Comments
Black & White Imagery System			
Blue Band (400-465nm)	1	3	Haze seriously affects its usefulness.
Green Band (500-600nm)	2	0	Low contrast limits its usefulness.
Red Band (600-700nm)	4	2	Generally more useable than B & W panchromatic imagery conventionally filtered 500-700nm; most useful visible band for soils.
Infrared Band (700-900nm)	7	6	Produces most useable B&W photographic imagery. Unfortunately many aerial contractors do not have 89B or 88A filters to utilize this band alone.
Infrared Band (800-1100nm)	8	7	Best single B&W band for flood imagery interpretation. Because these wavelengths are beyond the capabilities of photographic systems, other considerations such as scanner availability and photogrammetric qualities of imagery may make this band less practical.
Panchromatic Film (500-700nm)	3	1	Conventional aerial imagery is not well suited for flood mapping.
Infrared Film (500-900nm)	5	4	Better choice than conventional panchromatic films, however the visible wavelengths make this system less useful. Use of 89B or 88A filters would improve imagery. (See Infrared Band, 700-900nm, above.
Color Imagery System			
Color Film (400-700nm)	6	5	Superior to any B & W imagery using visible spectrum.
Color Infrared Film (500-900nm)	9	8	Most widely useable imagery technique. Film is widely available; standard filters used; standard metric cameras can be used; photogrammetric capabilities; good for interpretation.
False color-multiband system:			
Blue and Infrared Bands	-	8	May be best for flood interpretation, but not appreciably better than color infrared imagery. Must be used with multiband imaging system and false color viewing equipment. Thus utility is limited to well equiped remote sensing centers.

*This table is intended to summarize some of the spectral and operational considerations for general flood inundation mapping. The suitabilities indicated are the authors subjective evaluation of the relative merit of the imagery systems listed. The numbers refer only to relative order: 9 indicating that the system is better than nine others or 2 indicating that it is better than only two other listed systems. Individual purposes for obtaining imagery may vary, but nothing listed with a rating lower than 4 is suggested for any flood inundation mapping purpose.

ADDITIONAL USES OF REMOTE SENSING TECHNIQUES

Floodplain Mapping or Flood Prediction

The eventual aim of mapping the occasional flood is to create a data base from which to predict the area that will be inundated by a major flood. This can be considered floodplain mapping versus flood mapping. This information is becoming increasingly important for proper and safe landuse management and planning. The immediate necessity for this data requires the development of more rapid--yet accurate--techniques. In the past, savings of time and money in mapping flood hazards have sometimes been accomplished at the expense of accuracy. However, the legal designation of the floodplain for landuse ordinances, insurance purposes, etc., must "be reasonable and not arbitrary," (Hogan, 1963, p. 252) to be upheld in court.

Attempts in Iowa to correlate soils with the area inundated by major floods have met with limited success in the past. The techniques used involved direct comparison of detailed soils maps with maps of the flooded areas (either actual or calculated flood-prone areas). The maps used for plotting flood boundaries are generally U.S.G.S., $7\frac{1}{2}$ minute series, 1:24,000-scale quadranges, with a five- or ten-foot contour interval. The correlations have been tenuous, but this is probably a reflection of the difference in the definition provided by the soils and topographic maps being compared. The contour interval of the topographic map is usually too great for analysis of the subtle relief on a floodplain. Conversely, the soils themselves generally reflect minor differences in relief. Recent work utilizing the remote sensing techniques discussed have provided different results. The more accurate definition of the boundaries of a major flood (100-year-recurrence interval) on large-scale infrared imagery, has provided a very close correlation between particular soil series and the limits of the Nishnabotna flood (Hoyer, et al. [in preparation]).

Figure 6 shows a portion of Cass County with the soil mapping units and the flood boundaries plotted. The following mapping units are generally within the flooded area: 1. Alluvial land (Au); 2. Ankeny (Ay); 3. Colo (Cg, Ch); 4. Humeston (Hu); 5. Nodaway (No, NW); 6. Marsh (Ma), 7. Wabash (Wa, Wb). Other soil units are generally in the boundary area of the 100-year flood. These are: 1. Judson (Jd, Jo); 2. Kennebec (Ke); 3. Nevin (Ne); 4. Zook (Zk, Zo). In several areas a precise flood boundary is difficult to define, and a diffuse boundary occurs on a very gradual slope. Nearly all of these problematic areas are mapped as Nevin soils. Another interesting correlation involves the bench-phase Marshall soils (Mn). This terrace soil is excluded from the inundated area. Where it is close to the river channel the escarpment of the bench marks the limits of inundation. The bench-phase Marshall soils have analogous soil series throughout most of the State of Iowa.

The Skunk River flood was the largest flood of record. Correlation of mapped flood boundary to Lee County soil maps supports the use of soil maps for flood prediction. With the flood of record, the Nevin soils which were somewhat problematical with the 100-year flood on the Nishnabotna, were completely flooded.

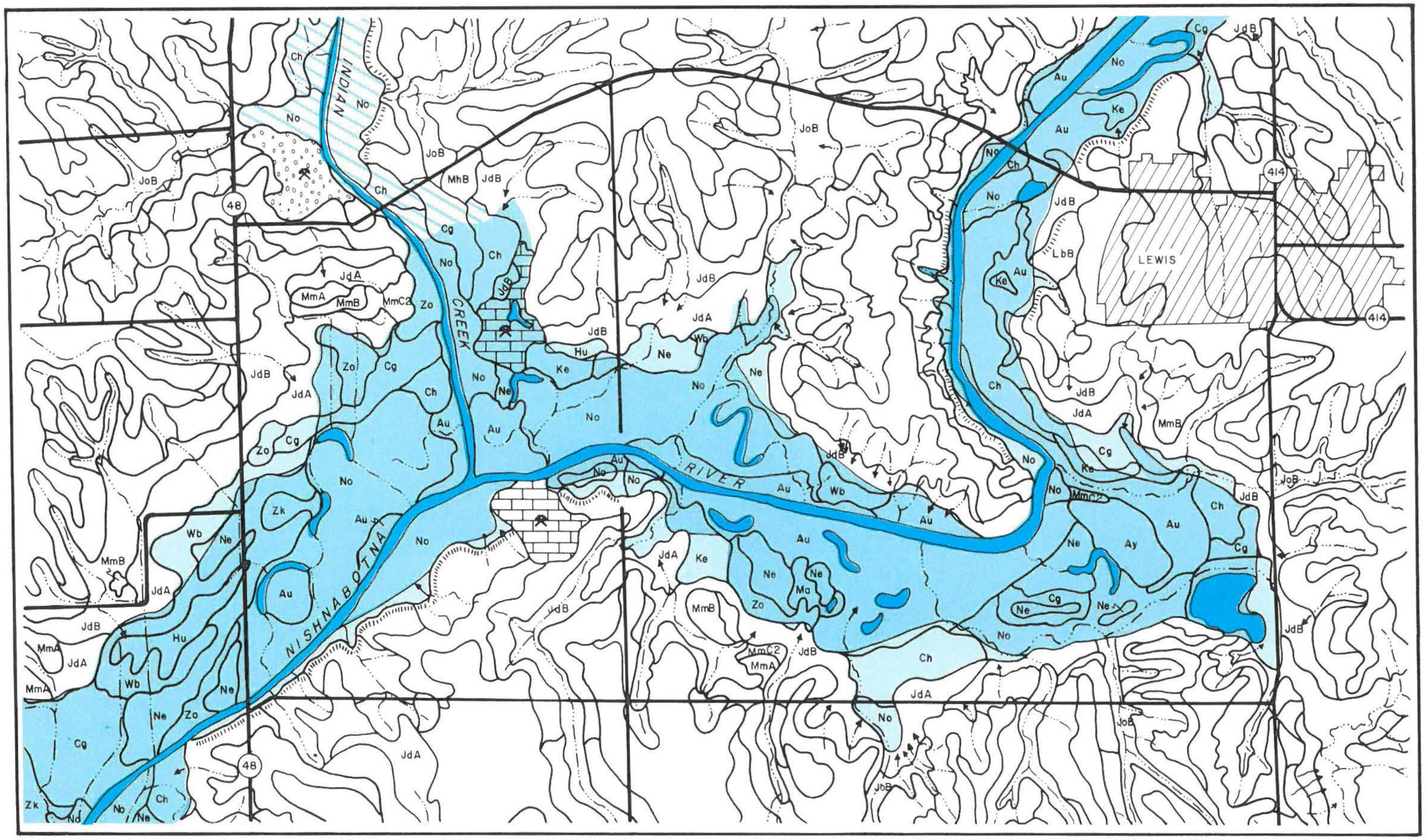


Figure 6. Flood Boundaries and Mapped Soil Units.

Soils Map: Jury, et al., 1969.

Interpreted as Flooded

No Imagery; Probably Flooded

Not Flooded; Soil Unit Frequently Contains Flood Boundary

JdB Other Indicated Soils Adjacent to Flooding; Soils Above Flooding Except Very Localized Flooding on Small or Intermittent Streams

DEVELOPING REMOTE SENSING TECHNOLOGY HAVING APPLICATION TO FLOOD INUNDATION AND FLOODPLAIN MAPPING IN IOWA

Use of Active Microwave Systems for Flood Mapping

In April of 1973 the U. S. Army Corps of Engineers located at Kansas City, Missouri, requested radar imagery from Department of the Army of portions of the Mississippi and Missouri Rivers near St. Louis. The platform provided was a twin-engined Army Mohawk reconnaissance aircraft and the sensor employed was an AN/APS-94D Motorola Side Looking Airborne Radar (SLAR) system. Imagery was acquired at 1:120,000 scale permitting synoptic coverage of the entire St. Louis area. The actively flooded areas show as black low radar signal return areas, and areas which have been flooded show as dark grey, moderately low return areas (Plate 9). The use of radar as a flood mapping tool has great potential for the following reasons:

1. Radar imagery of the flooded area can be obtained under any weather conditions.
2. Imagery of the flood crest can be obtained in hours of darkness.
3. Radar imagery can be acquired in synoptic fashion permitting surveillance of a large flooded area.
4. The latent effects of flooding, particularly high soil moisture, strongly influence radar signals, and these effects can be mapped after floodwaters have returned to the main channel.
5. Selection of specific radar wavelengths, or use of multispectral radar, may allow elimination of signal return from trees unaffected by flooding and may permit wet soils and standing water to be mapped under vegetative canopies.

The major limitation of imagery radars is the allowed resolution of 30 feet for civilian radar imagery systems. This limitation does not permit accurate measurements to be made on radar imagery for some floodplain mapping purposes.

Application of Satellite Acquired Data for Flood Mapping

Imagery acquired by orbiting satellites has proved valuable for regional evaluation of floods (Hallberg, et al., 1973). Evaluation of ERTS-1 satellite data of the Nishnabotna flood in Iowa revealed that the synoptic and multispectral imaging ability of the ERTS satellite allowed regional analysis of major flooding. The major limitations of the ERTS system for flood inundation mapping are the following:

1. Daytime flood observations are required.
2. Clear weather conditions are necessary if flood data are to be gathered.
3. The 18-day cycle of the satellite may not provide timely data.
4. The resolution of the ERTS-1 system does not permit mapping at scales larger than 1:250,000, unless computer processing is utilized.

The following attributes, listed in order of importance, would be desirable for satellite systems applicable to flood inundation mapping:

1. Continuous monitoring capability. This requires either a geosyncronous satellite or a satellite with a minimum cycle of five days.
2. A multispectral imaging system. The multispectral scanner of ERTS appears to be adequate, except that a blue band should be included.
3. Rectangular resolution on the order of 10 meters, or linear resolution of five meters.
4. All weather, day or night imaging capability. This would require a radar imager with resolution in the order of 30 feet, or best allowed by the Department of Defense.
5. Rapid telemetry, processing, and distribution of data to users. Civil defense planning requires almost real-time data.

Currently NASA is planning an Earth Observatory Satellite to be launched in 1979, an ERTS-C Satellite to be launched in 1978, a Synchronous Earth Observatory

Satellite (SEOS) to be launched in 1981, and shuttle missions commencing in 1979. These satellite and orbital systems could be configured with existing imaging hardware capable of providing the required data for flood inundation mapping on a synoptic basis.

SUMMARY CONCLUSIONS

1. Infrared radiation (700 to 1,100 nm) is by far the most important and useful spectral region for mapping floods either after flood cessation or concurrent with a flood crest. The characteristics of photographic-infrared radiation, including the absorption of these wavelengths by water, the reduced infrared reflectance of wet soils and stressed plant species, and differences in reflectance between snow and ice, make the photographic infrared band the most useful for flood-inundation mapping.

2. The addition of color aids photo interpretation in both the visible and near-visible wavelengths. Black-and-white panchromatic films are generally unacceptable and color films are generally better for flood mapping in the visible portions of the spectrum. Black-and-white infrared film may produce a usable product for mapping flood inundation, but color-infrared film is superior. For multiseasonal flood mapping and especially for late-summer flood mapping, color-infrared film (Kodak 2443) seems to be the best available film. Multispectral imagery, combined with color-additive viewing techniques is actually the best approach for flood-mapping interpretation. However, data-handling problems, smaller-areal coverages of the multiband camera, and the information needs of agencies involved in floodplain management make multiband imagery less desirable than color-infrared imagery.

3. Stereoscopic viewing aids flood mapping especially in areas in which interpretation based on color or tone is difficult. Proper overlap should be provided to allow stereoscopic viewing and to allow photogrammetric operations such as topographic map production. This could provide data useful for engineers and persons in floodplain management and planning.

4. This aerial flood mapping technique allows flood inundation to be mapped a minimum of seven days after flood crest in late summer, and at least five days after flood recession in spring. Winter flooding could be mapped in at least these time periods. Flood inundation may be mapped, at least in some areas, for up to 26 days after flooding. Within these time constraints, it should be possible to acquire imagery under acceptable weather conditions.

5. Detailed mapping of inundation from large-scale imagery indicates a close correlation between large-magnitude floods and particular soil series. Further analysis may allow the quantification of soils in terms of the frequency, magnitude, and distribution of floods. This, in turn, may possibly provide the capability for the detailed flood-inundation prediction required for rational landuse planning.

6. Radar-imaging systems may be excellent flood-mapping tools. Flood inundation can be synoptically mapped in hours of darkness and under any weather conditions when active microwave systems are employed.

7. ERTS satellite data supports the conclusions of the low-altitude investigations. Evaluation of ERTS-1 imagery indicates that it is useful for small-scale, regional appraisal of flooding. Satellite systems having the greatest potential application to flood mapping should provide continuous multispectral monitoring of flooding; a rectangular resolution on the order of five meters; and all weather, day or night, imaging capability.

EXAMPLES OF FLOOD IMAGERY

The following figures are presented as a pictorial summary of many of the conclusions drawn from flood-inundation studies using remote sensing techniques. They were selected to indicate the spectral response that flooding on various ground covers produce. As the purpose of this research is to produce operational utilization of aerial techniques, operational film-filter systems are stressed. Often, film-filter combinations are simulated by the use of the multispectral imagery and additive imagery techniques. This is especially true for the color imagery.

A.

B.

Plate 1. Comparison of red, A (595-685 nm) and infrared, B (740-900 nm) bands imaging April, 1973 flood shortly after the flood crest. The junction of the North and South Skunk Rivers represent two streams with unlike sediment load at the time these images were produced. Notice that the contrast between the soils and water is greater in the infrared band for both the high sediment load stream (North Skunk) and the low sediment load stream (South Skunk).

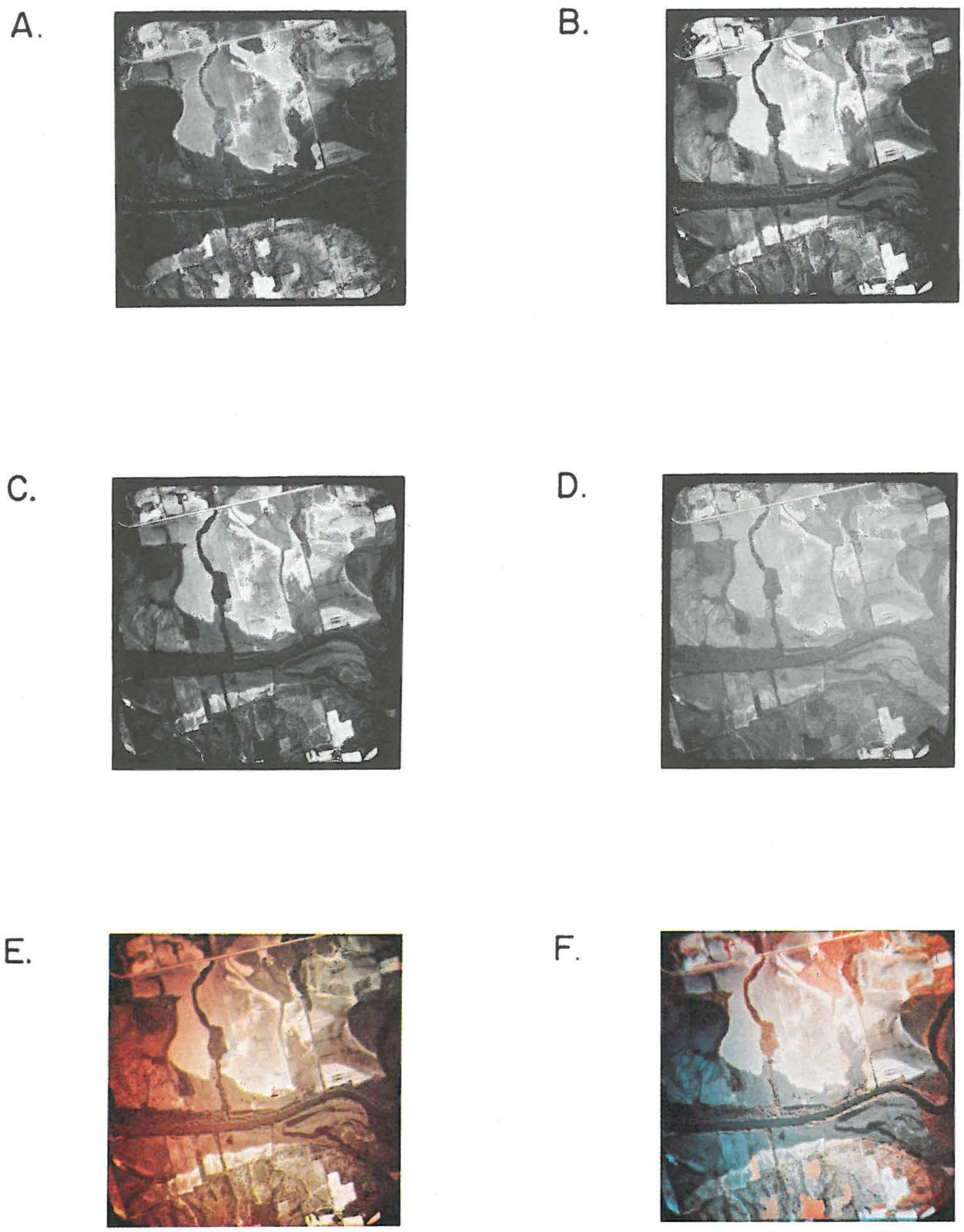


Plate 2. Five days after flood recession on a landscape cover of bare soils predominantly. All bands effectively discriminate flood boundaries on the bare soils. However, contrast is greatest with infrared band (A) and decreases with the red (B), green (C), and blue (D) bands, respectively. Color (E) and color infrared (F) adds very limited information on flood inundation in areas completely covered by bare soils.

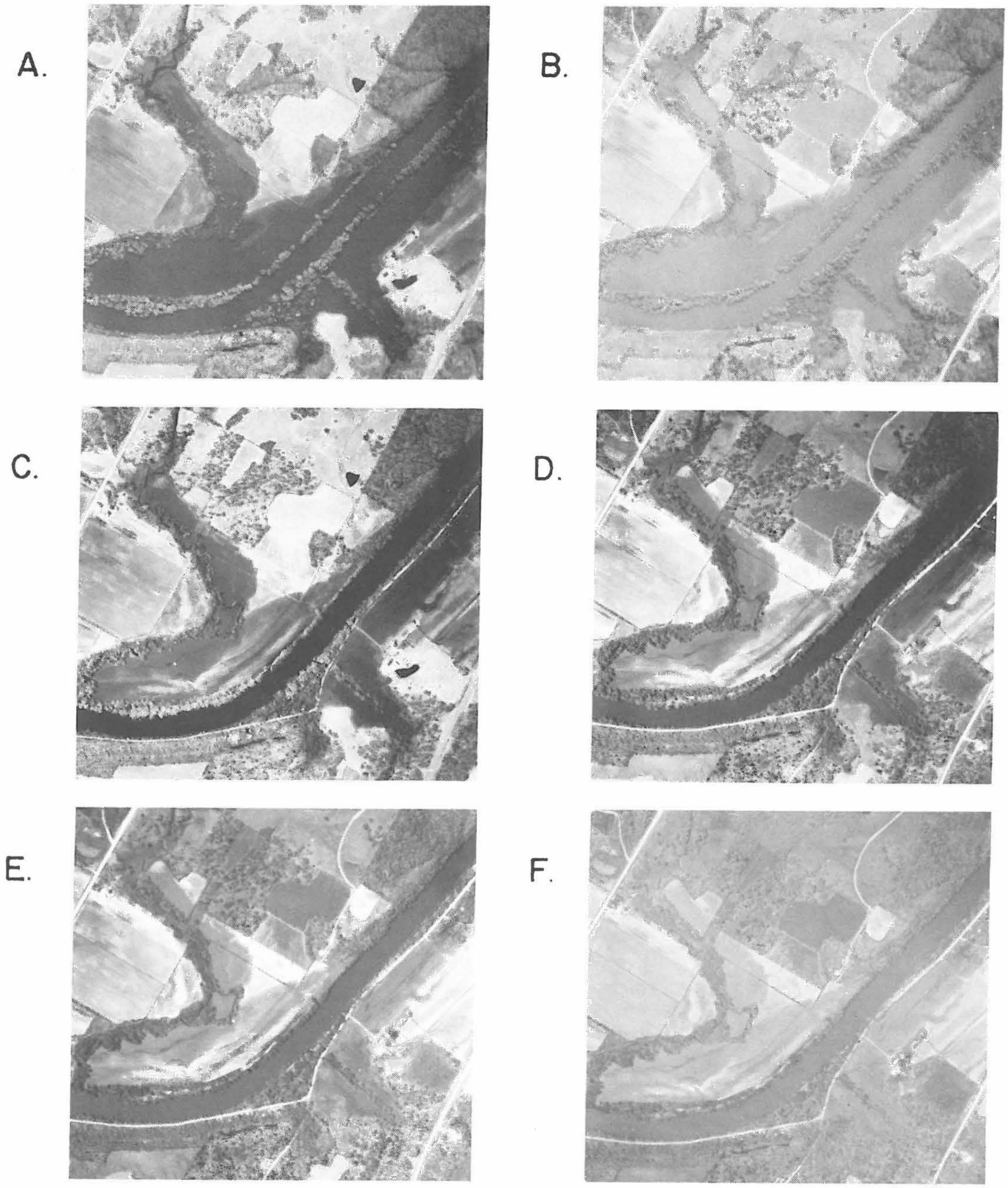


Plate 3. Multispectral images from late on the Skunk River in Iowa. Images taken shortly after flood crest: A. Infrared band (740-900 nm); B. Red band (595-685 nm). Images taken 5 days after flood crest: C. Infrared band; D. Red band; E. Green band (480-570 nm); F. Blue band (400-465 nm). The ground cover is primarily bare soils, with some green pasture and budding trees. At flood crest, the boundary of the flood water is well defined in areas of bare soil, on both the red and infrared bands. After flood crest the inundated area remains easily mapped. The reduced reflectance of the soils that were flooded is apparent in all bands but greatest in the red and infrared bands. However, in vegetated areas the infrared band provides the most accurate interpretation.

A.

B.

C.

Plate 4. Visible wavelengths--Multispectral images of September 1972, East Nishnabotna River flood. The area pictured is 10 miles south of Atlantic, Iowa, and includes a continuous canopy of vegetation. The images were produced two days after recession of floodwaters. These are the three bands used in normal black-and-white panchromatic aerial photography. Such films record the portions of the reflected energy least important for photographically mapping floods after flood cessation. Often the blue wavelengths are filtered out, to reduce atmospheric scatter, and of these three bands the blue can be most useful in delineating inundated areaa. (B) Green band (480-570 nm) flooded area is not easily identified. The amount of reflected energy is not affected by the flood. (C) Red band (595-685 nm) like the green band, the flooded area is not well defined. Compare these images with the following images which utilize reflected infrared radiation.

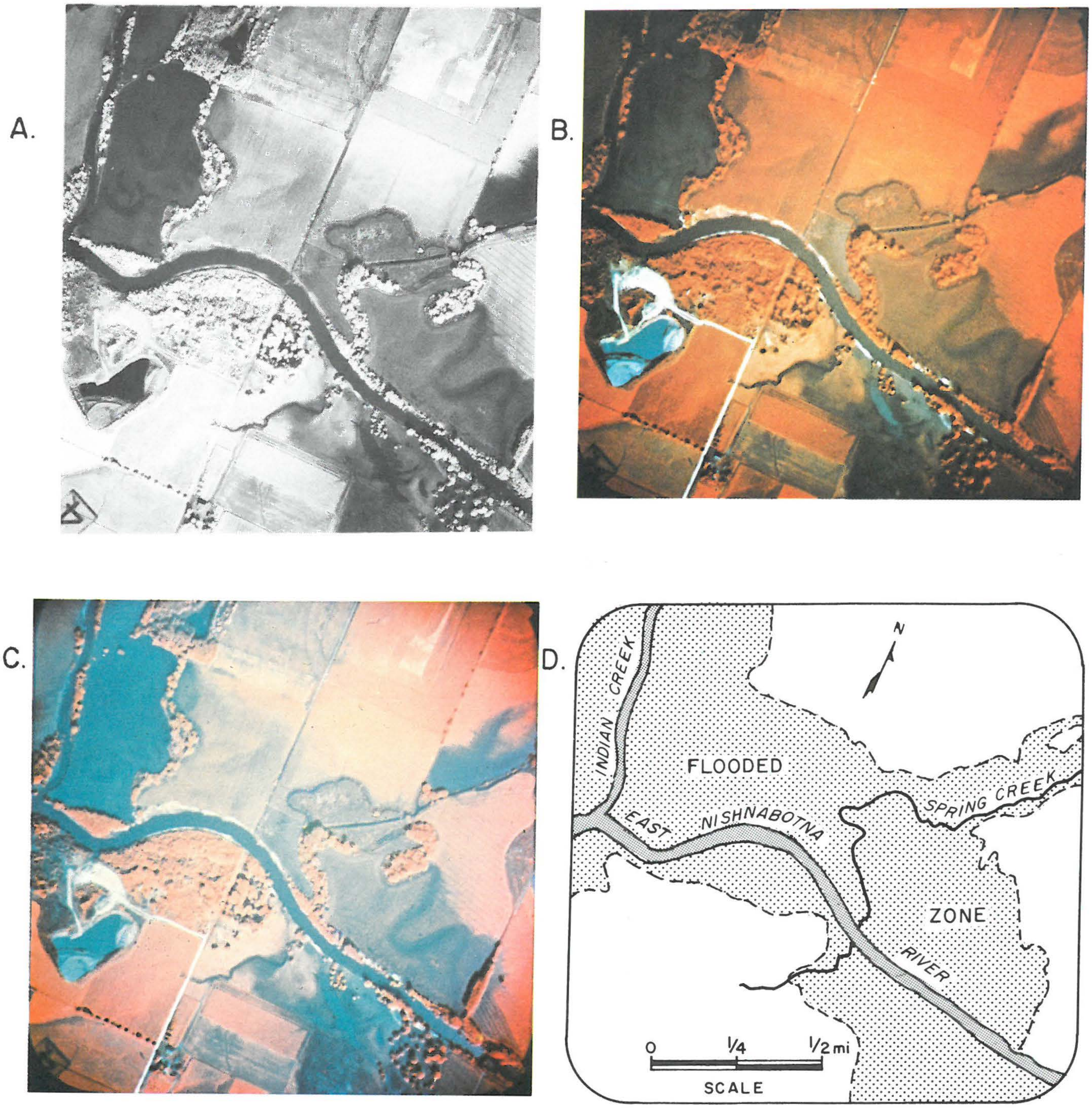
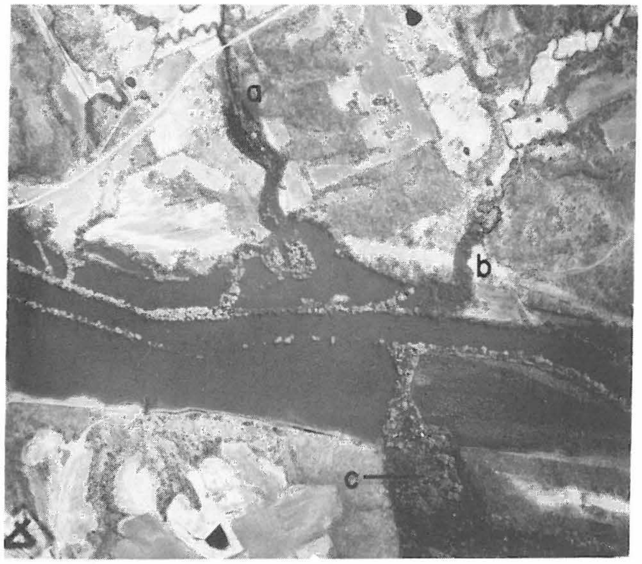


Plate 5. Infrared and color composite images of September, 1972, East Nishnabotna River flood. (A) Infrared band (740-900 nm) darker tones delineate where floodwaters stood two days before this image was taken. (B) Color infrared composite; green, red, and infrared bands false colored to simulate color infrared film. The addition of color aids interpretation. Color-infrared film is the best film for operational flood mapping on vegetated areas. (C) False-color composite: This combines the blue and infrared bands in color. This may be the best discriminator of the flooded area, which appears blue to purple. (D) Map of the flooded area in the multispectral images.

A.



B.

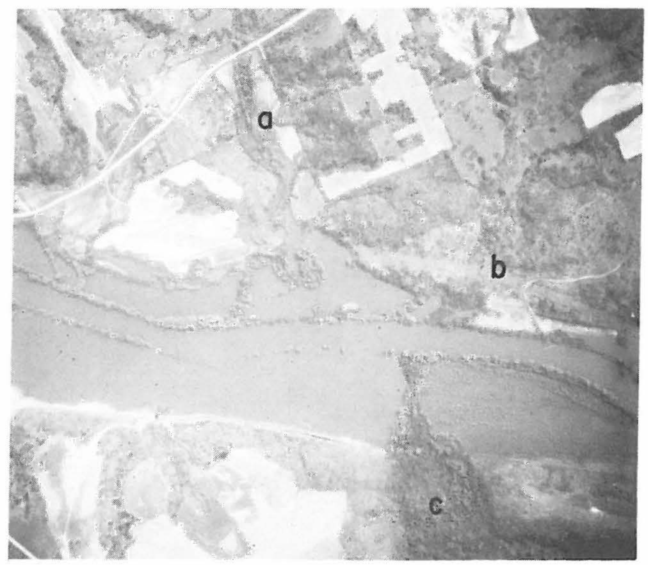
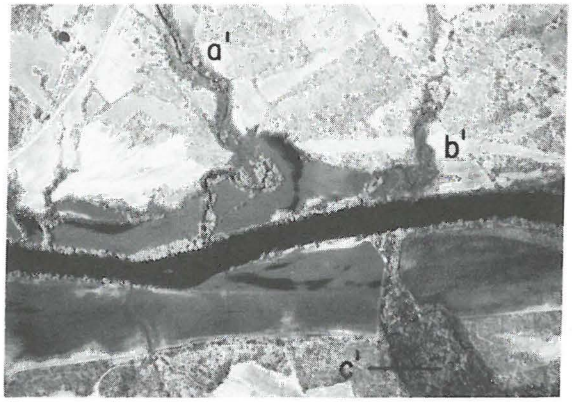
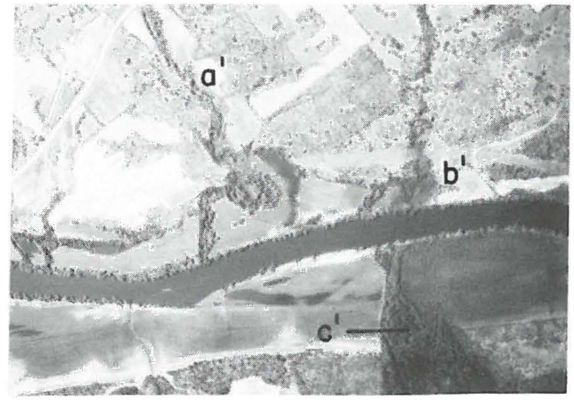


Plate 6. Infrared-sensitive films most adequately aid flood-inundation mapping. At flood crest, flood delineation is most apparent on infrared band (A). Red band (B) or any black-and-white panchromatic film is less suitable, particularly in vegetated areas (a, b, and c). Five days after flood recession, the infrared band (C) is still far superior to the red band (D) especially in these same vegetated areas (a', b', and c'). Frequently when black-and-white infrared film is used, a Wratten 12 (minus blue) filter is employed. Comparison of image C, produced with an 89B filter, and image E, simulating the use of minus blue filter, indicates that flood detail is lost with this practice. Color aides interpretation. Image F simulates the image a color film would produce and image G simulates a color-infrared image. The color-infrared image is best for flood interpretation.

C.



D.



E.

F.

G.

A.

B.

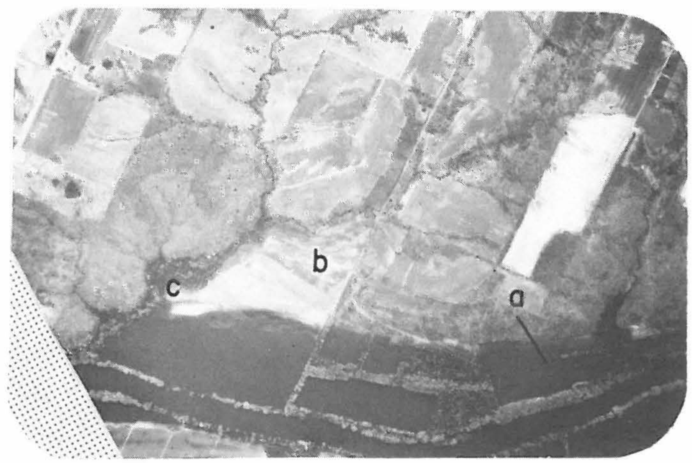
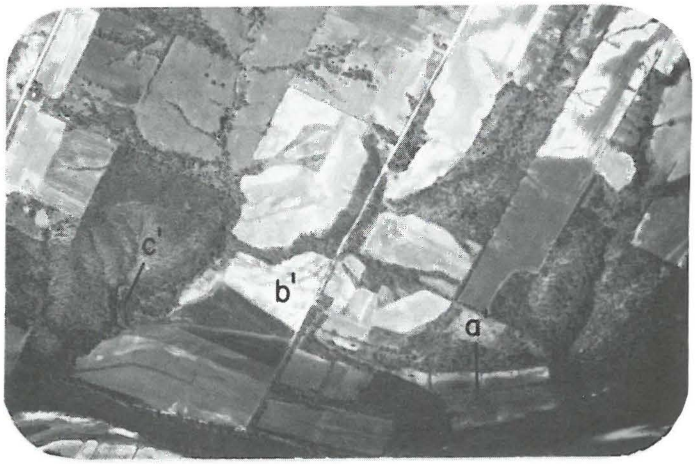
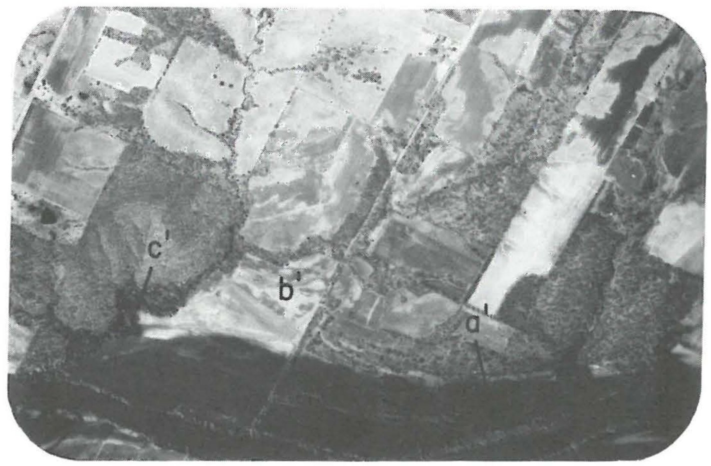


Plate 7. Comparison of several types of imagery produced in late April on the Skunk River, Iowa. The ground cover is complex consisting of bare soils, green cover crops, and budding trees. Red (A) and infrared (B) band imagery was produced concurrent with the flood crest. On either band the flood boundary may be interpreted on bare soils (a) and vegetated fields (b). In the forested area (c) only the infrared band indicates flood inundation. Five days after the flood recession, the red band (C) only adequately defines the flood boundary on the bare soil (a'). Poor definition is produced on the vegetated field (b') and the forest (c'). However, the infrared band (D) again defines the flood in all three areas (a', b', and c'). Image D is produced with an 89B filter on black-and-white infrared film, Kodak 2424. More conventionally aerial contractors may use this film with a Wratten 12 filter. Image E simulates this practice, combining multiband imagery from the green, red, and infrared bands. Note that flood boundary definition is lost by this practice particularly in the vegetated field (b'). The color infrared composite image (F) combines the information contained on the infrared band with the interpretive advantages of color. It provides the most satisfactory imagery both for interpretation and for operational procedures.

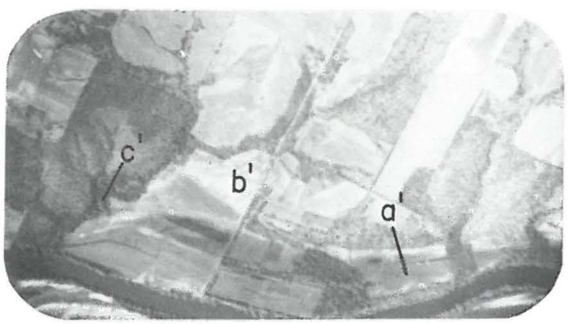
C.



D.



E.



F.

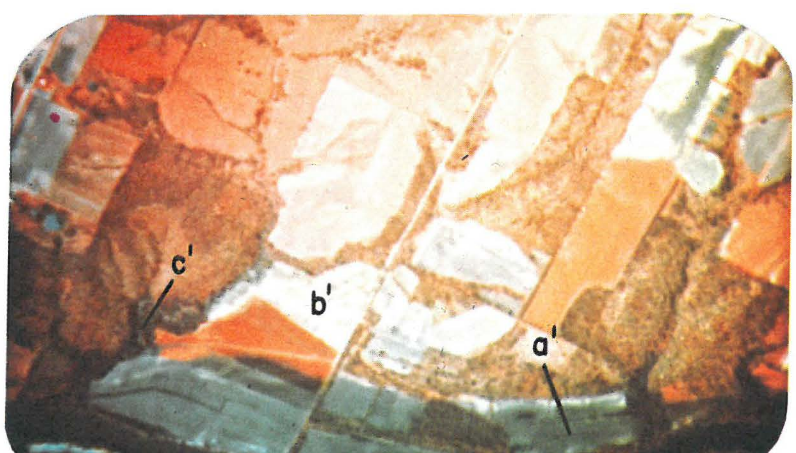
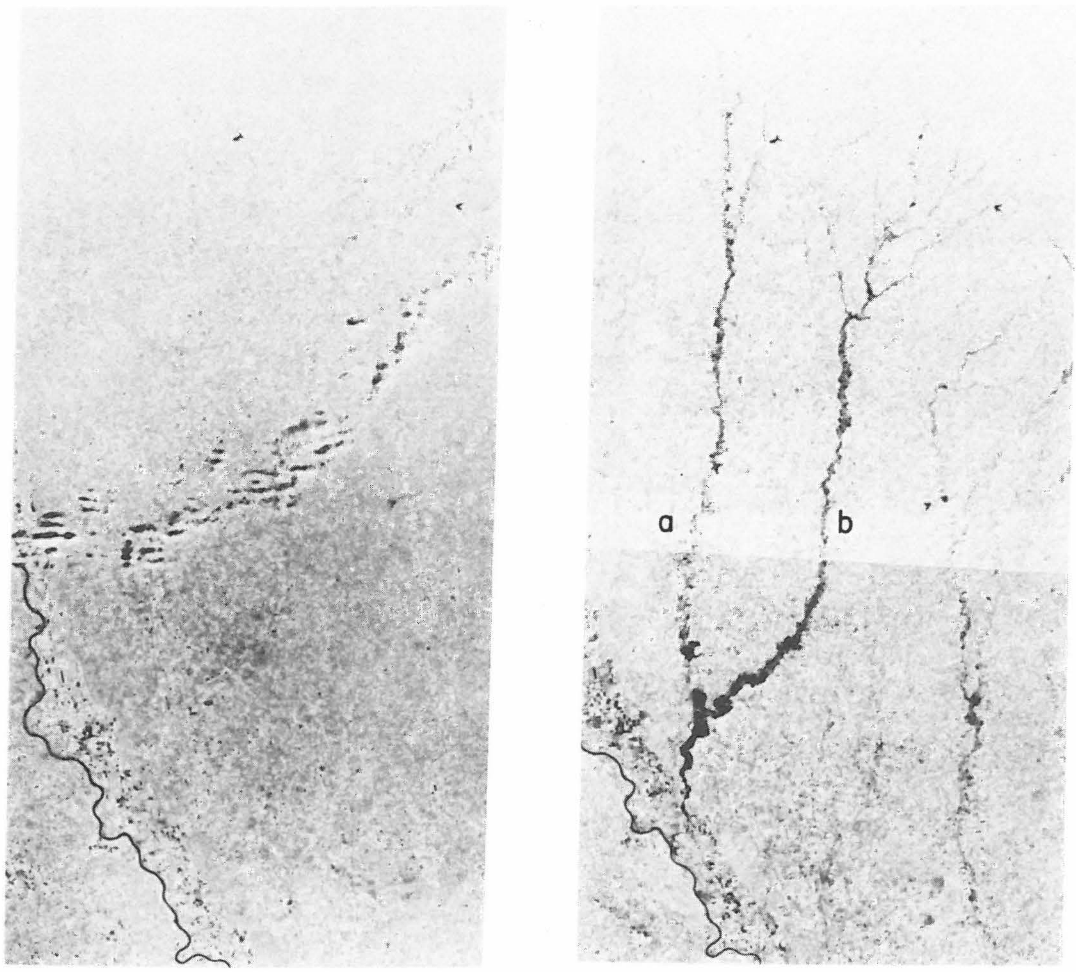


Plate 8. Winter flooding on Iowa River. January black-and-white infrared image of flood below Wapello, Iowa. Camera used Wratten 12 equivalent filter. Flooded areas have light tone.

Plate 9. Missouri River flood imagery, St. Louis area. Acquired by AN/APS 94-D Motorola Radar using a U. S. Army Mohawk Reconnaissance aircraft. Imagery was acquired in May 1973, for U. S. Army Corps of Engineers, Kansas City, Missouri. Water appears as black, indicating areas of no signal return because its surface is smooth to a wavelength of about .1 foot. Radar energy is thus specularly reflected from flooded area, away from the radar antenna. (Courtesy of Charles O. Rucker, Kansas City District, Corps of Engineers).



ERTS-I
MSS 0.8 - 1.1μm BAND
WEST CENTRAL IOWA
AUGUST 13, 1972

ERTS-I
MSS 0.8 - 1.1μm BAND
WEST CENTRAL IOWA
SEPTEMBER 18, 1972

Plate 10. ERTS-1 MSS-7 (800-1,100 nm) images of the Nishnabotna basin area, southwestern Iowa. The Missouri River is in the southwest portion of the images. Left image was obtained August 13, 1972. Except for the Missouri River no streams or valleys are apparent. In the right image, obtained September 18, 1972, the reduced infrared reflectance of the inundated areas along the West (a) and East (b) Nishnabotna Rivers are readily apparent, in contrast with the highly reflective vegetation. The image was obtained seven days after the flood crest. The images were used at 1:250,000 scale for a rapid regional appraisal of the flooding and the calculation of total acreage inundated (Hallberg, et al., 1973). Some inundated areas are also noticeable in the Nodaway River valley to the east.

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