Geo/SAT 2

FLOOD ANALYSIS:
1993 MISSISSIPPI FLOOD

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INTRODUCTION:

Large sections of the upper Mississippi River Basin experienced major flooding during the summer of 1993. Many small communities and local governments throughout the region were faced with providing immediate assistance and emergency services to the flooded areas. In the flood's aftermath these same governments were requested to help the flood impacted areas to recover with aid from the state governments and federal agencies. To receive aid, in many cases the government units were required to delineate the amount of area flooded. This instructional module outlines a simple approach, using satellite imagery and basic mathematical logic, to identify the amount and location of the flooded areas. Major floods occur every year throughout the world impacting hundreds of communities. The approach presented in this module might help those communities with respect to future floods as well as those communities still dealing with the recovery problems associated with the 1993 Mississippi flood.

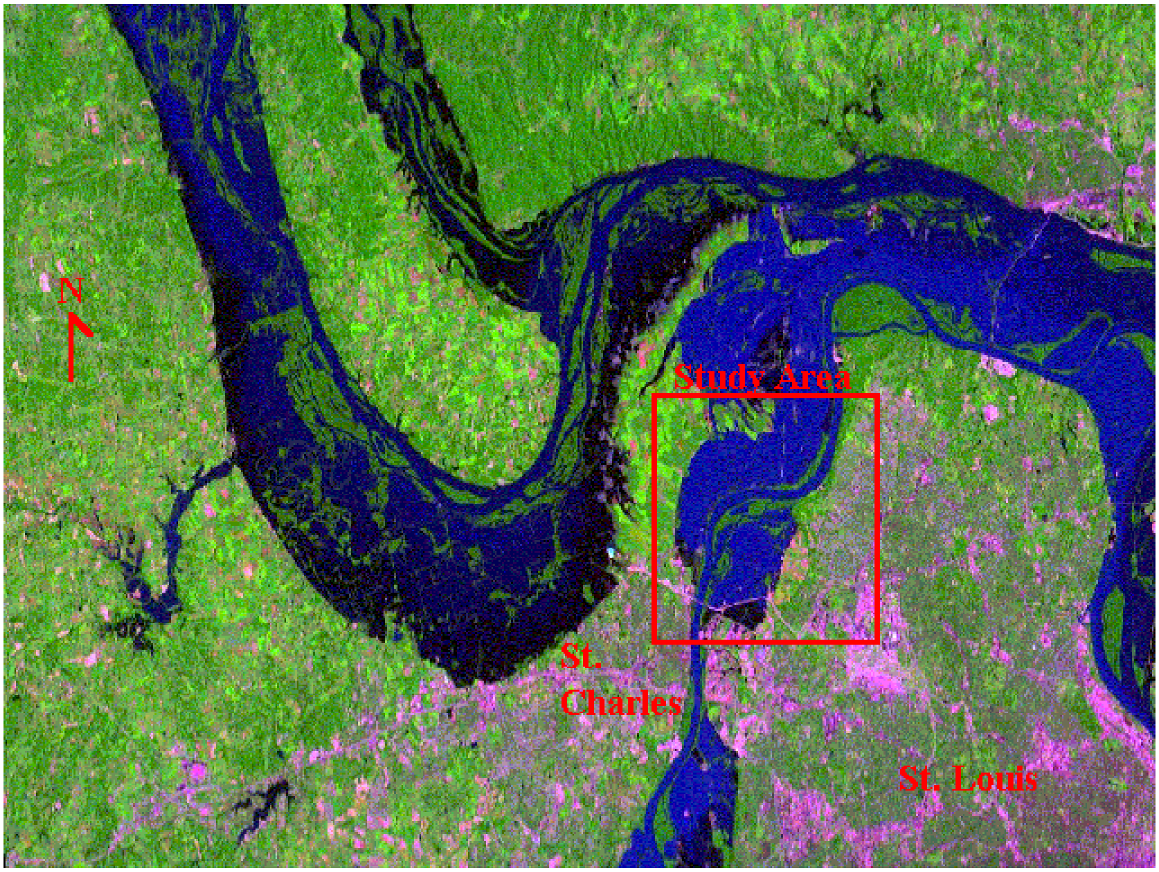


FIGURE 1

The purpose of this instructional module is to present a methodology to determine the amount of area directly affected by floodwater. This methodology employs change detection requiring a base image data set and an image during the flood period. Both data sets are from Landsat TM images and cover a study area of 512 by 512 pixels. They are geocorrected creating twenty-five meter pixels. The base image depicts conditions present on July 4, 1988 and the flood image shows the region on July 19, 1993 during the height of the flood. Figure 1, which is a false color image taken over St. Louis, Missouri on July 29, 1993 using a special NASA airborne scanner, shows the study area of St. Charles and the Missouri River. It also shows a portion of St. Louis and the Mississippi and Illinois rivers at flood stage.

BACKGROUND:

Mississippi Basin

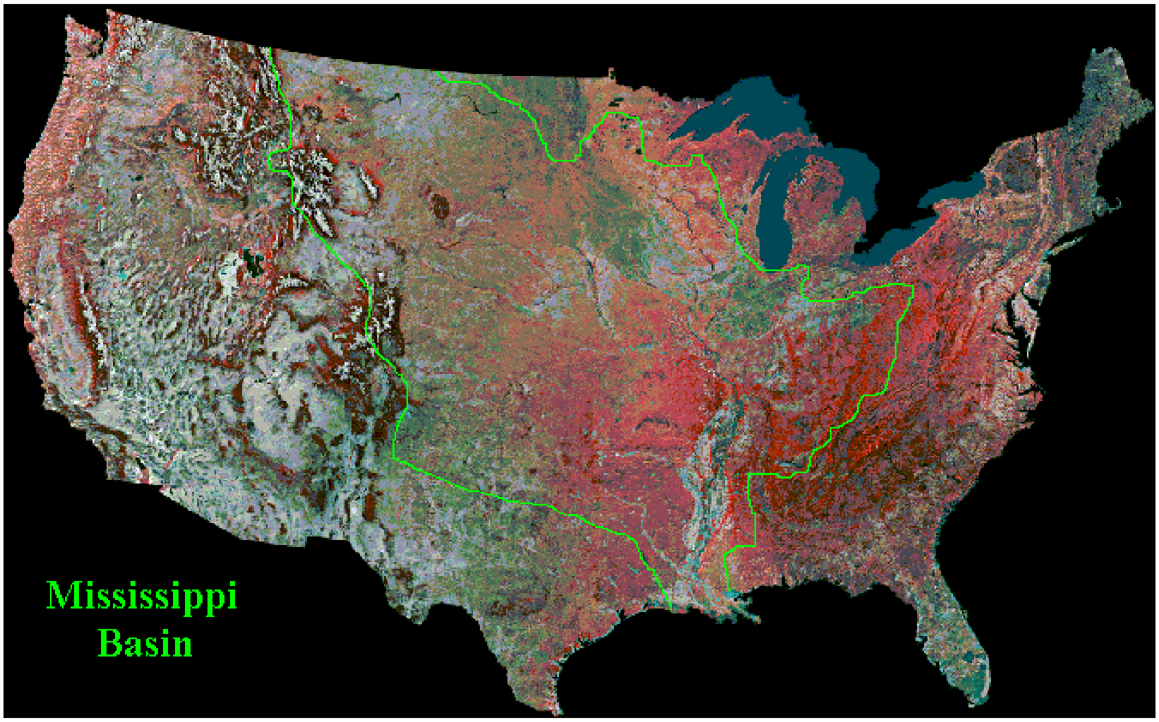


FIGURE 2

The Mississippi basin, the largest river basin in the United States, forms a wedge of 1,243,000 square miles (3,220,000 sq. km.) in the center of the continent. (Figure 2.) As the Mississippi River system drains toward the Gulf of Mexico, the basin narrows, centering on the state of Louisiana. Although the basin stretches into the alpine pastures of the Rocky Mountains and the wooded valleys of the Appalachians, it covers mainly the rich grain belts of the Midwest and the Great Plains. Thirty-one states and two Canadian provinces contribute water to the Mississippi system.

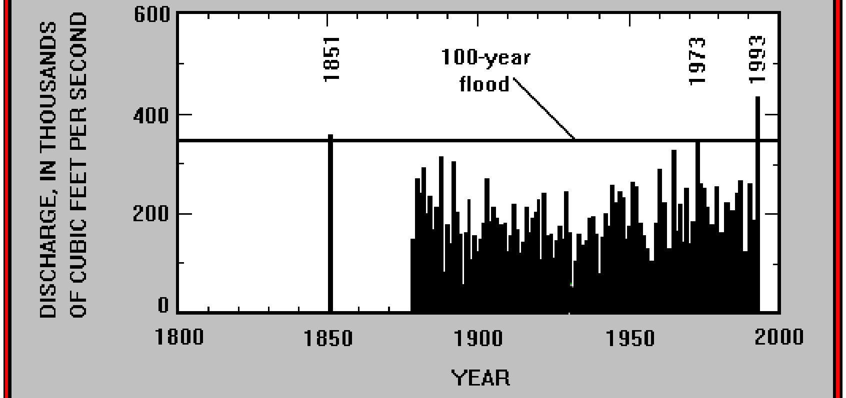
The Mississippi River suffers from a mistaken nomenclature. The main trunk of the river is created by the union of three great branches, one of which is the upper Mississippi. This branch, from which the entire system is named, is the smallest of the three branches. The Missouri branch is longer and covers a much larger drainage basin, and the Ohio branch is larger in both size and volume of water. The upper Mississippi, which terminates at the juncture with the Missouri River, drains 171,500 square miles (444,300 sq. km.). In contrast, the Missouri basin covers approximately 530,000 square miles (1,373,000 sq. km.) and the Ohio basin about 202,000 square miles (523,000 sq. km.). The Ohio, with its many tributaries draining the ridges and valleys of the Appalachian Mountains, has a basin in which rainfall is more than twice that in the larger Missouri basin. The Ohio basin pours a greater volume of water into the Mississippi system than the other two main branches combined. Below the Ohio, the lower Mississippi gathers water from several other smaller basins, namely the Arkansas and the Red River.

The lower Mississippi meanders considerably and has a quite wide floodplain, especially in comparison to the floodplains of the Missouri, upper Mississippi, and Ohio. The river also becomes very wide, usually ranging from 800 to 1,500 yards (730-1,370 meters), and deep with the center of the channel varying between 50 and 100 feet (15-30 meters).

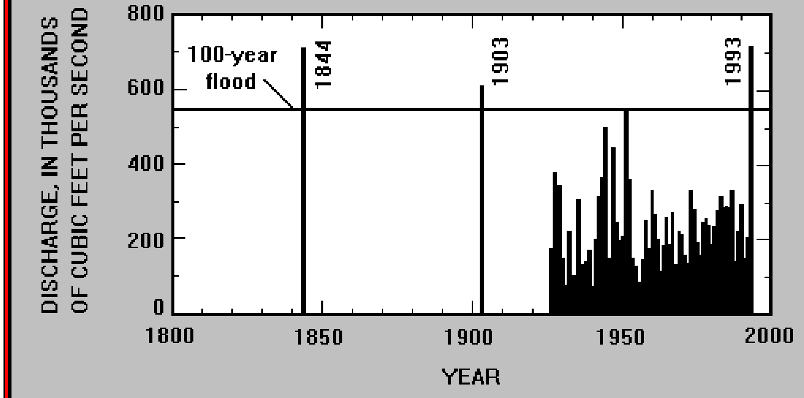
Historic Floods

The Mississippi system has experienced several major floods within this century. Until the 1993 flood, the 1927 flood was considered the greatest inundation of the Mississippi within the last hundred years. Over 700,000 people were forced to leave their homes; 246 people and 165,000 head of livestock drowned; and property damage exceeded $364 million. In 1937, heavy rains drenched the lower Mississippi, creating a lake nearly the size of Lake Superior in area. Several smaller floods in the 1940s and 1950s plagued the basin and severe floods hit the upper basin in 1965 and 1973. The 1993 flood was concentrated in the upper Mississippi basin and the middle and lower sections of the Missouri basin. The Ohio basin, which generally accounts for about 70 percent of the total volume within the system, was not experiencing any major flooding. The discharge from the Ohio basin was being controlled during the flood period by holding water back in the numerous reservoirs on the river and its tributaries. This action plus the much larger channel and floodplain of the lower Mississippi reduced greatly any flooding in the lower Mississippi valley.

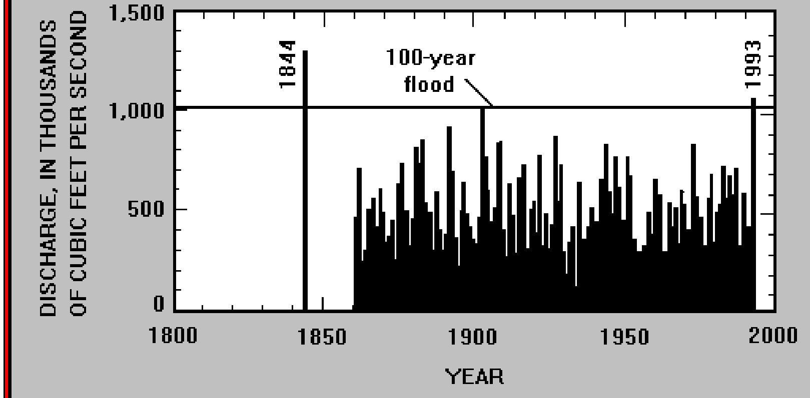
Within the flooded area, the 1993 flood reached record levels. (Figure 3.) On the upper Mississippi at Keokuk, Iowa, peak discharges exceeded significantly the previous record discharges in 1973 and 1851 and went well above the 100 year flood mark. At Boonville, Missouri, the 1993 peak discharge on the Missouri matched the 1844 flood and exceeded the 1951 and 1903 floods, all three of which were identified as 100 year or greater floods. The discharge might have been higher than the estimated 1844 peak if it was not for a number of reservoirs within the upper and middle Missouri basin holding water back. The upper Mississippi basin does not have as large reservoirs as the Missouri. At St. Louis, where the Missouri and upper Mississippi merge, the 1993 peak discharge was above the 100 year flood mark, but below the 1844 level. Again, flood control through dams held the 1993 flood discharge level down; these dams and their large reservoirs did not exist in 1844.



Mississippi River at Keokuk, Iowa



Missouri River at Boonville, Missouri



Mississippi River at St. Louis Missouri

FIGURE 3

Weather Conditions

Throughout the flooded areas, precipitation levels for the seven month period of January through July 1993 ranged one and one-half to two times higher than the average for the same seven months during 1961-1990. A persistent eastward-flowing jetstream extending from central Colorado to northern Wisconsin created a weather-front convergence zone across the upper Midwest. Moist, warm air originating over the Gulf of Mexico collided along this jet stream with cooler air masses from central Canada. The cool air, being heavier, forced the warm, wet air to rise, and in the process, increased the air's relative humidity to the point of producing precipitation. This pattern brought almost continuous precipitation to the region throughout the spring and summer of 1993. In addition, several major rainstorms occurred in mid-June and July. In southern Minnesota and northern Iowa, 2 to 7 inches (5.08-17.78 centimeters) of rain fell on June 17-18. In central Iowa, 2 to 5 inches (5.08-12.7 centimeters) came down during July 4-5, followed by another 2 to 8 inches (5.08-20.32 centimeters) on July 8-9. On July 15-16, 2 to 7 inches (5.08-17.78 centimeters) dropped over western Minnesota and eastern North Dakota and on July 22-24, 2 to 13 inches (5.08-33.02 centimeters) of rain fell across the area reaching from Nebraska to Illinois. The combination of persistent rain over a seven month period and major storms brought about the flood. Flood-control reservoirs within the region were at or near capacity and the ground was saturated.

In addition to the persistent and heavy rainfall, the region experienced, especially during June, frequent storms with gusty winds and quarter-size and larger hailstones. A large number of funnels and tornadoes were spotted. The three month period of April, May, and June in the Upper Mid West generally exhibits an even frequency of tornadoes. Preliminary reports indicate only 11 tornadoes or funnels where sighted during April within the region with another 12 in May. However, in June, 54 funnels or tornadoes were spotted, more than twice the number recorded in the previous two months. Floods are often accompanied by other severe weather conditions adding to the problems faced by people residing in the flooded region.

Human and Economic Impacts

The human and economic impacts from a flood of this magnitude are difficult to measure. The flood crested from five to sixteen feet above flood stage. At Des Moines, Iowa, the Des Moines River reached 34.3 feet (10.45 meters) on July 11, 11.3 feet (3.44 meters) above the official flood level. On July 13, at Quincy, Illinois, the Mississippi peaked at 32.2 feet (9.81 meters), almost twice the flood level of 17 feet (5.18 meters). At St. Louis on August 1, the river topped 49 feet (14.93 meters), 6 feet above the previous highest recorded level and 16 feet above the official flood level. At that time, 7.5 million gallons (28 million liters) of water flowed past the city's landmark Gateway Arch every second, six times the normal amount for that time of the year. As of July 19, at least 40,000 homes and businesses had been damaged or destroyed and some 70,000 people were homeless. Some 40 blocks of downtown Davenport were under water and nearly every river town between St. Paul and St. Louis on the upper Mississippi experienced major flooding which lasted for days. Ironically, these river communities, surrounded by water, found themselves without drinking water as well as without water for cleaning, cooking, and sanitation. Wells were polluted, and septic and sewage systems backed up creating major health problems. In Des Moines alone, a community of 250,000 people, 18 sewage plants were breached by the flood, causing microbes to enter nearly 800 miles (1287 kilometers) of piping throughout the city. It took about a month to disinfect the system once the water had receded. Streets and buildings were laminated with a brown stew consisting of raw sewage, industrial waste, and agricultural pesticides, an excellent growing environment for bacteria.

Farming, the major economic activity throughout the region, was especially hard hit since some of the best cropland is situated on the floodplains. On August 9, near the end of the flood, the estimated cost of flood damage had reached $12 billion, $8 billion of which had been suffered by farmers. Also, on August 9, the U.S. Department of Agriculture announced that an estimated 8 million acres (3.25 million hectares) of farmland had been flooded and another 12 million acres (4.88 million hectares) were too soaked to yield crops, a total area greater in size than the entire state of South Carolina. Corn and soybean yields were well below normal. By July 12, the U.S. Department of Agriculture had cut its 1993 forecast of corn production by 7.6 percent and soybeans by 3.4 percent. Even though other sections of the country made up some of the loss in the production of these crops, the economic impact spread throughout the businesses within the region. All of the activities which normally support and depend on farming were hard hit. A tremendous amount of soil was washed away, and in 1994, many farmers with floodplain fields faced the huge task of removing tons of debris and reshaping the land in order to remove drainage problems within fields. Some fields were not worth salvaging.

St. Charles

The satellite imagery associated with this instructional activity centers on the Missouri River as it flows by the community of St. Charles and the northwestern portion of St. Louis. St. Charles is the political seat of St. Charles County and is situated on some bluffs about 100 feet (30.7 meters) above the Missouri River. In 1769, the French established the first trading post in the region and named it Les Petites Cotes or The Little Hills. It was later renamed St. Charles and was incorporated as a city by the French in 1795. In 1803, along with the other areas under the Louisiana Purchase, St. Charles became part of the United States. When Missouri became a state, St. Charles was the first state capital from 1821 to 1825. Throughout its history, the city has been linked to the Missouri River, initially as a shipping center of items being brought down the river, and more recently as a fast growing suburban community requiring land transportation lines across the river to St. Louis.

St. Charles County covers 586 square miles (1518 sq. km.) which includes an eastward triangular shaped extension bordered on the north by the Mississippi River and the south by the Missouri River. Figure 4, which is a three-band composite image acquired by the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) on April 17, 1994, onboard the space shuttle Endeavour, shows St Charles County outlined in red. The eastern end of this extension is the point at which these two large rivers merge, and this entire section of the county forms one large floodplain. In fact, the township which covers this section is appropriately named, River. The dark blue areas represent very flat surfaces such as floodplains; whereas, the brown areas identify rough surfaces such as hills. According to the 1990 census, the county had a population of 212,907 but River township which covers a major portion of the county had a population of only 7,298. The city of St. Charles with a population of 53,000 is the largest incorporated community in the county and most of the larger communities are clustered together on the highlands.

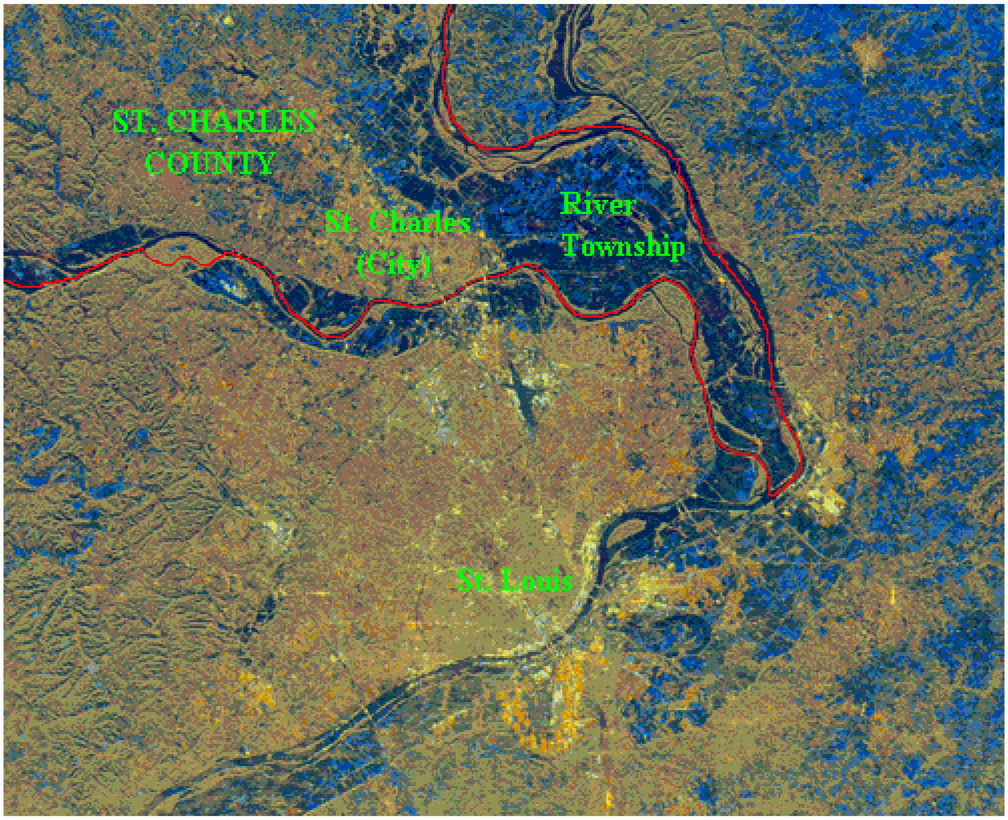


FIGURE 4

On the morning of July 16, 1993, two days before one of the satellite images was taken, the flood waters poured over the top of an abandoned railroad embankment being used as a levee just north of St. Charles and linked the Missouri and Mississippi rivers to form a 20 mile long body of water. Studying the first image in conjunction with this image will show that the flood waters on the Missouri River had spread out to cover a portion of Boone township and adjacent areas across the river. At St. Charles, the combination of bluffs on the north side of the river and levees on the south side had created a narrow neck through which the flood waters had to flow. Once beyond this neck, the waters had expanded again covering large sections of River township and small portions of St. Louis County. This entire flood water pattern is in the shape of an hour glass and represents the classic problem associated with levee construction. See the next section on floodplain management, especially the portion on levees. As the water flows through the stem, it gets higher and moves faster. It comes out of the stem moving at a very fast speed, particularly in the main channel. The Missouri River, just downstream from St. Charles, makes a ninety degree turn to the southeast. The railroad embankment which formed a portion of the levee on the north side of the river runs adjacent to the river and turns with the river. Although it is not known why the railroad embankment collapsed, the sequence of conditions just described could have placed considerable pressure on the embankment, especially in the curved section where the embankment was perpendicular to the water shooting out of the stem. This flood has created a heated debate between environmentalists and engineers as to the value of levees. The Mississippi basin has over 7,000 miles (11479 kilometers) of levees. The environmentalists want the flooding rivers to spread across their natural floodplains and not be blocked; the engineers are under a great amount of pressure to protect the property of those people living on or near the floodplains, and levees are viewed as one way to accomplish this task. In working through this instructional module consider the pros and cons of trying to control a flood.

ANALYSIS:

In establishing an approach to determine the geographic extent and location of the flooded area, this analysis is based on understanding and employing the spectral characteristics of the various bands in the Landsat data sets. Also, simple mathematical operations are applied rather than using sophisticated statistical techniques which often create problems for local government decision makers who are generally not trained in the use of quantitative methods.

This mathematical approach deals with first identifying which image bands relate best toward solving the environmental hazards problem and secondly determining how mathematically to merge spectral bands into one final image from which the needed information can be obtained. Starting with the 1988 data set as the base year, the initial step was to find one band which clearly separated water areas from land surfaces. The visible bands, as often is the case, showed variation within water bodies but did not provide sharp differentiation between water and other surfaces. The three reflected infrared bands did detect water areas as solid bodies with little reflective variation which is the normal condition when working in the near and middle infrared portions of the spectrum. Comparing these three bands to the St. Charles United States Geological Survey 7.5 minute topographic map, band 4 related extremely well to the water features displayed on the map. The map was originally prepared in 1954 and photorevised in 1968 and 1974. Even though the U.S. Midwest suffered through a severe drought during the 1988 summer, the water level of the Missouri River and adjacent smaller water bodies within the study area did not vary significantly between what was indicated on the map and the band 4 image. The data ranges for bands 5 and 7, the other two infrared bands, were too clustered making it difficult to separate water from a variety of other surfaces. Band 4 did possess a problem in that its lower data values, which indicate water areas, were also identifying the tops of commercial and industrial buildings. This problem will be addressed later. In general band 4 represented the best spectral band for the base year image. Band 6, the thermal band, was not considered due to its low spatial resolution.

Basically, for the same considerations used in choosing band 4 from the 1988 image, band 4 from the 1993 data set was the best in identifying the flood conditions. To enhance both bands, they were stretched to make full use of the absolute data range (0-250). The dynamic ranges for band 4, 1988 and band 4, 1993 were 12-200 and 15-173, respectively. Rather than automatically using the minimum and maximum values associated with the bands to stretch the data, the bands' histograms were examined to select values that reduce the effect of the extreme conditions within the data. The software provided the ability to display the statistics and histograms for images. In this analysis the minimum and maximum values used to stretch the data generally grouped the lower and upper .05 percent of the dynamic data range at the lower and upper levels of the absolute data range respectively. In other words, the minimum and maximum values used for band 4, 1988 and band 4, 1993 were 14-140 and 22-141, respectively. These values were converted to 0 and 250 and all of the other band values in between were adjusted to the new scale. Figure 5 demonstrates the difference between the regular bands and the stretched bands. The stretched bands provide more visual detail. In addition, the stretched bands are based on the same scale.

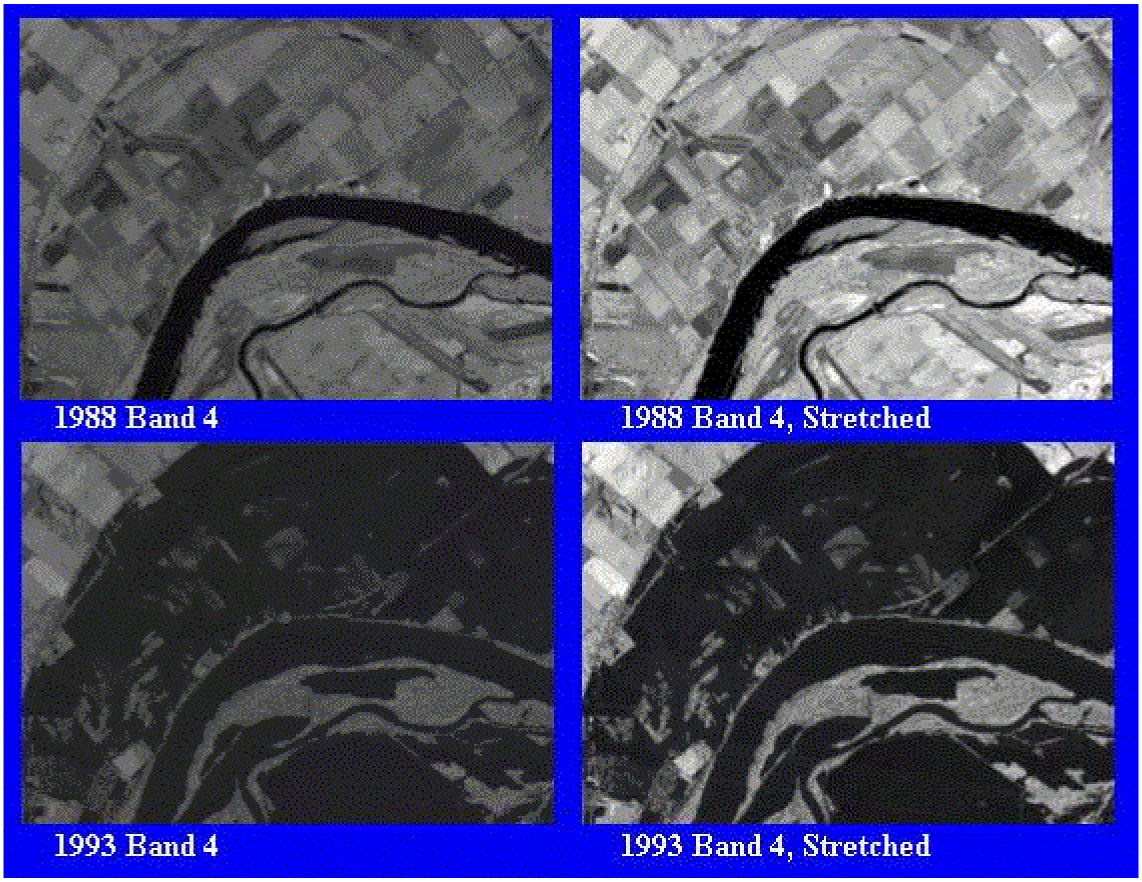


FIGURE 5

The two stretched images were added together and scaled between 0-250 to produce a new image. Water had low reflectance values in both of the stretched bands. By adding the permanent (river channels and ponds) water surfaces as shown in the 1988 band to the same areas in the 1993 band, low values were generated which made it possible to separate the permanent water areas from the flooded areas. The flooded areas in the 1993 band also had low reflectance values but when added to the high values associated with the land condition in the 1988 band, the flooded areas had higher values than the permanent water areas. The high land reflectance values in both images created values higher than those related to the permanent water or flooded areas. Figure 6 shows the results of this mathematical process. The permanent water conditions appear as very dark areas, the flooded surfaces as dark areas but not as dark as the permanent water surfaces, and the areas not covered by water as light surfaces.

FIGURE 6

This approach worked well except for certain commercial/industrial areas which were being identified as permanent water or flooded areas in the new image. This condition can be seen in the lower right corner of the generated image, Figure 6. To correct this problem a third band, band 7 of the 1993 data, was added to the new image. An examination of this band, Figure 7, shows little reflectance confusion between permanent water areas and commercial/industrial areas. Like the other two bands, this band was also stretched and then added to the combined images of the two band 4s. The final image was scaled between values of 1 and 250. The commercial/industrial areas materialized as bright surfaces and were not confused with dark, wet surfaces.

FIGURE 7

A density slice of the final image (Figure 8) enabled a separation between permanent water, flooded areas, and dry land surfaces. To determine the density slice ranges for these three classes, a histogram for this image was generated which showed three distinct clusters. The density slice ranges were: 1-20 (permanent water), 21-100 (flooded areas), and 101-250 (dry land). The density slice function within the software allows an investigator to create a classified image and provides a pixel count for each class. Table 1 shows a numerical break down of the three classes. Knowing the number of pixels associated with each class and the size of a pixel (25m x 25m), it was possible to calculate the amount of area covered under each class.

FIGURE 8

TABLE 1

Surface	Pixels*	Acres	Hectares	KM^2
Permanent Water	14578	2251	911	9.11
Flooded Land	80813	12480	5050	50.50
Dry Land	166753	25753	10422	104.22

The final product is the classified image (Figure 9) which shows permanent water as dark blue, flooded land as light blue, and dry land as brown. The numerical values associated with this image vary between 1 and 3, corresponding to the three classes. This image can become a theme layer in a raster-based geographic information system (GIS). An examination of the image revealed dry land adjacent to the river in several areas. These areas related to the one- to five-year flood plain which had been left unused and had become covered by trees. Most likely, the satellite's scanner was detecting the reflectance from the crowns of these trees and found it hard to record the flood water under the trees. A natural continuation of this instructional module would be to explore the use of other bands for the purpose of separating these flooded areas from other dry lands.

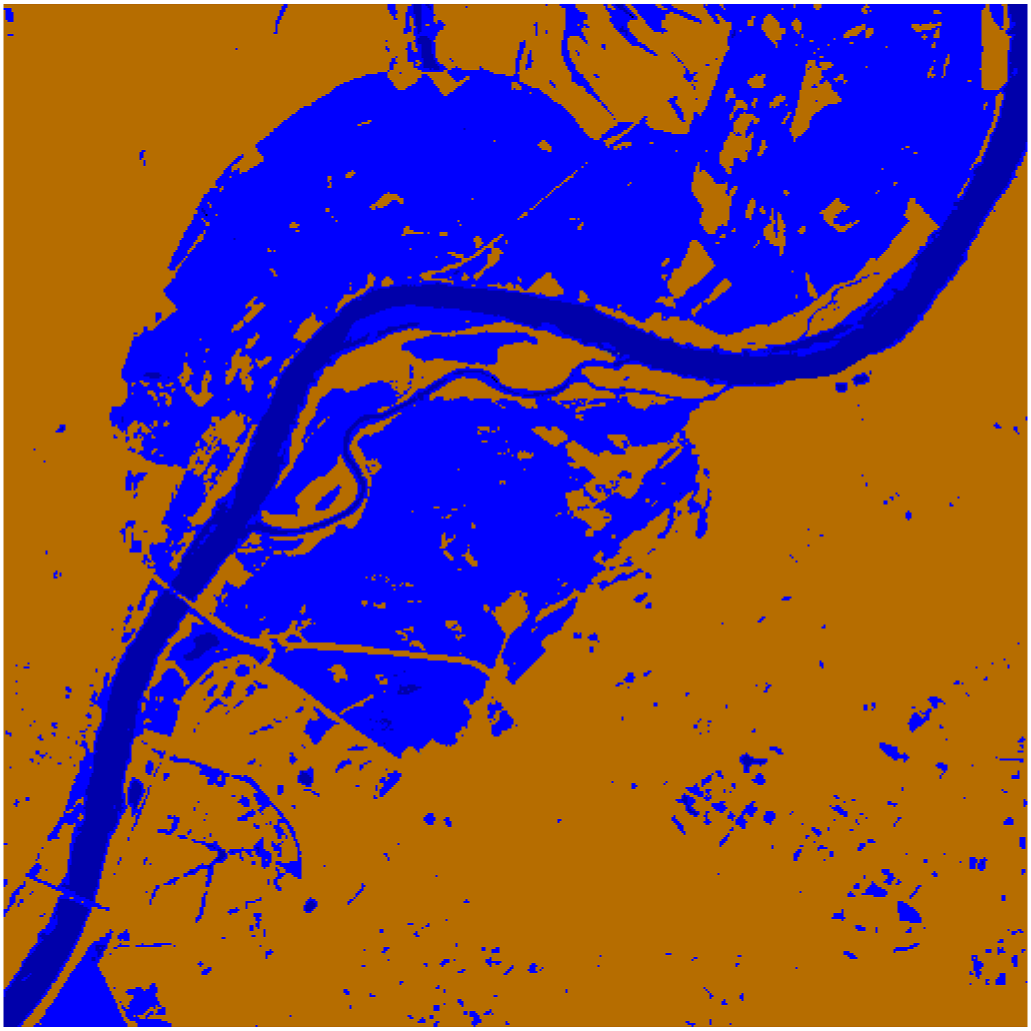


FIGURE 9

This mathematical approach was compared to the results from a principal component test based on using 8 spectral bands (1,3,4, and 7 from the 1988 data set and 1,3,4, and 7 from the 1993 data set). The results from the two approaches were almost identical with respect to geographic location and amount of area covered by the three classes. However, few people dealing with the problems created by a flood will have a background to understand principal components; they are more likely to comprehend the logic associated with the mathematical approach. As an environmental hazard, annual flooding impacts hundreds of communities throughout the world. For government relief efforts to be effective the rapid location and extent of flooding must be determined.

Through a relatively simple digital image processing approach, with Landsat thematic mapper data sets, the extent of flooding in the St. Charles, Missouri area was effectively and accurately mapped. Such approaches offer local communities opportunities for gathering such information in a rapid and inexpensive manner.

MATERIALS AND REFERENCES:

St. Charles, Missouri, United States Geological Survey 7.5 Minute Topographic Quadrangle (Map) corresponds directly with the data sets in area and clearly helps in identifying various physical and cultural features.

NOVA produced an excellent 60 minute video on the 1993 Flood, entitled Flood! which covers St. Charles County and the various problems produced by a flood. The video has some very nice oblique aerial images of the flood and some GIS animation. It can be acquired from WGBH, 19 Gregory Drive, South Burlington, VT 05403, USA. (800) 255-9424. The price is $19.95 plus shipping and tax.

General References:

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- Alan Mairson, *The Great Flood of '93*, National Geographic Magazine, Vol. 185, No. 1, pp. 42-81, January 1994.