Ege Coğrafya Dergisi, 12 (2003), 103-118, İzmir
Aegean Geographical Journal, 12 (2003), 103-118, Izmir—TURKEY

FLOOD STUDIES USING GEOGRAPHIC INFORMATION SYSTEMS (GIS): 1993 BIG MIDWEST FLOOD (USA)

Murat KARABULUT

Kahramanmaraş Sütçü İmam Üniversity Department of Geography
mkarabulut@ksu..edu.tr

(Teslim: 30 Ekim 2001; Düzeltme: 25 Kasım 2002; Kabul: 6 Ekim 2003)
(Received: October 30, 2001; Revised: November 25, 2002; Accepted: October 6, 2003)

ABSTRACT

Flooding is a serious national problem in the USA, Turkey and throughout the world and affects every community, because many small communities are entirely on floodplains and large parts of some major cities are similarly sited. The United States upper Midwest was subjected to severe flooding during summer of 1993. Heavy rainfall in the Mississippi and Missouri River basins from April through August caused flooding of many Midwest Rivers. Damage estimates include 48 flood-related deaths and a total economic damage of more than $12 billion. Much can be done to reduce the impact of floods on property damages and agricultural lands. In recent years government agencies include Geographic Information Systems (GIS) in their management systems, because GIS allow examination and management large amount of spatial and tabular data which would be impossible or impractical using manual interpretation. In this research flood problems investigated using GIS in St Luis area. The results indicate that GIS can be used to assist in flood studies and floodplain management by analyzing several coverages.

Key words: GIS, flood, floodplain, management, landuse

Öz

Seller ABD, Türkiye ve bütün dünyada her toplumu etkileyen çok önemli bir ulusal problemdir, çünkü bir çok küçük topluluk tamamen taşkın ovalarında ve bazı büyük şehirlerin geniş parçaları da benzer şekilde yerleşmiştir. ABD'nin Orta Batı eyaletleri 1993 yılında çok şiddetli sel felaketi ile karşı karşıya kalmışlardır. Mississippi ve Missouri ırmaklarının havzalarında Nisan ile Ağustos ayları arasındaki periyotta bir çok küçük ırmak taşarak sel felaketine sebep olmuştur. Yaklaşık olarak 12 milyar dolarlık maddi zarar meydana gelirken, felakette 45 kişide hayatını kaybetmiştir. Sellerin sebep olduğu maddi kayıpları ve tarımsal araziler üzerindeki zararlarını azaltabilmek için bir çok tedbir alınabilir. Bu nedenle hükümetler ve ona bağlı kamu kurumları Coğrafik Bilgi Sistemlerini (CBS) bünyelerine dahil etmişlerdir, çünkü CBS manual yöntemlerle kullanılması çok zor ve zaman alıcı olan büyük mekansal ve tablosal verilerin düzenlenmesi ve değelendirilmesini çok hızlı şekilde yapar. Bu araştırmada St. Louis şehri yakınlarında meydana gelen sel felaketi CBS kullanarak incelenmiştir. Elde edilen sonuçlar CBS'nin sel alanlarının incelenmesi ve taşkın ovalarının yönetimi ve işletilmesi sürecinde çok kullanışlı olduğunu ortaya koymuştur.

Anahtar kelimeler: CBS, sel, taşkın ovası, işletme, arazi kullanım

INTRODUCTION

Among the landscape transformation caused by natural processes or human activities, floods are extremely important geographic phenomena because of the human and property losses associated with the natural events. Flooding is a serious problem in Turkey and throughout the world. In Turkey, some of the villages and cities are affected by overflowing water from the small creeks or rivers. Cities and towns, such as İzmir (1995), have received varying degrees of damage from excessive waters for years. Floods in Turkey have destroyed several bridges, factories, stores, and homes and have taken several human lives in 1995 (Sezer, 1997). For example, during 1995 İzmir flood, 63 people lost their life while 322 buildings were destroyed completely and more than 10000 buildings were damaged in various degrees (Sezer, 1997).

Several government agencies prepared numerous plans and management systems in order to the effects of floods in the United States and throughout the world. Much can be done to reduce the impact of floods on property damages and agricultural lands. In recent years, many countries have included Geographic Information Systems (GIS) in their management systems because GIS can be used as an effective tool for assessing flood hazards, modeling, monitoring, mapping the extent of floodplains and flood prone areas. However, Turkish scholars and government agencies have not used GIS techniques in flood studies yet because of GIS being new in Turkey. Therefore, this study mainly discusses GIS methods in flood studies by introducing several aspects of GIS to Turkish scholars and government agencies.

Capabilities of GIS in Flood Studies

In order to assess flood conditions and predict potential impacts of floods, comprehensive techniques and models need to be created. Creating a model is usually difficult, however the use of GIS can simplify this task by integrating different types and levels of data, information and human knowledge. Additionally, using GIS in model building allows the more alternative plans to be generated and assessed. Modeling is used to understand the geographic processes and evaluate strategies for the efficient operation. Minimum input data for modeling floods includes hydrological data (river and its properties such as discharge, volume, channel width, shape and slope), landuse (agricultural, natural vegetation, wetlands, residential or other), topographic and soil data (elevation, slope, soil types), climatic data (precipitation, storms, evaporation), and demographic data. All these data can be used to model flood problems in such areas by using GIS techniques (Lanza and Siccardi, 1995).

Mapping is also important function of GIS that has capability to relate data across layers to allow spatial analysis. GIS could also allow monitoring flood events. Monitoring is an expensive and difficult in flood studies due to the nature of the event which requires understanding of the surrounding features. GIS has the ability to monitor each flooding event for cause, frequency, duration and quantity of floods. Measurement function of GIS can be used to assess flood hazard throughout the floodplain management such as calculating and assessing property losses (counting destroyed homes and buildings), measuring flooded farmlands, assessing damages on infrastructure (destroyed roads and bridges).

Using spatial analysis capabilities of a GIS into flood response system can increase the effectiveness of floodplain management. Besides increasing speed and scale of data manipulation, GIS can also enhance the interpretation flood characteristics such as flood depth and direction.

PREVIOUS STUDIES

GIS have become one of the important tools for applied research in many environmental, social and physical sciences. Delineation of floodplains and extent of flooded areas, hazard assessment, flood prediction and hydrologic modeling are the specific areas where GIS can be useful in terms of floodplain management. For example, Tkach and Simonovic (1997) have studied to compare floodplain management strategies in GIS environment. They used raster GIS (IDRISI) evaluate existing flood protection approaches. Similar to this paper Consuegra et al. (1995) used GIS in terms of flood and floodplain delineation and hazard assessment in agricultural areas. They indicate that grid based GIS (IDRISI) software is very useful to present distribution of water surface elevation for flooded areas. The authors also indicate that floodplain delineation and mapping flood characteristics requires the development of specific hydrologic modeling.

In their article, Lanza and Siccardi (1995) indicate that using GIS extremely accurate in assessment of flood damage at the regional and local scale and suggest that traditional flood prediction techniques are no more useful for reliable assessment. To implement effective flood protection strategy, it is critical to utilize both flood modeling and GIS technologies. Fredericson et al. (1994) suggest that successful usage of GIS in flood studies is reliant upon developing interfaces between GIS and numerical flood models such as HEC –1 (Hydrologic Engineering Center) model. They express that GIS can be improve the interpretation of typical hydrologic and hydraulic model input. According to this article, it is possible to determine flood depth and to identify sites lying within the flood prone areas by overlying water surface map on the topography map.

A CASE STUDY: THE 1993 BIG MIDWEST FLOOD

The United States Upper Midwest was subjected to severe flooding during summer of 1993. Heavy rainfall in the Mississippi River basin from April through August caused flooding of many Midwest Rivers such as the Mississippi, Missouri, and Kansas rivers. This event concentrated in the Upper Mississippi, and in the Middle and Lower Missouri River basins. This flood was unusual for the area because it occurred so late in the spring-summer runoff season. Unusually high flood discharges were recorded for in many locations. The flooding also was unique and unusual for its long duration and widespread severe damage. For example, Missouri River in St. Charles County near St. Louis, Missouri crested 5.3 m above normal flood stage. Nine Midwestern states were impacted by the floods with more than 45000 km^2 of land inundated and at least 48 people killed. During this flood also 22000 homes were damaged or destroyed, 85000 residents were evacuated from their homes. The economic losses in property damage were roughly estimated at 12 billion dollars (Williams, 1994).

The identification of the magnitude and damage caused by floods is an activity demanded by many government agencies as a first step in order to respond to these natural disasters. GIS is a valuable technique for the evaluation of effected areas.

STUDY AREA

The area for this research is section of the Missouri River near the St. Louis area in Missouri (Figure 1). This area is depicted in two Landsat TM images one taken July 4, 1988 and the other July 18, 1993 (Figure 2) after extended period of heavy rain. The study area is one of the fastest growing urban areas in Midwest. For this reason the potential gain of mitigation flood damages is very high. There are other several reasons to choose this area as a study area. These factors are: First, it is located near to junction of the Missouri and the Mississippi rivers. Therefore, the study area has a history of severe property damages from flooding as a result of being close to junction of two river systems. Second, flood frequency averages once every other year, with major flood episode occurring once every six years on average (in 1993 over 35% of St. Charles county was inundated). Third, several government agencies have discussed numerous floodplain management measures, and there are several ideas about mitigation of flood affects.

Climatic Conditions

Meteorological factors such as rainfall, which is the direct cause of most floods, vary in time and place in the Missouri River basin. Usually annual peak floods are caused by individual storms. For example, the nature of rainfall, its duration and intensity, and its distribution is relative to the drainage basin. Most storms and heavy rainfalls are local, and it is the drainage basin experiencing the maximum precipitation that runs the risk of a flood. The 1993 flood represented that the amount of precipitation and duration of rainfall are closely related to overflow in the study area (SAST, 1994).

In 1993, the climatic condition of this area was largely affected by the passage of high and low-pressure systems around the Midwestern United States. The weather was governed by cyclonic storms that moved from west to east bringing adequate rainfall. Low-pressure systems, which carried warm and humid air masses, form in the Gulf of Mexico and moved northeastward, normally passing over the study area and collided high-pressure systems form western Canada which carried cold air southward across the Midwestern United Studies. The resultant unstable air masses persisted through out the Missouri river basin and caused unusual rainfall storms during spring and summer 1993 (Kunkel et al., 1994).

Hydrologic Characteristics

The discharge of the Missouri River which is one of the largest tributaries of the Mississippi River varies from year to year, season to season and day to day in the study area. At the normal discharges during non-flood seasons, the water level in the channel stands from 4.5 to 5.5 m below the adjacent floodplain surface with a mean discharge of about 1100 to 1400 m^3/s. The wet and dry periods generally affect stream flow characteristics. Precipitation, snowmelt and ground water are the three principle factors contributing to total stream flow within a drainage basin. Figure 3 illustrates the flow characteristics of the Missouri River discharge near St. Louis.

Precipitation in the Missouri River basin was greatest during the period of March through July in 1993 (Figure 3a). By the late June most flood-control reservoirs were at or near capacity, and ground was saturated from excessive rainfall. From mid-June through early august 1993, severe flooding in the study area followed by heavy and persistent rainfall from January through July (Figure 3a). The magnitude and timing of several rainfall events in late June and July combined with wet antecedent climatic conditions were principle causes of the severe flooding in the study area. Rainfall totals from January to July 1993 were two times larger than average rainfall totals. Therefore, rainfall and resulting runoff were above average throughout the Missouri river basin from April to June 1993, and streams were generally bankfull at the end of June. Flooded areas reached record levels with peak discharges in many areas of region. The monthly discharges volumes for April through June were more than 50 percent of normal (Figure 3). The Missouri River was 5.3 m above normal flood stage during the 1993 flood.

Floodplain Geomorphology

The floodplain of the lower Missouri is narrow and relatively steep. Its surface configuration is a product of an actively shifting and sinuous channel that has permitted a reworking of the floodplain in recent times. Typical floodplain landforms in the floodplain are natural levees, point bars, oxbow lakes and backland deposits. Figure 4a shows typical geomorphologic features in the study area. The river channels is bordered by flat bottomland areas (3 to 15 km wide) which are incised an average of 60 to 120 m below the surrounding upland surfaces. The superficial geology is characterized by postglacial river alluvial deposits lying over interbedded shale and limestone bedrock (Schmudde 1969, SAST, 1994). The alluvial deposits include sand and pebble gravel in the lower part and contain interbedded sand silt and clay in the uppermost 1.5 to 4.5 m (Figure 4a).

Geomorphic effect of the 1993 flood

During the 1993 flood, geomorphic changes on the floodplain include erosional and depositional alteration of surface (Figure 4b). These geomorphic changes were generally associated with levee breaks which were result of many mechanisms such as overtopping by floodwater, liquefaction of levee material and mass failure. Artificial levees were constructed from locally available materials which is uncompacted topsoil. During the 1993 flood, large hydraulic heads and flow constriction through narrow openings in the levee breaks generated zones of intense scour areas. Most levee failures were occurred at the intersection of old and present river channel (SAST, 1994). Flow through the levee breaks also transported large amount of sediment onto floodplain (Figure 4b). The scour zone areas were represented by deep erosion, generally more than 2 m, with steep sides. Depositional features include sand splay deposits and point bar deposits. Sand deposits were thickest and coarsest closer to the scour zones. Extensive areas of the study area used for agriculture were covered with sand deposits, some of which were as much as 4 m. Mud deposition seemed to be limited in extent (Holmes, 1993).

OBJECTIVES

The objectives of this study are to use GIS to:

1- Delineate the extent of flood plain and flood extent,

2- Determine the land use changes by comparing 1879 land use map with current satellite imageries,

3- Identify the most critical section of the river channel which is subject to the levee failure (evaluation of levees).

4- Interpret flood process (Causes and result of floods)

GIS COVERAGES

Development of floodplain data base management system for flood studies requires the collection, storage and analyzing of great amount of spatial and tabular data, because many environmental and human factors can have an impact on flooding. Therefore, following parameters can be considered to evaluate flooding issues in the study area. The data can be divided into three conceptual components: physical, land use and environmental. From each division, data can be organized into separate layers and input into the database. The physical divisions could consist of (a) hydrological layers containing data on rivers, lakes, streams, channel characteristics, discharge and flood probability such as 100- and 500- year flood level, (b) a topographical data including the land elevation data in the form of counter lines, slope characteristics and spot elevation data, (c) a soil layer consisting of the soil location of different types of soil. The land use coverage which consists classification of different parcels of land such as agricultural, urban, natural vegetation, wetland and forest. This division will also include levee data (levee material, number of failures). Environmental data can be organized into layers representing (a) climatic data, (b) water quality data and (c) wild habitat.

For this study, it was possible to obtain spatial information for the first two groups of data (Table 1).

Table 1. Thematic layers and principle attributes

Layer	Entity
Land use/land cover	Urban and agricultural rangeland, water, barren land grass, wetlands, forests and bushes
Surface hydrology	Rivers, streams, ponds, floodplains, flood extent (1993), flood elevations (10-, 50-, 100-, 500-year flood elevation)
Flood probability	100-year and 500-year flood
Levees	Flooded 1993, failure date, type (agricultural, residential), previous failures, levee materials, elevation and height, repair cost, failure type (overtopping and breach)
Transportation	Federal, state and city highways, roads and rail roads

Hydrologic data

Hydrological aspects of flood hazards need to be considered. To have an approximate knowledge of the discharge of the river, hydrological information must be used because flooding is very much related to the discharge of the river. When the discharge of river exceeds capacity of the river channel, river starts to overflow throughout its floodplain therefore it is very critical to know discharge and discharge capacity of river channel to predict future flood and to decide flood protection strategy. This will also include both precipitation and characteristics of catchments basin. In this study following hydrologic coverages were used to evaluate flooding issues in the study area. Coverages are present and old river, 100- and 500- year flood level, 1993 flood extension and boundary of the floodplain (Table 1).

Land use/cover

Land use/cover properties have a strong affect on flooding because land use/cover is a determinant factor on the surface runoff. There is a strong relationship between river flow discharge and land cover types. Especially urbanization has a drastic impact on the hydrologic regimen by creating large impermeable areas, hence cause to increase flood risk. These areas decrease infiltration rate and increase rate of surface runoff. The removal of natural vegetation also change infiltration rate. In the study area European settlements have changed most of the land areas from forest to agricultural land. This situation caused to increase surface runoff and force to the Missouri River to change its channel several times. All these changes lead to increase peak flows and cause severe flooding events. Land use characteristics of the study area include orchard, forest (deciduous, evergreen), bushes, willows, sandbar, grassland, marsh, open water, and urban.

Levees

Levees are very important structural flood control measures, however sometimes these features fail and cause more severe damages. For this reason in flood studies levees must be considered to evaluate flood processes. In the study area many levees failed and increased flood level through out the floodplain. The levee date set consists of location of levees, elevation at specific points along the levees, levee sponsorship, dates of breaches, previous failures, levee types, area protected, levee length, and cost of 1993 repairs (Table 1).

METHODS AND ANALYSIS

GIS is useful to delineation of floodplain boundary and flood extent areas. Using GIS techniques and remote sensing, the Missouri River floodplain and 1993 flood extent areas were delineated. The steps involved in study for flood analysis included (1) image geocoding, (2) unsupervised classifications, (3) polygon recoding (during flood classification), intersects, and overlay, and (4) delineation of floodplain, flood extent and flood risk areas (Figure 5).

GIS techniques allow delineating floodplain boundary by using DEM model and remote sensing techniques. Floodplain of the study area has been delineated and classified by using several criteria such as following continuous bluffs, dissected bluffs, and slope properties. The extension of floodplain in the study area can be seen in Figure 6.

The extension of flooded areas in 1993 can be seen in Figures 2 and 7. According to figures, floodwater covered most of the floodplain from its channel to 500-year floodplain boundary. In the study area, overflowed water covered almost 100% of the 100-year floodplain (Figure 7).

According to literature (SAST, 1994), land use layer (Figure 8) and satellite images (Figure 2) land use categories for this early settlement period (1879) represent that much of the study area dominated by grassland, deciduous forest and sandbar. By comparing landuse layer and satellite imagery of the area, we can determine that dramatic changes have been occurred in the study area. In the study area, the Missouri River floodplain contains prime agricultural lands because these low-lying areas have fertile soils and convenient topography. In spite of flooding problems, the floodplain is also used as building sites for residential and commercial developments and transportation network at an increasing rate (Figure 2). The Missouri River has been channelized and stabilized to protect agricultural lands from frequent flooding. This channelization has led to change river crossection and caused to destroy or diminish sandbars that were located middle of the river. For example in the study area the width of the channel has decreased almost 50% in hundred-year period. This situation decreases capacity of river channel and finally force to river overflow throughout its floodplain during heavy rain and snow melting season. Hence, the river starts to overflow throughout its floodplain and inundate residential and agricultural areas.

In the study area, probably the most important parameters are levees because these features are built to prevent flood. However, most of the artificial levees failed during the 1993 flood and increased damages. In the study area almost 90 % of the levee failure resulted from levee breaching. Especially levee breaches are located at points of intersection between present channel and older channels, along the tributaries crossing the high-energy floodplain and along high velocity areas. Therefore, old channel cross-section with present river is high-risk areas for flooding in the study area. By using overlay operation, high risky areas have been delineated in the study area (Figure 8). Circles represent these risky areas along the river.

According to Figure 7, 17621 acres residential area flooded in 1993. These areas have been flooded four times before current flood. By comparing Figure 7 with Figure 8, it can be easily seen that these areas are located next to intersection between old and present river channel.

Table 2. Levee types and damage assessment

Levee type	Area (hectares)	Repair cost ($)	Previous failure
Residential	4702.86	4506342	4
Industrial	2428.19	2210934	4
Agricultural			
Levee 1	1214.06	996782	5
Levee 2	1092.65	862867	5
Levee 3	5862.28		0

Table 2 represents levee type and damage assessment. Even though residential levees were built to protect people from as much as 500-year flood, these levees failed even under 100-year flood elevation. The Figure 8 represents these areas that are located along high energy-floodplain and junction of two river channels. These results that are represented in Table 2 were derived from layers by using GIS functions such as overlay and intersects.

According to Table 2. Residential, industrial and agricultural levees failed several times before 1993 in contrast in natural vegetation areas such as grassland had not failed before 1993.

CONCLUSIONS

The United States upper Midwest subjected to severe flooding during summer of 1993. Millions of acres of agricultural and urban lands in the study area were flooded (inundated) for several weeks. Damage was exceeded $12 billion. This paper has presented basic model relating flood delineation and hazard assessment along the Missouri river floodplain. The results showed that GIS can be used to assist in flood studies and floodplain management by analyzing several coverages. GIS can also allow producing different flood scenarios to evaluate different flood issues. GIS techniques are also useful to join people floodplain management because many simple and user-friendly GIS softwares can make people to understand different flood scenarios. Additional work can be conducted in the area of relating flooding to soil loss and water quality with in the GIS framework.

REFERENCES

Chrismen, N. 1997, *Exploring Geographic Information Systems*, Jhon Willey, New York.

Consuegram, D. F., F, Joein, Vitalini, F., 1995, “Flood delineation and impact assessment in agricultural land using GIS technology”, in GIS Assessing Natural Hazard, ed. Carrara, A. and F. Guzetti, pp.177-198, Kluwer Academic Pub.

Fredericson, K.E., J.D. Westervelt, and D.M. Jhonston, 1994, A GIS/Hydrologic modeling graphical user interface for flood prediction, U.S. Army corps and Engineers, Research report.

Holmes, R.R., 1993, Sediment transport in the Lower Missouri and central Mississippi rivers, June 26 through September 14, 1993, U.S. Geological Survey Circular, 1120-A, 23 p.

Kunkel, K.E., S.A. Chagnon and J. R. Angel, 1994, “Climatic aspect of the 1993 Upper Mississippi River basin flood”, Bulletin of American Meteorological Society, vol. 75, pp. 811-822.

Lanes, L. and M. Conti, 1994, “Remote sensing and GIS: Potential application for flood hazard forecasting”, EGIS, pp. 21-32.

SAST, 1994, *Science for Floodplain Management into the 21st Century*, Washington.

Schmudde, T. H., 1963, “Some aspects of land forms of the Lower Missouri River floodplain”, Annals of the Association of American Geographers, vol. 53, pp. 60-73.

Sezer, L. I., 1997, “İzmir'de 3-4 Kasım 1995 Karşıyaka-Çiğli Sel Felâketi (Meteorolojik-Klimatolojik Açıdan Bir Yaklaşım)”, Ege Coğrafya Dergisi. vol: 9, pp: 161-188, İzmir.

Tkach, R.J., S.P. Simonovic, 1997, “A new approach to multi-criteria decision making in water resources”, Journal of Geographic Information and Decision Analysis, Vol.1, pp. 25-43.

Tkach, R.J., S.P. Simonovic, 1997, GIS and the floodplain management planning process in Washington State, Water Resources Research report No.36, University of Manitoba.

White, S.W., Migalewitz, P.J., Maidment, D.R. and Ridd, M.K., 1996, “GIS modeling and visualization of the water balance during the 1993 Midwest Floods”, AWRA Symposium on GIS and Water Resources, September 22-26, FT. Lauderdale, FL.

Williams, J., 1994, “The great flood”, Wheatherwise, vol. 47, pp. 18-22.

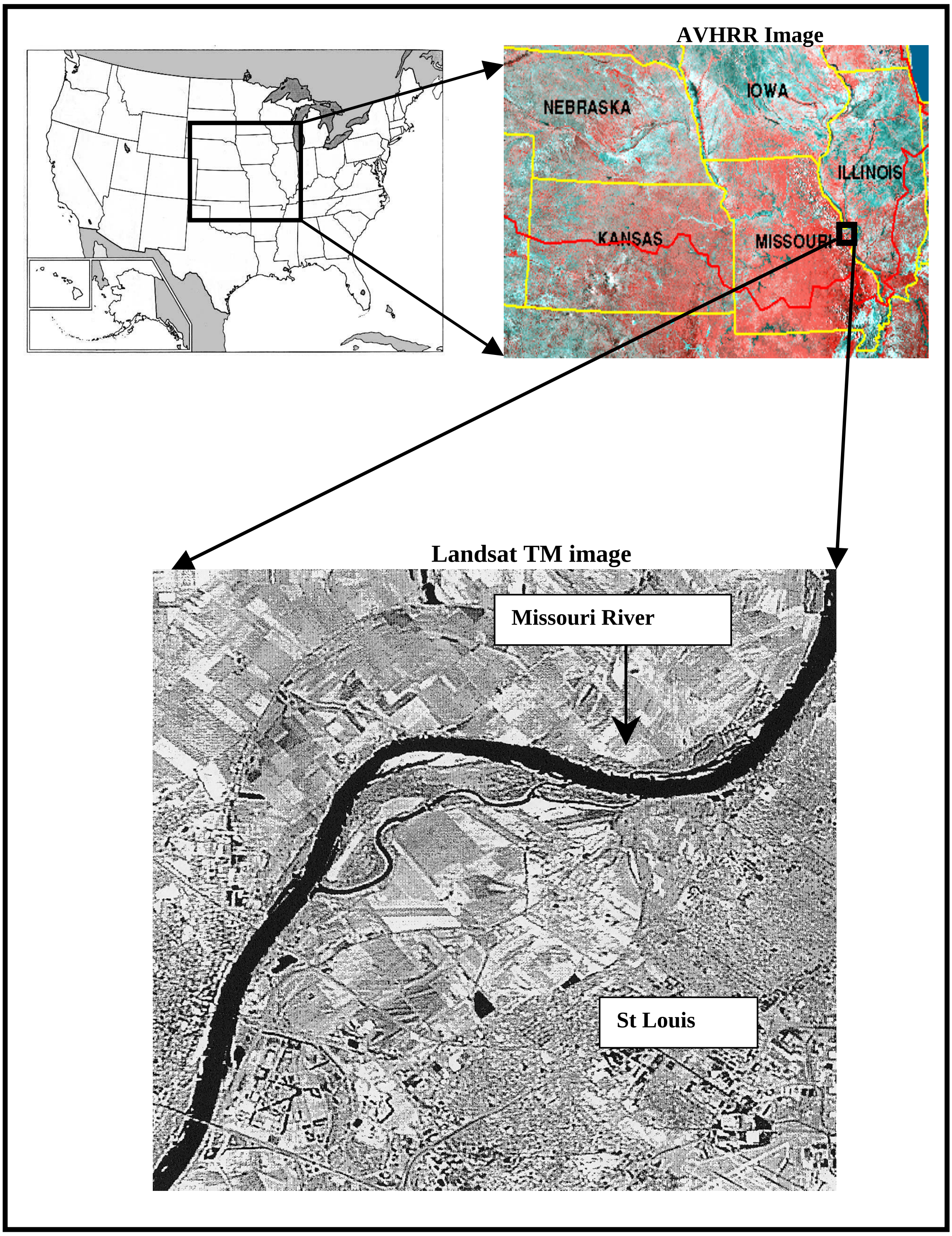

Figure 1. Location of the study area (Landsat TM infrared image was acquired on July 4, 1988)

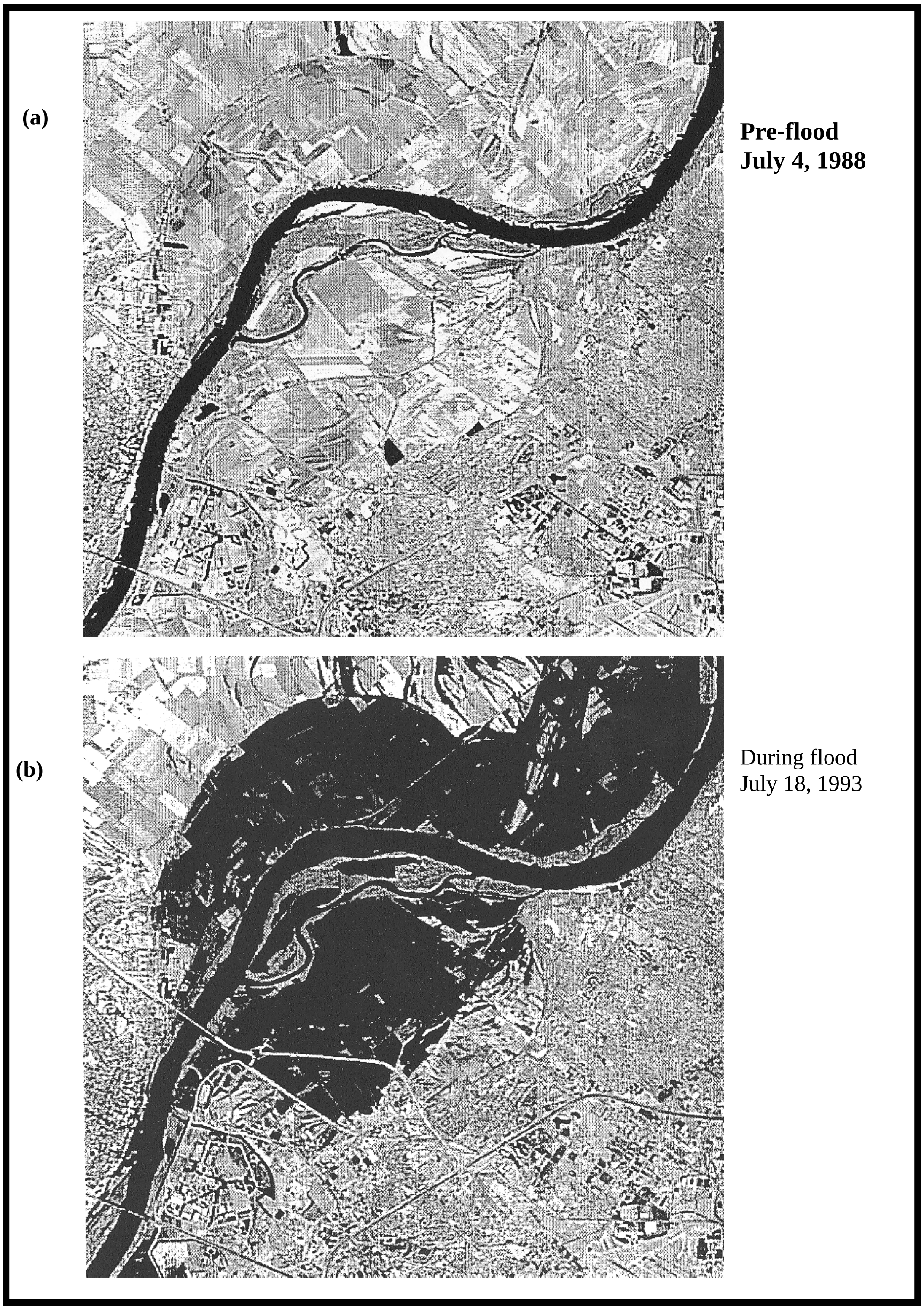

Figure 2. Landsat TM infrared band images of the study area, a) Before flood, b) after flood.

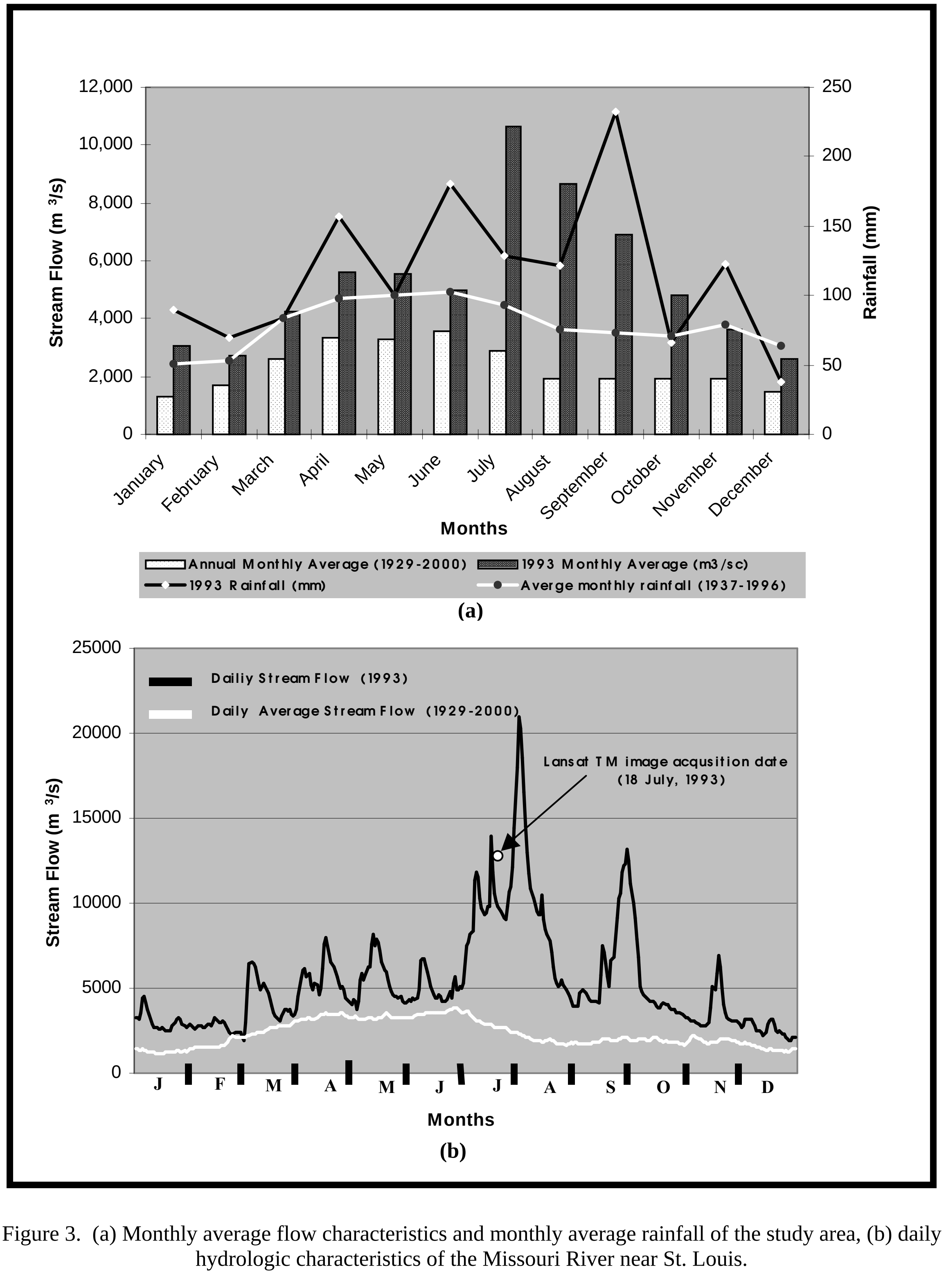

Figure 3. (a) Monthly average flow characteristics and monthly average rainfall of the study area, (b) daily hydrologic characteristics of the Missouri River near St. Louis.

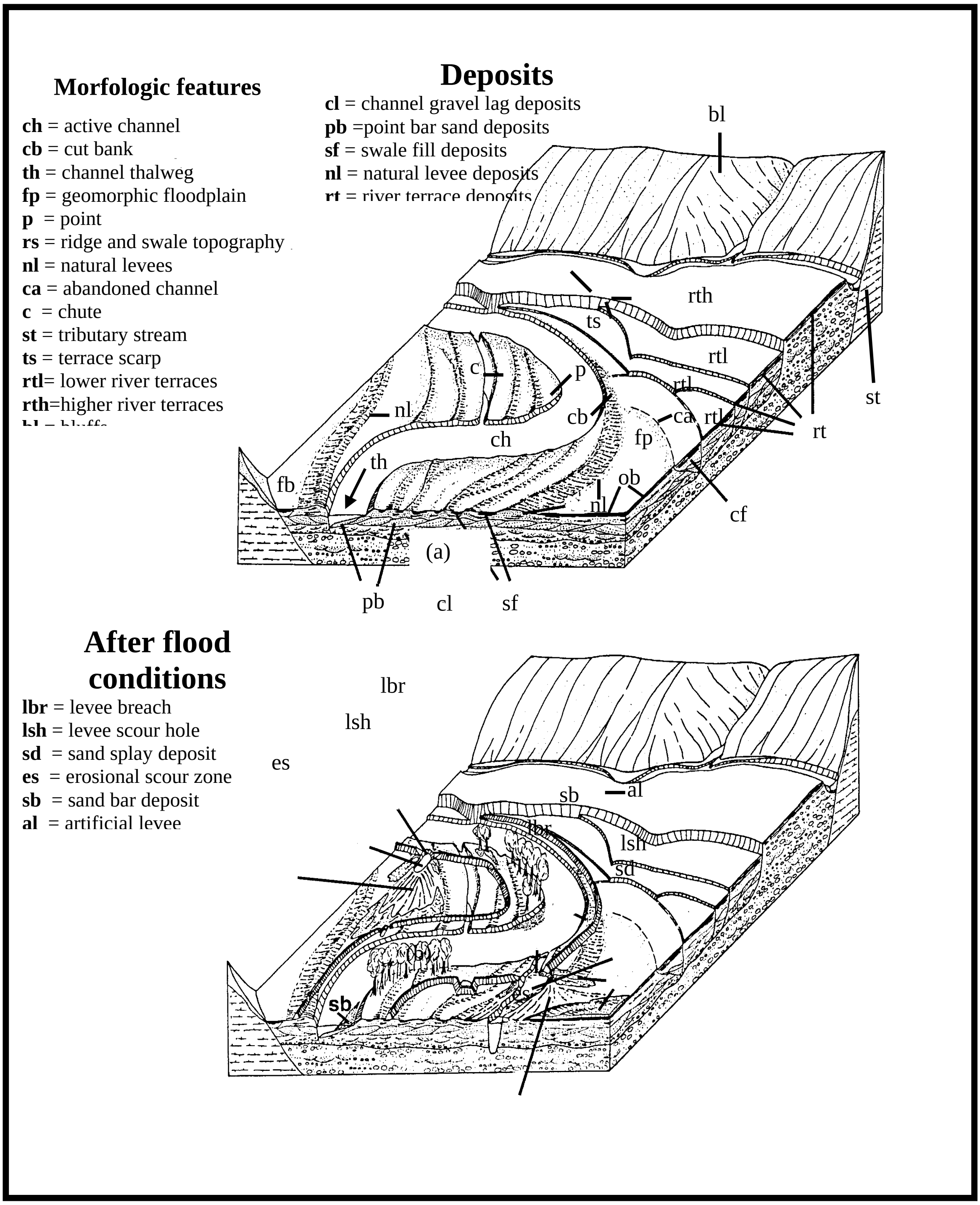

Figure 4. (a) Natural morphologic features and conceptual floodplain stratigraphy of the Missouri River, (b) after flood condition of the flood plain. During 1993 flood, the floodplain inundated bluff to bluff (SAST, 1994).

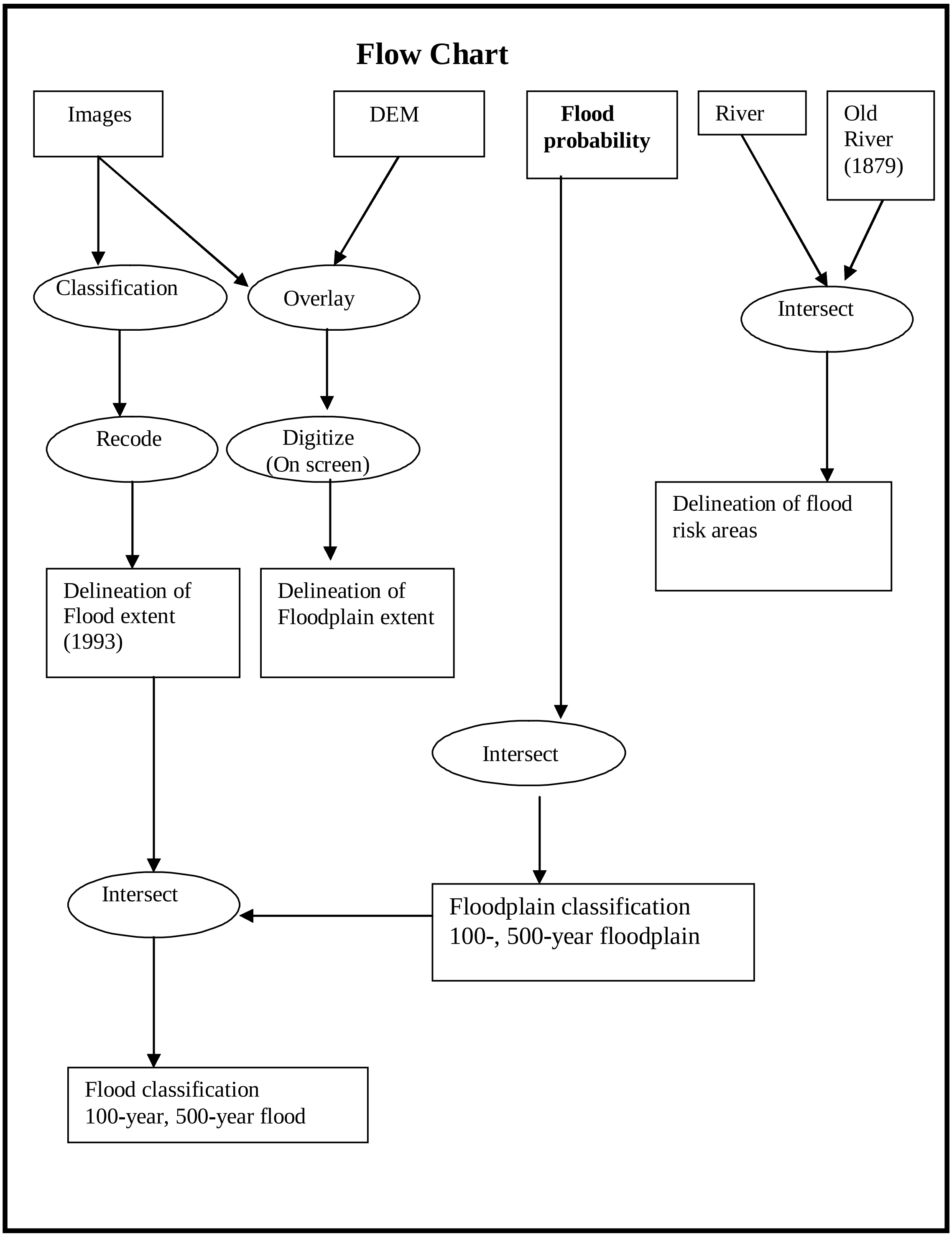

Figure 5. The steps involved in flood delineation and risk analysis using GIS

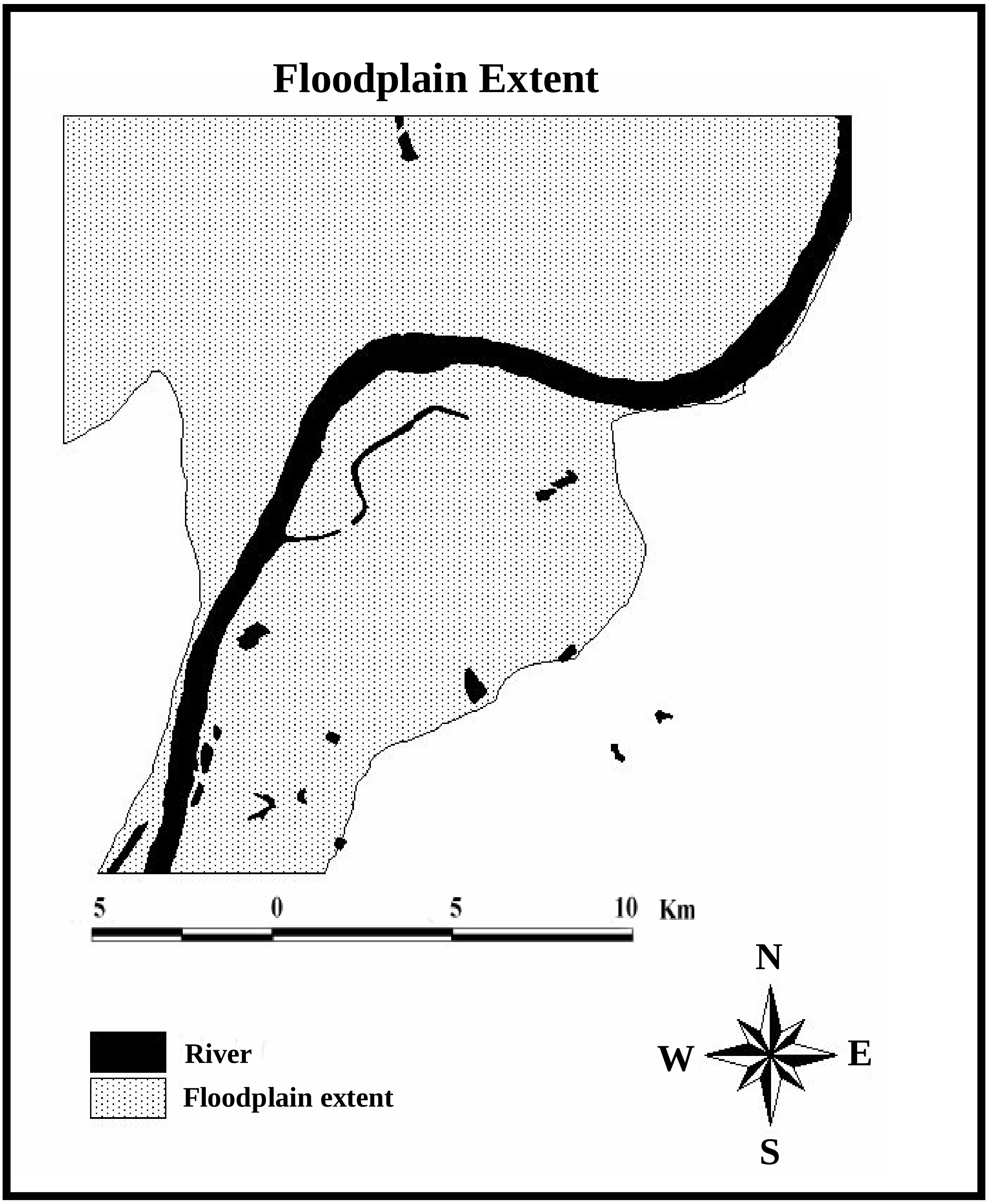

Figure 6. Extent of floodplain (Missouri River is bordered by 3 to 15 km wide floodplain).

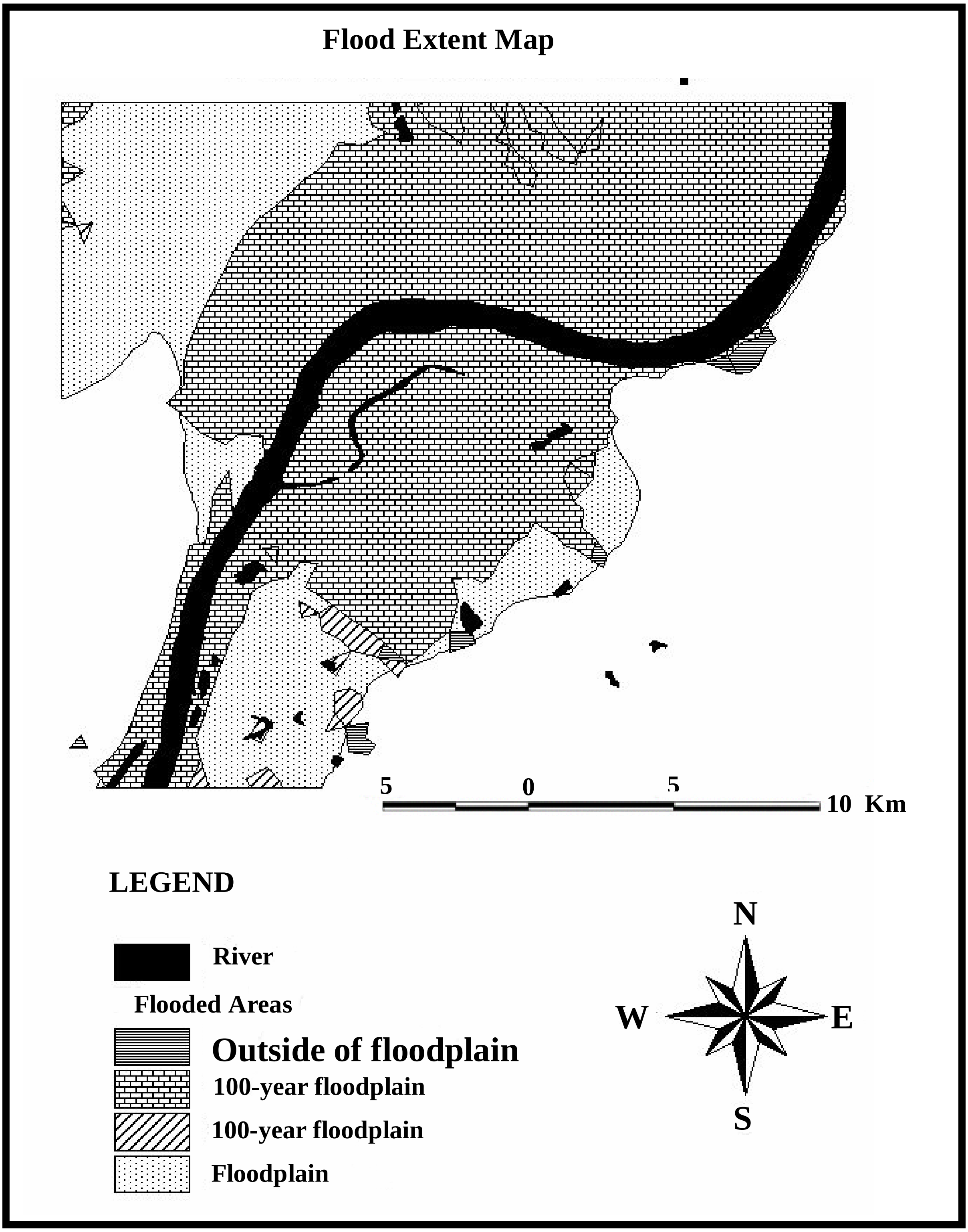

Figure 7. Flooded areas in 1993 (Flood Classification). Most of the floodplain areas were *covered by 100-year flood which caused severe damages along the river.*

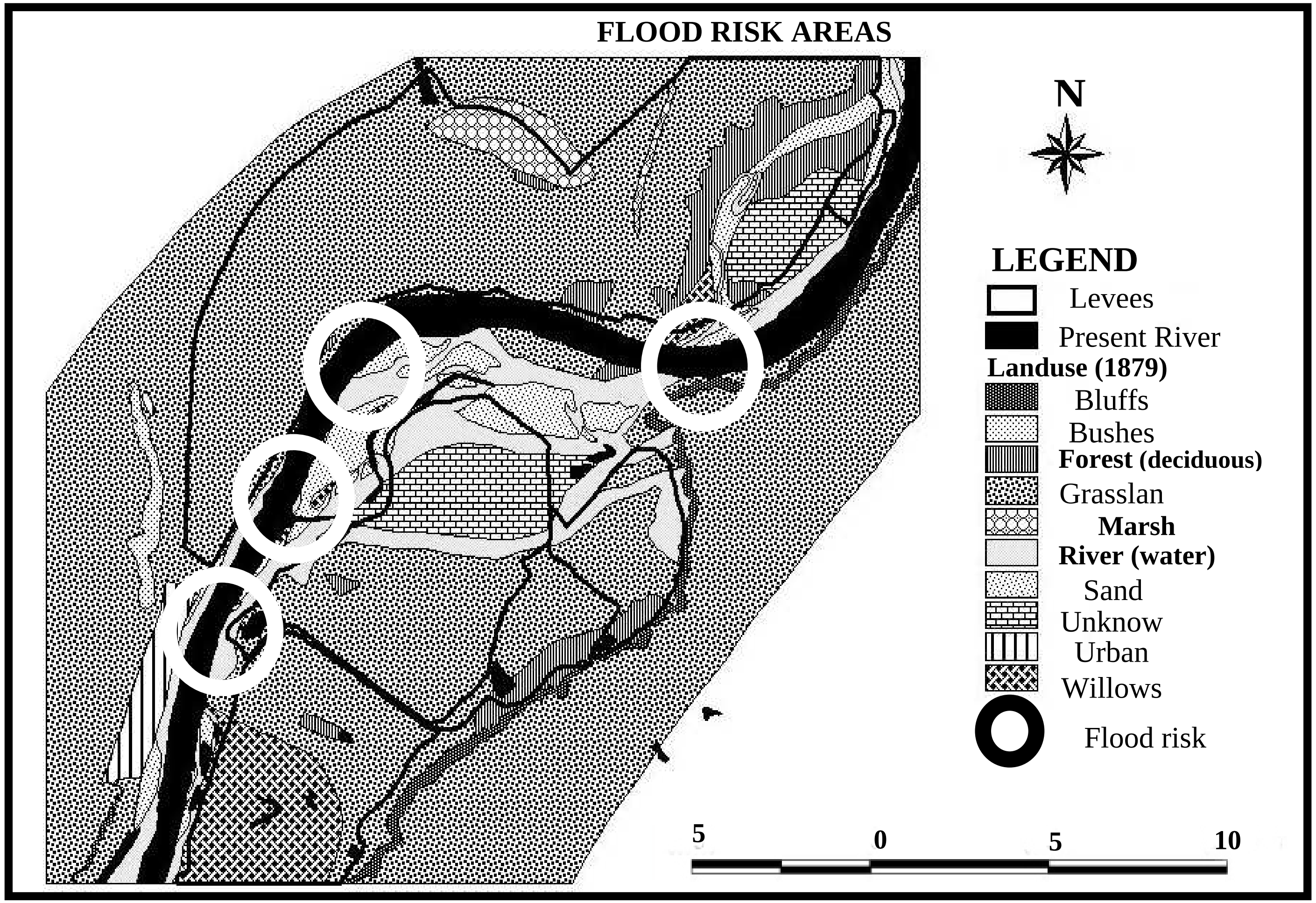

Figure 8. Flood risk areas which are located on the intersection of old and present river channels.