PROJECT COMPLETION REPORT

Identification of High-Risk Atmospheric and Surface Conditions for Urban Flash Flooding in Louisiana

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Abstract

This study identified and cataloged significant flash floods that occurred in Louisiana's main urban areas, defined and described the synoptic atmospheric environment leading to flash flooding, and compared and contrasted the atmospheric and surface conditions that develop into urban flash floods in different parts of the state. The potential for flash flood occurrence can be estimated from the number of days having daily rainfall totals of ≥ 2 inches. Actual days of occurrence of flash floods will take place on about 25% - 50% of the potential flash flood days. In general, the southernmost cities of Louisiana have a higher potential for flash flood occurrence than the northernmost cities. Spring is the season most prone to both potential and actual urban flash flooding, although fall and early winter are also flood-prone seasons throughout most of Louisiana. Urban flash flooding has increased in frequency in recent years in Monroe and Alexandria, but decreased in Lafayette.

Most urban flash floods in Louisiana occur in response to a frontal situation, supported by an upper air trough or cutoff low to the west, and frequently a squall line in association with the front. Disturbed tropical weather from tropical storms and hurricanes is also a source of flash flooding, primarily in summer and fall. The degree of soil moisture storage was found to be an important determinant of whether a potential flood would become an actual flood.

An Urban Flash Flood Geographic Information System (UFFGIS) was developed to monitor the nature of changing surface conditions in select urban basins. High-risk scenarios were used to describe the potential for future flooding in each city.

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Introduction

Flash flood "warnings" and "watches" are issued frequently in Louisiana by the National Weather Service due to the state's great potential for experiencing high-intensity, short-duration convectional precipitation events. Because of generally low relief, ample vegetative cover, and well-developed soils, many rural areas of Louisiana have the ability to accommodate most of these intense rainfall events without exhibiting excessively "flashy" streamflow regimes. The hydrographs of catchments in urbanized areas of the state, however, tend to exhibit the steep rising and falling limbs characteristic of hydrographs in more arid regions because of impervious surfaces, reduced infiltration capacity, and artificial drainage networks consisting of canals, storm sewers, culverts, and ditches. As urbanization continues, the potential for severe flash flooding in cities throughout the state will increase. This study addresses the physical origins of flash floods that have occurred in Louisiana in the past, in order to identify high-risk conditions that might cause flash flooding in the future.

Purpose and Objectives

The purpose of this study is to identify "high-risk scenarios" of both atmospheric and surface conditions that are likely to produce severe flash flooding in urban areas of Louisiana. The project has five main objectives:

1. To identify and catalog significant flash floods that have occurred in Louisiana's main urban areas over the last 30 years.

2. To define and describe the synoptic atmospheric environment and the antecedent surface conditions related to these catalogued flash floods.

3. To apply a previously developed flash flood classification scheme to Louisiana's urban flash floods, and adapt it to specific local conditions where necessary.

4. To compare and contrast the atmospheric and surface conditions that develop into urban flash floods in different parts of the state, and identify any significant geographic patterns that may be present.

5. To define and describe high-risk scenarios for the development of flash floods in Louisiana's main urban centers.

Background and Related Research

The phenomenon known as a **flash flood** has been defined in a variety of ways. Some examples are: "a local flood of relatively great volume and short duration that generally results from heavy rainfall in the immediate vicinity" (Webster's Third New International Dictionary, 1971, p. 865), or "a flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area" (Huschke, 1959, p. 224). The common elements of most definitions of flash floods are: local occurrence of the flood in small streams or tributaries, fast rise and fall of the flood hydrograph, and generation of the flood by intense, localized, convectional rainfall events. The limited areal extent and short-lived nature of flash floods make their prediction and analysis difficult using conventional meteorological and hydrological instrumentation and techniques. Recently, a useful classification scheme has been developed by R. A. Maddox and his colleagues for defining the meteorological events that generate flash floods (Maddox and Chappell, 1979; Maddox and others, 1979; Maddox and others, 1980). The diagnostic characteristics that define each category in the classification are related to local properties of temperature, moisture, instability, wind speed and wind direction at various levels in the atmosphere. Furthermore, each category is associated with a particular synoptic-scale weather pattern of both surface and upper-level circulation features. An advantage of the scheme is that it bridges small-scale and large-scale atmospheric activity, ultimately tying a local flash flood event into the broader regional pattern that is linked to large scale circulation features. The scheme was originally developed for 151 flash floods occurring throughout the United States, including a few Louisiana events, but flash floods associated with weather systems of tropical origin were purposely excluded (Maddox and others, 1979). Maddox and his colleagues subsequently expanded and refined the classification for flash floods in the western United States (Maddox and others, 1980). Other researchers have used similar approaches to classify the synoptic and mesoscale environments of heavy rainfall events, and a few of these studies have focused on Louisiana and other Gulf coastal regions, where some of the highest rainfall intensities in the nation have been experienced (e.g., Belville and Stewart, 1983; Belville and Goetsch, 1983). Based on an analysis of 70 storms, a synoptic climatology classification for heavy rainfall events in Louisiana was developed by Johnson and others (1987). This scheme, which includes elements of the Maddox approach to flash flood classification, was used in this project as the basic framework to describe the primary atmospheric circulation patterns that cause flash flooding in Louisiana's urban areas.

In addition to the atmospheric input that generates a flash flood, antecedent surface conditions are of great importance in dictating the magnitude and severity of a flood event. The important control of impervious surface conditions on runoff in urbanized areas has contributed to the need for a special focus on urban hydrology and hydrometeorology. Such an approach seeks to analyze the changing streamflow regimes brought about by the gradual or rapid transformation of predominantly undisturbed rural catchments to areas undergoing development (Leopold, 1968; Smith, 1969; Hall, 1984; Huff, 1986). For years, municipal and state agencies have been using standard design techniques, such as the Soil Conservation Service (SCS) Runoff Curve Number method (Soil Conservation Service, 1986), to determine peak flows for design purposes in small urban catchments (<2000 acres) by taking into consideration the infiltration rates of different soil types, as well as the type of surface cover, cultivation practice, and percent of impervious areas. For larger drainage areas, the rainfall-runoff response is better represented by a model that accounts for changing soil moisture conditions prior to and during a rainfall event, in addition to the land use characteristics of the basin. Examples of such models are the Stanford Watershed Model (Crawford and Linsley, 1966), the U.S. Geological Survey Rainfall-Runoff Model (Dawdy and others, 1972), and the Distributed Rainfall-Runoff Routing Model (Dawdy and others, 1978).

Whatever method is used to evaluate the problem of peak flow events and flash flooding in urban areas, the basic components of the analysis are: (a) the **atmospheric input** of precipitation, and (b) the **antecedent surface and soil moisture conditions** of the catchment.

Atmospheric Input

Currently, the precipitation input that is used most widely in standard hydrologic procedures is the selection of a "design storm" of a given magnitude from the Rainfall Frequency Atlas of Hershfield (1961), commonly referred to as U.S. Weather Bureau Technical Paper No. 40. More recent publications have provided insights into precipitation frequency patterns in the eastern and central United States (Frederick and others, 1977), but few attempts have been made to link these design storms with the actual synoptic patterns and circulation features that can produce these magnitudes of precipitation. By examining data and maps from the actual meteorological processes that produce flash floods, a better understanding can be obtained of the physical factors that result in design storms of different magnitudes and frequencies.

Antecedent Surface and Soil Moisture Conditions

Some recent studies have addressed changing land use patterns and runoff in an urban catchment in Louisiana -- Ward Creek, in Baton Rouge (Izadjoo, 1985; Baker, 1987) -- but a systematic analysis of land use and runoff has not been undertaken in most of the urban areas in Louisiana. This study provides the groundwork for a systematic inventory of land use change in selected urban catchments across the state in order to assess the impact of varying surface conditions on future urban flash flooding.

In addition to land use, the infiltration capacity of the underlying soil is an important component of an urban catchment's potential for flooding. This study presents information on the drainage characteristics of the soils in representative urban catchments throughout the state and also addresses the role of antecedent soil moisture conditions on the occurrence of flash flooding. Antecedent soil moisture conditions have been treated in runoff models in a variety of ways (Crawford and Linsley, 1966; Dawdy and others, 1972; Dawdy and others, 1978), some of which require extensive model calibration or additional data. The climatic water budget model developed by C.W. Thornthwaite (Thornthwaite and Mather, 1955) provides a simple algorithm that uses daily or monthly precipitation and temperature data to account for additions and withdrawals of water from soil moisture storage. The model has been applied to the evaluation of streamflow variations (Mather, 1979; Muller, 1982) and it is an effective index of varying soil moisture conditions that can be easily computed with readily available climatic data. In this study, the climatic water balance proved to be effective as an indicator of the antecedent soil moisture conditions in urban catchments prior to flash flood events.

Methods and Procedures

The research for this project was conducted in six separate phases of analysis, or tasks, that correspond roughly to different aspects of the project's five main objectives. The original plan was to conduct these analyses in exactly the same manner for each of the seven main urban areas of Louisiana, however, equivalent data were not always available in each city, and some of the more time-consuming data collection procedures could not be completed for all the cities without a major investment of additional effort after the project period ended. A compromise was reached by selecting a geographically representative subset of three cities for detailed analysis that could be used to enhance the limited information obtained from all seven of the cities. Due to the city of New Orleans' unique artificial drainage and pump infrastructure, the flash flooding problem in that city was treated as a special case. Following is a synopsis of the procedures and analyses conducted in each phase of the study.

Phase 1: Flash Flood Catalog

The objective of this first phase of research was to identify and catalog significant flash floods that have occurred in Louisiana's main urban areas over the last 30-35 years. The time period 1950-1985 was chosen as the base period, because most (but not all) data sources were consistently available for this period. Due to the short-lived and localized nature of flash flood events, this essential first phase of the project proved to be one of the most difficult tasks to accomplish. The lack of agreement on the definition of a "flash flood" made a systematic tabulation of these events difficult. While gaged streamflow records provide an excellent source of information on the frequency and magnitude of flooding in medium to large drainage areas, these records are less likely to reveal information about the more localized flooding in streets, drainage canals, and small urban streams that has come to be known as "urban flash flooding." Many of the small urban basins that are experience such flooding are ungaged. Gaged precipitation records can be used to augment discharge records in ungaged areas, but because of some of the circumstances discussed below, the precipitation record alone is not the best indicator of whether or not a flash flood has occurred. To compile the flash flood catalog for this study, it therefore was necessary to use several different approaches -- individually, and in combination -- to identify the most "significant" urban flash floods.

Gaged Stream Discharge Records. A compilation was made of gaged streams that drain the project's urban areas. Many of these had drainage areas greater than 1000 square miles. After a review of their flood records it was determined that streams of this size had hydrographs that were more responsive to large-scale regional precipitation events than to localized intense rainfall. A few smaller urban basins were identified, but many of these had very short or discontinued gaged records and could not be used to catalog the occurrence of flash floods in any systematic fashion. It was decided that the gaged streamflow record would be of limited value as the sole source for the compilation of the flash flood catalog, but that it would be an important indicator of larger scale precipitation and flooding events, during which localized flash flooding often occurs.

Storm Data Publications. Descriptions of storms, death, injury, and damage statistics are listed chronologically by state in a monthly publication of the National Oceanic and Atmospheric Administration (NOAA) entitled Storm Data. A tabulation was made of the occurrence of local flash floods and regional floods in Louisiana during the years covered by this monthly publication (1959-present; 1973-1978 were missing). The corresponding hourly precipitation records for these events were also compiled and selected storm events were plotted in hyetographs to show the temporal distribution of rainfall. The Storm Data records yielded information on 138 flood events that occurred from 1959-1972 and 1979-1987. Whether or not a storm or flood event is listed in Storm Data depends in part on the severity of the event and the reliability and consistency of local reporting of the event to the National Weather Service. This tabulation formed the core of the flash flood catalog, but it was believed that many more significant urban flash flood events had occurred without being reported in Storm Data. Data for years during which the publication was not available also needed to be compiled in some systematic way, hence other approaches to compiling the flood catalog were investigated.

Flood Insurance Studies. As part of the National Flood Insurance Program (NFIP), flood insurance studies have been conducted in the major cities of Louisiana. Because these studies focus on urban areas specifically, it was thought that these might be an additional source of information about urban flash flooding. Each of the studies included a section on major storms and urban floods of the past, but often only the year of the flood (not month or day) was given and the lists were limited to only about 10 of the most significant floods occurring in the 20th century. Although the studies were not particularly useful for providing any additional information to the catalog of urban flash floods, they did provide a good discussion of the principal flooding problems in each city, as well as a description of flood protection measures that had been completed in various urban channels. The studies also included computed 10-, 50-, 100-, and 500-year peak discharges (or flood elevations) and flood profiles for the major drainages in the city.

Tabulation of Daily Rainfall Totals. The most comprehensive and consistent source of information about the *potential* for flash flooding in each of the cities was obtained by a tabulation of daily rainfall totals greater than or equal to 2 inches (see **Appendix A**). Although many of the known flash floods were generated by daily rainfalls much greater than 2 inches, the 2 inch cutoff was chosen to select a large enough subset of days on which floods may have occurred under varying antecedent moisture conditions. As will be discussed below, the occurrence of a 2 inch or greater daily rainfall is no guarantee that a flash flood took place on that day, but the compilation of these days provides the best indicator of the times when a flash flood may have been experienced in each of the various cities. This tabulation was then used with information found in newspapers and other sources to determine whether or not a flash flood was actually observed on these days (see the following section).

Systematic Newspaper Documentation. Accounts of urban flooding found in the local newspapers turned out to be some of the best sources of information for development of the flash flood catalog. Using the tabulation of daily rainfall totals described above, the daily newspapers at times of heavy (≥ 2 inch) rainfall were examined to see if there were reports of any local flooding associated with the rainfall. Because of the time-consuming nature of this type of research, a geographically representative subset of cities was used for this phase of the analysis. The cities and corresponding newspapers examined were: Monroe (News Star World), Alexandria (Daily Town Talk), and Lafayette (The Daily Advertiser). Based on the newspaper accounts, the following items of information were collected for each of the days listed in the daily rainfall tabulation: whether or not any flooding occurred; if flooding did occur, whether it was moderate or severe; if flooding did occur, whether it was street flooding only or whether it also included flooding due to backwater effects and overbank inundation from nearby rivers; and, if flooding did occur, whether or not there were any other additional items of interest about the flood. From this systematic documentation of reported flood events, a time series plot of flash flood occurrence from 1950-1985 was produced for each city. These time series formed the basis for a temporal analysis of flash flood variability at each location, as well as a spatial analysis of variations in flash flood occurrence across the state.

From these varied approaches to developing the flash flood catalog, the final catalog developed in Phase 1 consists of the following: (1) an **overview of the flash flooding hazard** in each city, compiled from several sources; (2) a comprehensive listing of **potential flash flood events** for each city, based on the tabulation of heavy rainfall days; and (3) a detailed listing of **documented**

flash flood events for the cities of Monroe, Alexandria, and Lafayette, based on the tabulation of heavy rainfall days and supported by newspaper documentation.

Phase 2: Synoptic Climatology Classification of Flash Floods

In Phase 2 of the project, the synoptic atmospheric circulation patterns that typically result in urban flash flooding in Louisiana were identified. This was accomplished by systematically analyzing the sequences of daily weather map patterns occurring prior to, and during, the flood events catalogued in Phase 1. The flood-producing weather patterns were categorized on the basis of signature patterns emerging from characteristic combinations of the following key features: surface fronts, squall lines, surface and upper-level wind flow and advection, air and dewpoint temperatures, short- and long-wave 500 mb level troughs, and tropical disturbances. Due to the large number of events that were studied, weather maps from the readily available publication <u>Daily Weather Maps - Weekly Series</u> were used to identify key patterns. In a few cases, more detailed analyses based on National Meteorological Center (NMC) surface charts and standard upper level charts were reviewed when available. The general framework for the synoptic climatology classification of flash floods used in this project was based on the scheme developed for heavy rainfall events in Louisiana by Johnson and others (1987) and the flash flood categories of R.A. Maddox (Maddox and Chappell, 1978; Maddox et al., 1979, 1980). The synoptic patterns and mesoscale environments in these classification schemes were originally defined on the basis of detailed NMC analysis charts, but the "signature" patterns observed on the daily weather maps series used in this project were generally sufficient to assign a flash flood event to one of these predefined synoptic categories. These categories and the types of flash flood events assigned to them are discussed below under "Principal Findings."

Phase 3: Documentation of Surface Conditions in Selected Urban Catchments

The aim of this phase of the project was to evaluate the surface conditions of typical urban catchments in Louisiana in order to assess the relative contribution that factors such as vegetation cover, percent of pervious and impervious surfaces, and soil type might have on the development and occurrence of urban flash flooding in the state. Initially the intent was to evaluate these surface features over different time periods using National High Altitude Photographs (NHAP), but the amount of time expended in digitizing, compilation, and analysis of the base maps alone precluded any extensive study of other time periods. The mapping efforts of the project culminated in an "Urban Flash Flood Geographic Information System" (UFFGIS) which consists of a series of base maps and corresponding information "levels" for selected urban catchments in Louisiana. Maps developed from this GIS were used in the project to explain some of the geographic variations in the urban flash flooding problem at different locations and to provide the real-world basis for various flooding scenarios developed in Phase 6.

Table 1. Basins Selected for Urban Flash Flood Study

CITY	BASIN	AREA (sq km)	PREDOMINANT GEOLOGIC UNITS[1]
Shreveport	Brush Bayou	81.8	Wilcox Group
Monroe	Youngs Bayou	60.9	Natural levees & recent alluvium
Alexandria	Hynson Bayou	28.0	Natural levees & recent alluvium
Lake Charles	Bayou Contraband	35.4	Prairie Terrace
Lafayette	Coulee Mine	60.6	Prairie Terrace
Baton Rouge	Bayou Fountain	105.2	Natural levees & recent alluvium
Baton Rouge	Ward Creek	49.4	Prairie Terrace

[1] Units based on Geologic Map of Louisiana (Louisiana Geological Survey, 1984)

<u>Selection of Representative Urban Catchments</u>. Seven drainage basins (Table 1) were selected for analysis in this phase of the project, based on the following criteria: (a) the basin had to be located in one of the seven largest cities in Louisiana; (b) the basin had to be in the process of being urbanized, i.e. basins entirely urban or entirely rural were rejected; (c) the basin had to be situated in a geologic and geomorphic setting that was typical of the area, usually either a Pleistocene terrace or the Holocene floodplain; and (d) the basin had to have a small enough drainage area to be responsive to typical flash flood conditions and exhibit a flashy hydrograph in response to heavy rainfall (generally less than 100 sq km (38.6 sq mi). Given these criteria, seven basins were selected in six cities. A New Orleans basin was not selected because the Soil Conservation Service (SCS) soil survey was not yet available for this area and we were unable to acquire preliminary results for base map data. An additional Baton Rouge basin was selected as a replacement.

Development of Urban Flash Flood Geographic Information System. To map and analyze the surface and land cover conditions in the selected urban catchments, an Urban Flash Flood Geographic Information System (UFFGIS) was created using the Intergraph Mapper program at Louisiana State University's Computer Aided Design and Geographic Information Systems (CADGIS) Laboratory. The UFFGIS consists of a series of digitized maps and data sets that can be combined and analyzed to provide various kinds of spatial information about each of the selected urban catchments. A large proportion of project time was spent in developing the base maps of the UFFGIS and setting up information "levels" containing data on drainage channels, basin boundaries, soils, and land use (see Figure 1). Preliminary land use information was mapped at the end of the project period, but time did not allow additional information on changing land use to be digitized into the system from 1:24,000 black and white High Altitude Photos (HAP). Future projects using the UFFGIS will be able to address land use changes specifically with the HAP coverage that has been obtained and is on file (see **Appendix B**).

U.S. Geological Survey 7½" polyconic topographic maps were digitized to create base maps of drainage channels and watershed boundaries for the UFFGIS. The watershed boundaries were interpolated from the topographic maps and digitized. Natural topographic divides were used where they could be determined, but artificial drainage and artificially altered watershed boundaries complicated the determination of a divide in several instances. In areas where there were constructed levees, the watershed boundary was mapped along the appropriate levee crest. For example, the western boundary of the Bayou Fountain watershed in Baton Rouge was mapped at the crest of the Mississippi River levee. The boundaries of Contraband Bayou watershed in Lake Charles were particularly difficult to map because of many artificial canals and deranged drainage. The certainty of its boundaries is not as good as those in the other study areas.

Soil Conservation Service (SCS) soil surveys were used to produce the soils data base in the UFFGIS. To determine a given watershed's susceptibility to flooding, the *hydrologic properties* of the soil units in the catchment had to be determined and mapped. Groups of soil units having similar hydrologic properties were defined based on SCS criteria and aggregated into one of four hydrologic soil groups (A, B, C, or D). The boundaries of the hydrologic soil groups were then digitized into a soils base map for each watershed.

To map and analyze the combined drainage and soils information, the drainage and soils base maps were merged into a universal transverse mercator map. Intergraph's Graphic Polygon Processing Utility (GPPU) was used to complex the boundaries of different soils and drainage units into polygons, and Polygon Attribute Crosshatching (PAX) was used to produce finished maps of each basin. To determine the amount of area contained in different groups of polygons, the AREA function of GPPU was used. Total area, percent area of each group in each basin, and total polygon perimeter in each basin were determined. In order to evaluate the simplicity or complexity of drainage and soils polygons within a basin, an Index of Simplicity was calculated for each basin by dividing the total area of the basin by the total length of the perimeters of all polygons contained within the basin. This index gives a measure of the degree of interfingering of polygons and the degree to which the area is divided into small polygons (i.e. the lower the Index of Simplicity, the greater the complexity of polygons within the basin).

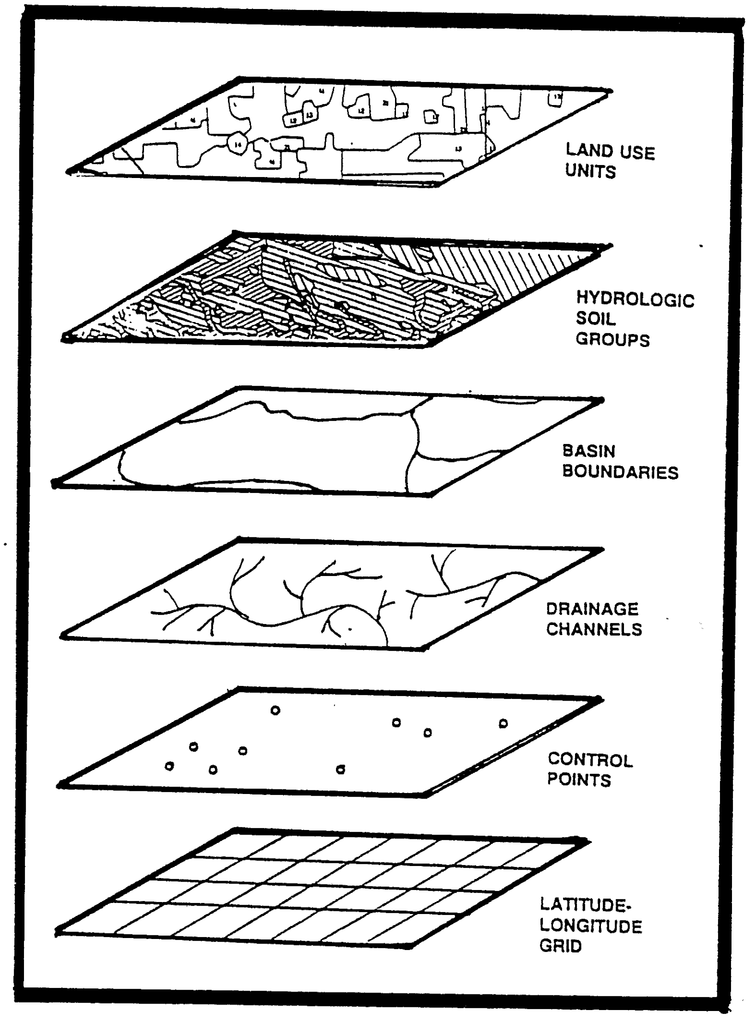


Figure 1. Schematic Representation of the Urban Flash Flood Geographic Information System (UFFGIS)

Land use data were obtained in digital form from a 1978 U.S. Geological Survey Land Use data base on file at the CADGIS Laboratory. The land use and land cover classification system in this data base is described in detail in Anderson and others (1976). Land use data files were attached as reference files to the UFFGIS and the boundaries of the watersheds were plotted on the land use base maps, however no further analysis of land use polygons was completed in this phase of the project.

The results of the mapping and analyses completed in the development of the UFFGIS are presented in a later section, under Principal Findings.

Phase 4: Assessment of Antecedent Soil Moisture Conditions

This phase of the project involved the study of soil moisture conditions prior to, and during, the occurrence of known urban flash flood events. The UFFGIS mapping in Phase 3 of the project was able to show the relative abundance and *spatial* variability of poorly drained and easily saturated soils in many of Louisiana's urban areas, however the purpose of this phase of the project was to identify the *temporal* variability of saturated soil conditions as a factor in flash flood occurrence. In particular, we wanted to test the hypothesis that -- even in urban areas characterized by large amounts of impervious surfaces -- the degree of saturation of the soil prior to a given rainfall event is an important determinant of whether the rainfall will result in a flash flood.

Antecedent soil moisture conditions have been determined in a variety of ways in hydrologic practice, some of which require extensive model calibration and data collection in the field. For the purposes of this project, the climatic water budget model of C.W. Thornthwaite (Thornthwaite and Mather, 1955) was used to determine daily variations in soil moisture. This model is based on an algorithm that uses daily or monthly precipitation and temperature data, along with computed potential evapotranspiration values, to account for additions and withdrawals of water from soil moisture storage. The model has been applied to the evaluation of streamflow variations (Mather, 1979; Muller, 1982) and it is an effective index of varying soil moisture conditions that can be easily computed with readily available climatic data.

Daily water budgets for agricultural experimental stations in Louisiana have been computed on a near real-time basis by the Louisiana Office of State Climatology (LOSC) for Shreveport (Red River Station), Alexandria (Dean Lee Station), Lake Charles, Baton Rouge (Ben Hur Station), and Citrus Station (Plaquemines Parish) since about 1982 for most stations. The daily soil moisture storage parameter, computed and graphed for these stations, was used to evaluate regional and temporal patterns of soil moisture storage across Louisiana for Phase 5 of the study. Additional daily water budgets were computed for Monroe and Lafayette and used in conjunction with the lists of documented urban flash floods (Phase 1) to examine the influence of antecedent soil moisture storage on the occurrence of flash flooding in these cities. Procedures and computer programs used to compute the daily water budgets are outlined in McCabe and others (1985).

Phase 5: Spatial and Temporal Analysis of Documented Urban Flash Floods

In this phase of the project, the spatial and temporal patterns of average and extreme rainfall events, soil moisture storage variability, and documented flash floods (obtained from Phases 1 through

4) were compared with "Technical Paper No. 40" (TP-40) intensity-duration-frequency (IDF) maps of precipitation (Hershfield, 1961) for Louisiana. These IDF maps are widely used to determine "design storms" for input into many standard hydrologic procedures. The purpose of this phase of analysis was to see if the information obtained in the project on heavy rainfalls and flash flooding, and their associated synoptic circulation patterns, would provide some physical explanations for the regional patterns and gradients depicted on standard Louisiana IDF maps. Plots were made of both mean monthly precipitation and the monthly frequency of rainfall events of different size at each of the seven urban stations. These were used to identify any broad regional patterns in how rainfall was spatially and seasonally distributed across the state. These patterns were then compared with the regional rainfall frequency patterns on the IDF maps. Case studies of the synoptic circulation patterns associated with known storms were used to provide plausible physical explanations for the spatial patterns observed on the various graphs and maps.

Phase 6: Specification of High-Risk Scenarios

The final phase of the project involved the synthesis of key findings from each of the previous phases to develop high-risk scenarios for the generation of flash floods in each of the state's major cities. Scenarios provide useful "as if" statements about possible future real world situations. Typically, they attempt "to set up a logical sequence of events in order to ask how, starting from a given condition, alternative possibilities....might evolve." (Ericksen, 1975, p. 11) While scenarios do not set out specifically to test hypotheses, they attempt to examine what might happen if a given hypothesis were true. Scenarios are developed from a base of real data which is then varied in imaginatively different, but logically consistent, ways (Polak, 1971). The scenarios developed for Phase 6 of the project were based on the kinds of physical processes and conditions that might logically occur in the representative urban catchments, using both documented land use/land cover conditions, and hypothetical future land use/land cover conditions. They were produced by combining information obtained in each of the previous phases of the project into different types of hypothetical flooding events in each city.

Principal Findings

This project approaches the problem of urban flash flooding from a process-based perspective. Its main focus is on how the natural processes of precipitation (P), infiltration (I), evapotranspiration (E), and runoff (Q) tend to operate in the urban environments of Louisiana. As Figure 2 illustrates, the pathways of water through these different processes tend to be far more complex in urban settings than in rural areas. Only the shaded boxes in the urban hydrologic cycle diagram are addressed in this study.

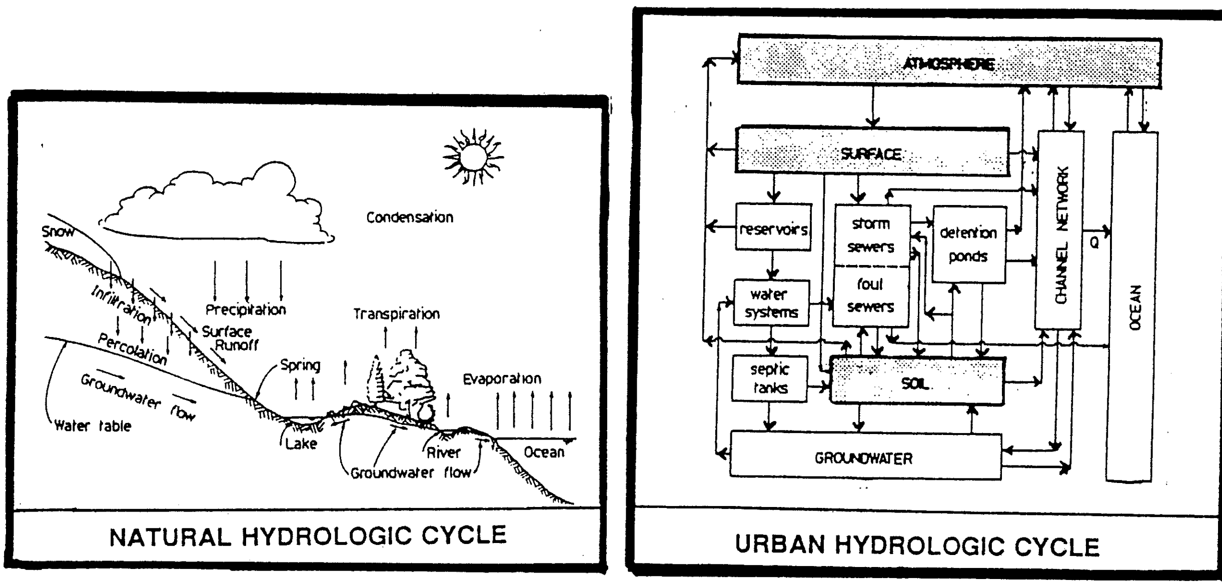


Figure 2. Natural vs. Urban Hydrologic Cycles (modified from Hall, 1984)

Within engineering circles, much work has been done on the modeling of the flow of stormwater through urban catchments, primarily for design purposes. In practice, the shaded boxes in Figure 2 usually are modeled, estimated, or abstracted based on design storms, curve numbers, empirical formulas, synthetic data, or some other standard method.

This project approaches the atmospheric, surface, and soil processes of the urban hydrologic cycle from a slightly different perspective by addressing the following questions: How do atmospheric inputs to the urban hydrologic cycle in Louisiana vary in space and time, both seasonally and interannually? What is the large-scale synoptic atmospheric environment that produces such variations? How do the surface conditions of soil and land cover in representative urban basins vary both spatially and temporally, and how might these variations affect infiltration? How does natural climatic variability influence soil moisture storage and what influence does soil moisture content have on runoff in an urban setting? And finally, how do these various processes manifest themselves in the occurrence of urban flash flooding in different parts of the state? The answers to these questions will provide a broader context for the urban flooding problem in Louisiana. The principal findings of this project are summarized below under the general headings of: **(1) spatial and temporal variability of the potential for urban flash flooding in Louisiana, (2) the synoptic atmospheric environment of urban flash flooding in Louisiana,** and **(3) land cover and soil factors that enhance urban flash flooding in Louisiana.** The conclusions of the study will be presented in the context of high-risk scenarios for urban flash flooding in Louisiana.

Spatial and Temporal Variability of the Potential for Urban Flash Flooding in Louisiana

The locations of Louisiana's seven main urban areas (New Orleans, Baton Rouge, Shreveport, Lafayette, Lake Charles, Monroe, and Alexandria) provide a good spatial representation for examining the urban flooding problems in different parts of the state. Flooding can result anywhere in Louisiana when one or more of the following occur: (1) *headwater flooding*, from high intensity and/or long duration precipitation in the headwater regions of a basin; (2) *backwater flooding*, from flood water that is retarded, backed up, or reversed in its course by an obstruction, an opposing current, or rising water; and (3) *riverine flooding*, from flood water that overtops the banks or levees of major rivers.

Flash flooding usually occurs as headwater flooding from high intensity precipitation in small drainage basins. It is especially likely to occur in urban settings which have large amounts of impervious surface area, because the capacity for natural storage and infiltration of precipitation is reduced, and flood water is conveyed directly into channels, canals, drainage ditches or streets. With the same input of precipitation, an urban basin will generally experience a greater peak discharge, a shorter time to peak discharge, and a greater total runoff volume than a rural basin of equal size (Figure 3). Backwater effects may also play a role in urban flash flooding, especially when drainage networks are insufficient to convey large amounts of surface runoff during high intensity precipitation events. In basins of low relief and when drainage ditches are inadequate or obstructed, backwater flooding may develop quickly enough to be considered "flash" flooding.

Potential and Documented Flash Flood Events. The history of urban flash flooding in a given area is extremely difficult to document in any systematic way because it occurs on such localized spatial scales and short temporal scales. Techniques for systematic data collection used on

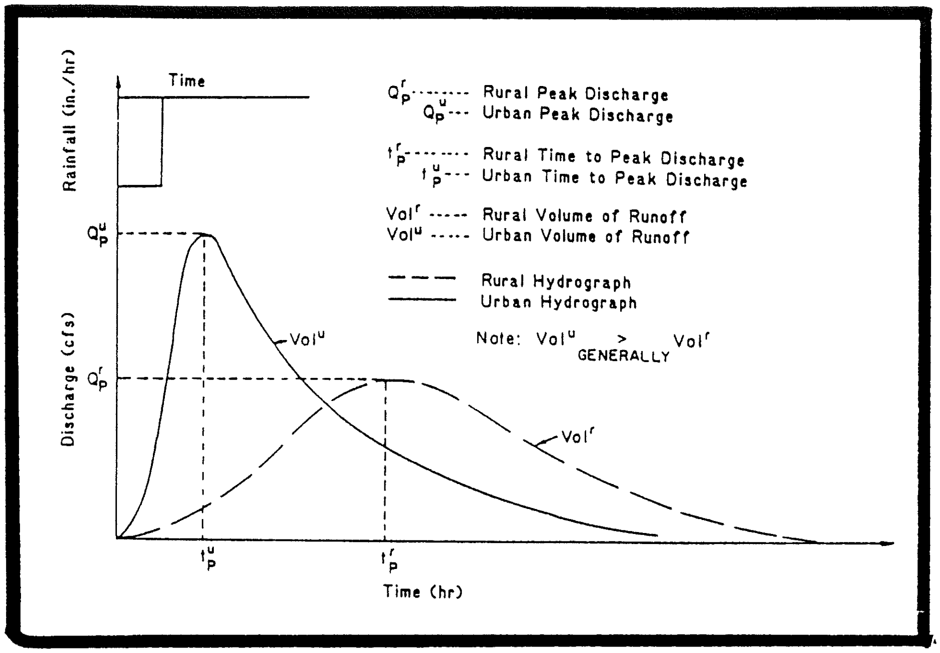


Figure 3. **Urban vs. Rural Basin Response to the Same Precipitation Input** (from Kibler, 1982)

larger streams, such as stream gaging, are not cost effective in small urban watersheds. As discussed earlier, for this study various methods were employed to compile a catalog of flash floods for each of the seven main urban areas of Louisiana. The results of this compilation include a comprehensive listing of **potential flash flood** events for each city, based on a tabulation of heavy rainfall days, and a specific listing of **documented flash flood events** for the cities of Monroe, Alexandria, and Lafayette, based on the tabulation of heavy rainfall days, supported by newspaper documentation. The potential flash flood listing (**Appendix** A) includes all those days having rainfall totals that equalled or exceeded 2 inches. These days provide the best indicator of the times when a flash flood may have been experienced in each of the various cities.

The relationship between *potential* and *actual* flash flood events was examined by comparing the monthly frequencies of potential flash flood days with the monthly frequencies of documented flash floods days -- over the same time period -- in the cities of Monroe, Alexandria, and Lafayette (Figures 4 through 6). For each of these locations, plots were made of the number of days in each month, during the period 1950-1985, having precipitation totals over 1.99" (≥ 2"), over 2.99" (≥ 3"), over 3.99" (≥ 4"), and over 4.99" (≥ 5"). A separate plot was then made of days on which urban flooding occurred at each location, based on newspaper reports. In the precipitation plots, the seasonality of heavy rainfall occurrence is most evident on the graphs of rain days over 1.99" and

2.99". The frequency of rain days over 3.99" and 4.99" is generally too low to identify any distinct seasonal patterns. The seasonal pattern of days over 1.99" appears to be the best predictor of the seasonal pattern of documented flash flood days, even though there are at least twice as many potential flood days as there are documented flood days.

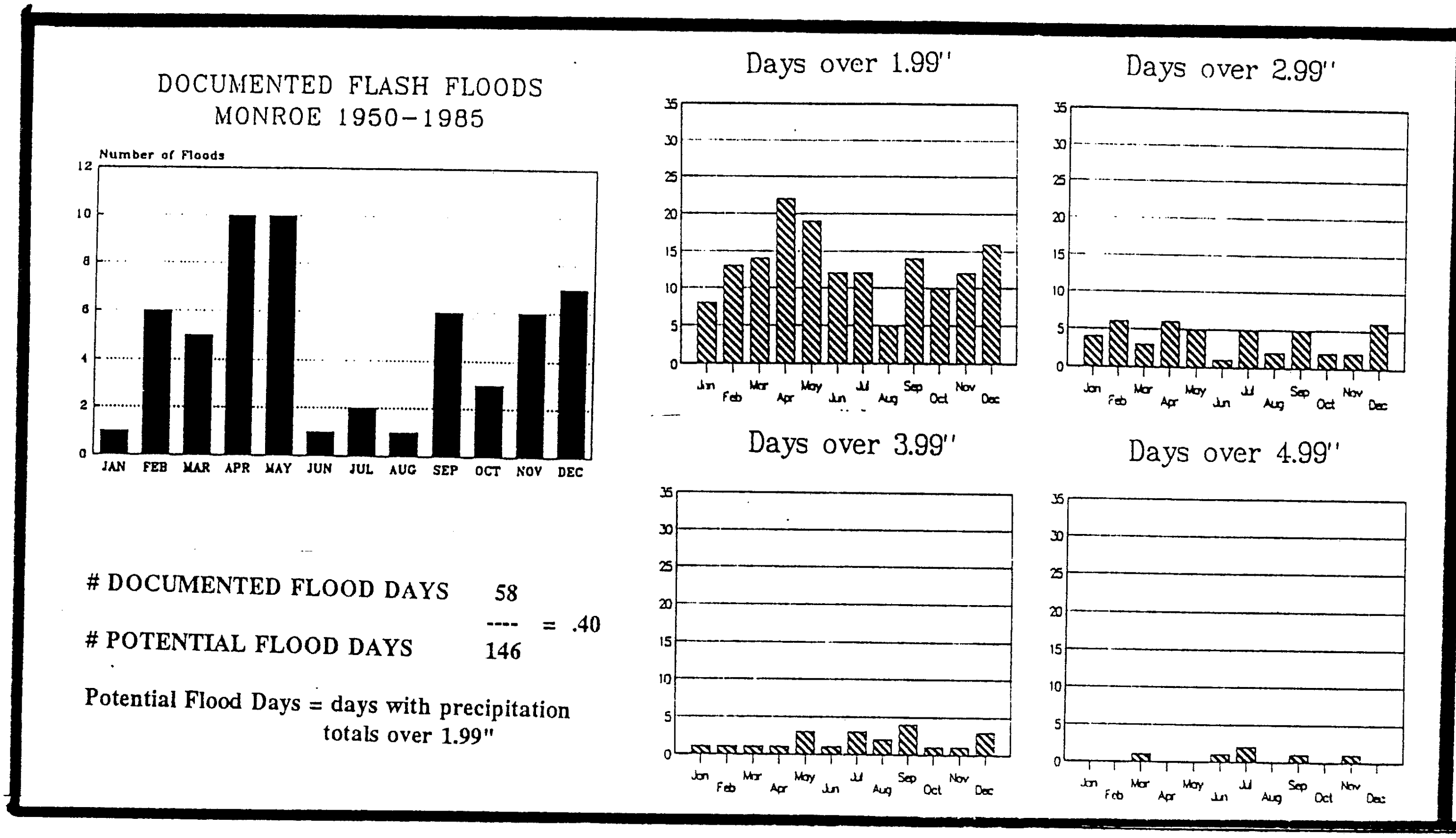


Figure 4. Monthly Frequency of Documented Flash Flood Days and Days with Precipitation ≥ 2, 3, 4, and 5 Inches -- Monroe (1950-1985)

At Monroe, (Figure 4), late spring (April and May) is the season with the most flash floods and the greatest number of heavy rainfall days, with secondary peaks occurring in September, November-December, and February. During these months, 40-50% of the rain days over 1.99" were associated with flash floods. During the low flooding months of June through August and January, less than 20% of the rain days over 1.99" experienced flooding. The annual ratio of documented flash flood days to potential flash flood days was 58/146 or 40%.

At Alexandria (Figure 5) flash floods are most frequent throughout spring (February through May), in fall (September and October), and in December. In spring, 50-60% of the rain days over 1.99" experienced flooding, and in fall and in December, 35-50% of the potential flood days

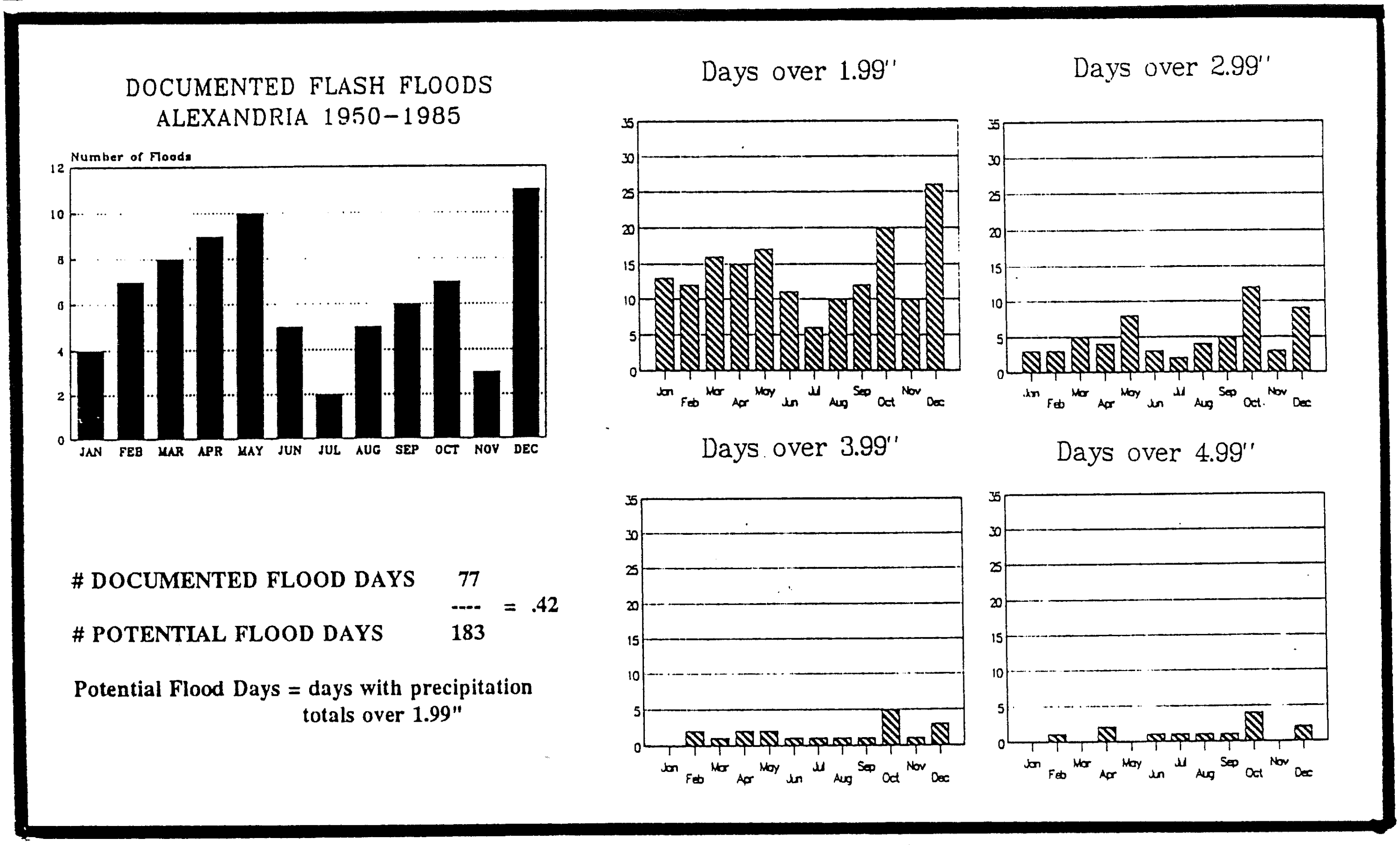


Figure 5. **Monthly Frequency of Documented Flash Flood Days and Days with Precipitation ≥ 2, 3, 4, and 5 Inches -- Alexandria (1950-1985)**

experienced floods. During the summer months, and during November and January, fewer documented flash floods occurred, but the number of potential flood days also tended to be lower, hence the ratio of actual to potential floods stayed in the 30-50% range. The annual ratio of documented to potential flood days at Alexandria was 77/183 or 42%.

At Lafayette, (Figure 6), twice as many documented flash floods occur in April than in any other month, and November and January experience the least flooding. More potential flash flood days occur at Lafayette in nearly all months than at the other two cities, however, the spring/fall seasonality of documented floods seen at Monroe and Alexandria is not as evident at Lafayette. Furthermore, the monthly frequencies of Lafayette's documented flood days are not as well represented by the monthly frequencies of potential flood days. In April, the ratio of documented to potential flood days is 37%, but the annual ratio at Lafayette is 54/208, or 26%.

These findings for three representative cities in Louisiana indicate that the frequency of days with rain ≥ 2" is a viable index for the seasonality of flash flooding, and for the *probable* occurrence

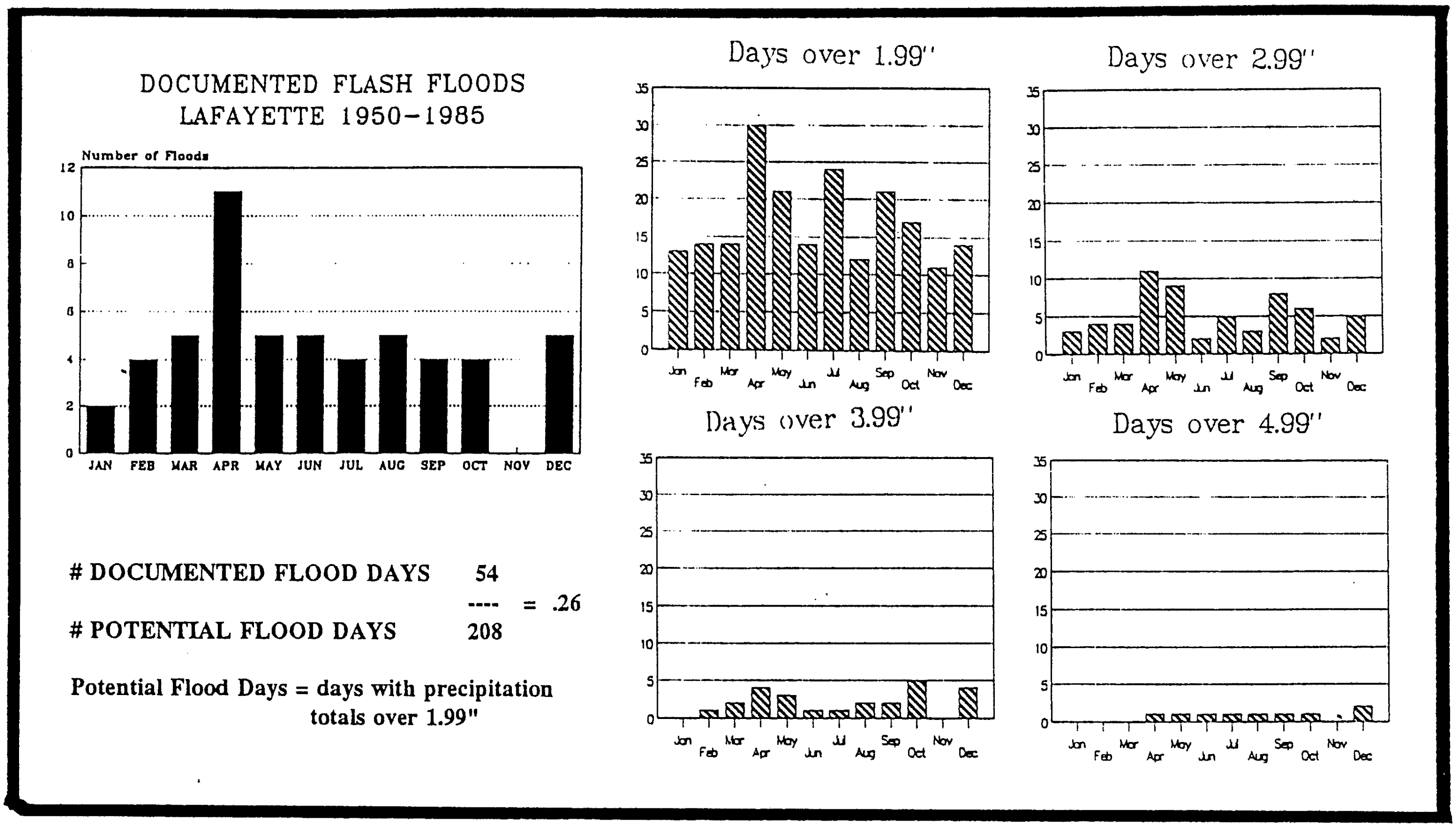


Figure 6. Monthly Frequency of Documented Flash Flood Days and Days with Precipitation ≥ 2,3,4, and 5 Inches -- Lafayette (1950-1985)

of flash floods in other cities. Additional information must be obtained to document the actual occurrence of a flood, but in the absence of such information, the precipitation climatology of a location can reveal a great deal about the likelihood of urban flash flooding at that site. The next section describes the precipitation climatology of the seven main urban areas of Louisiana.

Precipitation Climatology of Louisiana. Louisiana's statewide climate is traditionally classified as "humid subtropical," however, within the state there are some distinct spatial variations in climate. A general south-to-north gradient is evident in the patterns of many climatic parameters when mapped on an annual, seasonal, or monthly basis. Figure 7 shows this gradient in the map of mean annual precipitation. The spatial variation of precipitation has a southeast-to-northwest orientation, with highest values in the southeast near New Orleans, lowest values in the northwest near Shreveport, and a slight secondary maximum of values in the central part of the state just south of Alexandria.

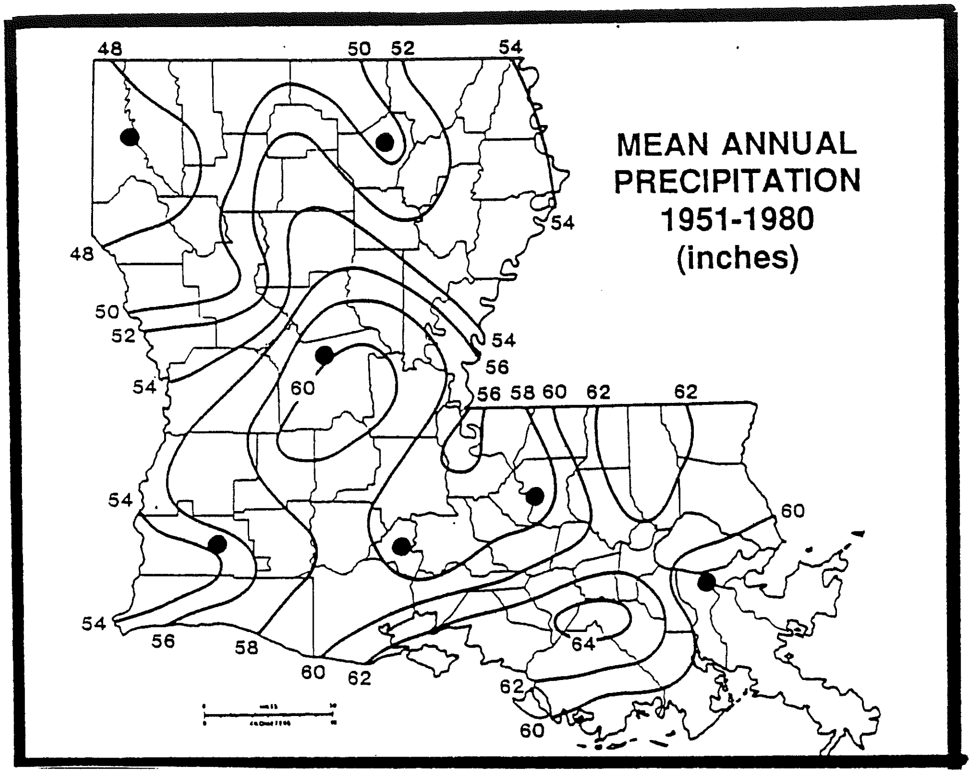


Figure 7. **Mean Annual Precipitation for Louisiana (from Fournerat, 1982)**

The general decrease in annual precipitation from south to north can be explained by the decrease in precipitable water vapor with increasing distance from the Gulf of Mexico and its warm, moist air masses. The secondary maximum south of Alexandria is due to a subtle topographic effect which enhances instability in the Gulf air masses and increases the likelihood of precipitation in this part of the state.

Plots of mean monthly precipitation for the seven main cities show north-south differences in monthly rainfall averages and monthly rainfall seasonality (Figure 8). Monthly averages are lower overall and more uniform from month to month in the northern cities of Shreveport and Monroe than in the southern part of the state. Baton Rouge, Lake Charles, Lafayette, and New Orleans show July as the wettest month of the year, and have a slight tendency toward more summer rainfall than winter rainfall. The months of June and October tend to be the driest at most of the sites.

A comparison of the seasonal regimes of mean monthly precipitation with the seasonal regimes of days with heavy rainfall (≥ 2", 3", 4", or 5") indicates that the occurrence of heavy rainfall days has a slightly different seasonality than that exhibited by the mean monthly rainfall regimes. In Figure 9, at nearly all sites, a definite spring/fall seasonality is apparent for days with rain ≥ 2", ≥ 3", and ≥ 4". April and May are the important spring months for these potential flash flood days throughout the state, and in the southeastern cities of Baton Rouge and New Orleans, February is also an important heavy rainfall month. In fall, no single month stands out consistently as having the

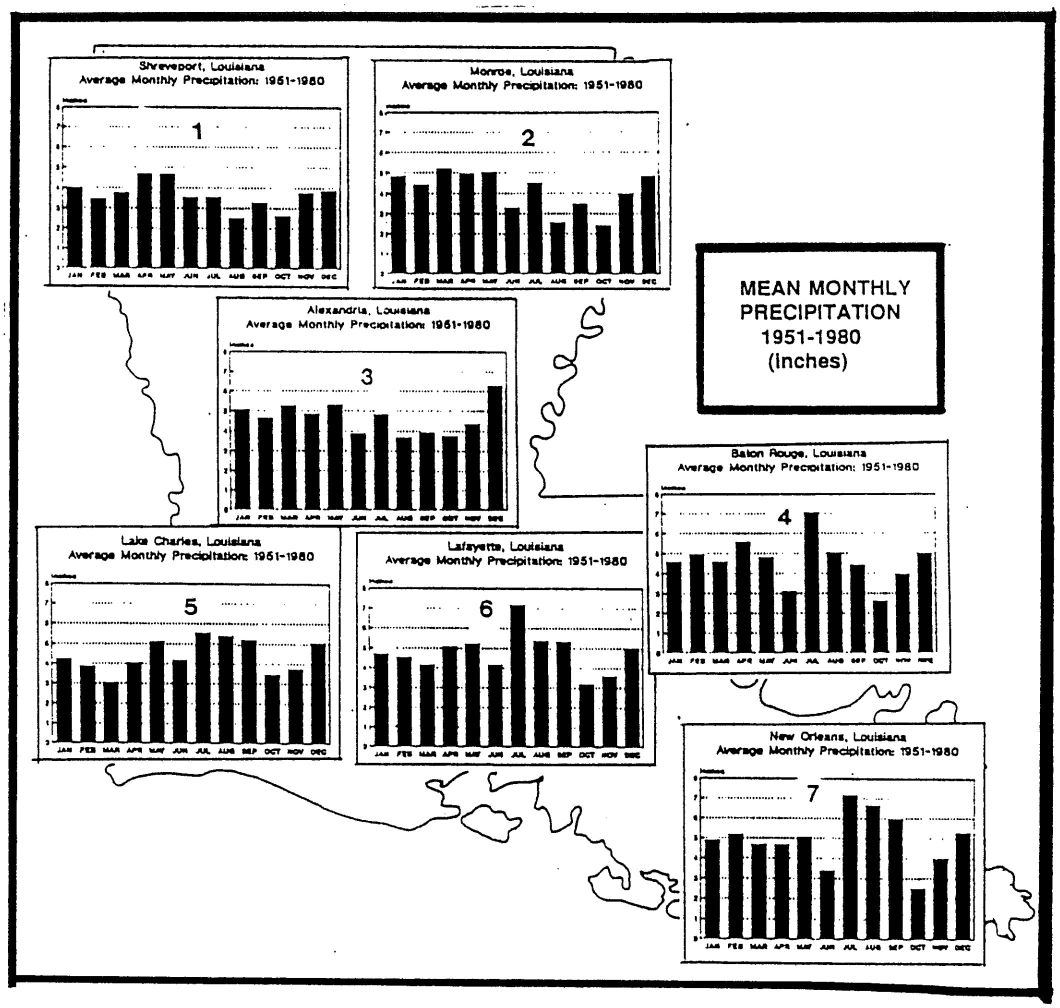


Figure 8. Mean Monthly Precipitation Regime for Seven Louisiana Cities 1951-1980

highest frequency of ≥ 2", 3", and 4" rainfall days, but a fall or early winter component of heavy rainfall days is nevertheless evident at every site centered on either September, October, or November. Additionally, at some sites, the month of December also experiences a high number of heavy rainfall days. Lake Charles, Lafayette, and Baton Rouge are the cities most likely to experience a large proportion of their heavy rainfall days in the mid-summer months of June through August. New Orleans also has a relatively high frequency of heavy rainfall days in summer, but even higher frequencies occur in spring and fall. The frequency of days having rainfall ≥ 5" is too low to identify any strong seasonal tendencies in the largest rainfall events, however Figures 9c and 9d both indicate that the cities most likely to experience the largest rainfall events (i.e., ≥ 4") are located in the southern half of the state.

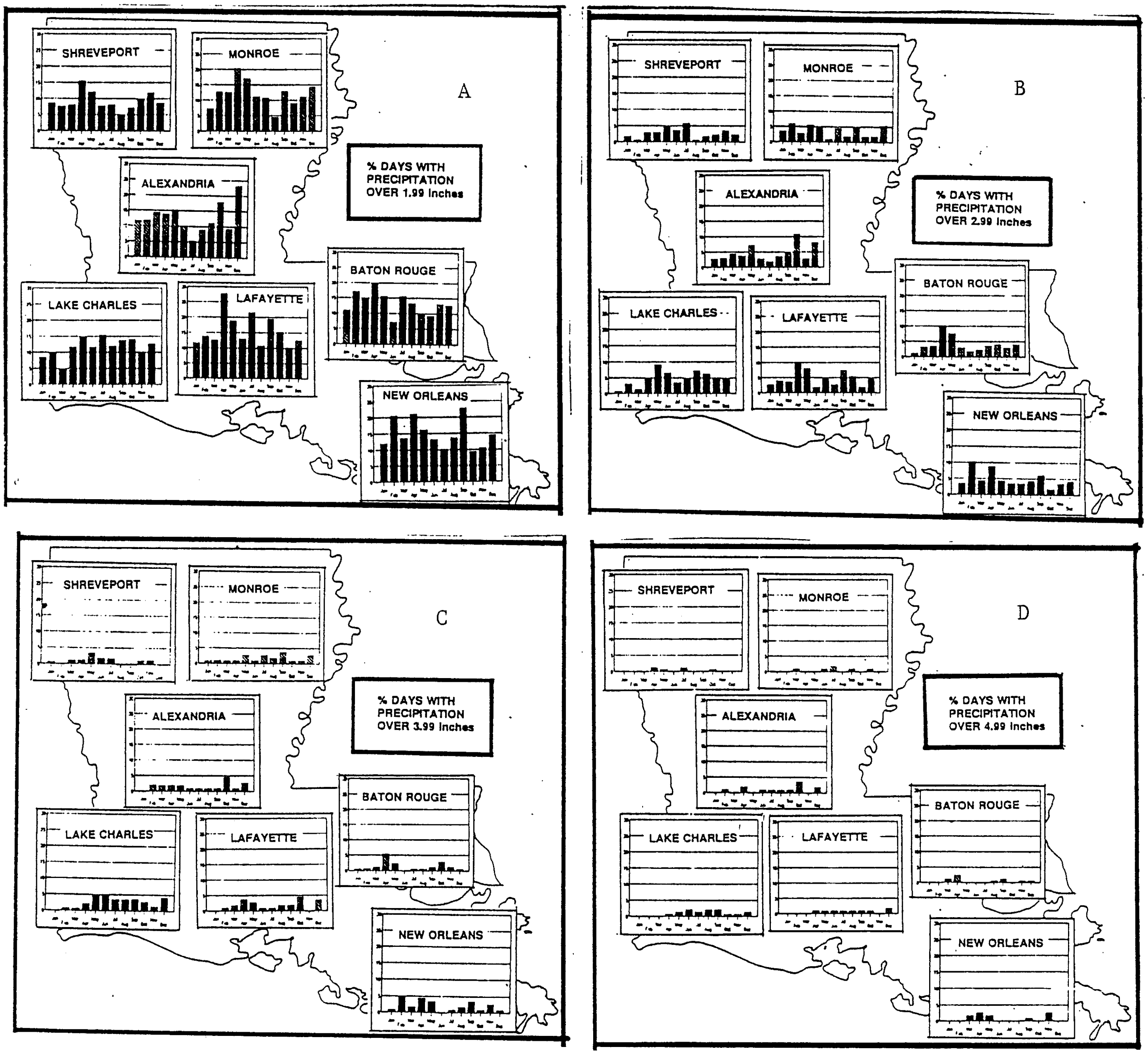


Figure 9. Monthly Precipitation Regimes of Days with Rain ≥ 2, 3, 4, and 5 Inches (in % of total days in record)

The above observations on the spatial variation of the occurrence of days having 2 or more inches of rain can be used to make inferences about the seasonality and spatial variation of potential flash flood days in Louisiana. For the state as a whole, the spring season -- specifically, April and May -- is the time of year with the greatest potential for urban flash flooding. The second most likely time of flash flooding is in fall or early winter. Mid-summer flash flooding is more likely to occur in Lake Charles, Lafayette, Baton Rouge, and New Orleans than it is in Alexandria, Monroe, or Shreveport. More total potential flash flood days occur in the southern half of the state, and this part of the state also has the greatest potential for receiving extremely large rainfall totals in a single day, and therefore experiencing the most severe urban flash flooding.

Temporal Variability of Urban Flash Flooding. The precipitation climatology described above provides information about the seasonality and spatial distribution of potential flash flooding in Louisiana, but says nothing about its intra-annual and inter-annual variability. To evaluate the temporal variability of urban flash flooding, the compilation of documented floods at Monroe, Alexandria, and Lafayette was plotted and examined. Time series plots of these flood events revealed information about: a) the existence of trends of increasing or decreasing numbers of floods over time; b) the tendency for flood events to cluster in time; and c) the frequency of flooding due to rainfall events of different sizes. Figures 10 through 12 show time series plots of documented urban flash floods and their associated precipitation totals for the cities of Monroe, Alexandria, and Lafayette. When viewing these three time series it should be noted that one important factor that determines the frequency of *documented* urban floods is the reliability and consistency over time of the reporting of floods by the newspapers in each city. No objective assessment of this reliability could be made, but it is believed that most substantial urban flood events received some mention in the press, even when other more newsworthy current events overshadowed the occurrence of a local flood. Another factor to be noted about this study's documentation of urban flooding through newspaper accounts is that, in order to limit the scope of the newspaper search, floods which may have occurred on days having less than 2 inches of precipitation were not documented. (This methodology probably affected only the smaller urban floods, causing them to be somewhat under-represented.)

The time series plots in Figures 10 through 12 cover the period from 1950 through 1985 and show the following: (a) the time of occurrence of each documented flash flood (year and month); (b) the associated daily precipitation total for each flood (vertical lines); (c) an indicator of whether the flood event had backwater (BW), or riverine (R), flooding associated with it in addition to headwater and street flash flooding; (d) an indicator of whether *only* backwater (BW), or riverine (R), flooding

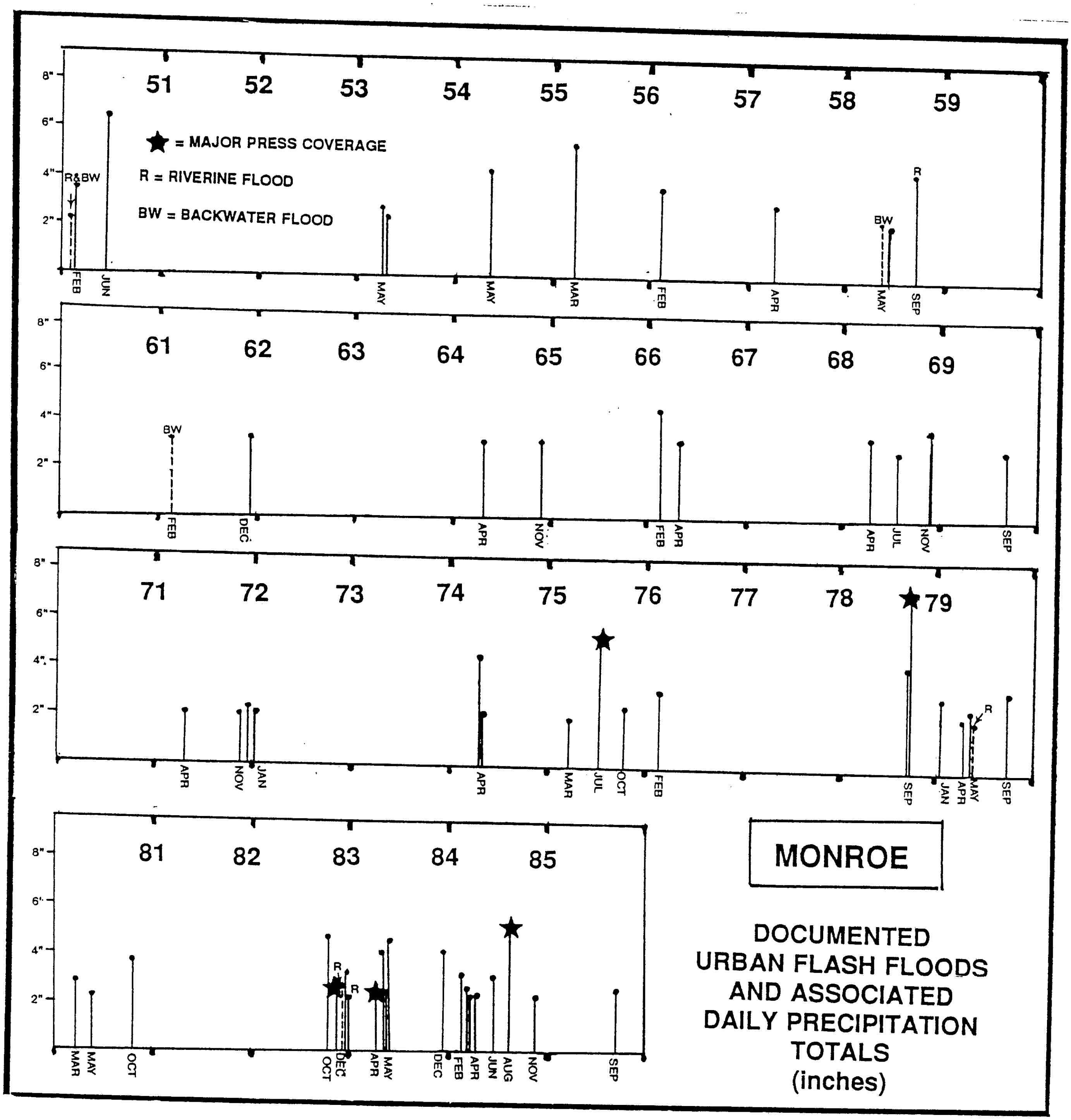


Figure 10. Time Series of Documented Urban Flash Floods for Monroe

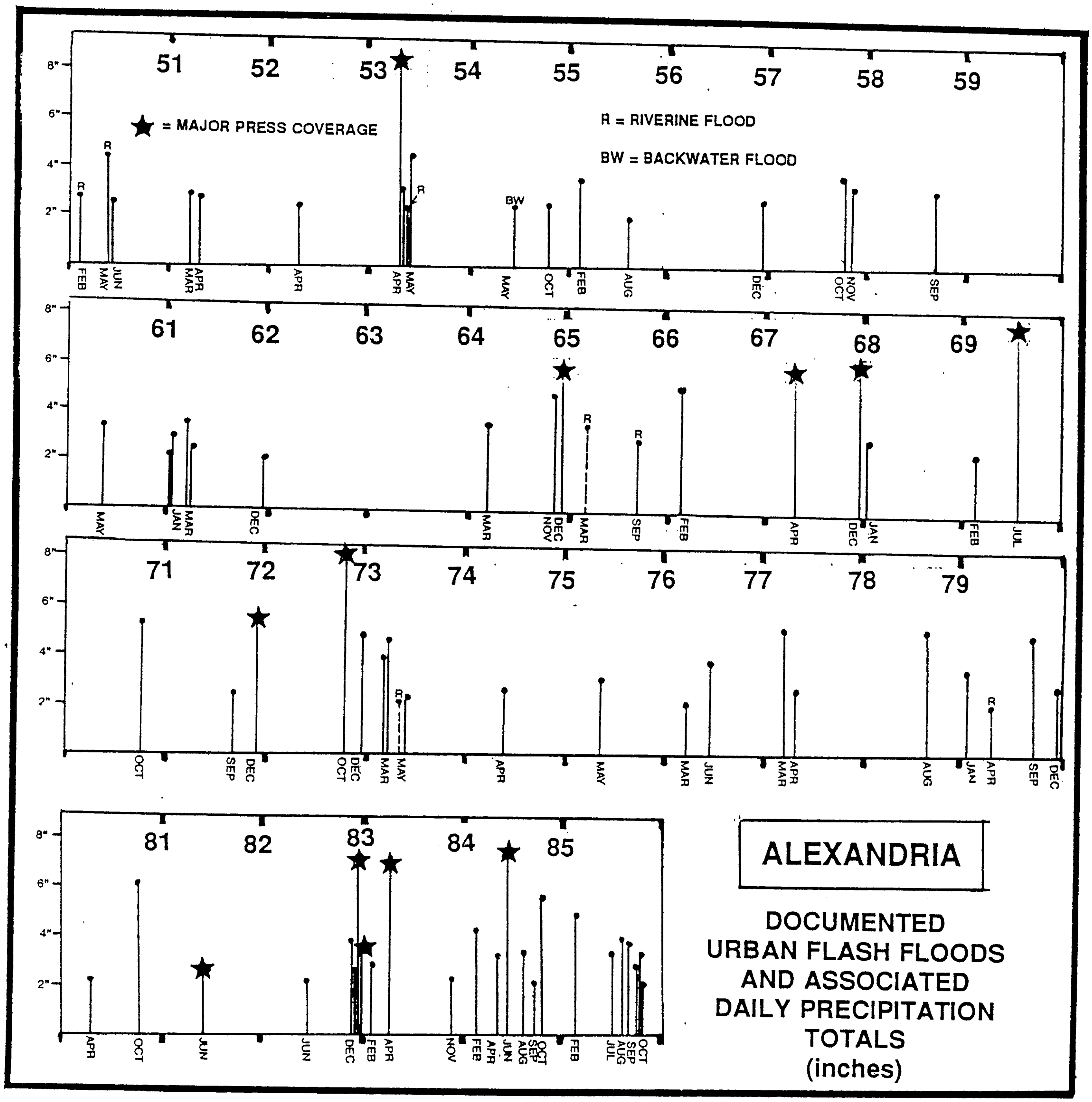


Figure 11. Time Series of Documented Urban Flash Floods for Alexandria

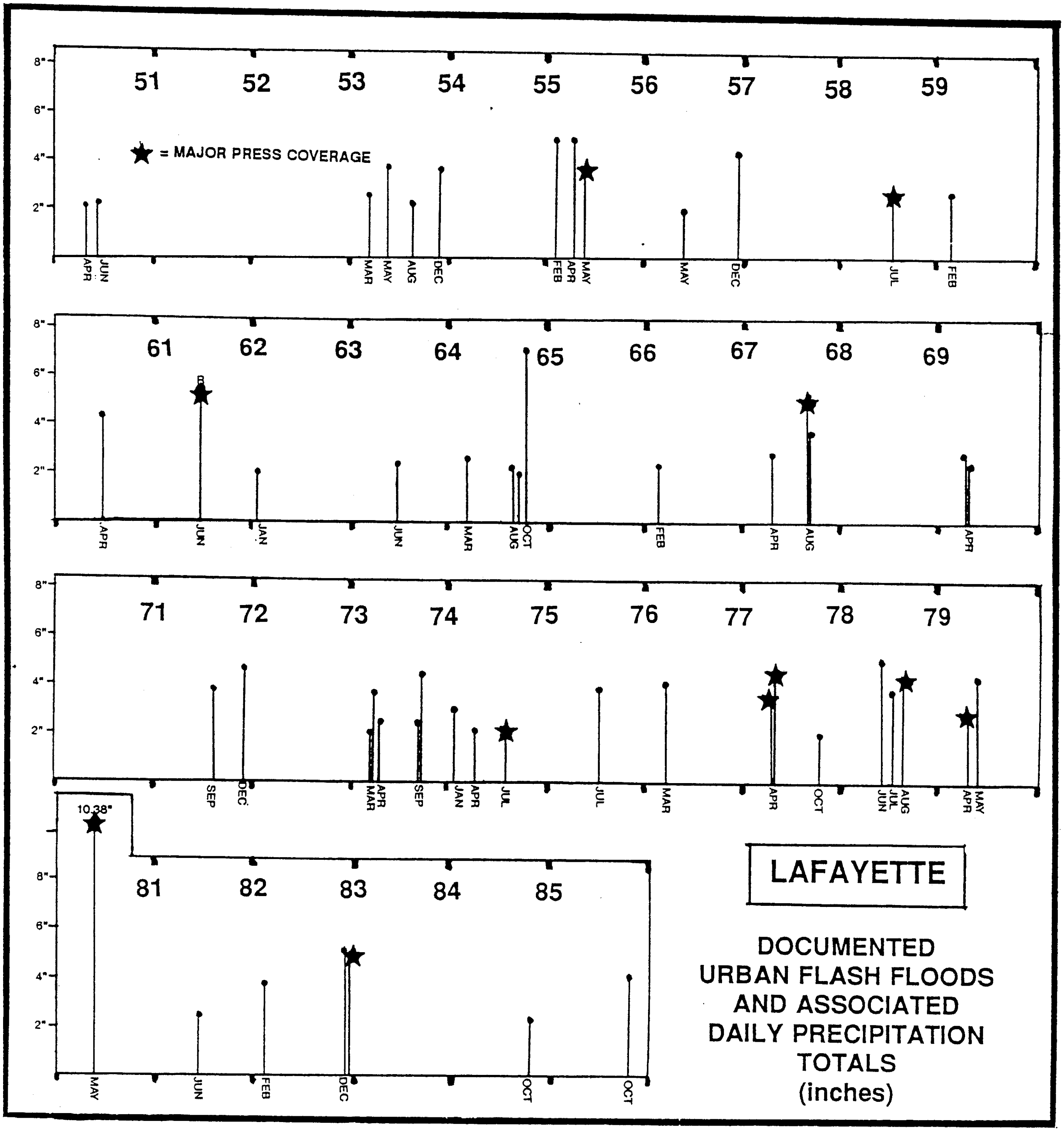


Figure 12. Time Series of Documented Urban Flash Floods for Lafayette

occurred, without accompanying headwater and street flash flooding (vertical dashed line); and (e) an indicator of the most severe flash floods in the time series (star symbol), based on the extent of newspaper coverage (headlines, photographs, number of articles, etc.).

All three sites experienced flash floods throughout the 1950-85 time period. Monroe and Lafayette had fewer floods than Alexandria, but the magnitudes of daily precipitation associated with the floods were higher on the average at Lafayette and Alexandria than at Monroe. All three plots show that there is a tendency for flash floods to occur in clusters rather than at regularly spaced intervals of time. When the number of floods per decade is examined at each site, some interesting trends emerge (see Table 2).

Table 2. Number of Documented Flash Floods per Decade and per Year

CITY		1950-59	1960-69	1970-79	1980-85	Decade Total
Monroe	#/decade	12	10	16	20	58
	avg #/year	1.2	1.0	1.6	3.3	
Alexandria	#/decade	18	16	19	24	77
	avg #/year	1.8	1.6	1.9	4.0	
Lafayette	#/decade	13	14	20	7	54
	avg #/year	1.3	1.4	2.0	1.2	

At Monroe, the number of floods per decade stayed essentially the same in the 50s and 60s, increased slightly (with more clustering) in the 70s, and then, in the documented six-year period during the 80s (80-85), the number of floods increased dramatically. At Alexandria, the number of floods per decade stayed about the same until the 80s when -- similar to Monroe -- the number of floods increased dramatically. Both increases of flooding in the 80s can be partially explained by a higher frequency of potential flash flood days ($\geq$ 2" rain) from 1980-85 in both Monroe and Alexandria (see Table 3).

Table 3. Number of Potential Flash Flood Days (≥ 2") per Decade and per Year

CITY		1950-59	1960-69	1970-79	1980-85	Decade Total
Monroe	#/decade	44	31	37	34	146
	avg #/year	4.4	3.1	3.7	5.7	
Alexandria	#/decade	49	36	47	51	183
	avg #/year	4.9	3.6	4.7	8.5	
Lafayette	#/decade	56	57	62	33	208
	avg #/year	5.6	5.7	6.2	5.5	

At Lafayette, however, the trend toward a recent increase in flood frequency is not evident. The greatest number of floods occurred at Lafayette in the 70s, and the frequency of flooding and potential flash flood days in the 80s appears to be about the same as that of the earlier decades of the 50s and 60s. Figure 12 indicates that the relatively low frequency of flooding in Lafayette during the 80s, (in comparison with 80's flooding at the other cites), resulted from a reduction in the number of floods occurring with rainfall totals less than about 4 inches. The frequency of 1980s floods from larger rainstorms at Lafayette is similar to that of other decades. Possible physically based reasons for these findings will be discussed in subsequent sections.

The Synoptic Atmospheric Environment of Urban Flash Flooding in Louisiana

Each of the events described above was produced by a specific set of atmospheric processes operating within the context of a larger scale synoptic atmospheric circulation pattern. Several researchers have developed classification schemes and found them to be useful for describing the typical patterns and processes that produce floods or heavy rainfall events. At the outset of this project, we planned to use the flash flood categories of R.A. Maddox to classify the floods of Louisiana. During the course of our analysis, another scheme (based on some of the same principles as the Maddox scheme) was investigated: the heavy rainfall event scheme of Johnson and others (1987). Since the Johnson scheme was developed for Louisiana specifically, the classification of flash floods done for this project relied heavily on it.

Figure 13 summarizes the basic elements of the "Louisiana Heavy Rainfall Types." A more detailed explanation can be found in Johnson and others (1987). In the development of the scheme,

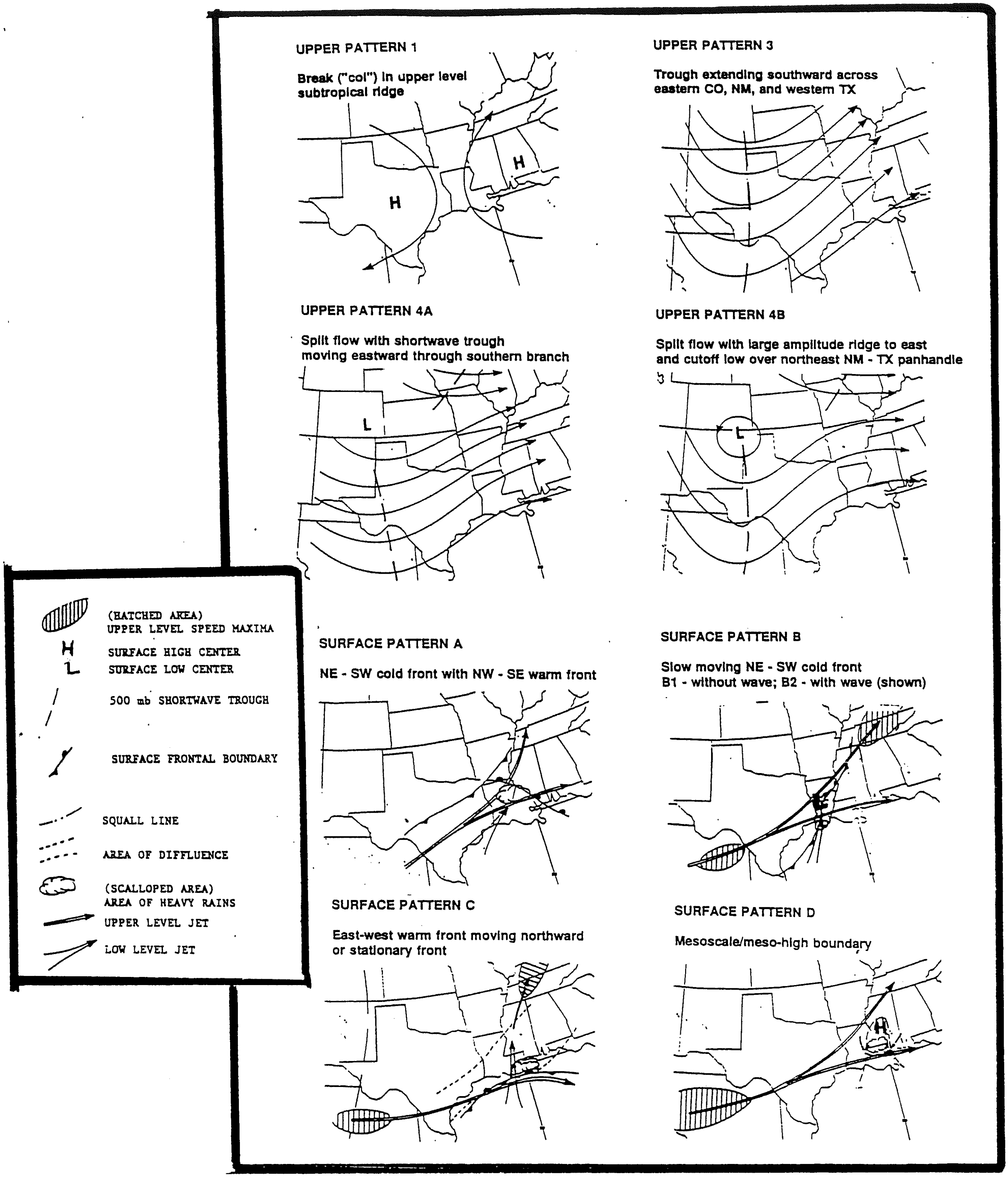


Figure 13. Typical Synoptic Patterns which Result in Heavy Rainfall in Louisiana (from Johnson and others (1987)

heavy rainfall events were first grouped by similar mid-tropospheric 500 mb flow patterns, and then grouped by surface synoptic patterns. The four typical upper air patterns (1 through 4) for heavy rainfall events in Louisiana are shown in the top part of Figure 13. Upper Pattern 1 is exclusively a summertime pattern and is distinct from the other three upper patterns which tend to occur more often in spring and winter. The four upper patterns can be associated with one or more of the four surface patterns (A through D) shown in the bottom half of Figure 13. An additional surface pattern -- Pattern T -- is not depicted in Figure 13. Pattern T is a tropical pattern associated with tropical storms and hurricanes. It occurs primarily during summer and fall.

Using this general framework to categorize surface and upper air patterns that produce heavy rainfall in Louisiana, daily weather maps for each of the documented flash flood at Monroe, Alexandria, and Lafayette were examined. The upper air patterns were easier to classify than the surface patterns because in many instances, a single daily weather map did not have enough detail on it to make a decision about which type of surface front was occurring.

The analysis of synoptic patterns showed that the most important upper air type for producing flash floods was Pattern 4B, a split flow with a large amplitude ridge to the east and a cutoff low somewhere over northeast New Mexico or the Texas panhandle. Second most important were Pattern 4A, with a shortwave upper air trough moving eastward and Pattern 3, with a deep north-south trough to the west. During summer, some instances of Pattern 1 were also associated with documented urban flash floods. The most important surface type was Pattern B, the northeast-southwest cold front, either with or without a wave along the front. Often this pattern was associated with a squall line ahead of the front. The second most important type was Pattern C. Pattern T, the tropical storm/tropical disturbance pattern was an important source of flash flooding in the summer and fall, especially during August - October, 1985, when Hurricanes Danny, Elena, and Juan all had an impact on Louisiana. Surface Pattern D was associated with several of the summer flash floods, and Pattern A also occurred, but infrequently.

Combining surface and upper air patterns, the most prevalent flash flood synoptic scenario was that of Upper Pattern 4B and Surface Pattern B. Except during times of tropical disturbed weather, the dominant feature for flash flood occurrence is a northeast-southwest oriented cold front, usually supported by a deep trough to the west, and often occurring with squall lines ahead of the front. This somewhat distinguishes Louisiana's flash flood environment from that of the Great Plains, where flash floods occur much more often with mesoscale convective complexes, mesohigh patterns, and warm ridges aloft, in addition to synoptic patterns with surface fronts and troughs aloft. Another factor that distinguishes Louisiana's flash floods from those occurring further north is the importance of tropical disturbed weather and the high intensity, long duration precipitation events than can be associated with T-type patterns.

Design Storms and Synoptic Climatology of Flash Flood Events. The results of the synoptic classification of flash flood events can be applied to gain a better understanding of the physical basis for the typical design storm that is used in hydrologic practice to estimate flash flood magnitudes or design drainageways and culverts. An examination of hourly precipitation plots for rainfall events produced by different synoptic situations, suggests that distinctly different hyetographs of precipitation will occur under different synoptic situations.

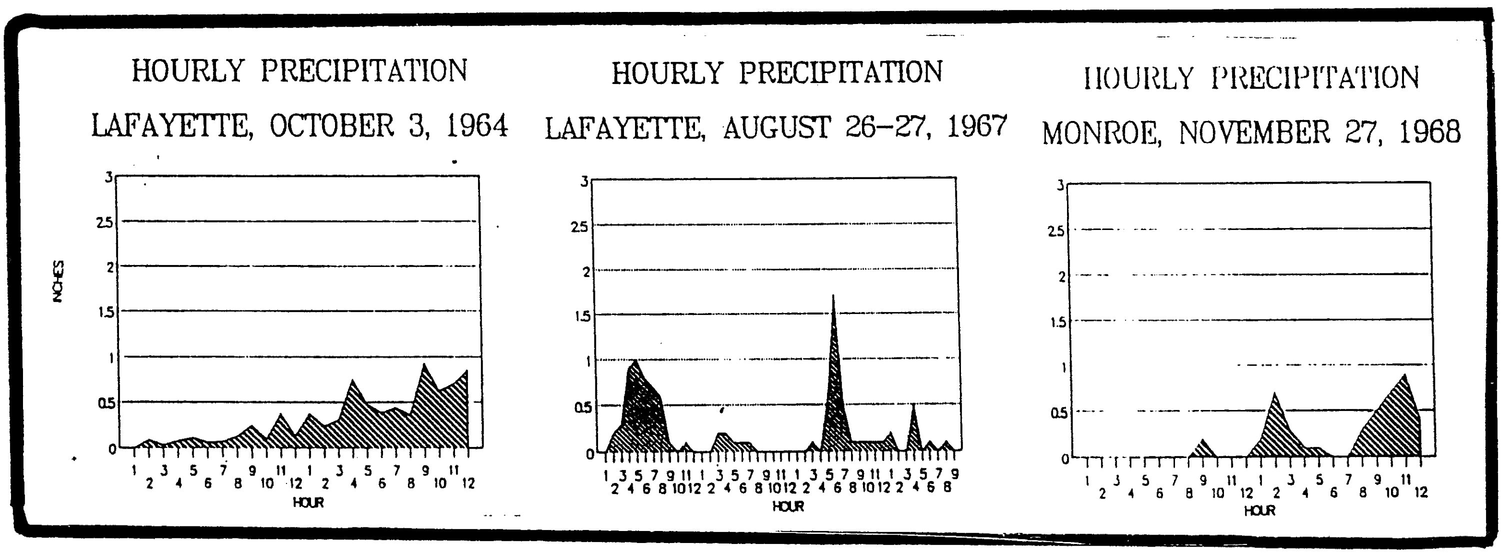
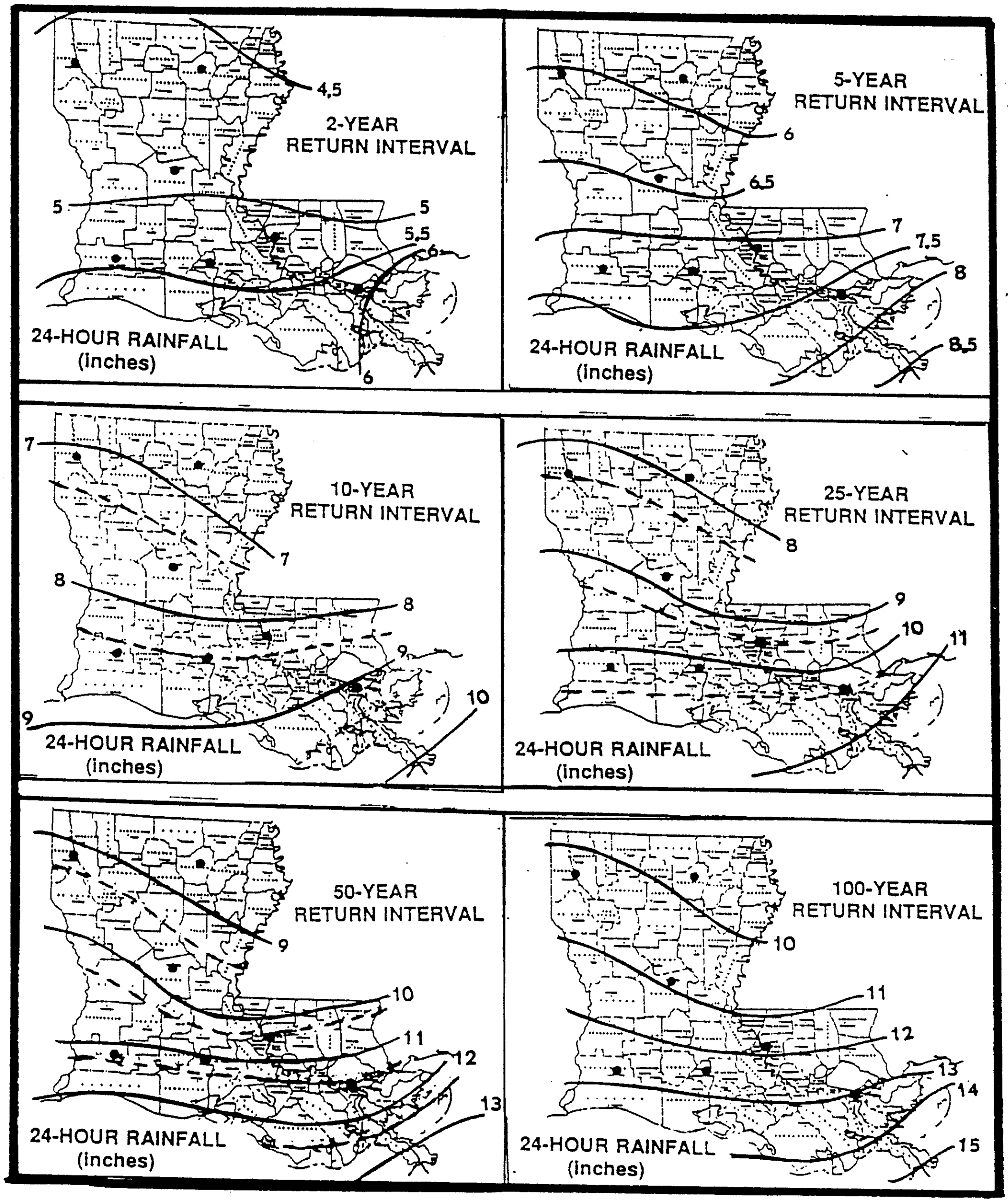


Figure 14. Hourly Precipitation Graphs for Rainfall Events Produced by Different Synoptic Mechanisms

Figure 14 shows hourly precipitation plots for rainfall produced by three different mechanisms. The rain at Lafayette on October 3, 1964 was related to Tropical Storm ux which had an extremely long duration and was punctuated by shorter episodes of more intense rain, typical of precipitation form a tropical storm. The summer rain event at Lafayette on August 26 and 27 was probably produced by Upper Pattern 3 and Surface Pattern D and shows evidence of short bursts of intense rain that may be related to mesohigh activity or squall lines that are anchored in place by the overlying trough. The November precipitation event at Monroe shows three pulses of longer duration precipitation associated with Upper Pattern 4B and Surface Pattern B. All three of these events produced urban flash flooding, but have differently shaped "design" rainfalls. Based on these preliminary findings, a future study might be able to determine the ideal design hyetograph for future precipitation events produced by different synoptic patterns. **Appendix B** includes several more hourly precipitation plots for each of the state's main cities.

The synoptic climatology of flash flood events can also bring some physical basis to the spatial patterns that are observed on design rainfall probability maps. Figure 15 is an enlargement of the Hershfield (1961) Technical Paper No. 40 maps for Louisiana. The south-to-north decrease in

Figure 15.



Design 24-Hour Rainfall Maps for Different Recurrence Intervals.

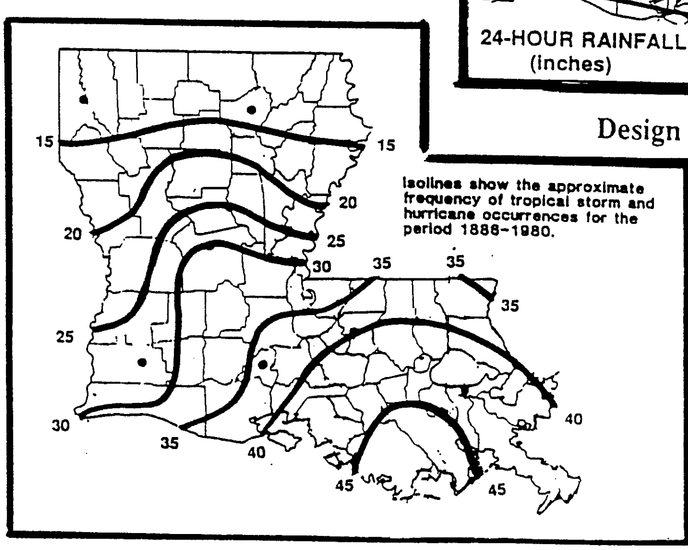


Figure 16.

Tropical Storm and Hurricane Occurrence in Louisiana, 1866-1980 design rainfall at different recurrence intervals may be a reflection of the way in which rain-producing fronts align themselves across the state under Surface Patterns A, B, or C. The gradient may also be a reflection of the decreasing frequency of tropical storm and hurricane paths from south to north (see Figure 16).

Land Use and Soil Factors that Enhance Urban Flash Flooding

The above findings have addressed the patterns and processes of atmospheric inputs that result in a high *potential* for flash flooding. Whether or not a given atmospheric input will actually result in a flash flood is largely dependent on characteristics of the land surface and underlying soil. On short time scales of days, weeks, and months, land cover properties -- such as vegetation type or land use type -- stay more or less constant, in contrast to the highly variable nature of precipitation. On longer time scales of years, decades, and centuries, land cover properties may change substantially and subsequently alter a region's flash flooding regime, even if precipitation characteristics stay essentially constant over the same time period. Usually both kinds of changes are going on at the same time, making the identification of direct causes of flooding difficult. Compounding the problem is the variability of soil moisture which fluctuates more slowly than daily precipitation variability, yet interacts with precipitation through infiltration, and can directly influence flooding when the soil moisture storage capacity becomes filled. A long term assessment of how urbanization affects flash flooding in a region must take each of these factors into consideration.

Phases 3 and 4 of the project were designed to examine the ways in which soil type, land cover, land use, and soil moisture might influence urban flash flooding in Louisiana. The UFFGIS was designed to address the spatial variability of land use, land cover, and soil type in representative urban basins in Louisiana. Soil moisture variability over time was addressed with a water balance model. The principal findings for both phases are given below.

The Urban Flash Flood Geographic Information System (UFFGIS). As represented in Figure 1, the UFFGIS consists of several information levels which include spatial data on drainage channels, basin boundaries, soil types, and land use. Maps can be constructed by superimposing levels. The principal results for this project include soil maps -- grouped into hydrologic soil groups -- and 1978 land use maps for the seven selected urban basins in Louisiana shown in Figure 17 (also see Table 1). All maps and accompanying data tables are presented in **Appendix C**. A summary of the findings will be presented here, using Youngs Bayou in Monroe as an example.

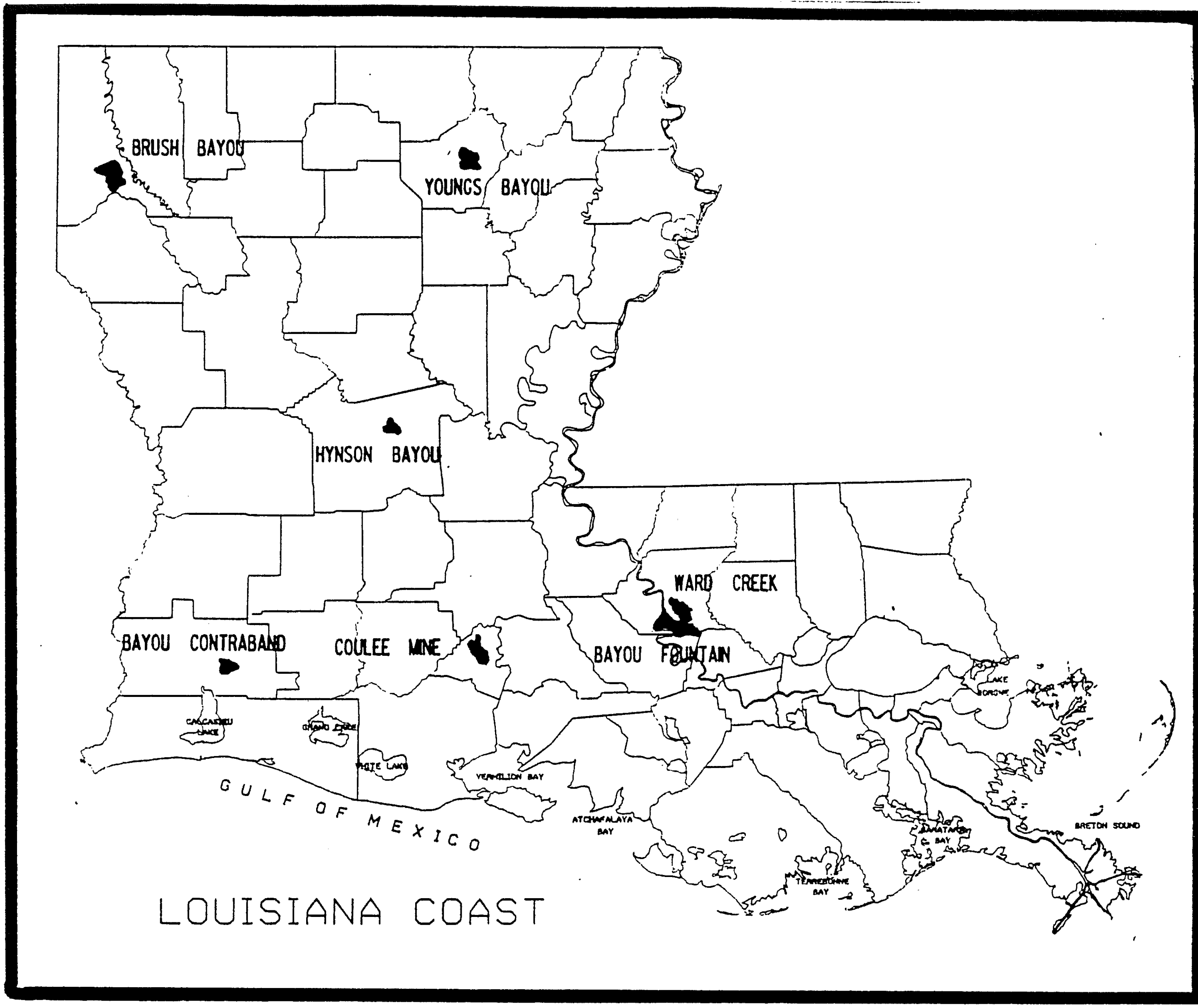


Figure 17. Locations of Urban Drainage Basins in UFFGIS

The soil maps use a classification of soil types, grouped together by their hydrologic properties, which was developed by the U.S. Soil Conservation Service (1972). Table 4 describes the four hydrologic soil groups which range from A soils, having good infiltration and low runoff potential, to D soils, having very slow infiltration and high runoff potential. Figure 18 and Table 5 show the results of the UFFGIS mapping of hydrologic soil groups for Youngs Bayou in the city of Monroe. Hydrologic soil groups are relatively complex in Youngs Bayou. The Index of Simplicity (area/perimeter) is relatively low compared with the other basins, indicating a fair amount of interfingering of soil groups. In general, soil drainage deteriorates in a downstream direction. There are large ares of well-drained group B soils (42.5%) along the western and northern perimeter of the basin, located along the natural levees of the Ouachita River and Bayou DeSiard, respectively. Poorly drained group C soils (29.9%) dominate the interior of the basin. Very poorly drained group D soils account for 26% of the basin, but they are concentrated in the lower southeast part of the basin where very flat terrain slows the natural flow due to gravity, compounding the drainage problem.

Table 4. Classification of Soils by Their Hydrologic Properties

CLASSIFICATION	TYPE OF SOIL
A (low runoff potential)	Soils with high infiltration capacities, even when thoroughly wetted. Chiefly sands and gravels, deep and well drained.
B	Soils with moderate infiltration rates when thoroughly wetted. Moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures.
C	Soils with slow infiltration rates when thoroughly wetted. Usually have a layer that impedes vertical drainage, or have a moderately fine to fine texture.
D (high runoff potential)	Soils with very slow infiltration rates when thoroughly wetted. Chiefly clays with a high swelling potential; soils with a high permanent water table; soils with a clay layer at or near the surface; shallow soils over nearly impervious materials.

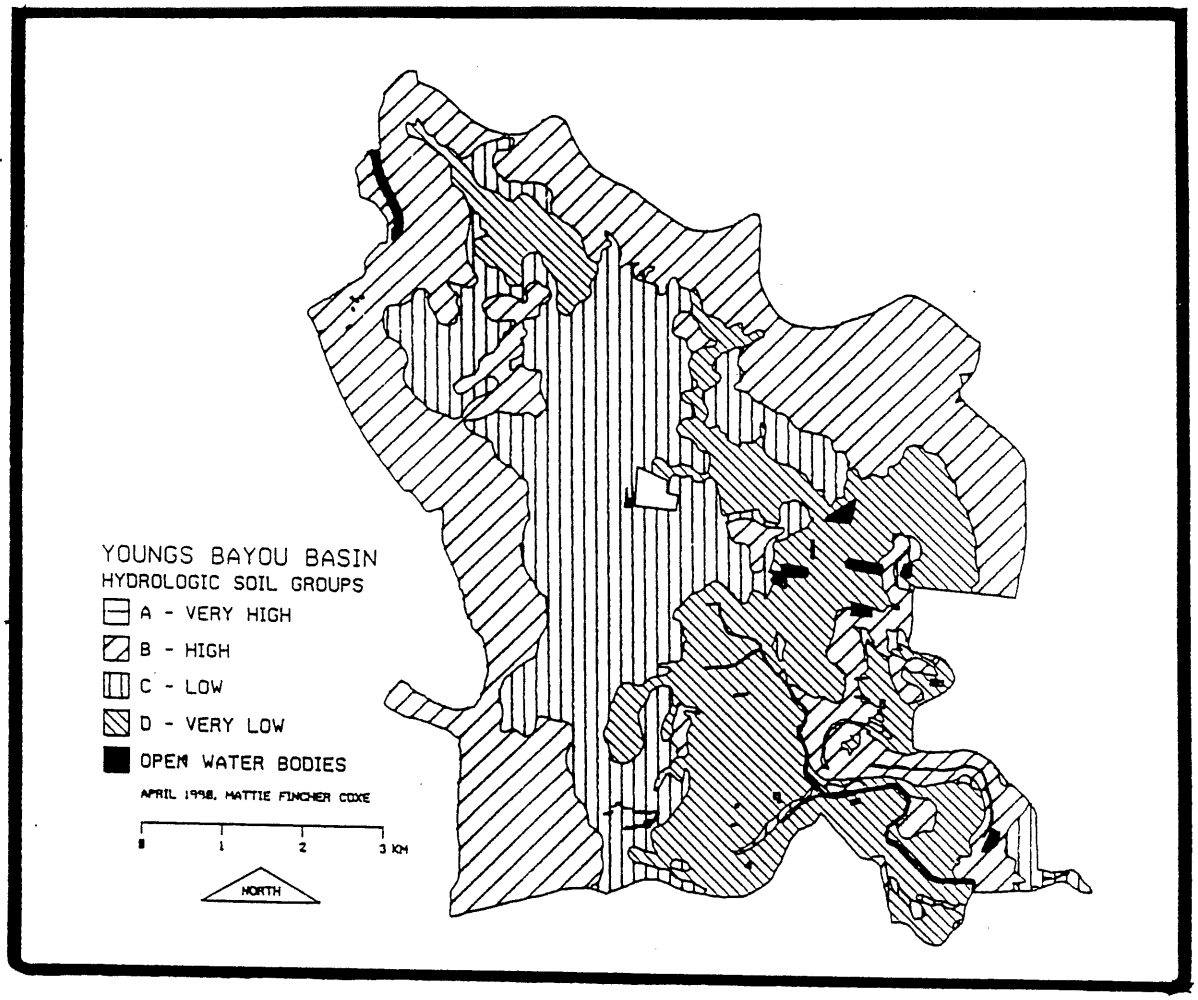
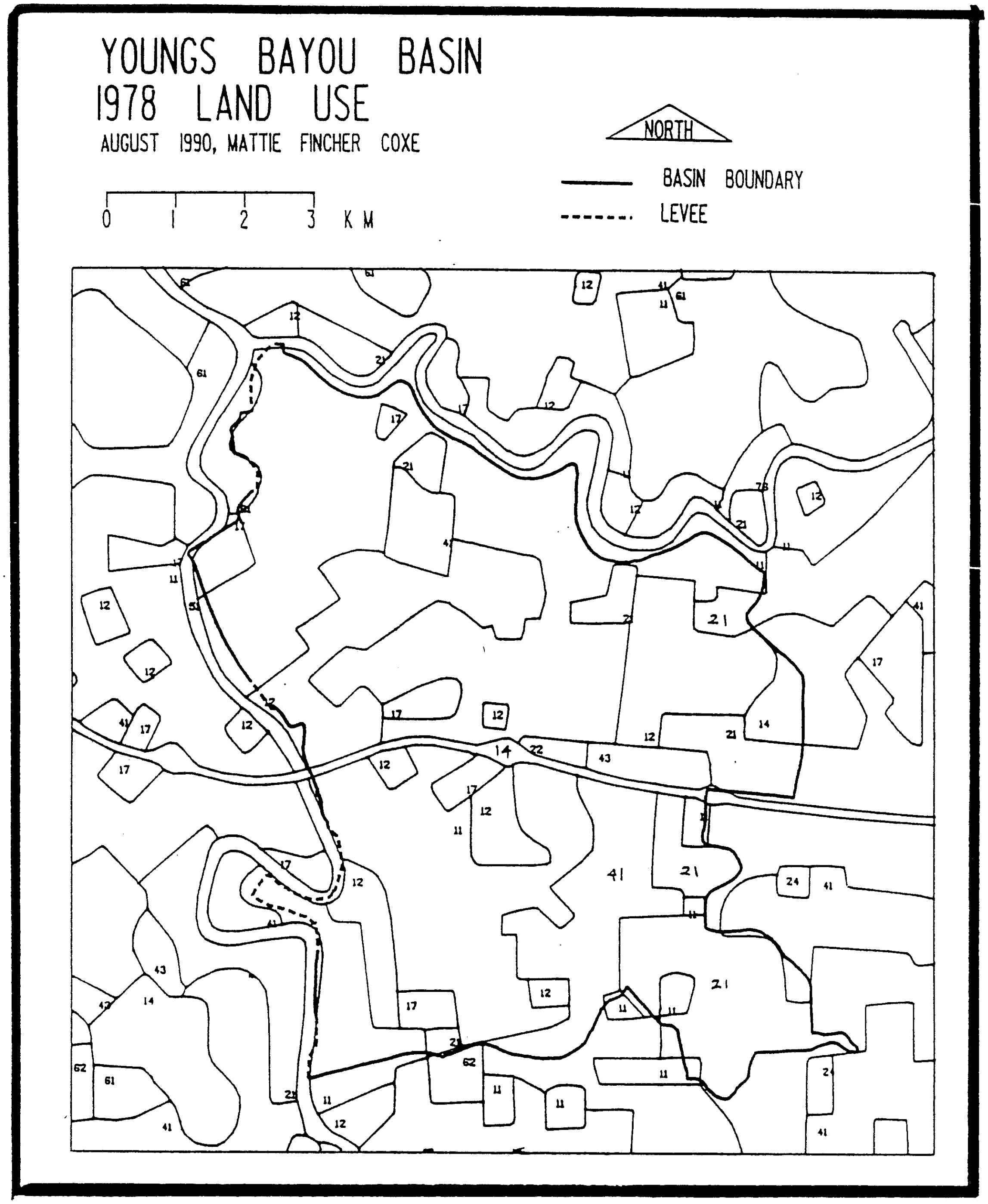


Figure 18. Hydrologic Soils Group Map for Youngs Bayou Basin, Monroe

Table 5. Percentage of Area in Various Hydrologic Soil Groups and Index of Simplicity

YOUNGS BAYOU Monroe		AREA			PERI-METER	INDEX OF SIMPLICITY
		hectares	%	%	km	area/perimeter
HYDRO-LOGIC SOIL GROUP	B	2584.12	42.45	98.26	115.49	
	C	1817.02	29.85		87.05	
	D	1580.69	25.96		97.08	
SEWAGE LAGOON - S		6.19	0.10	1.74	1.09	
OPEN WATER - W		80.52	1.32		36.90	
WASTE DUMP - X		19.41	0.32		1.92	
ALL		6087.95	100.00	100.00	339.53	17.93



Percent of Basin Area in Different Types of Land Use

BASIN / % USE	Urban Land (1)	Agricultural Land (2)	Rangeland (3)	Forest Land (4)	Water (5)	Wetland (6)	Barren Land (7)
Youngs Bayou	74.3	13.6	0.0	11.6	0.0	0.5	0.0

Figure 19. Land Use Map for Youngs Bayou Basin, Monroe

Table 6. Description of Land Use Units (from Anderson and others, 1976)

1 Urban or Built-up Land
- 11 Residential
- 12 Commercial
- 13 Industrial
- 14 Transportation, Communications, and Utilities
- 16 Mixed Urban or Built-up Land
- 17 Other Urban or Built-up Land

2 Agricultural Land
- 21 Cropland and Pasture
- 22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
- 24 Other Agricultural Areas

3 Rangeland
- 32 Shrub and Bush Rangeland

4 Forest Land
- 41 Deciduous Forest Land
- 42 Evergreen Forest Land
- 43 Mixed Forest Land

5 Water
- 52 Lakes
- 53 Reservoirs

6 Wetland
- 61 Forested Wetland
- 62 Nonforested Wetlands

7 Barren Land
- 76 Transitional Areas

Corresponding land use for Youngs Bayou is shown in Figure 19. The numbered areas represent different types of land use and land cover according to the classification system devised by Anderson and others (1976). Table 6 indicates the type of use associated with each numbered area. In Youngs Bayou, urban or built-up land comprises roughly 74.3% of the basin, agricultural land is 13.6%, forested land is 11.6% and wetlands comprise 0.5% of the basin. This land use composition indicates that -- although Youngs Bayou is already an "urban" basin -- there is the potential for much more of the basin to become urbanized. The UFFGIS will allow the future monitoring of that urbanization over time. The potential for future urbanization and the dominance of group C and D soils mark Youngs Bayou as a high-risk area for future urban flash flooding. Indeed, the basin has already been identified as one in need of a proposed drainage project and is discussed in detail in the 1986 report on flood problem areas and damage reduction measures, <u>Flood Control in Louisiana</u> (Gulf South Research Institute, 1986).

Summary of Hydrologic Soil Group UFFGIS Maps. Appendix C contains maps and tables for the other basins in the UFFGIS. The soil surveys that form the basis for the hydrologic soil group maps were performed at different times and with different standards for classifying altered urban soils. Soils with no hydrologic group classification ranged from .34% of the Coulee Mine Basin in Lafayette to 7.46% of the Brush Bayou Basin in Shreveport. Water bodies and soils whose natural characteristics have been destroyed by urbanization or other anthropogenic activities account for most of the unclassified areas. Typical examples of this type of soil are interstate highways and railroad yards in Shreveport. As such they probably have very poor drainage characteristics similar to or worse than group D soils. Less abundant areas such as pits, hazardous waste sites, and "man-made" soils probably also have very poor drainage. The classification differences due to varying survey time and method are therefore relatively insignificant because the disturbed soils occur in low percentages in each basin and they are probably similar to the predominant group D soils.

There were no examples of hydrologic soil group A soils (well-drained) in any of the study basins. Most soils were in groups C and D, the least drained groups. The Index of Simplicity calculated for each basin's soil map indicates the degree to which the soil drainage units are divided into very small, irregular areas. The lowest index (9.9) was for Ward Creek in Baton Rouge, a very complex basin; and the highest index (44.1) was calculated for Hynson Bayou, the basin with the simplest soil map. Following are some additional observations on the soils maps for individual basins.

Brush Bayou - Poor soil drainage prevails in the Brush Bayou Basin. Simple, very poorly drained group D soils accounted for 89.3% of the area. Group C accounted for an additional 1.5%. There are only minor areas of well-drained group B soils, 1.8%. The poorly drained soils are distributed throughout the basin. Urban soils lacking natural character are 7.1% of the unclassifiable soils. They are concentrated in the northeast portion of the basin.

Hynson Bayou - The distribution of hydrologic soil groups is simple in the Hynson Bayou Basin. Nearly two-thirds of the basin is a single unit of well-drained group B soils (67.6%). The other third (32%) is a single unit of very poorly drained group D soils. The group D soils predominate in the interior of the basin.

Bayou Contraband - Soil drainage in the Bayou Contraband Basin is simple, and uniformly very poor. Very poorly drained group D soils account for 94.6% of the basin. Well-drained group B soils are a mere .4% of the basin. There are no group C soils at all. The remainder is primarily severely disturbed urban soils.

Coulee Mine - Soil drainage is complex in the Coulee Mine Basin. The upper basin consists of intertwined ribbons of very poorly drained group D soils (29.3%) and poorly drained group C soils (47.5%). This area is a part of the Prairie Terrace scarred by ancient uplifted meanders of the Mississippi River. It is studded with marais, small round waterfilled "potholes" formed by the ancient Mississippi River. In contrast the lower basin consists of well-drained group B soils (22.9%). Drainage improves in a downstream direction.

Bayou Fountain - The distribution of the hydrologic soil groups in the Bayou Fountain Basin reflects very complex surficial geology. The area consists primarily of Holocene deposits of the Mississippi River such as natural levees, meander belts, and backswamps. An artificial levee reduces overbank flooding from the Mississippi. There is a much older and smaller region of Prairie Terrace on the east side of the basin. Two-thirds (65.5%) of the area consists of very poorly drained hydrologic group D. The "Bottoms," Elbow Bayou Backswamp, Bayou Fountain Backswamp, Selene Bayou Backswamp, and Bluebonnet Swamp account for most of this area. Natural levees, ridge-and-swale meander belt topography, and recent stream alluvium in the Prairie Terrace account for the remainder of group D. Poorly drained group C soils (29.3%) form several significant features. They form a complex pattern intermeshing with group D soils in the Pleistocene uplands. Drainage is poorer adjacent to streams in the uplands. There is a sharp boundary of steep well drained Terrace soils dividing the uplands from the lowlands. In the lowlands there is a large area of group C soils in the northwest basin probably due to an old meander belt. Along the southwestern perimeter there are numerous crevasse ribbons extending eastward from the Mississippi River in the vicinity of Manchac Bend. The southern perimeter is the natural levee of Bayou Manchac.

Ward Creek - The hydrologic soil groups form a complex pattern in the Ward Creek Basin. It is an upland area of the Prairie Terrace. Slightly more than half the basin consists of poorly drained group C soils (52.9%) adjacent to streams. Most of the remainder are very poorly drained group D (40%) soils.

In general, soil drainage varies significantly even within the same geomorphic zones. Coulee Mine, Bayou Contraband, and Ward Creek basins have very different drainage characteristics despite both being located predominantly in the Prairie Terrace. Ward Creek basin is relatively well drained compared to Bayou Contraband. Soil drainage has opposite trends along Youngs Bayou and Coulee Mine. Along Youngs Bayou soil drainage becomes poorer downstream, while along Coulee Mine soil drainage becomes better downstream. Opposing trends in the relative location of poorly drained and very poorly drained areas may be seen in different regions of the Prairie Terrace. In the upland areas of the Coulee Mine and Bayou Fountain basins the most poorly drained soils are found adjacent to streams. In the Ward Creek basin soil drainage is less poor adjacent to the streams. Youngs Bayou and Bayou Fountain basins have similar backswamp situations with drainage deteriorating away from the major rivers. Brush Bayou and Bayou Contraband have similar large very poorly drained soil units despite being in different geologic zones.

To summarize the findings of the UFFGIS on the soils maps one might say that although Louisiana basins are very diverse, soil drainage is predominately poor to very poor. Neither distance to streams, nor general geologic zone are infallible indicators of drainage. Each area must be studied independently for flood conditions. The presence of levees significantly affects the flood hazard. In some cases natural levees may have relatively well drained soils as long as the artificial levee is intact.

Failure of the levees may abruptly subject relatively well drained areas to major flooding. This pattern may foster complacency among people who live on natural levees.

Summary of Land Use UFFGIS Maps. In a manner similar to that of the soils maps, the land use maps in Appendix C show variations from basin to basin, with different degrees of complexity. Table 7 summarizes the percent of area in different types of land use for the seven study basins.

Table 7. Percent of Basin Area in Different Types of Land Use

BASIN / % USE	Urban Land (1)	Agricultural Land (2)	Rangeland (3)	Forest Land (4)	Water (5)	Wetland (6)	Barren Land (7)
Brush Bayou	65.9	1.87	0.0	25.0	0.67	0.0	6.6
Youngs Bayou	74.3	13.6	0.0	11.6	0.0	0.5	0.0
Hynson Bayou	76.7	15.4	0.0	0.73	0.0	4.4	2.8
Contra-band B.	63.8	21.1	4.2	8.1	2.0	0.3	0.5
Coulee Mine	36.7	62.5	0.0	0.6	0.0	0.0	0.2
Ward Creek	77.4	8.3	0.0	12.4	0.0	0.0	1.8
Bayou Fountain	14.5	49.3	0.0	18.8	0.0	15.6	1.7

The table and maps show that most of the study basins are one-half to three-quarters urbanized. Bayou Fountain and Coulee Mine are the least urbanized basins; agricultural land is the most abundant land use in these two basins. Brush Bayou and Bayou Fountain still have up to 25% forest land, but most of the other basins are characterized by agricultural land as their second major land use.

The results of the land use part of the UFFGIS indicate that there is room for additional urbanization in all of the study basins. Some basins, such as Bayou Fountain, experience severe flash flooding even with a relatively low percentage of urbanization in the basin. This can be explained by Bayou Fountain's high percentage (65%) of group D soils with their high runoff potential. By superimposing different levels of information in the UFFGIS, areas most at risk to urban flash flooding can be identified, both now, and in the future.

Temporal Variability of Soil Moisture and Urban Flash Flooding. The UFFGIS mapping showed that, even in the most urbanized basins, there is enough permeable area in a city drainage basin to influence runoff rates through infiltration. Depending on the dominant hydrologic soil group, some basins will experience less infiltration than others. However, if soils are saturated from previous rainfall events, even the most permeable soils will not be able to take in any more moisture delivered by a new storm, and flash flooding will result. The monitoring of soil moisture levels can therefore help to explain the occurrence of flash flooding from seemingly insignificant rainfall events. A convenient measure of soil moisture storage variability can be obtained from climatic data alone by computing daily water budgets for a given area through the use of a climatic water budget model (Thornthwaite and Mather, 1955). Figure 20 shows daily variations in soil moisture storage, computed from such a model, over a six-year period for four locations in Louisiana. (The Red River station is near Shreveport, the Dean Lee station is near Alexandria, the Ben Hur station is near Baton Rouge, and the Citrus station is located south of New Orleans.) The figure shows that soil moisture storage varies both spatially and from year to year. For example, contrast the June levels of moisture stored at Baton Rouge in 1988 with those of 1989. During times of high soil moisture storage levels, any amount of precipitation is likely to generate runoff, whereas during times of depleted soil moisture, often only the largest rainfall events will generate significant runoff (Figure 21). If both heavy rainfall and high soil moisture levels occur together, an extremely severe flash flooding event can result. This was the scenario that produced severe flash flooding in Baton Rouge during June 1989 when the remnants of Tropical Storm Allison dumped over 10 inches of rain over a four-day period at the end of June when soil moisture storage levels were unseasonably high. In this project, the relationship between soil moisture levels and flash flooding was examined by observing how often a potential flash flood day ($\geq$ 2" rain) resulted in a documented flash flood, when soil moisture storage levels were high or low. Daily water budgets for both Monroe and Lafayette were used, along with the list of documented flash floods for these cities. The results of this comparison indicated that, in most cases, the soil moisture level from preceding days was an important determinant of whether or not a potential flood event would become an actual flood event. However, there were several instances when the intensity and delivery rate of the precipitation was far more important than soil moisture in determining the occurrence of a flood. There were not enough cases of high soil moisture and *no* flood, or low soil moisture *with* a flood to determine any kind of "threshold" precipitation intensity

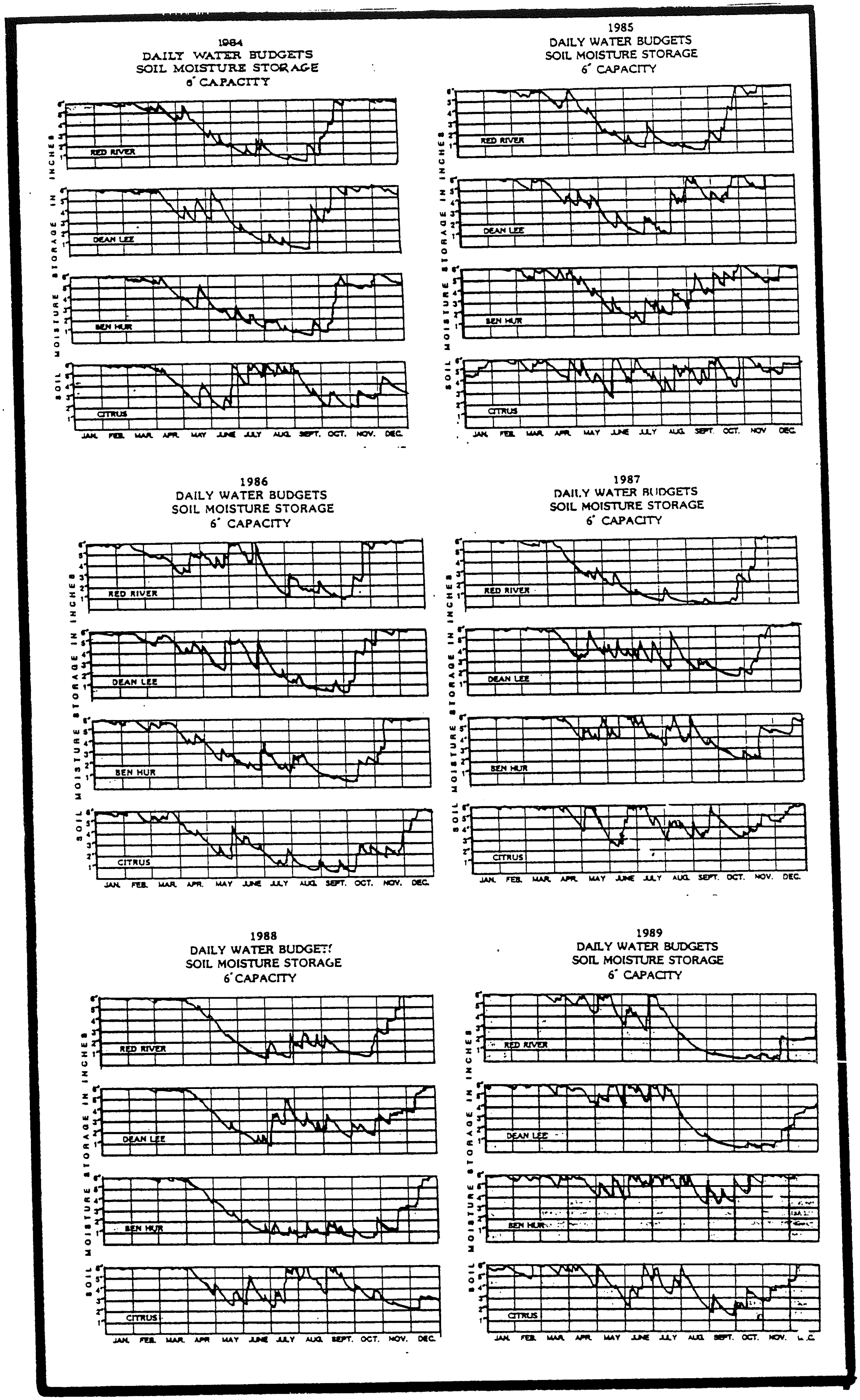


Figure 20. Computed Daily Soil Moisture Storage for Four Locations in Louisiana

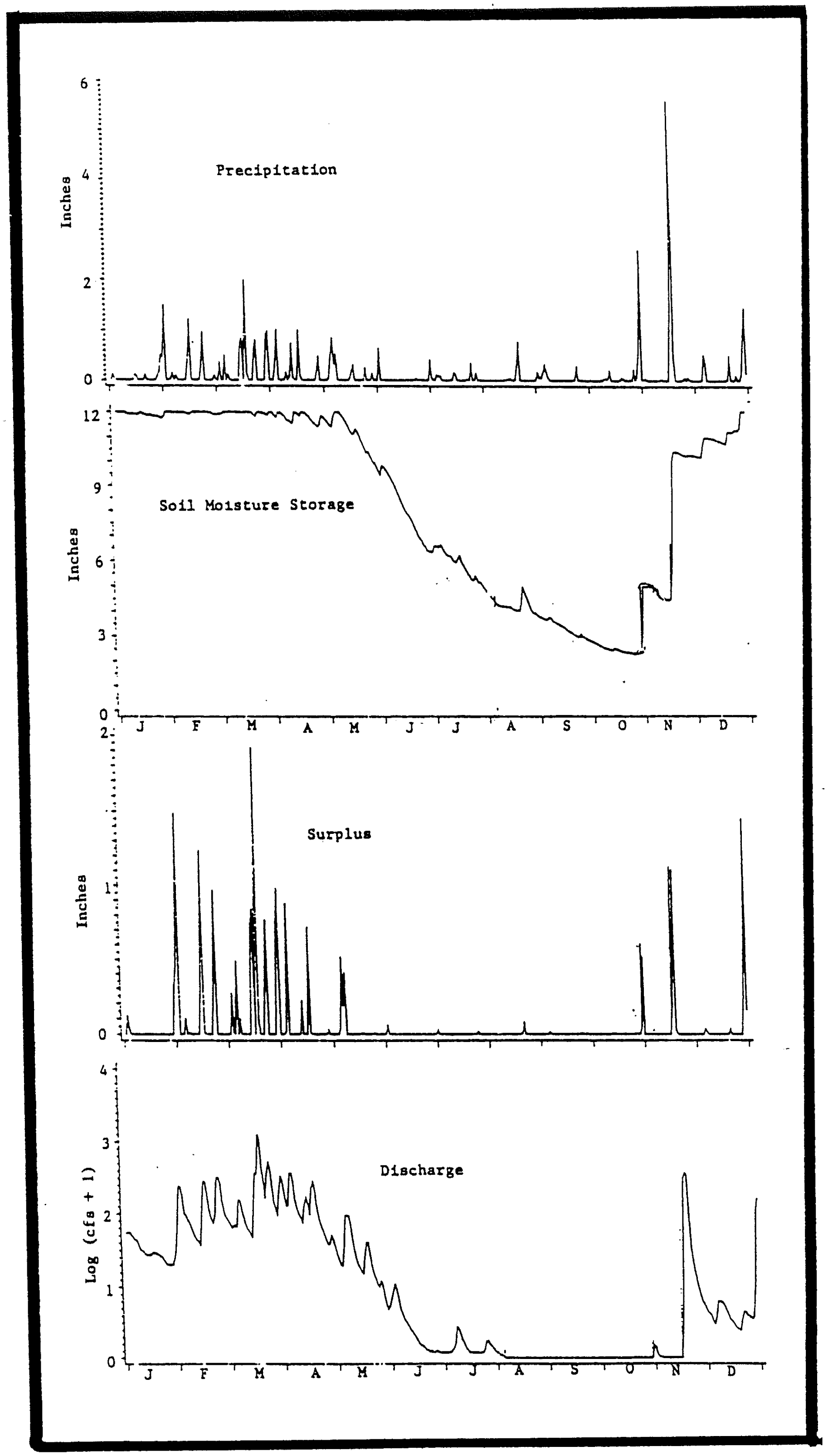


Figure 21. Relationship Among Precipitation, Soil Moisture Storage, Surplus, and Discharge

that would consistently override the soil moisture factor to produce a flood. The preliminary results from this project suggest that, with more cases to study, such a threshold might be determined for a given site.

Conclusions

The objectives of this study have been to identify and catalog significant flash floods that have occurred in Louisiana's main urban areas; define and describe the synoptic atmospheric environment leading to flash flooding using a previously defined classification scheme; compare and contrast the atmospheric and surface conditions that develop into urban flash floods in different parts of the state; and finally, to define and describe high-risk scenarios for the development of flash floods in Louisiana's main urban centers. The following conclusions can be drawn.

(1) Flash flooding is a problem in urban areas throughout the state. Based on the documentation of floods compiled in this study, urban areas will experience an average of at least 1½ to 2 major urban flood events a year, and in the 1980s, this average increased to an average of 3 to 4 documented events per year for some cities.

(2) The potential for flash flood occurrence in the cities of Louisiana can be estimated from the number of days having daily rainfall totals of ≥ 2 inches. Actual days of occurrence of flash floods will be about 25% - 50% of the potential flash flood days, depending on a variety of factors. In general, the southernmost cities of New Orleans, Baton Rouge, Lafayette and Lake Charles have a higher potential for flash flood occurrence than the northernmost cities of Shreveport and Monroe. Alexandria appears to have a higher potential for flash flooding and more actual documented flash floods than might be expected, given its distance from the Gulf. Alexandria is located just north of a region that gets enhanced rainfall on an annual basis due to a subtle topographic effect, and this may be a factor in its unusual response to potential and actual flash flooding.

(3) Although summer is the wettest season -- on an average monthly basis -- for Lake Charles, Lafayette, Baton Rouge, and New Orleans, spring is the season most prone to both potential and actual urban flash flooding throughout the state. Fall and early winter are also flood-prone seasons, but severe flash flooding can occur in any month of the year.

(4) Based on the compilation of documented floods, urban flash flooding has increased in frequency in recent years in Monroe and Alexandria, but has decreased slightly from a peak in the 1970s in Lafayette. This increase in flood frequency appears to parallel a corresponding increase in

the occurrence of heavy rainfall days, hence it may, or may not be, a direct response to increased urbanization, which has taken place at all major cities in the state.

(5) The synoptic atmospheric patterns that generate flood-producing rainfall have distinct characteristics and can be classified. Based on this classification, most urban flash floods in Louisiana occurred in response to a frontal situation, supported by an upper air trough or a cutoff low to the west, and frequently a squall line in association with the front. Fronts generally were aligned in an east-west or northeast-southwest orientation across the state. Stationary fronts were often aligned along the coastline. Disturbed tropical weather, including excess moisture from remnants of tropical storms and hurricanes, was also a factor in urban flash flooding, primarily in summer and fall. Regardless of the synoptic pattern, distance from the Gulf of Mexico and its source of warm, moist air appears to be the main reason for much higher rainfall totals and flooding in the southern part of the state. This is also the region most affected by tropical storm paths.

(6) An Urban Flash Flood Geographic Information System (UFFGIS) was developed to monitor the nature of changing surface conditions which may be a factor in urban flash flooding. Detailed mapping of both soil type and land use revealed that most of the soils underlying urban basins in the state have slow infiltration rates. No basin in the study was completely urbanized, and there appears to be much room for continued urbanization, which will pose more high-risk situations for urban flooding. Of all the basins, Ward Creek in Baton Rouge was the most urbanized, and Bayou Fountain, also of Baton Rouge, was the least. Both basins experience flash flooding problems, suggesting that factors other than the percentage of impermeable surfaces in a basin, such as soil drainage properties, antecedent moisture conditions, etc., must be seriously evaluated when attempting to assess the flood hazard.

(7) The degree of soil moisture storage was found to be an important determinant of whether or not a potential flash flood would become an actual flash flood. A computed time series of daily soil moisture storage was used successfully to explain most instances of flooding, or the lack of it, given a precipitation event of a reasonable size. Instances when flooding occurred even when soil moisture storage levels were low were usually related to intense rainfalls.

Epilogue: Some High-Risk Scenarios for Louisiana Cities

Shreveport - Shreveport has the lowest annual precipitation of the seven cities in this study and is furthest away from the Gulf and its source of precipitable water vapor. Soil moisture storage values near Shreveport tend to be the lowest in the state, especially in the spring and summer. Brush Bayou, its main urban basin, was about two-thirds urbanized in 1978 and one-fourth of the basin was in forest land. In fact, it is the *most* forested of all seven case study basins. No specific mention is made of any chronic flooding problems within the Brush Bayou basin in the 1986 "Report of Flood Problem Areas" (Gulf South Research Institute, 1986). What then would contribute to a high-risk scenario for urban flash flooding in this part of Shreveport? Brush Bayou's soil map shows that almost 90% of the basin is underlain by soils of the poorest drainage ability and the greatest runoff potential (Group D soils). Hence despite the relatively large percentage of forested land, and the tendency for the soil to be unsaturated during a good part of the year, infiltration into the soil will be very slow during a rainstorm of any size. The highest risk for urban flash flooding at this site would occur with an extremely large and high intensity precipitation event that would most likely be produced by a stalled spring front or by remnant moisture from a tropical storm in summer. A search of Appendix A shows that a daily rainfall of 12.05 inches was measured at Shreveport on 24 July 1933, and even larger events are possible, based on the maps for the 100-year return interval design storm (Figure 15).

Monroe - Monroe also has a relatively low annual precipitation total, low soil moisture content, and relatively few heavy rainfall events, due to distance from the Gulf. Almost three-quarters of Youngs Bayou, its main drainage basin, was urbanized in 1978. The underlying soils are a complex mix of Group C and D soils and because of their poor drainage ability and relatively low relief, a pump system is needed to handle the runoff generated by large storms. Backwater flooding from Bayou LaFourche is also a problem according to the 1986 "Report of Flood Problem Areas." Monroe's time of greatest flash flooding potential is in April and May, due to frontal storms, but its largest recorded precipitation events have occurred in summer (6.68 inches in June 1950 and 6.12 inches in July 1933). Either a spring stalled front or a summer tropical storm remnant would provide the highest risk scenario for flash flooding in Monroe. If pumps were to fail, or backwater effects occur, an even worse scenario would probably ensue.

Alexandria - Of the three cities where flash floods were documented in this study, Alexandria experienced the most flooding between 1950 and 1985. The city also showed the greatest increase in both documented and potential flash floods during the 1980s. Indeed, both the precipitation and flooding regime of this city is unique. According to the "Report of Flood Problem Areas" the city contains a number of areas that experience flooding problems of a chronic nature. Inadequate drainage into Bayou Rapides and backwater effects from diversion channels and canals compound the problem. In 1978 the basin of Hynson Bayou was more than three-fourths urbanized, and development has continued since them. The underlying soils in Hynson Bayou are relatively simple, having a 68% to 32% ratio between Group B soils with high drainage ability and Group D soils with very low drainage ability. Backwater flooding is a major problem in the basin. Alexandria has experienced numerous instances of daily rainfalls ≥ 6 inches, most of which have occurred between October and December; however, its greatest daily total of 9.75 inches during 1930-1985 occurred in July (7/25/33; same storm as Shreveport's record-breaking total). A high-risk storm event would be a frontal system occurring in late spring or December, or a tropical storm system occurring in summer.

Lake Charles - Lake Charles has a fairly consistent precipitation regime from month to month and receives more spring and summer heavy rainfall than most other parts of the state. Flooding problems have been severe due to low elevations, backwater effects from the Calcasieu River, and hurricanes. Bayou Contraband in Lake Charles was about 64% urbanized in 1978, but has since undergone extensive development with subdivisions, shopping malls, and an airport just outside the drainage boundaries. The underlying soils complex in the basin is simple: almost 95% Group D, having very low drainage ability. Lake Charles' daily precipitation record of 15.67 inches (on 16 May 1980) is the largest occurring at any city in this study. A daily rainfall of 10.22 inches was also experienced here in August of 1962. The high-risk flash flood factors in Lake Charles have a slightly different emphasis than those of the other cities. Summer hurricane rainfall will produce the highest risk, along with backwater effects, and possible tidal inflows from the Calcasieu River.

Lafayette - Of the cities whose floods were documented in this study, Lafayette was the only city to show a decrease in flooding in recent years. The effect of backwater from the Vermillion River is minimized by flow regulation, and a natural storage region during flood flow reduces the effect of overbank flooding. One of the few areas that experiences urban street flooding is a subdivision in the Coulee Mine basin, which in 1978, was only 37% urbanized and 63% agricultural land. The soils underlying Coulee Mine are a complex mixture of Group B, C, and D soils, with C being the most abundant. April is the dominant month of both heavy precipitation and documented flash flooding, and the city's heaviest rainfalls have occurred in spring due to frontal systems: 10.38 inches (16 May 1980) and 7.84 inches (21 April 1979). Additional heavy rainfalls have occurred in summer and fall due to tropical storms and hurricanes, and these also would contribute to a high-risk flooding situation in this city which appears to be the least flood-prone of all seven in the state.

New Orleans - New Orleans experiences the highest annual precipitation of the seven main cities, and has the highest number of potential flash flood days. No sample basin was examined for the city, partly because the artificial drainage system of pumps would override the importance of any natural features in the basin. Heavy rainfalls are likely to occur in nearly every month in New Orleans. In fact, the record rainfall during the period 1948-85 fell during November, a relatively dry month at most of the other cities. A detailed examination of the New Orleans heavy rainfall regime can be found in Keim (1990) and its many flood problems are elaborated in the flood problem area report (Gulf South Research Institute, 1986).

Baton Rouge - Urban flooding problems abound in Baton Rouge and include riverine, backwater and headwater flooding. The two study basins illustrate two different aspects of the problem. Ward Creek is a heavily urbanized basin with a complex of Group C and D low drainage soils. In 1978 Bayou Fountain was almost 50% agricultural land, 19% forested land, and 16% wetland, in comparison with its relatively small urbanized area of 14.5% Since that time urbanization in the Bayou has continued and brand new subdivisions have faced severe flooding problems. The poor drainage ability of the underlying soils compounds the problem. High-risk flash flood scenarios occur under heavy rainfall conditions due to either persistent spring frontal systems or summer rainfall from a dissipating tropical storm, such as Allison in June, 1989.

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APPENDIX A

List of Daily Rainfall Totals for Days Having ≥ 2 Inches

STATION: ALEXANDRIA

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
30 511	4.41	30 519	3.55	301024	2.20	301130	3.45	3012 5	3.00	301226	2.24	31 111	2.55
31 3 7	2.73	311120	3.77	3112 8	2.60	32 112	3.62	32 126	2.30	32 221	2.87	3210 4	2.94
321125	2.52	321222	2.10	33 2 7	3.52	33 4 9	2.07	33 414	3.60	33 427	2.08	33 526	2.31
33 716	2.68	33 724	2.42	33 725	9.75	33 729	2.05	331218	2.16	34 3 2	2.43	34 3 3	2.48
34 728	2.23	341121	2.20	341228	2.73	35 427	2.06	35 5 6	2.20	35 520	5.46	35 928	2.60
3512 8	3.30	37 424	2.65	37 5 1	5.16	3710 3	5.35	371018	2.93	38 219	2.46	38 319	3.04
38 328	2.15	38 4 6	4.60	38 418	2.31	38 610	3.40	38 815	3.85	3811 4	2.86	39 111	2.02
39 112	2.56	39 129	2.62	39 518	2.93	391025	3.39	391223	2.93	40 411	2.09	40 429	3.43
40 617	4.44	40 8 4	2.74	40 8 8	2.42	40 923	3.61	401111	2.81	401123	3.79	41 5 4	4.53
41 5 5	3.40	41 530	3.84	41 726	2.56	41 9 2	3.02	411030	7.40	411222	2.35	42 4 8	4.52
42 6 5	2.35	42 812	2.07	421227	4.63	43 9 1	3.64	4311 6	2.27	4312 3	2.22	44 5 4	2.10
44 7 1	2.18	44 8 8	3.10	4411 8	2.81	45 2 4	2.52	45 515	2.58	45 7 1	2.88	46 2 8	2.05
46 425	3.16	461111	2.92	47 117	2.38	47 411	3.27	47 420	2.05	47 624	3.72	47 920	4.76*
4712 5	2.02	471215	2.19	48 413	2.26	48 425	2.43	4811 5	6.08	481118	4.24	481126	2.95
49 326	3.47	49 427	2.87	49 723	2.96	49 8 4	2.43	4910 4	2.50	491217	2.43	50 212	2.73
50 429	2.16	50 513	4.49	50 6 3	2.51	501018	5.47	5011 3	2.78	51 1 2	2.10	51 327	2.83
51 421	2.77	51 5 2	2.29	5112 8	3.36	52 127	2.06	52 2 1	2.81	52 423	2.45	52 523	2.09
52 716	2.52	5211 9	2.16	5212 4	2.01	53 311	3.06*	53 429	8.55	53 5 5	3.14*	53 513	3.45
53 517	2.30	53 518	4.40	531026	3.50	5312 3	2.88	54 121	2.30	54 415	2.00	54 5 1	2.50
541013	2.60	55 2 5	3.63	55 517	2.00	55 8 5	2.03	5510 1	2.90	56 122	2.00	56 3 3	2.04
56 7 9	2.78	561213	3.36	561222	2.75	57 331	2.13	571016	3.19	571023	3.66	5711 8	2.25
571113	3.38	58 622	2.27	58 823	3.20	58 917	3.04	59 6 2	2.35	591217	3.13	60 5 5	3.44
601030	2.02												

NO. OF MISSING OBSERVATIONS: 319
TOTAL NO. OF DAYS EXAMINED: 11323
NO. OF DAYS [P >= 2.0]: 155

* - indicates that the value could be an accumulated total for a period of more than one day

STARTING DATE: 30 1 1 ENDING DATE: 601231

STATION: ALEXANDRIA

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
61 1 7	2.10	61 1 8	2.90	61 317	3.52	61 330	2.46	61 626	2.57	6111 3	2.05	611113	2.06
611218	2.10	62 1 5	2.52	62 629	2.57	62 830	2.12	64 3 2	3.42	641115	4.25	641211	6.00
65 3 1	3.50	65 910	2.00	65 923	3.06	651218	2.40	66 210	5.23	66 421	2.84	6612 9	2.30
67 414	2.63	67 415	5.95	671030	4.43	671215	6.10	671218	2.23	68 1 9	2.93	68 813	2.53
6812 1	2.87	69 222	2.40	69 318	2.10	69 723	7.93	6912 6	3.40	691230	2.20	70 5 2	3.30
70 624	3.80	701012	5.41	71 5 7	2.17	71 916	2.60	7112 6	5.58	7112 7	2.42	72 120	2.86
72 916	2.60	721023	8.12	721221	2.99	73 2 1	2.50	73 316	4.00	73 325	4.65	73 4 7	2.43
73 5 2	2.17	73 5 7	2.28	73 9 5	2.08	73 9 6	2.96	731012	2.03	74 413	2.72	74 522	2.18
74 618	2.40	7412 7	2.00	75 5 4	3.15	751016	3.51	751026	2.55	76 331	2.33	76 5 8	2.34
76 6 1	2.25	76 616	3.99	76 718	2.66	77 3 4	5.01	77 421	2.74	77 5 2	3.31	7711 2	3.07
78 124	2.02	78 6 7	3.00	78 829	5.03	79 120	3.60	79 224	2.27	79 421	2.14	79 920	3.52
79 921	5.00	791031	3.29	791123	2.37‡	791213	2.78	80 123	3.01	80 2 9	2.79	80 328	2.60
80 412	3.85	80 426	2.15	801018	6.10	81 3 4	2.00	81 330	2.40	81 6 6	2.46	82 216	2.88
82 331	2.13	82 421	2.00	82 621	2.16	82 8 7	2.00	82 912	3.07	8212 1	3.76	8212 4	2.50
821226	7.20	821227	3.40	83 2 1	2.76	83 3 5	2.18	83 324	2.23	83 4 6	6.90	83 414	2.22
83 516	3.40	83 519	2.30	83 8 3	2.95	83 8 9	2.87	83 921	2.61	831123	2.28	8312 3	2.45
831211	2.18	84 212	4.03	84 4 3	3.25	84 4 9	2.11	84 6 7	7.32	84 7 9	2.19	84 8 6	3.30
84 923	2.12	841021	5.55	8411 2	2.00	841127	2.62	85 224	4.85	85 7 4	3.31	85 816	3.87
85 9 3	3.80	851015	2.80	851024	2.45	851028	3.25	851030	2.15	851212	2.38		

NO. OF MISSING OBSERVATIONS: 3
TOTAL NO. OF DAYS EXAMINED: 9131
NO. OF DAYS [P >= 2.0]: 132

STARTING DATE: 61 1 1 ENDING DATE: 851231

‡ - indicates that the value could be an accumulated total for a period of more than one day

STATION: SHREVEPORT WAO AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
30 1 8	2.08	30 126	2.04	301129	2.40	311028	2.17	311119	2.20	311212	2.80	32 1 4	2.48
32 330	3.72	32 625	2.52	33 330	2.90	33 715	3.27	33 723	5.11	33 724	12.05	3310 1	2.21
34 1 3	2.29	34 3 2	3.10	341120	3.10	35 120	3.15	35 5 4	4.43	35 5 5	2.19	351027	2.03
3512 6	2.60	36 3 4	2.06	37 1 1	2.36	371017	2.82	3711 9	2.78	371115	3.84	38 4 7	2.30
3811 3	2.05	3811 6	2.37	39 112	2.58	39 2 2	2.99	391111	2.23	391222	3.38	40 4 6	2.67
40 429	2.49	40 628	2.30	40 828	2.46	401122	3.07	401123	2.22	401212	2.03	401226	2.28
41 1 1	2.37	41 219	2.25	41 5 5	4.57	411030	4.03	411122	2.19	42 4 8	2.41	42 425	5.25
42 513	2.63	42 518	3.42	42 823	3.00	43 325	2.44	43 417	2.06	44 328	4.37	44 5 2	2.46
4412 5	3.17	441231	2.44	45 118	2.63	45 3 3	4.35	45 4 1	2.27	45 422	3.15	45 515	2.99
45 712	3.15	4510 5	2.75	46 1 4	4.20	46 429	2.25	46 513	2.09	46 531	2.10	46 6 8	3.01
47 219	2.34	47 312	2.35	47 4 7	2.62	47 4 8	2.28	48 525	2.20	4910 4	6.81	491021	2.68
491231	2.46	50 429	2.71	50 7 6	3.36	50 831	2.45	5112 8	2.30	52 211	2.40	52 310	2.03
52 412	3.26	52 528	2.42	53 122	2.32	53 428	5.52	5312 2	2.50	5411 3	2.79	55 2 4	2.22
55 412	2.57	55 520	2.19	55 523	4.65	55 722	3.54	55 8 3	2.97	56 4 5	2.65	56 5 1	2.40
57 218	2.17	57 427	2.94	57 612	3.57	57 912	2.39	571022	3.87	5711 7	2.00	58 426	2.60
58 616	2.03	58 626	4.04	58 921	2.42	59 214	2.29	60 625	2.79	60 826	2.75	60 925	3.53

NO. OF MISSING OBSERVATIONS: 5
TOTAL NO. OF DAYS EXAMINED: 11323
NO. OF DAYS [P >= 2.0]: 112

STARTING DATE: 30 1 1 ENDING DATE: 601231

* - indicates that the value could be
an accumulated total for a period
of more than one day

STATION: SHREVEPORT WSO AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
61 619	3.70	61 912	2.90	61 913	2.57	6110 1	2.42	6112 9	2.30	62 625	2.29	62 829	2.01
631121	2.86	64 4 5	2.04	64 424	2.40	64 426	2.07	64 818	2.04	65 922	2.47	651211	3.35
67 531	4.41	68 1 9	2.84	68 427	2.10	68 718	2.12	68 915	4.91	691117	4.64	691118	2.66
70 430	2.15	70 526	2.15	701027	2.95	701220	2.81	71 215	2.00	711118	3.10	72 1 1	2.11
72 721	2.72	72 729	4.30	721026	2.72	73 324	2.17	73 424	2.04	73 7 7	3.46	7311 4	2.14
7312 3	3.16	74 311	2.05	74 6 7	4.08	74 7 5	2.70	74 724	2.70	74 9 8	2.04	741028	2.41
76 531	2.63	76 914	2.30	76 917	3.08	77 211	3.08	77 3 3	2.19	78 410	2.33	78 5 6	4.65
78 829	2.38	79 1 6	2.07	79 119	3.17	79 330	3.20	79 422	3.06	79 920	2.24	791030	2.19
791121	3.80	81 5 9	5.23	81 6 5	2.28	81 9 1	2.67	82 728	3.44	821214	2.83	83 2 5	2.95
83 221	2.74	83 521	2.19	83 6 5	4.02	831210	2.52	84 212	2.97	84 3 4	2.04	84 5 7	3.49
8410 6	2.16	841020	2.62	841021	2.33	85 320	2.22	85 610	2.31	85 7 3	3.26	851014	3.01
851124	2.10	851211	2.30										

NO. OF MISSING OBSERVATIONS: 0
TOTAL NO. OF DAYS EXAMINED: 9131
NO. OF DAYS [P >= 2.0]: 79

STARTING DATE: 61 1 1 ENDING DATE: 851231

‡ - indicates that the value could be an accumulated total for a period of more than one day

STATION: NEW ORLEANS WSCMO AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
48 3 3	2.53	48 3 5	7.87	48 9 3	2.70	48 913	4.74	481116	2.00	481121	2.25	481126	2.75
49 329	2.05	49 428	2.80	49 611	2.21	49 9 4	2.17	50 213	2.80	50 4 3	2.39	50 6 6	3.81
51 328	3.97	51 416	2.58	51 831	2.07	52 127	2.31	52 214	2.17	52 331	2.60	52 412	2.63
52 519	2.18	521230	3.36	53 214	2.46	53 322	2.20	53 425	4.22	53 628	3.98	53 716	3.20
531119	6.18	531122	2.05	531211	3.03	54 5 3	3.25	54 621	2.20	54 720	2.80	54 916	3.58
54 930	2.15	541231	2.17	55 116	3.13	55 2 5	3.50	55 520	2.62	55 727	2.67	55 8 1	2.15
55 9 4	3.55	56 215	3.32	56 613	2.66	56 7 9	2.00	56 923	4.06	56 930	2.53	561219	2.19
561223	2.38	57 4 4	3.62	57 8 1	2.48	57 830	2.06	57 917	2.73	57 918	2.73	58 120	3.17
58 323	2.39	59 223	3.06	59 224	2.34	59 3 5	2.77	59 511	2.15	59 531	9.85	59 6 8	2.91
60 327	2.53	60 4 2	2.30	60 5 6	2.35	60 717	3.00	60 8 2	2.25	60 910	3.22	6010 5	2.04

NO. OF MISSING OBSERVATIONS: 1
TOTAL NO. OF DAYS EXAMINED: 4749
NO. OF DAYS [P >= 2.0]: 70

STARTING DATE: 48 1 1 ENDING DATE: 601231

* - indicates that the value could be an accumulated total for a period of more than one day

STATION: NEW ORLEANS WSCMO AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
61 221	4.75	61 317	3.57	61 716	2.78	611113	5.37	62 619	3.18	63 119	2.79	63 218	2.09
63 519	2.16	63 9 7	2.00	63 916	3.01	6311 9	3.61	64 1 6	3.98	64 319	2.49	64 414	2.34
6410 3	2.19	641211	2.52	65 122	3.25	65 910	2.84	651218	2.26	66 1 3	2.29	66 1 4	2.20
66 226	2.35	66 521	2.78	66 715	2.64	66 731	4.29	661010	2.21	67 2 6	4.49	67 414	2.15
67 719	2.12	67 9 6	2.09	671030	2.54	6712 9	3.45	69 8 8	3.06	70 3 3	2.73	70 516	2.01
70 811	2.10	70 821	2.68	701215	2.87	71 628	2.20	71 9 4	5.39	71 915	2.52	71 916	2.12
72 120	2.50	72 512	4.70	72 6 9	2.76	721026	3.18	721118	2.90	73 324	5.10	73 4 7	2.00
73 416	3.27	73 417	3.13	73 524	2.04	73 616	2.22	73 9 6	2.08	73 913	2.26	731219	2.20
731225	4.01	74 123	2.03	74 125	2.32	74 2 2	3.75	74 326	4.24	74 415	2.34	74 511	2.54
74 521	2.35	74 9 7	2.86	75 414	2.44	75 430	2.79	75 529	2.22	75 6 8	2.14	75 610	2.20
75 8 1	4.82	751016	2.30	7511 5	8.52	761029	2.11	761214	2.04	761225	2.43	77 420	3.88
77 822	3.16	77 824	2.09	77 9 5	4.98	77 915	2.83	771011	2.03	771229	2.55	78 124	4.60
78 125	2.13	78 412	2.40	78 5 3	6.25	78 629	2.43	78 7 5	2.02	78 711	3.35	78 814	2.64
78 822	4.77	781126	2.05	7812 4	2.58	79 2 5	2.11	79 2 6	4.15	79 322	2.02	79 422	2.40
79 920	2.09	80 111	2.35	80 222	2.27	80 329	3.25	80 4 2	4.85	80 412	5.27	80 413	3.28
80 516	4.49	80 518	2.23	80 923	2.77	801126	2.38	81 210	4.33	81 5 5	2.79	81 610	3.25
81 830	2.14	82 2 2	3.83	82 424	2.71	82 912	2.27	8212 3	3.55	8212 4	2.16	83 2 1	4.85
83 2 5	3.35	83 2 9	2.19	83 4 7	6.41	83 422	5.31	83 622	2.41	83 9 6	2.74	831012	2.84
831119	2.17	831227	3.93	84 319	2.31	84 520	2.30	84 612	2.45	84 8 3	3.33	85 2 5	3.64
85 224	3.15	85 320	2.87	85 723	2.73	85 811	2.90	85 815	2.23	851027	4.20	851029	2.01
851212	2.94												

NO. OF MISSING OBSERVATIONS: 0
TOTAL NO. OF DAYS EXAMINED: 9131
NO. OF DAYS [P >= 2.0]: 141

* - indicates that the value could be an accumulated total for a period of more than one day

STARTING DATE: 61 1 1 ENDING DATE: 851231

STATION: LAKE CHARLES WSO AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
48 826	2.70	481127	2.12	49 2 8	2.16	49 224	2.03	49 321	3.06	49 329	3.33	49 6 7	4.80
4910 3	2.39	4910 4	3.29	491020	2.16	491217	2.34	50 6 3	5.47	50 620	5.10	50 7 6	2.19
50 927	2.04	501018	2.35	51 129	2.14	51 327	4.75	51 912	2.29	52 2 1	4.14	52 4 4	2.01
52 423	3.33	52 519	3.45	52 716	7.29	52 717	4.11	5212 4	4.66	53 424	5.08	53 518	4.62
53 710	2.13	53 730	2.20	531026	2.59	5312 3	2.11	54 729	2.27	5411 4	2.38	55 115	2.55
55 2 5	3.13	55 8 3	3.13	5510 7	2.33	5511 6	2.05	56 5 2	2.32	561213	3.73	561222	4.25
57 317	2.34	57 416	4.06	57 421	2.05	57 430	2.34	57 627	6.76	57 926	3.09	571015	3.38
571113	4.92	58 323	2.01	58 722	2.68	58 813	2.38	58 824	2.85	58 921	4.97	59 130	2.63
59 2 2	2.00	59 211	2.91	59 224	2.18	59 511	2.98	59 724	2.30	59 725	4.63	5911 4	2.12
591216	2.37	60 429	4.57	60 713	2.82	601118	2.44	601227	2.20				

NO. OF MISSING OBSERVATIONS: 2
TOTAL NO. OF DAYS EXAMINED: 4749
NO. OF DAYS [P >= 2.0]: 68

STARTING DATE: 48 1 1 ENDING DATE: 601231

* - indicates that the value could be an accumulated total for a period of more than one day

STATION: LAKE CHARLES WSO AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
61 217	3.31	61 619	2.31	61 7 9	2.00	611113	10.00	62 6 4	2.26	62 828	3.90	62 829	10.22
621127	2.90	621228	2.06	63 218	3.16	63 917	3.85	64 630	4.96	64 917	2.35	641210	4.50
65 122	2.10	65 3 1	2.26	65 520	2.59	65 822	2.00	66 418	2.62	66 421	2.09	66 513	3.23
66 613	4.05	66 722	3.00	661111	3.48	67 413	3.60	67 521	4.20	671029	2.66	6712 9	5.89
68 622	3.54	68 7 2	2.73	681130	3.21	69 214	2.67	69 221	2.70	69 4 5	3.83	69 412	3.15
69 5 5	2.08	69 719	3.63	69 720	2.67	6912 6	2.89	7010 6	4.27	701011	3.87	701027	7.20
71 511	4.14	71 7 2	2.28	71 8 4	2.24	71 916	2.31	7112 5	5.85	72 120	2.18	72 129	2.07
72 827	2.82	72 924	3.05	721022	4.10	721026	2.19	7212 5	2.04	73 323	3.43	73 417	5.50
73 5 2	3.91	73 9 4	3.86	73 9 5	4.96	73 912	5.54	7311 5	2.09	731219	2.38	74 119	3.56
74 510	3.01	74 521	2.42	74 531	2.20	741028	2.70	7412 6	2.19	75 1 7	2.71	75 421	3.23
75 721	2.27	75 916	3.94	751126	3.35	76 6 1	2.06	76 617	2.10	761029	2.88	77 113	2.73
77 420	3.60	77 614	3.82	77 823	5.87	771129	3.14	78 124	2.10	78 6 6	2.54	78 828	5.88
78 9 9	2.12	79 420	3.79	79 530	5.53	79 725	6.36	79 814	2.13	79 920	9.64	791122	3.11
80 327	2.72	80 516	15.67	80 727	2.07	80 728	4.21	801018	3.45	8012 9	2.32	81 2 5	2.43
81 531	4.40	81 610	4.94	81 611	2.32	81 726	2.26	82 513	2.97	82 616	2.40	82 8 7	2.31
82 830	2.50	82 911	6.63	821127	2.72	821226	4.79	83 131	2.49	83 2 5	2.24	83 520	4.82
83 812	2.31	83 9 6	2.52	83 919	2.12	84 1 9	2.59	84 519	3.23	84 520	3.27	84 7 1	2.00
84 8 4	3.10	84 921	2.97	84 922	2.09	8410 7	2.40	8410 9	2.29	841014	2.47	8412 2	2.80
85 320	2.55	85 523	2.06	85 815	4.10	851027	4.04	851028	3.24				

NO. OF MISSING OBSERVATIONS: 0
TOTAL NO. OF DAYS EXAMINED: 9131
NO. OF DAYS [P >= 2.0]: 131

STARTING DATE: 61 1 1 ENDING DATE: 851231

* - indicates that the value could be an accumulated total for a period of more than one day

STATION: BATON ROUGE WSO AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
30 129	2.65	30 3 2	2.76	30 519	3.60	30 520	2.14	3010 8	2.10	301116	2.17	31 1 5	2.30
31 112	2.36	31 5 4	2.16	31 712	2.39	31 821	3.47	32 1 6	2.05	32 124	2.00*	32 222	3.00
32 430	2.45	32 521	2.32	32 920	2.77	321016	2.36	321026	2.00	321125	2.62	33 421	2.40
33 527	2.35	33 717	2.00	33 8 7	2.00	3311 2	2.06	331122	2.30	34 2 1	2.00	34 617	3.90
34 727	2.55	3410 1	2.72	341010	2.44	341120	3.88	35 121	2.28	35 211	2.30	35 420	3.23
35 520	3.00	35 714	2.30	351212	3.98	351229	2.15	36 823	2.37	36 9 6	2.44	37 1 5	2.29
37 119	2.00	37 5 1	3.22	371018	2.10	38 222	2.15	381226	2.30	39 6 9	2.00	39 818	2.16
39 831	2.27	40 8 1	2.58	40 8 2	2.25	401111	3.70	41 712	2.12	411223	2.03	42 1 1	4.57
42 215	2.74	42 4 8	6.36	42 622	2.07	42 8 4	2.60	42 917	2.82	421227	2.02	43 317	3.24
43 321	2.35	43 326	2.16	43 9 2	2.94	43 917	2.63	43 919	2.01	4311 7	3.70	431225	2.95
44 323	2.88	44 423	2.00	44 612	2.29	44 8 3	3.45	44 8 9	2.24	44 929	2.30	4411 9	2.09
45 1 7	2.30	45 122	2.44	45 2 5	2.00	45 326	2.08	45 4 1	2.00	45 425	2.10	45 817	2.00
46 1 5	2.00	46 3 8	2.81	46 316	2.05	46 512	2.02	46 514	2.05	46 6 1	3.03	46 7 5	3.14
461110	2.40	47 313	7.29	47 618	2.29	47 919	3.79	471110	2.24	4712 9	2.67	48 3 2	2.27
48 3 5	2.56	48 527	2.94	481121	2.43	481126	5.04	4812 7	2.59	49 321	3.31	49 422	2.82
49 711	2.62	50 1 6	2.07	50 213	2.48	50 3 3	2.44	50 4 3	2.84	50 6 6	2.47	50 620	3.20
5012 5	3.33	51 328	2.15	51 728	2.72	51 925	3.32	5111 1	2.09	52 4 4	2.56	53 322	3.43
53 424	4.10	53 5 3	2.36	53 518	4.83	53 821	3.28	5312 3	3.43	5312 9	3.97	54 5 2	4.55
54 729	2.10*	55 115	2.01	55 2 5	3.40	55 4 9	2.64	55 410	2.72	55 412	2.07	55 520	3.75
551125	2.32	56 4 9	2.42	56 720	2.33	57 926	3.60	58 112	2.00	58 323	2.99	59 2 2	3.25
59 511	3.51	59 7 1	2.56	59 7 7	2.31	59 731	2.02	59 8 1	2.62	591216	2.81	60 5 6	2.02

NO. OF MISSING OBSERVATIONS: 38
TOTAL NO. OF DAYS EXAMINED: 11323
NO. OF DAYS [P >= 2.0]: 147

* - indicates that the value could be an accumulated total for a period of more than one day

STARTING DATE: 30 1 1 ENDING DATE: 601231

STATION: BATON ROUGE WSO AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
61 217	4.51	61 317	2.36	61 426	2.15	61 710	3.54	61 911	3.53	611113	4.20	611215	2.02
611217	2.35	62 1 5	2.65	62 427	6.30	62 6 9	3.00	62 628	2.03	6210 1	3.40	621228	2.15
63 7 4	2.06	64 1 6	2.10	64 217	2.06	64 3 1	2.37	64 314	2.15	64 712	2.70	6410 3	4.84
6410 4	4.02	65 216	2.48	65 3 1	2.83	65 910	3.99*	6511 5	2.22	66 210	2.17	66 212	3.65
66 216	2.16	66 226	2.09	66 413	2.16	66 421	3.21	66 7 2	2.72	67 414	11.99	67 711	2.40
67 713	2.10	68 1 1	2.08	68 812	2.78	68 822	2.37	681213	2.07	69 221	2.11	69 413	4.53
69 710	4.26	6910 7	4.06	70 3 3	3.69	70 5 2	3.02	701027	2.10	701223	2.00	71 318	2.24
71 7 1	2.45	71 916	2.32	71 921	2.23	711128	2.09	7112 5	3.05	72 5 7	4.85	72 511	2.28
72 716	2.73	7212 5	2.21	73 324	5.25	73 416	4.32	73 417	2.96	73 5 7	3.19	73 9 5	2.03
73 912	6.31	7311 4	2.82	731224	3.35	74 1 3	2.10	74 119	2.32	74 2 2	2.40	74 326	2.53
74 4 1	2.23	74 8 4	2.31	75 1 7	3.39	75 110	2.41	75 414	3.09	75 430	3.92	75 8 1	2.57
75 8 3	2.15	76 2 6	2.56	76 510	2.99	77 2 3	2.20	77 421	3.63	77 5 2	3.13	77 7 8	2.21
77 824	2.30	77 9 5	5.38	77 910	2.47	771121	2.08	771129	2.45	78 5 3	2.65	78 5 7	3.58
78 7 8	2.19	78 8 6	2.00	78 829	2.60	781126	2.37	79 222	2.27	79 223	3.03	79 3 2	2.35
79 421	5.24	79 422	3.56	79 530	2.73	79 711	2.77	791213	2.16	80 229	2.32	80 329	2.19
80 4 2	3.95	80 412	4.54	80 413	3.33	80 516	4.25	80 619	2.93	80 721	2.23	80 731	2.15
801018	4.73	801122	2.31	81 2 5	2.90	81 5 5	2.47	82 215	2.74	8212 3	7.22	821226	2.89
83 4 5	5.03	83 4 6	4.19	83 6 6	3.13	83 8 1	5.11	831211	3.42	84 226	2.34	8410 8	3.20
841017	2.52	841022	4.70	85 225	2.06	85 716	2.45	85 815	2.82	851027	2.15	851212	2.13

NO. OF MISSING OBSERVATIONS: 1
TOTAL NO. OF DAYS EXAMINED: 9131
NO. OF DAYS [P >= 2.0]: 133

STARTING DATE: 61 1 1 ENDING DATE: 851231

* - indicates that the value could be an accumulated total for a period of more than one day

STATION: LAFAYETTE FAA AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
48 3 2	2.52	481126	4.72	49 321	3.62	49 329	2.08	49 529	2.42	49 815	6.18	4910 4	3.85
4910 7	4.00	491030	2.96	50 1 5	2.39	50 429	2.03	50 6 3	2.27	50 619	2.83	50 620	2.38
5012 5	4.30	501226	2.28	51 328	2.17	51 617	2.04	51 728	2.27	52 222	2.77	52 4 4	3.01
52 423	2.10	52 519	3.01	52 9 1	3.09	53 314	2.59	53 424	3.72	53 429	2.07	53 513	2.09
53 518	3.78	53 821	2.21	531121	3.28	5312 3	3.61	54 7 7	2.41	54 729	5.66	55 115	2.51
55 2 5	4.91	55 4 9	2.41	55 410	4.97	55 520	3.43	5512 1	2.29	56 2 3	2.06	56 3 3	2.43
56 5 2	2.16	56 527	2.00	561115	2.57	561219	4.37	57 318	2.32	57 416	2.51	57 421	2.25
57 5 1	4.45	57 627	3.69	57 911	3.18	57 926	2.17	571015	4.09	58 414	3.33	58 619	2.23
58 711	2.63	59 130	2.77	59 2 2	3.96	59 223	2.02	59 224	2.72	59 511	2.91	59 6 8	2.24
591013	2.10	591216	2.54	60 429	4.36	60 7 9	2.22	60 731	3.28				

NO. OF MISSING OBSERVATIONS: 4
TOTAL NO. OF DAYS EXAMINED: 4749
NO. OF DAYS [P >= 2.0]: 68

STARTING DATE: 48 1 1 ENDING DATE: 601231

* - indicates that the value could be
an accumulated total for a period
of more than one day

STATION: LAFAYETTE FAA AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
61 515	2.75	61 619	5.71	61 828	2.71	61 913	2.19	611113	3.71	611215	2.61	62 126	2.02
62 427	2.99	62 531	2.64	6210 1	2.55	621228	2.53	63 620	2.39	63 726	2.06	63 917	5.92
64 1 6	2.13	64 3 1	2.65	64 5 1	2.15	64 7 2	2.19	64 7 3	2.88	64 822	2.29	64 916	2.00
6410 3	7.10	65 3 1	3.13	65 821	2.26	65 910	3.79	66 212	2.54	66 215	2.27	66 421	3.63
66 613	2.40	66 8 6	2.00	66 927	2.34	67 326	2.06	67 415	2.75	67 521	2.24	67 7 4	2.31
67 7 6	2.15	67 713	2.70	67 722	2.82	67 826	5.01	67 827	3.77	671030	3.53	6712 9	2.27
671219	2.29	68 524	3.32	68 617	2.19	68 9 4	2.53	681130	2.25	69 221	2.46	69 323	2.59
69 4 5	2.66	69 412	2.77	69 413	2.34	69 416	2.29	69 819	2.05	70 824	2.56	70 924	2.01
701012	2.18	701027	2.34	71 726	2.07	71 916	3.83	7112 5	5.09	72 120	2.81	72 428	3.46
72 512	2.89	72 616	2.47	72 730	2.22	7212 5	2.52	73 323	2.04	73 324	3.71	73 416	2.34
73 417	2.52	73 9 4	2.51	73 9 5	4.41	7311 5	2.62	74 119	3.03	74 2 6	3.18	74 4 1	2.25
74 412	2.13	74 727	2.02	74 826	2.03	74 9 8	2.46	75 1 7	3.09	75 527	2.11	75 630	2.07
75 711	3.84	75 719	2.33	76 2 6	2.00	76 324	4.04	76 325	2.17	76 5 7	2.04	76 8 2	2.01
76 928	3.66	761029	2.81	761128	2.73	761225	2.08	77 113	2.17	77 420	3.51	77 421	4.40
77 7 9	2.10	77 720	2.07	771011	2.11	78 124	2.52	78 6 6	5.21	78 719	3.95	78 828	4.32
781126	2.60	79 123	3.03	79 222	2.03	79 3 2	4.15	79 421	7.84	79 422	2.71	79 426	2.27
79 530	4.46	79 725	3.65	79 825	2.06	79 920	2.87	80 4 2	3.54	80 413	2.58	80 516	10.38
80 919	2.30	80 930	2.35	801018	4.90	801122	2.17	801126	2.17	81 610	2.48	81 7 2	2.13
82 215	3.82	82 9 3	2.15	82 911	3.73	8210 7	2.09	821127	2.34	821130	2.17	8212 3	5.05
821226	4.87	83 2 5	2.14	83 520	3.12	83 521	3.28	84 520	2.75	841014	2.33	841022	4.18
841023	2.22	8412 2	2.14	85 116	2.17	85 127	2.01	85 320	2.67	85 7 2	2.26	85 930	3.19
851023	4.07	851027	2.78										

NO. OF MISSING OBSERVATIONS: 1
TOTAL NO. OF DAYS EXAMINED: 9131
NO. OF DAYS [P >= 2.0]: 149

* - indicates that the value could be an accumulated total for a period of more than one day

STARTING DATE: 61 1 1 ENDING DATE: 851231

STATION: MONROE FAA AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
30 516	2.20	30 517	3.10	30 519	4.10	3010 7	3.12	3010 8	2.23	301028	2.00	301130	2.18
3012 5	2.11	31 1 5	2.59	311120	2.00	311213	3.10	311214	2.50	311217	2.10	311218	2.95
32 1 5	2.72	32 112	2.87	32 126	3.35	32 130	2.07	32 221	3.30	32 331	2.62	32 526	2.52
321210	3.17	33 420	2.97	33 5 5	3.15	33 716	2.42	33 724	2.73	33 725	3.64	33 726	6.12
33 813	2.43	33 815	2.27	3312 6	2.17	34 1 4	3.10	34 3 2	2.47	34 325	2.17	34 326	2.25
34 7 7	4.27	34 729	2.68	3411 3	3.12	341121	5.38	3412 3	2.28	35 121	2.53	35 3 5	2.70
35 520	2.22	351028	2.00	351111	2.85	3512 7	2.42	36 1 6	2.67	36 7 2	4.36	36 9 9	2.47
361130	2.09	37 321	2.17	37 612	2.11	37 710	2.10	37 711	2.39	37 9 6	2.27	3710 3	2.45
371018	3.10	371223	2.97	38 1 1	2.68	38 4 6	2.69	38 4 7	2.74	38 416	2.37	38 518	2.99
471110	3.28	471114	2.31	48 2 8	2.32	48 212	2.70	48 3 1	2.19	48 413	2.73	481116	2.03
481118	3.19	481215	4.66	49 1 2	3.49	49 614	2.11	49 712	2.82	4910 4	4.28	50 1 5	3.23
50 2 9	2.13	50 212	3.39	50 5 1	2.36	50 6 3	2.66	50 621	6.68	501018	2.12	51 1 2	4.18
51 327	2.22	51 421	2.13	51 618	2.72	51 913	2.77	511220	4.05	52 127	3.39	52 423	2.00
5211 9	2.20	53 220	2.48	53 429	2.99	53 5 4	2.86	53 516	2.28	5312 3	2.54	54 5 1	4.34
54 527	2.22	54 718	3.50	55 321	5.48	55 412	2.67	55 523	2.42	55 714	4.22	56 2 2	3.63
56 4 5	2.83	56 7 9	2.26	57 4 3	3.01	57 627	2.84	571022	2.37	571113	2.28	58 323	2.20
58 429	2.37	58 518	2.19	58 615	2.44	58 920	4.49	59 7 1	2.52	59 9 4	2.60	591013	2.28
591216	2.16	60 717	2.31										

NO. OF MISSING OBSERVATIONS: 397
TOTAL NO. OF DAYS EXAMINED: 8401
NO. OF DAYS [P >= 2.0]: 121

STARTING DATE: 30 1 1 ENDING DATE: 601231

NOTE : Number of missing observations does not include station closure period from July 1938 through July 1947

* - indicates that the value could be an accumulated total for a period of more than one day

STATION: MONROE FAA AP

YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec	YrMoDa	Prec
61 220	3.18	61 317	2.34	6111 2	2.25	611122	2.40	6112 9	3.20	62 411	3.57	621117	2.76
63 726	2.24	64 3 2	2.04	64 424	3.03	641127	3.03	641210	4.05	65 329	3.69	65 910	4.37
66 2 9	4.46	66 420	3.15	66 918	2.05	6612 8	2.41	67 413	2.29	68 4 2	2.00	68 4 8	3.39
68 722	2.70	68 9 3	2.04	68 915	2.51	681127	4.30	69 517	2.55	69 525	2.32	69 9 4	2.88
6912 6	2.29	691229	2.25	70 5 1	2.72	70 623	2.43	701011	2.68	71 221	2.07	71 422	2.04
711118	2.22	711216	2.39	72 1 1	2.13	72 1 3	2.27	731013	2.22	731224	2.56	74 1 6	2.01
74 411	4.48	74 422	2.24	75 312	2.02	75 610	2.31	75 7 8	5.33	751015	2.57	76 217	3.25
76 628	2.20	76 828	4.16	7612 6	2.51	77 3 3	3.91	77 311	2.41	78 5 7	3.68	78 914	4.30
78 915	7.23	7812 3	2.26	79 119	3.08	79 223	2.75	79 4 2	2.39	79 5 4	2.48	79 511	2.00
79 9 2	2.90	79 920	3.37	791122	2.65	791212	2.97	80 316	2.70	80 329	2.11	80 515	2.19
80 516	2.21	801027	3.82	82 419	2.62	82 616	2.88	821012	4.62	821119	2.24	821127	2.51
8212 3	2.86	821225	3.41	821226	3.15	821227	2.16	83 2 9	2.04	83 4 7	2.20	83 515	4.05
83 519	2.10	83 520	4.25	8312 3	4.04	84 212	3.11	84 3 4	2.46	84 327	2.28	84 4 2	2.29
84 6 6	2.17	84 627	3.00	84 820	4.78	841118	2.19	85 210	2.69	85 223	2.27	85 627	2.55
85 8 7	2.34	85 9 3	2.43	85 925	2.14								

NO. OF MISSING OBSERVATIONS: 33
TOTAL NO. OF DAYS EXAMINED: 9131
NO. OF DAYS [P >= 2.0]: 101

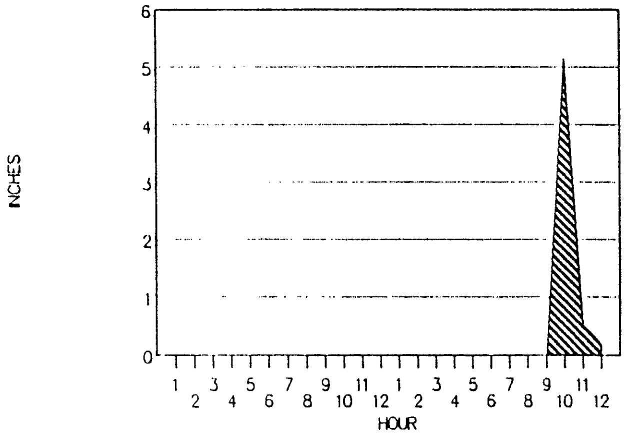
STARTING DATE: 61 1 1 ENDING DATE: 851231

* - indicates that the value could be
an accumulated total for a period
of more than one day

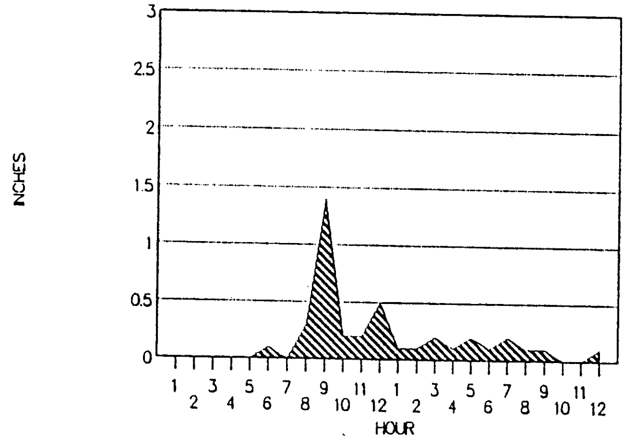
APPENDIX B

Hourly Precipitation Hyetographs for Selected Storm Events

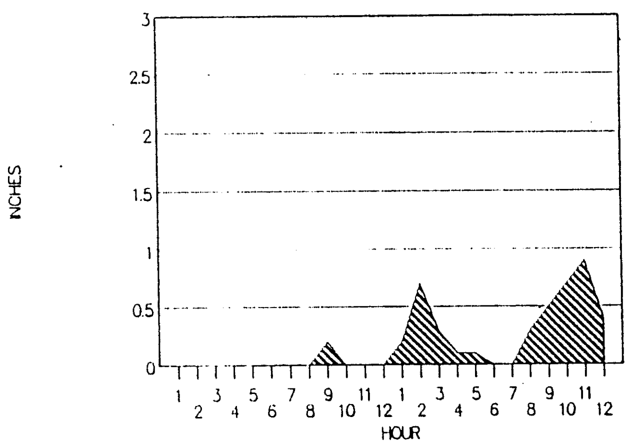
HOURLY PRECIPITATION
MONROE, FEBRUARY 9, 1966



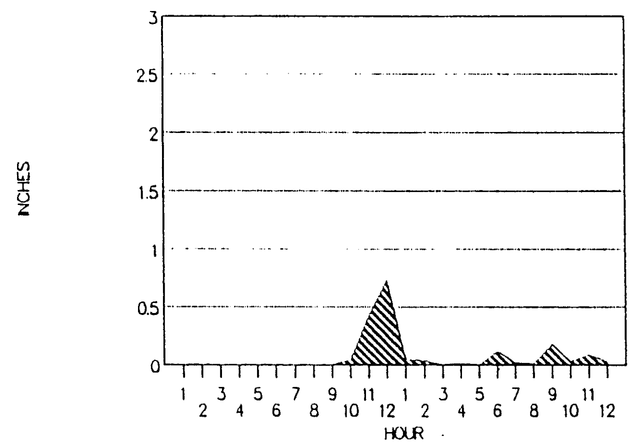
HOURLY PRECIPITATION
MONROE, APRIL 8, 1968



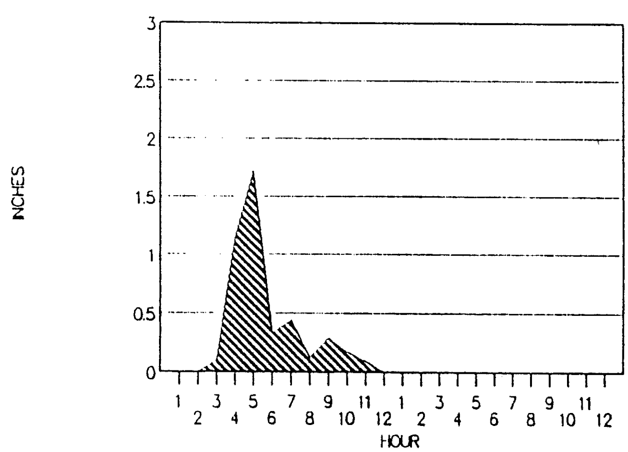
HOURLY PRECIPITATION
MONROE, NOVEMBER 27, 1968



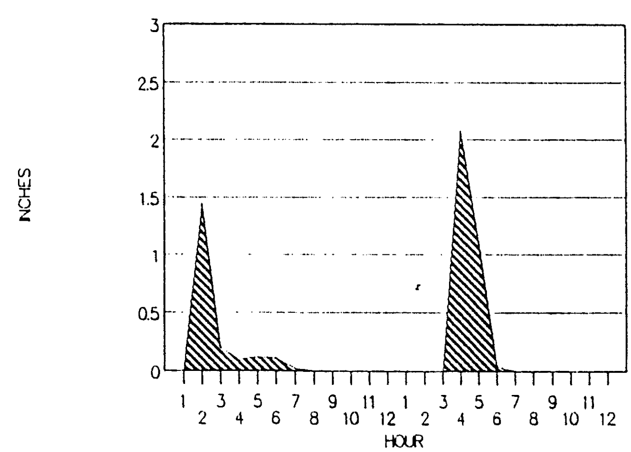
HOURLY PRECIPITATION
SHREVEPORT, FEBRUARY 9, 1966



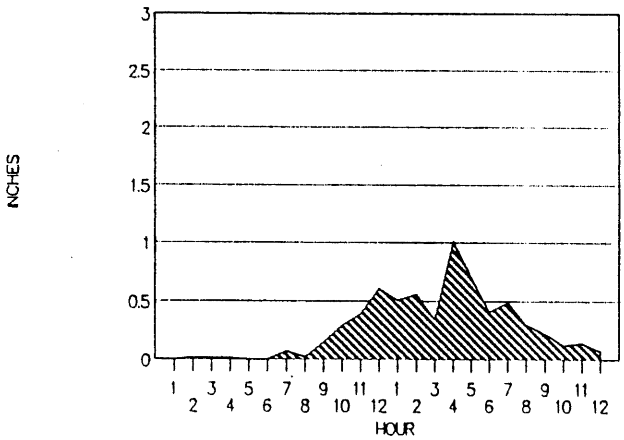
HOURLY PRECIPITATION
SHREVEPORT, MAY 31, 1967



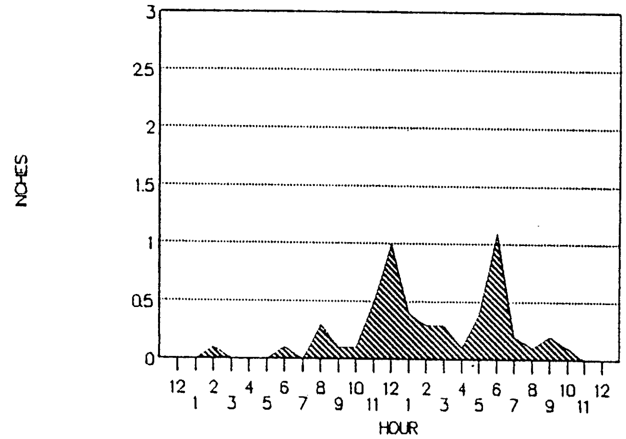
HOURLY PRECIPITATION
SHREVEPORT, MAY 9, 1981



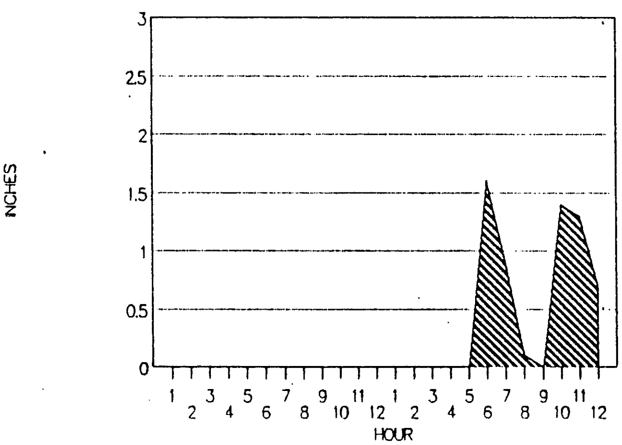
HOURLY PRECIPITATION
ALEXANDRIA, DECEMBER 10, 1964



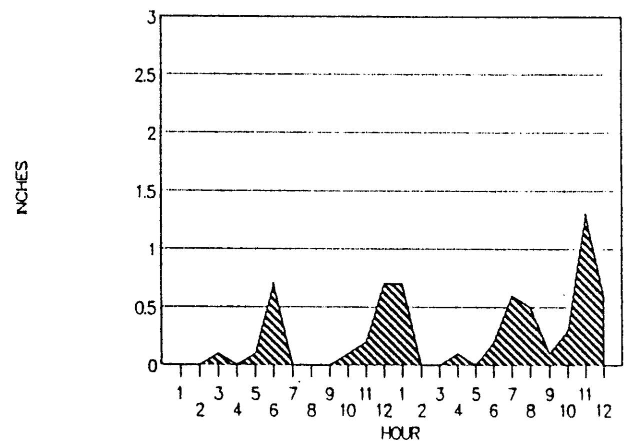
HOURLY PRECIPITATION
ALEXANDRIA, FEBRUARY 9–10, 1966



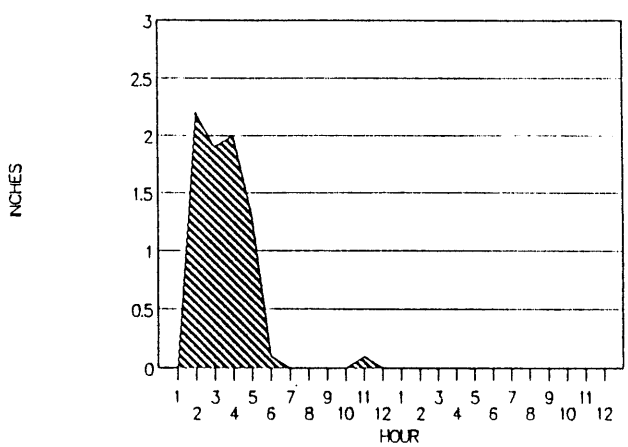
HOURLY PRECIPITATION
ALEXANDRIA, APRIL 14, 1967



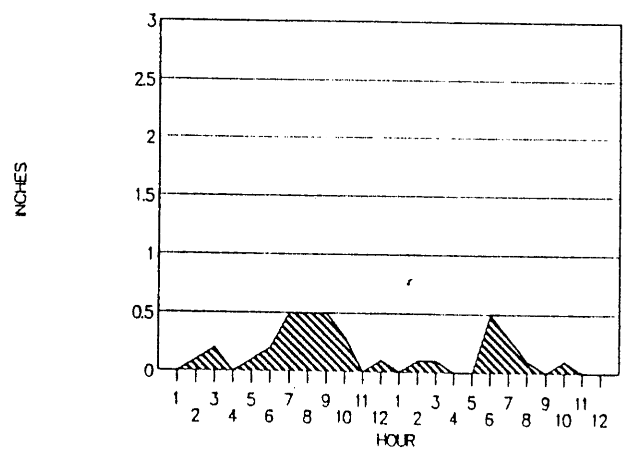
HOURLY PRECIPITATION
ALEXANDRIA, DECEMBER 14, 1967



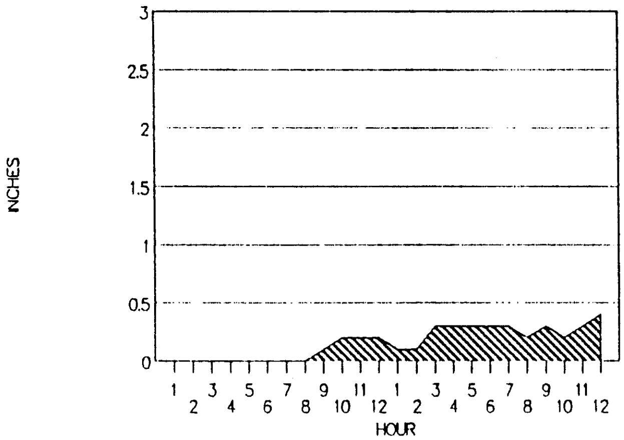
HOURLY PRECIPITATION
ALEXANDRIA, JULY 23, 1969



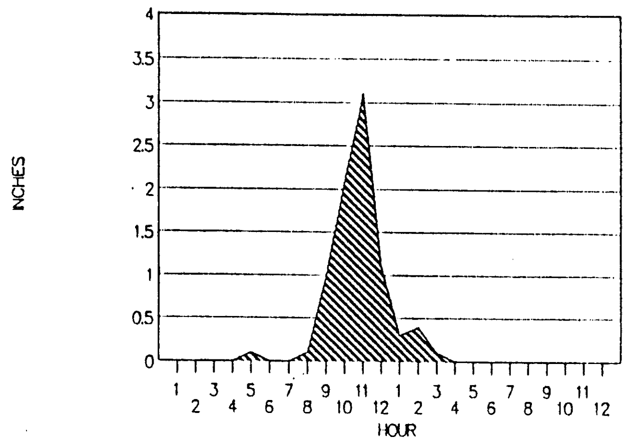
HOURLY PRECIPITATION
ALEXANDRIA, DECEMBER 2, 1971



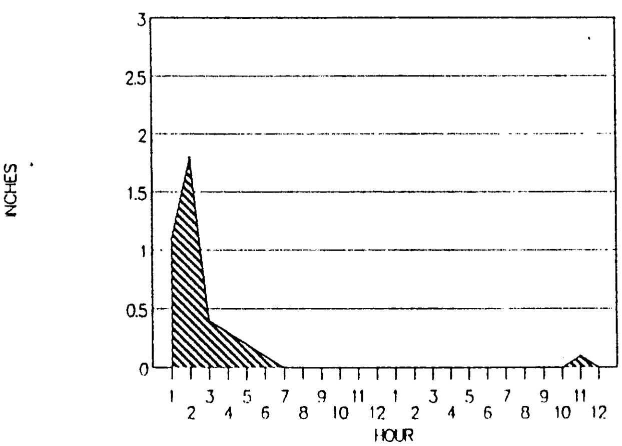
HOURLY PRECIPITATION
ALEXANDRIA, DECEMBER 5, 1971



HOURLY PRECIPITATION
ALEXANDRIA, OCTOBER 22, 1972

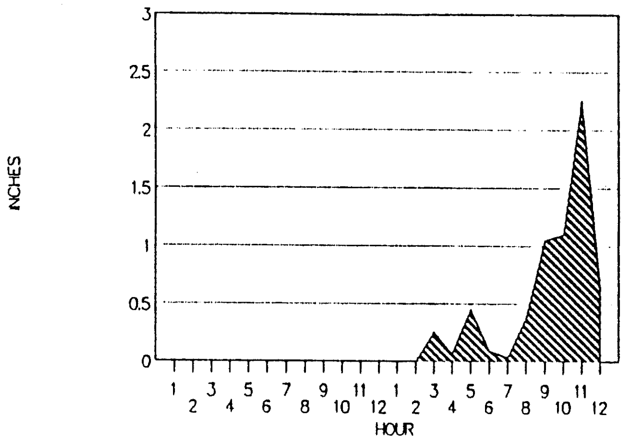


HOURLY PRECIPITATION
ALEXANDRIA, APRIL 12, 1980



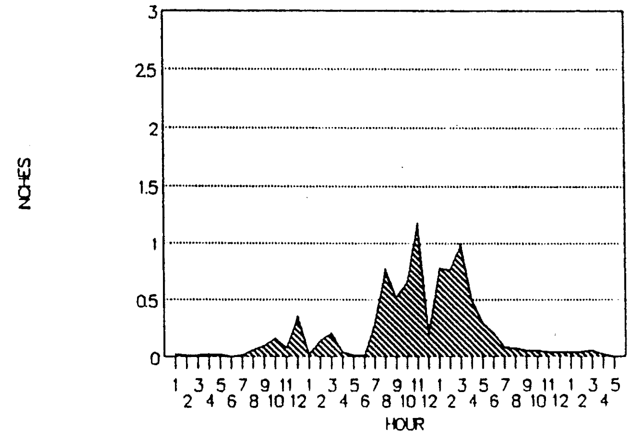
HOURLY PRECIPITATION

BATON ROUGE, APRIL 27, 1962



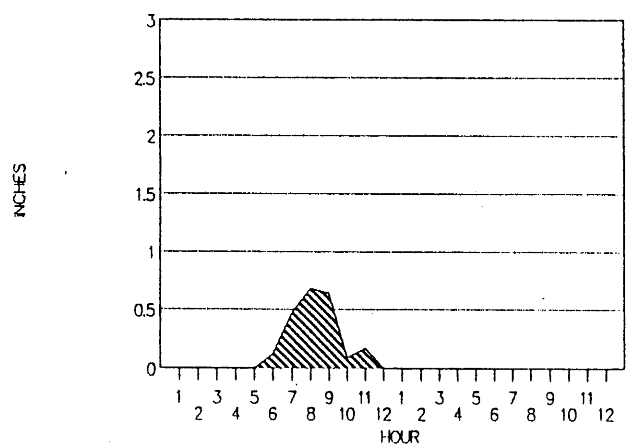
HOURLY PRECIPITATION

BATON ROUGE, OCTOBER 3–4, 1964



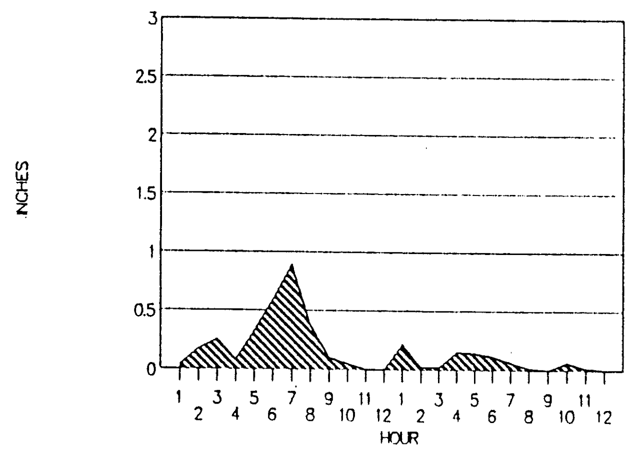
HOURLY PRECIPITATION

BATON ROUGE, FEBRUARY 10, 1966



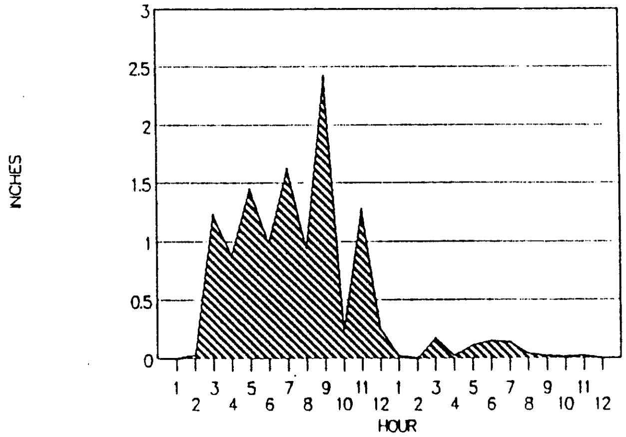
HOURLY PRECIPITATION

BATON ROUGE, FEBRUARY 12, 1966



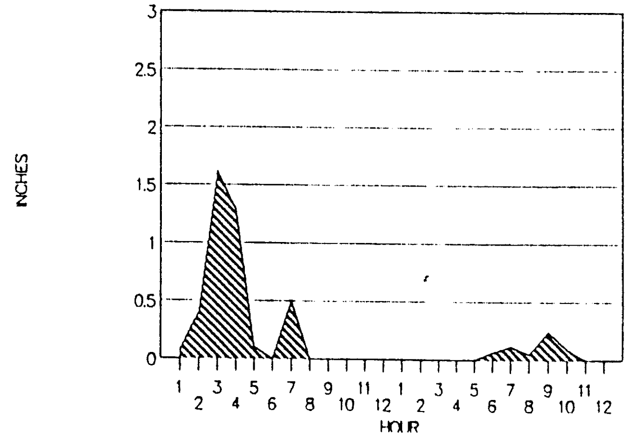
HOURLY PRECIPITATION

BATON ROUGE, APRIL 14, 1967



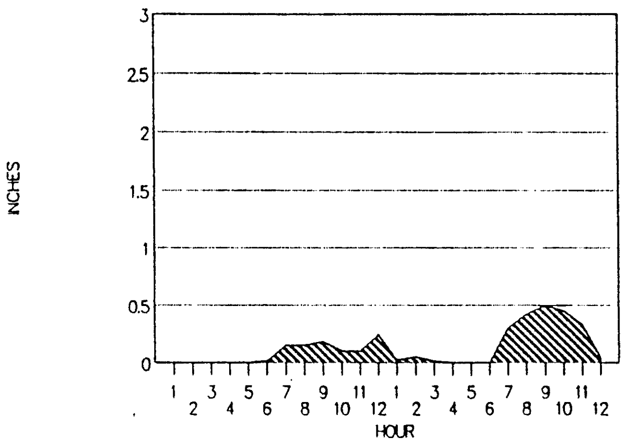
HOURLY PRECIPITATION

BATON ROUGE, OCTOBER 7, 1969



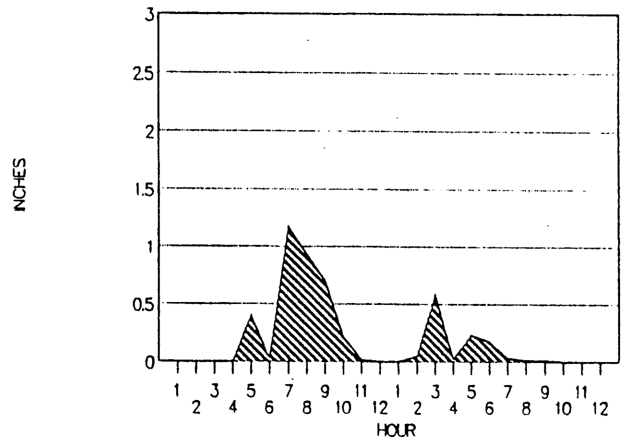
HOURLY PRECIPITATION

BATON ROUGE, DECEMBER 5, 1971



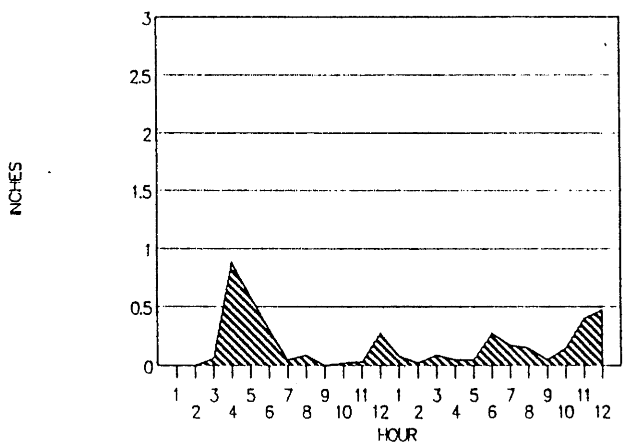
HOURLY PRECIPITATION

BATON ROUGE, APRIL 12, 1980

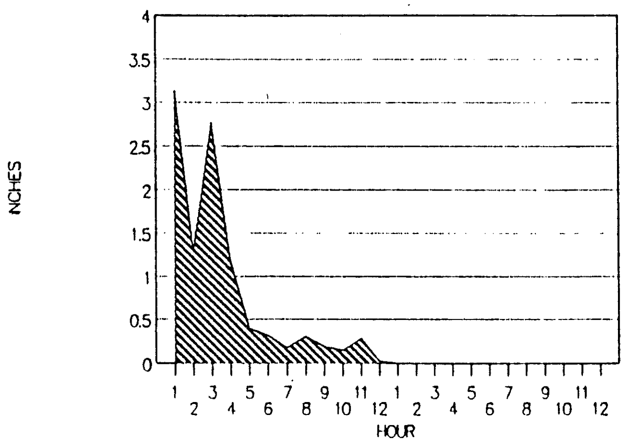


HOURLY PRECIPITATION

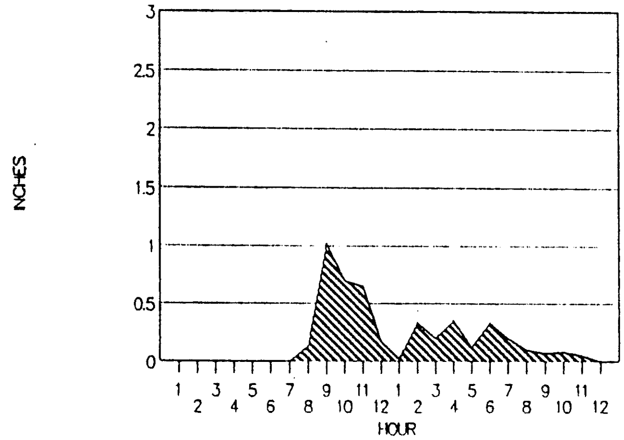
BATON ROUGE, MAY 16, 1980



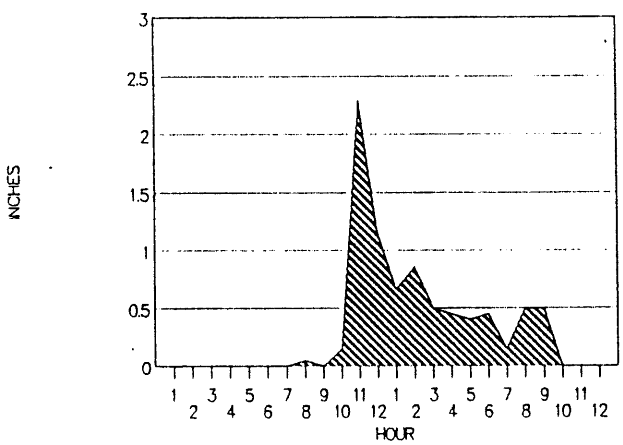
HOURLY PRECIPITATION
LAKE CHARLES, AUGUST 29, 1962



HOURLY PRECIPITATION
LAKE CHARLES, DEC. 10, 1964



HOURLY PRECIPITATION
LAKE CHARLES, OCT. 27, 1970



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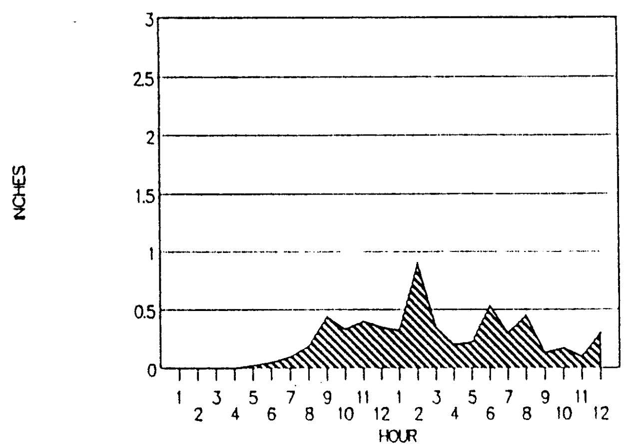
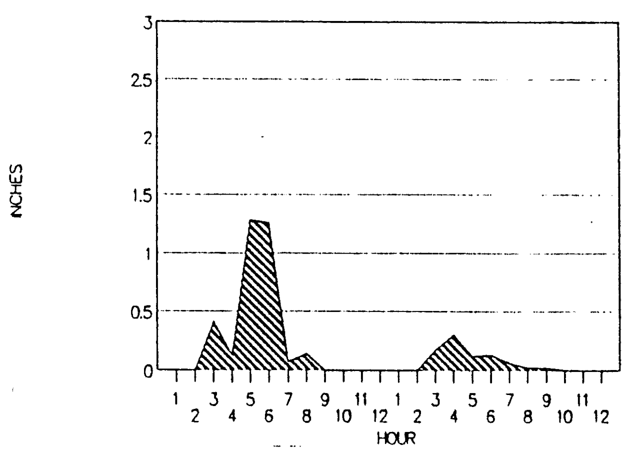
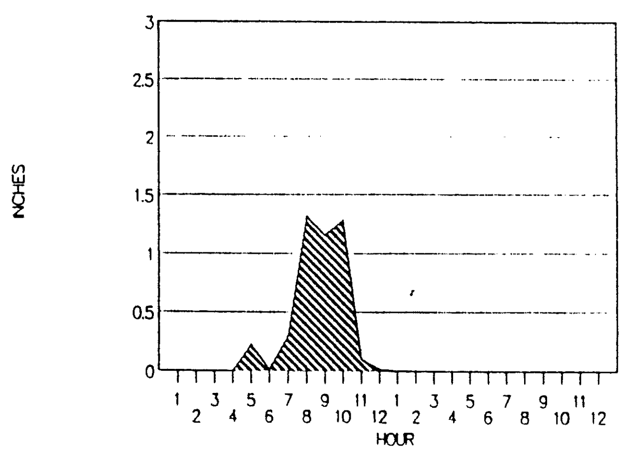
LAKE CHARLES, DEC. 5, 1971



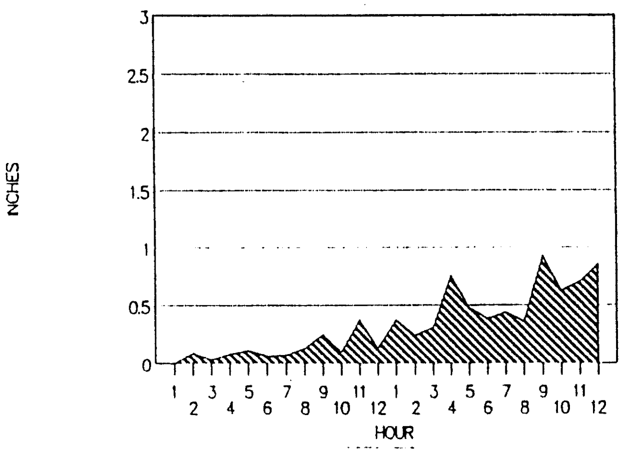
HOURLY PRECIPITATION
LAKE CHARLES, OCT. 22, 1972



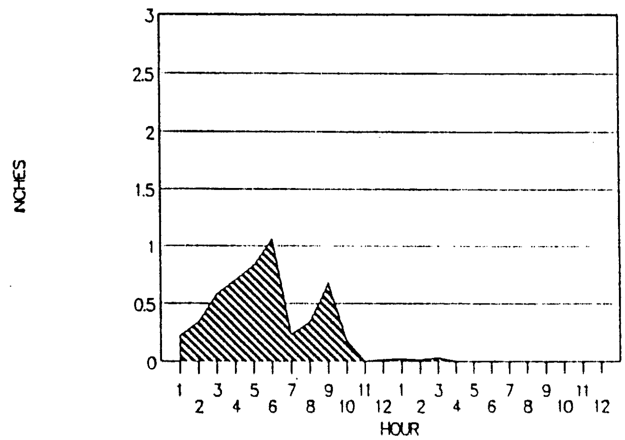
HOURLY PRECIPITATION
LAKE CHARLES, MAY 31, 1981



HOURLY PRECIPITATION
LAFAYETTE, OCTOBER 3, 1964



HOURLY PRECIPITATION
LAFAYETTE, SEPTEMBER 10, 1965



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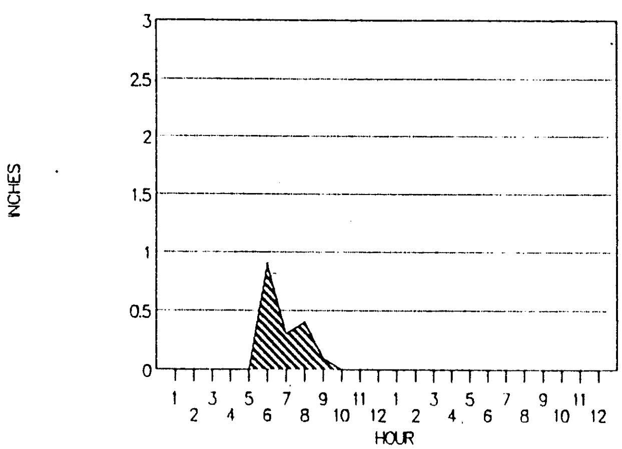
LAFAYETTE, FEBRUARY 10, 1966



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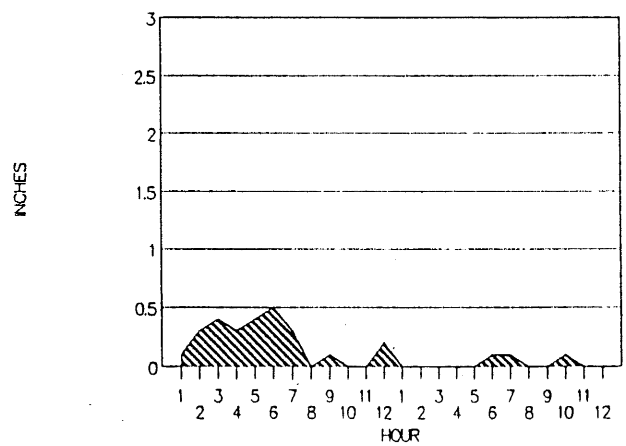
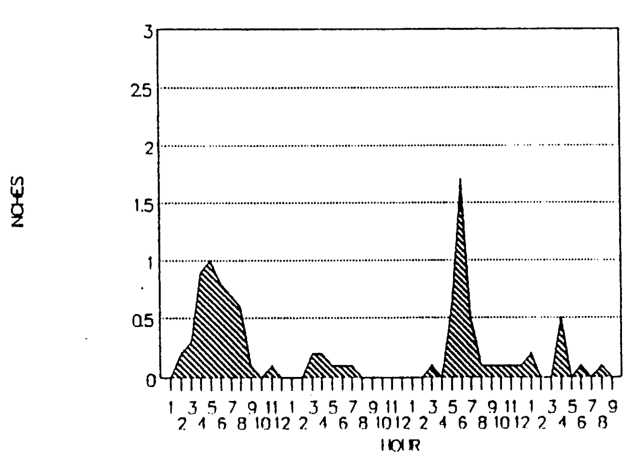
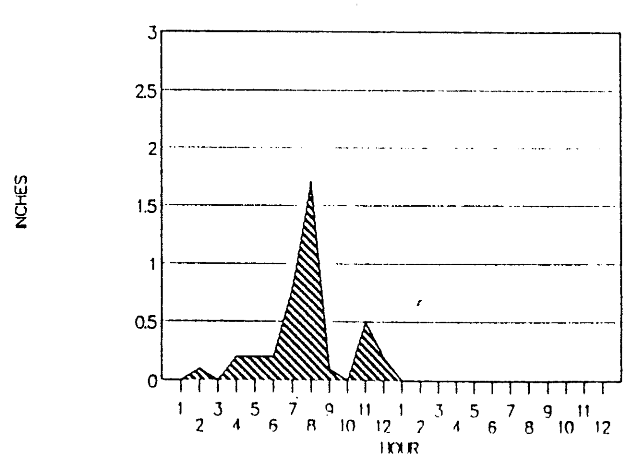
LAFAYETTE, FEBRUARY 12, 1966



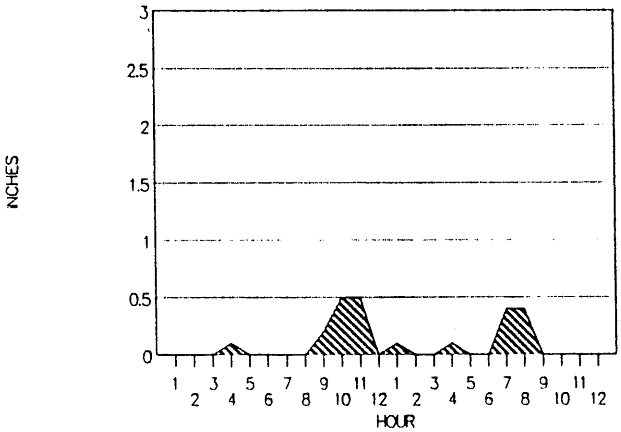
HOURLY PRECIPITATION
LAFAYETTE, AUGUST 26–27, 1967



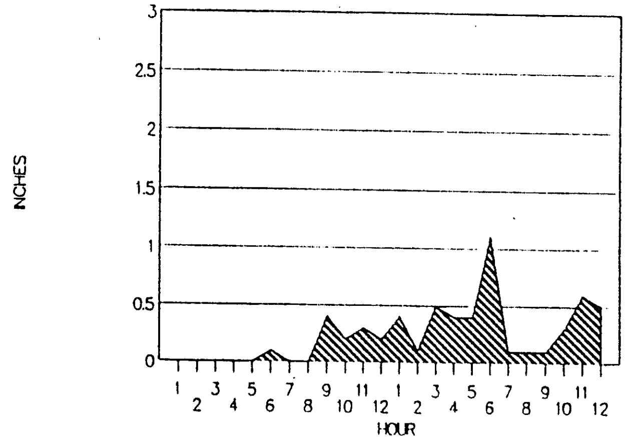
HOURLY PRECIPITATION
LAFAYETTE, SEPTEMBER 16, 1971



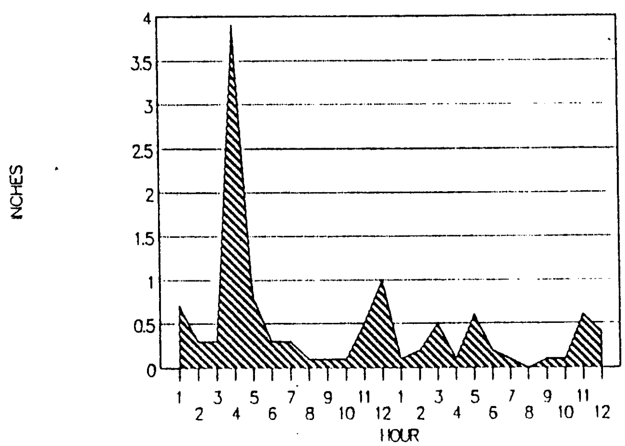
HOURLY PRECIPITATION
LAFAYETTE, DECEMBER 2,1971



HOURLY PRECIPITATION
LAFAYETTE, DECEMBER 5, 1971

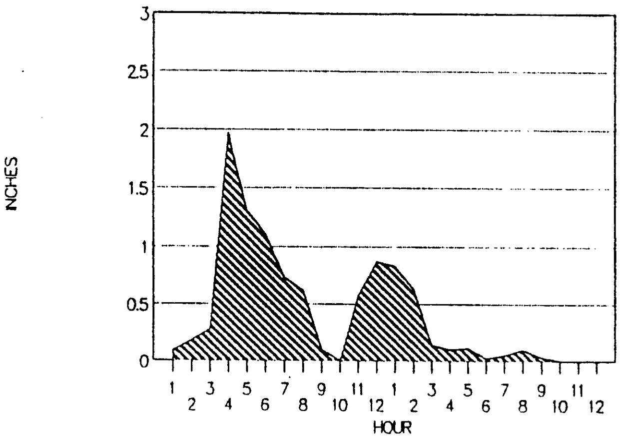


HOURLY PRECIPITATION
LAFAYETTE, MAY 16, 1980



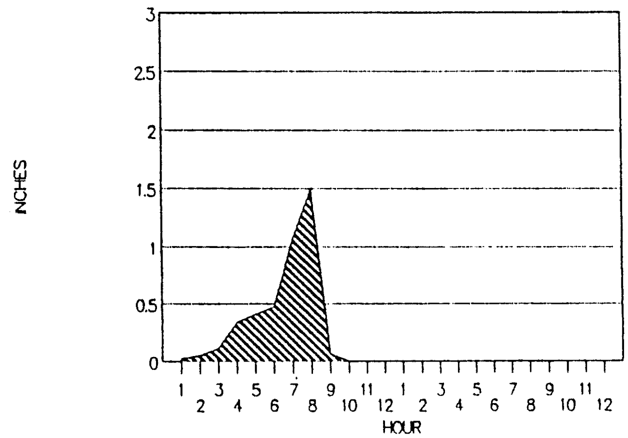
HOURLY PRECIPITATION

NEW ORLEANS, MAY 31, 1959



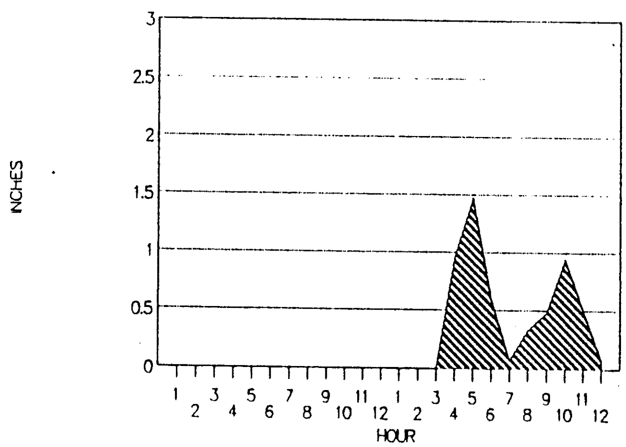
HOURLY PRECIPITATION

NEW ORLEANS (A), NOV. 9, 1963



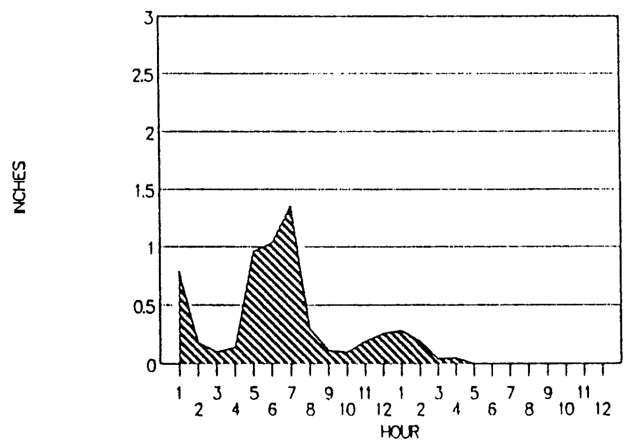
HOURLY PRECIPITATION

NEW ORLEANS (A), JAN. 22, 1965



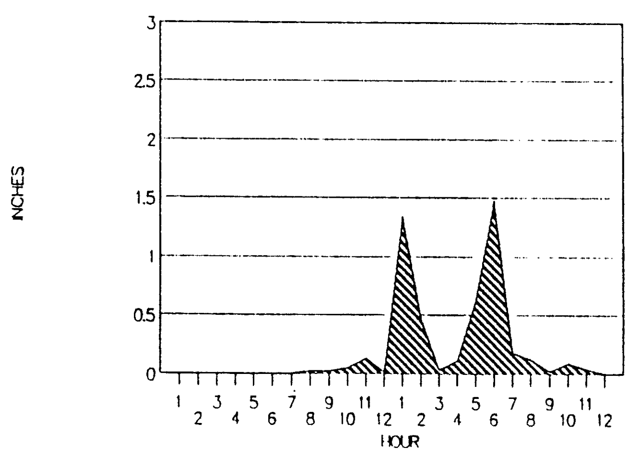
HOURLY PRECIPITATION

NEW ORLEANS (A), FEB. 6, 1967



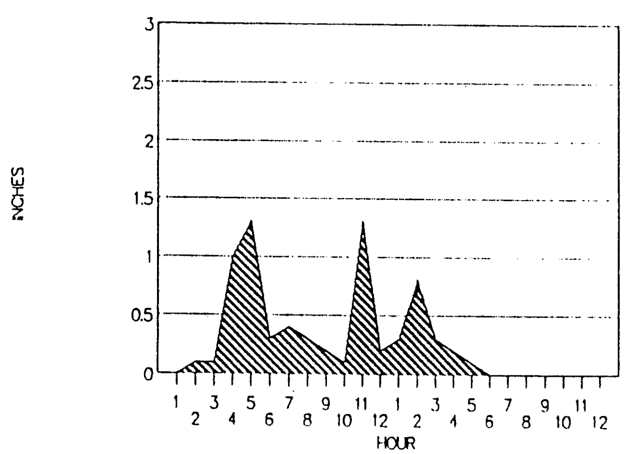
HOURLY PRECIPITATION

NEW ORLEANS (M), MAY 12, 1972



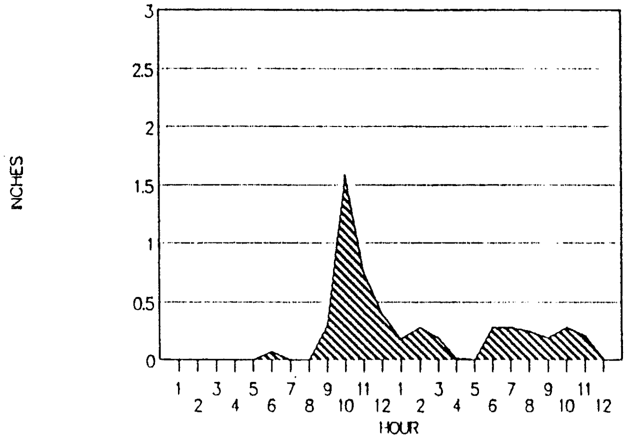
HOURLY PRECIPITATION

NEW ORLEANS (A), APRIL 2, 1980



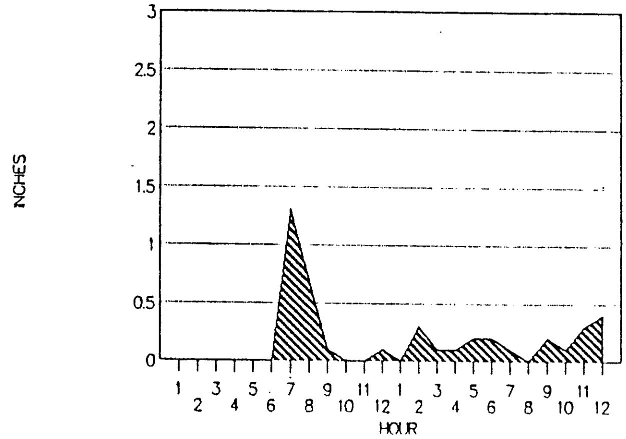
HOURLY PRECIPITATION

NEW ORLEANS (M), APRIL 12, 1980



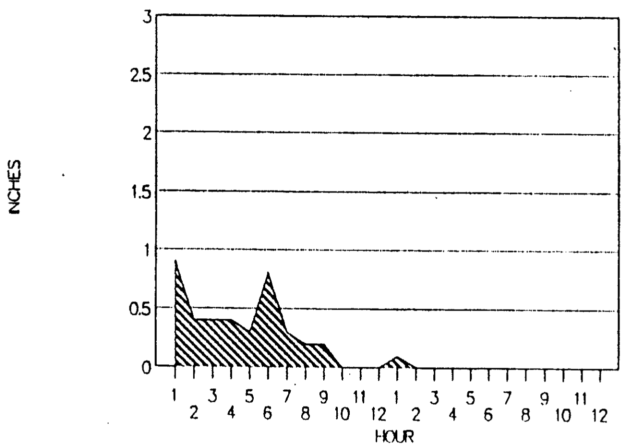
HOURLY PRECIPITATION

NEW ORLEANS (A), MAY 16, 1980



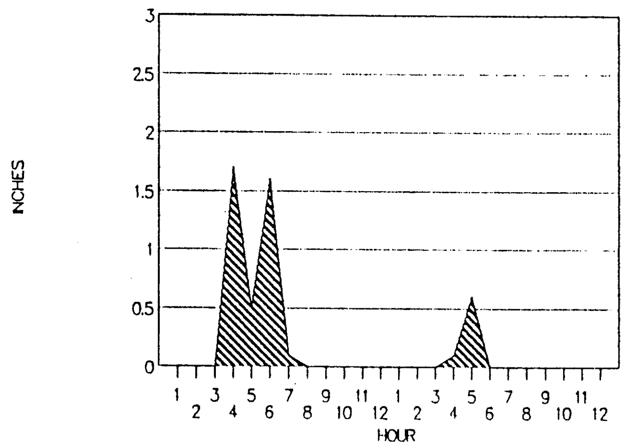
HOURLY PRECIPITATION

NEW ORLEANS (A), MAY 5, 1981



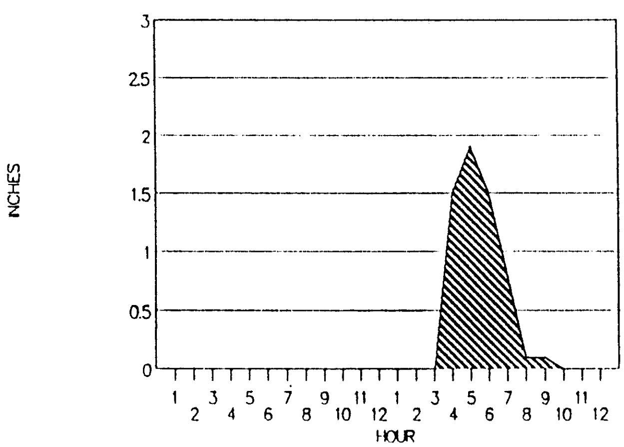
HOURLY PRECIPITATION

NEW ORLEANS (A), JUNE 1, 1981



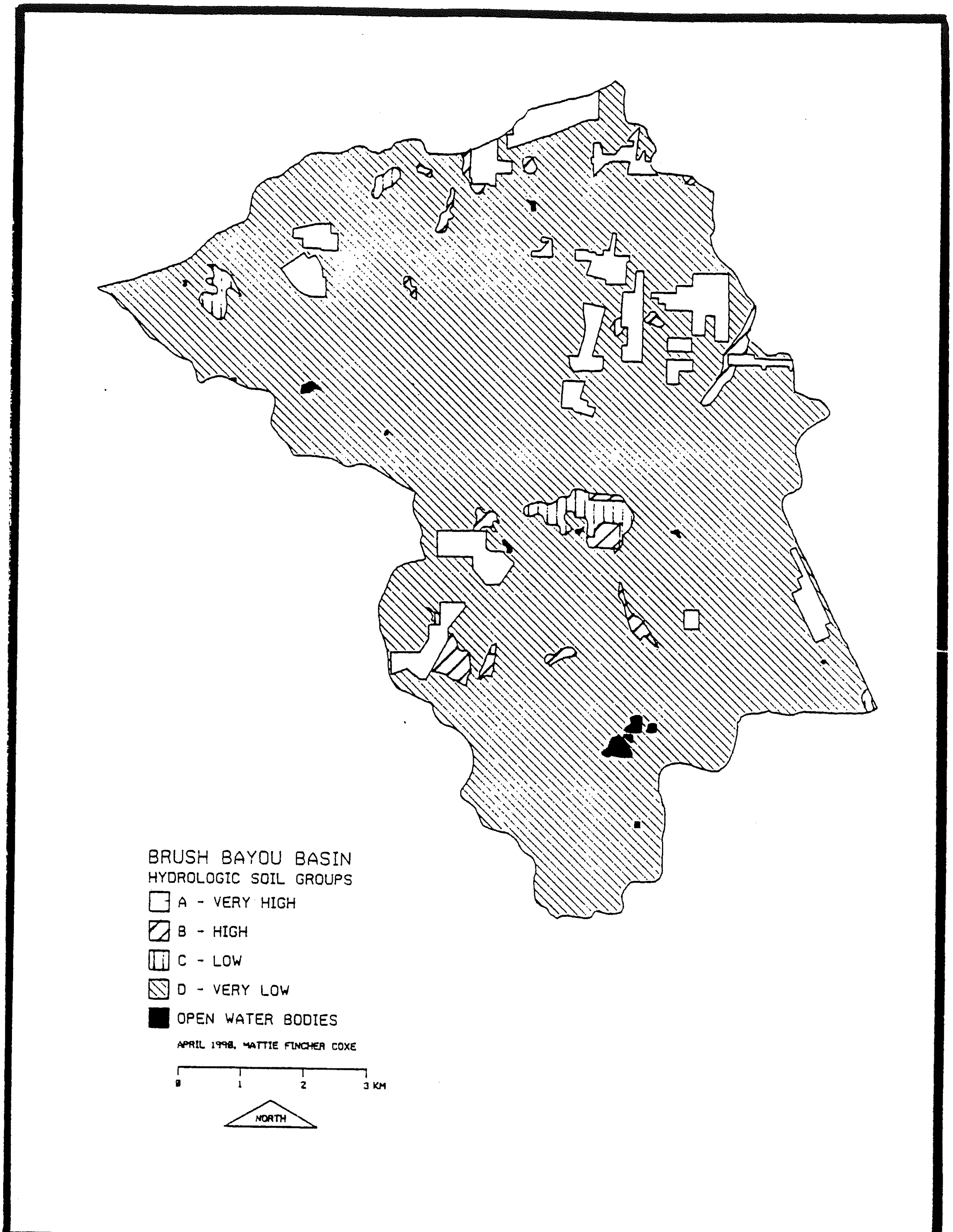
HOURLY PRECIPITATION

NEW ORLEANS (A), JUNE 10, 1981

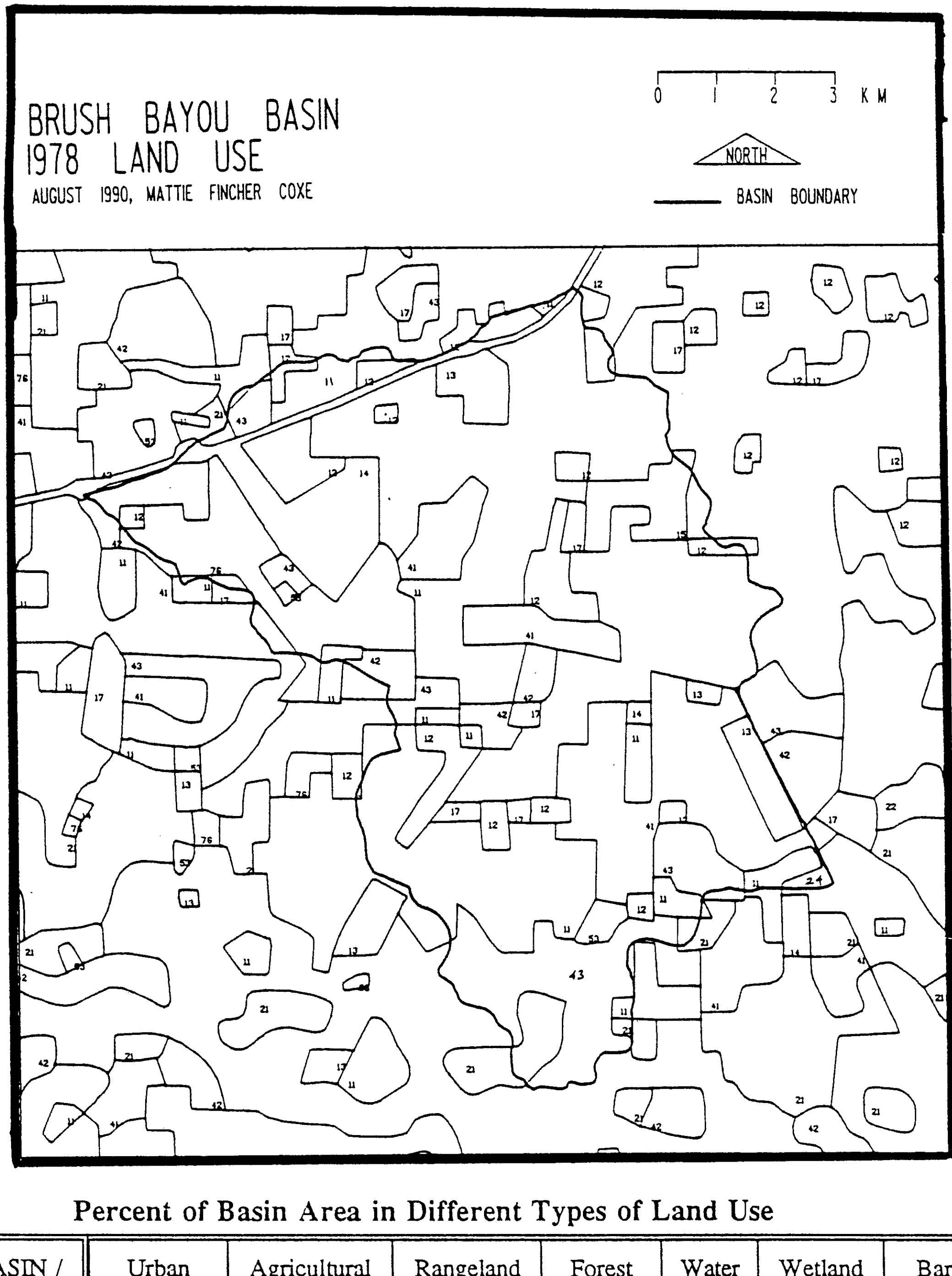


APPENDIX C

Maps and Charts of the Urban Flash Flood Geographic Information System (UFFGIS)

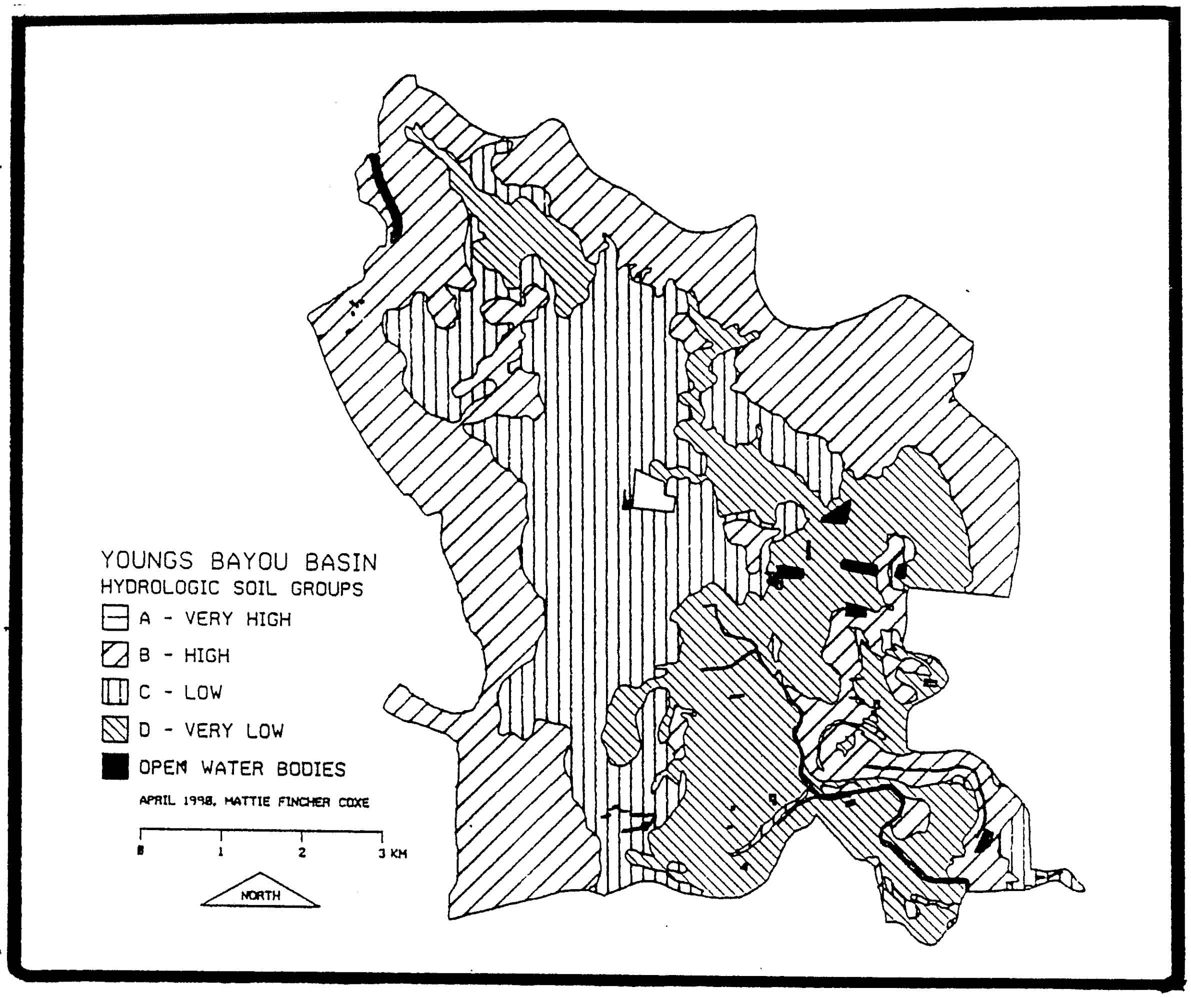


BRUSH BAYOU Shreveport		AREA			PERI-METER	INDEX OF SIMPLICITY
		hectares	%	%	km	area/perimeter
HYDRO-LOGIC SOIL GROUP	B	147.97	1.81	92.54	24.30	
	C	118.52	1.45		14.10	
	D	7300.65	89.28		136.60	
SEWAGE LAGOON - S		21.01	0.26	7.46	4.01	
OPEN WATER - W		8.42	0.10		3.65	
URBAN DISTURBED - U		580.62	7.10		53.95	
ALL		8177.19	100.00	100.00	236.61	34.56

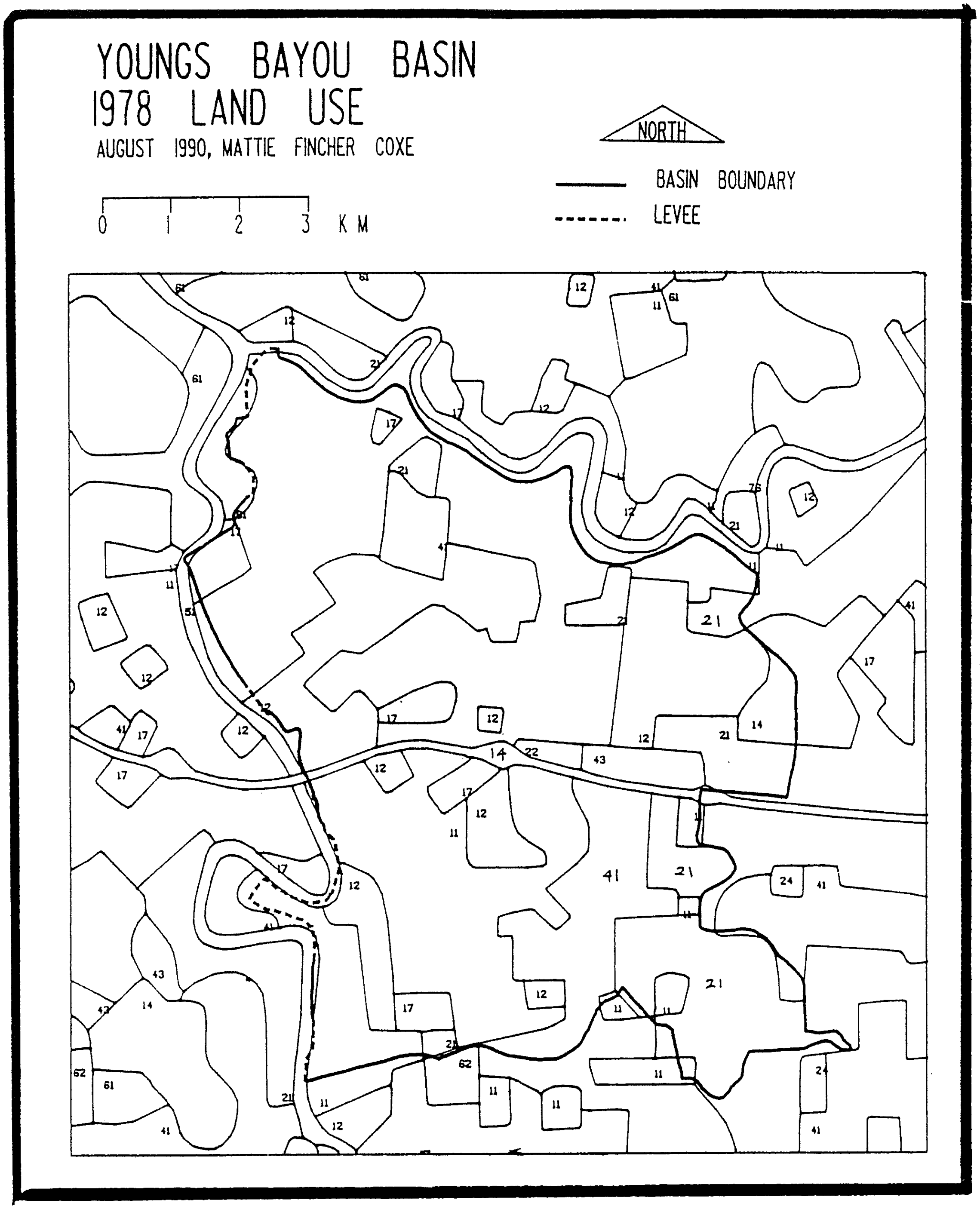


Percent of Basin Area in Different Types of Land Use

BASIN / % USE	Urban Land (1)	Agricultural Land (2)	Rangeland (3)	Forest Land (4)	Water (5)	Wetland (6)	Barren Land (7)
Brush Bayou	65.9	1.87	0.0	25.0	0.67	0.0	6.6

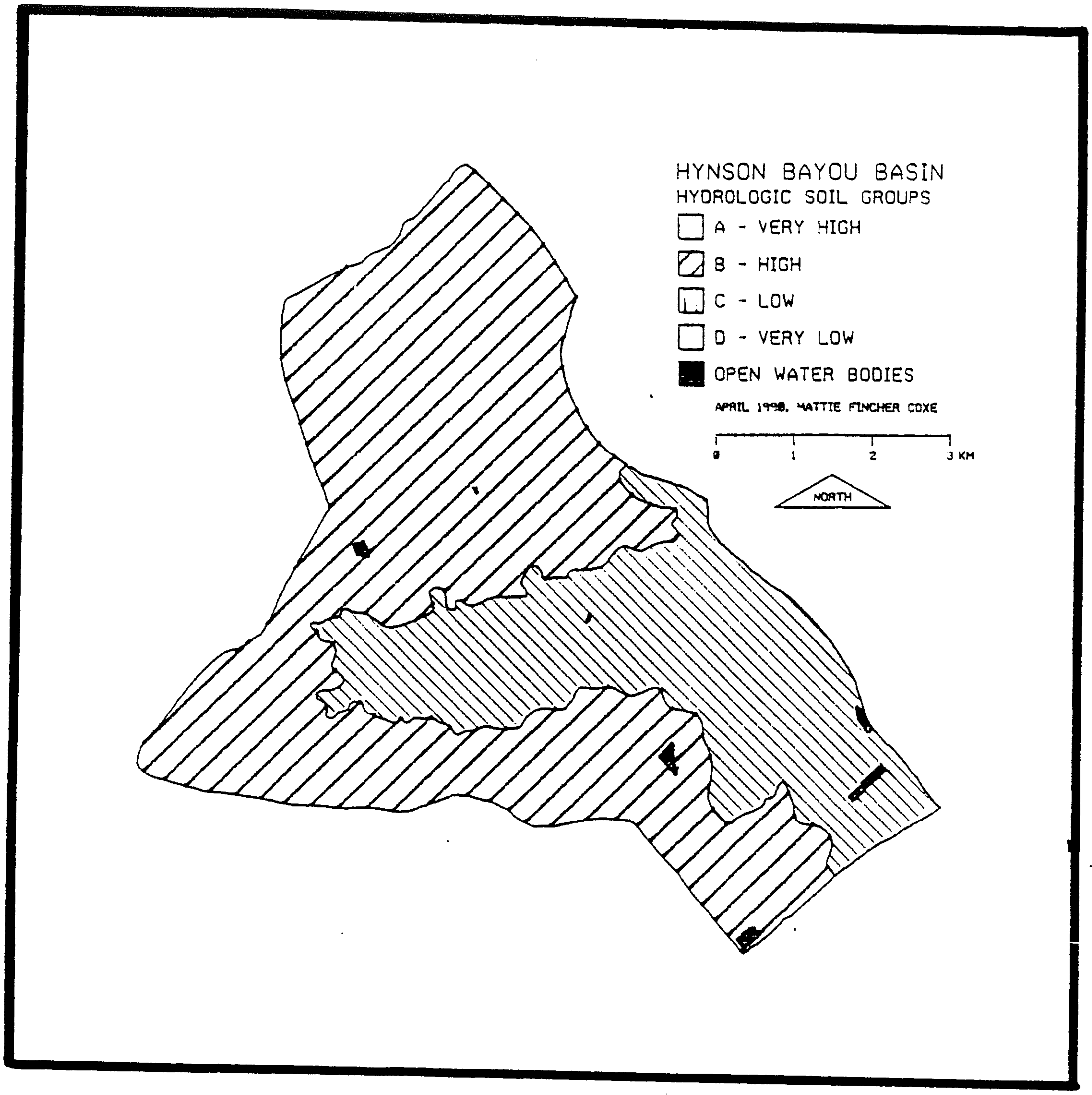


YOUNGS BAYOU Monroe		AREA			PERI-METER	INDEX OF SIMPLICITY
		hectares	%	%	km	area/perimeter
HYDRO-LOGIC SOIL GROUP	B	2584.12	42.45	98.26	115.49	
	C	1817.02	29.85		87.05	
	D	1580.69	25.96		97.08	
SEWAGE LAGOON - S		6.19	0.10	1.74	1.09	
OPEN WATER - W		80.52	1.32		36.90	
WASTE DUMP - X		19.41	0.32		1.92	
ALL		6087.95	100.00	100.00	339.53	17.93

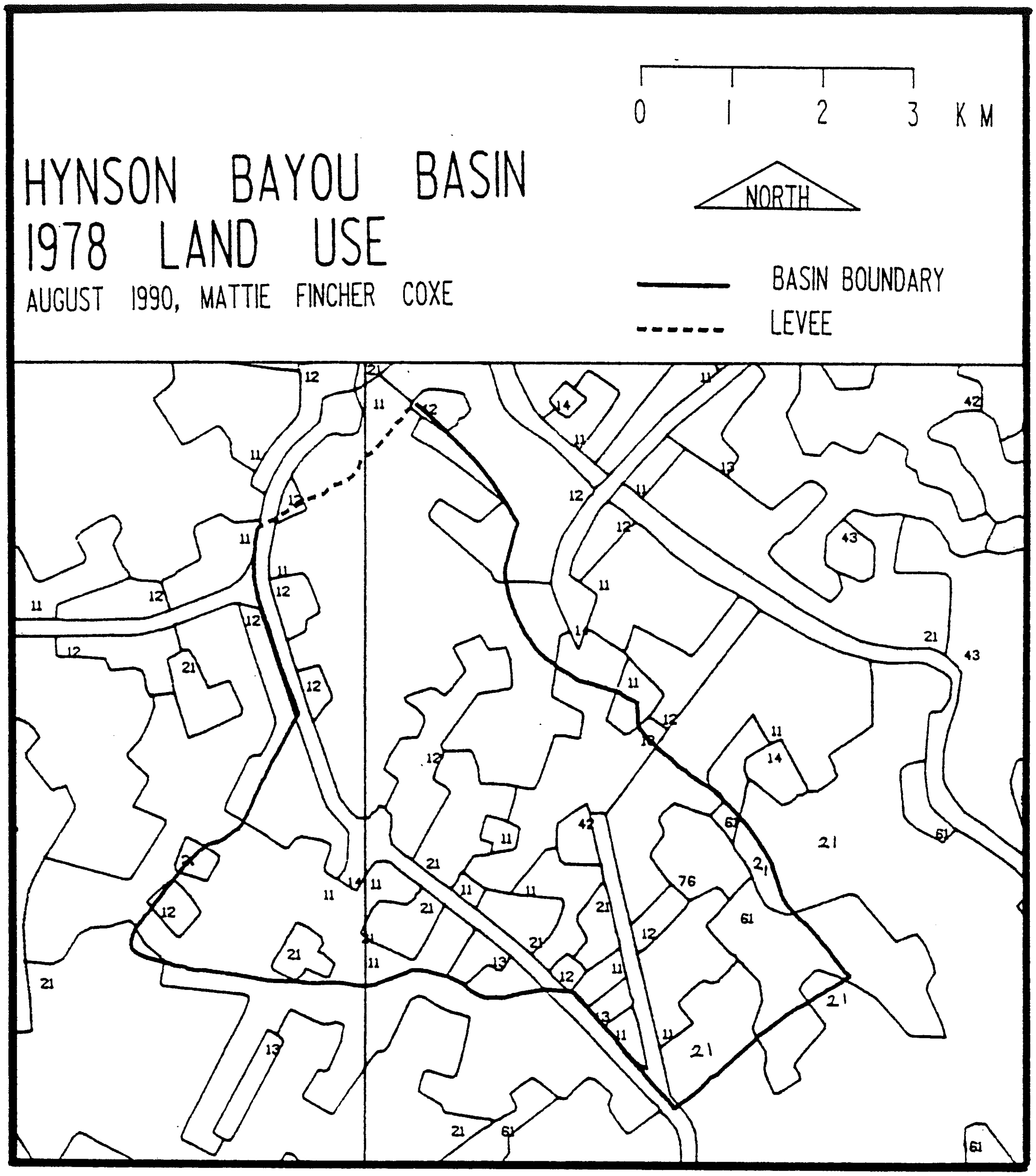


Percent of Basin Area in Different Types of Land Use

BASIN / % USE	Urban Land (1)	Agricultural Land (2)	Rangeland (3)	Forest Land (4)	Water (5)	Wetland (6)	Barren Land (7)
Youngs Bayou	74.3	13.6	0.0	11.6	0.0	0.5	0.0

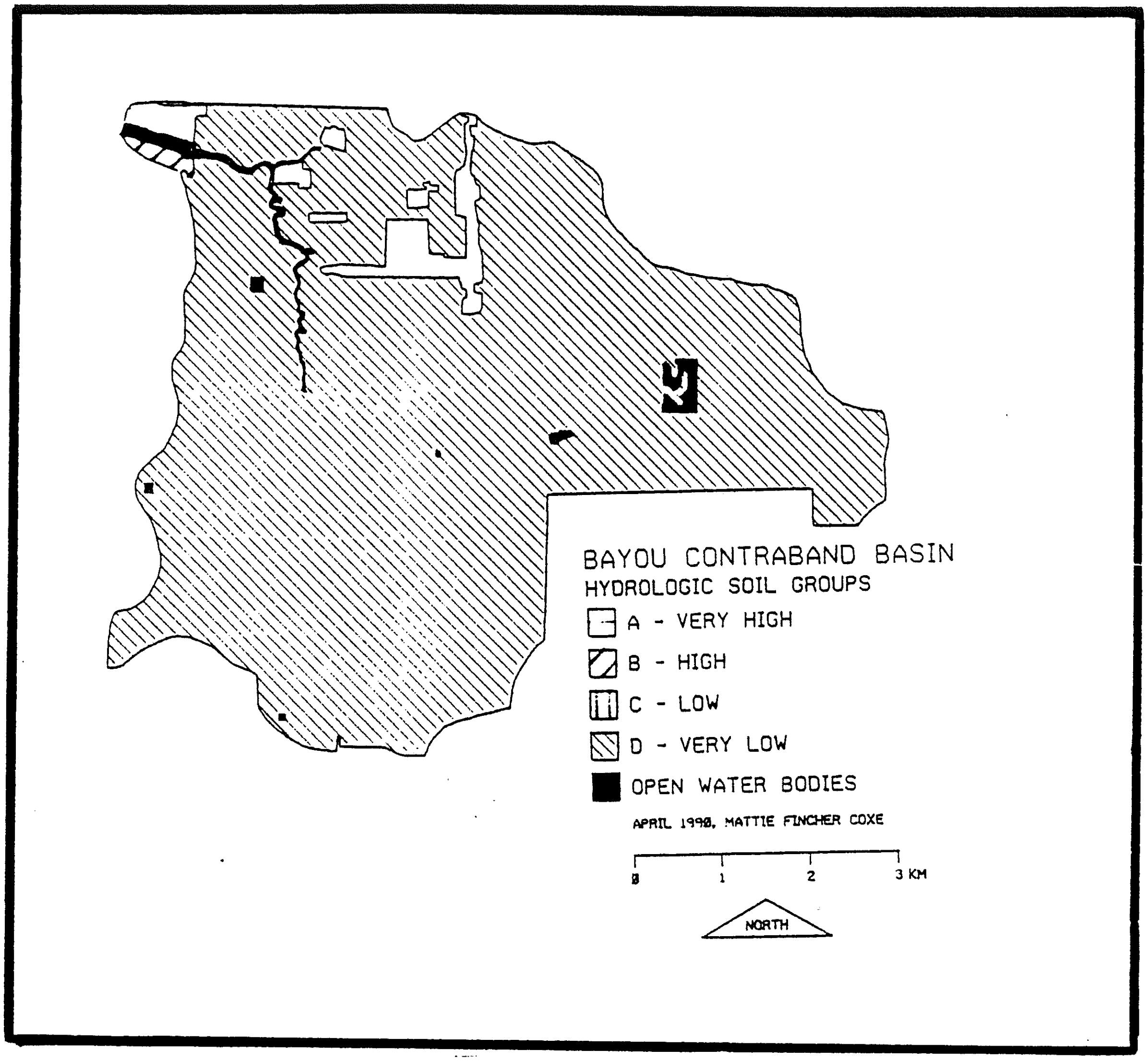


HYNSON BAYOU Alexandria		AREA			PERI-METER	INDEX OF SIMPLICITY
		hectares	%	%	km	area/perimeter
HYDRO-LOGIC SOIL GROUP	B	1888.44	67.55	99.55	36.56	
	D	894.65	32.00		22.67	
OPEN WATER - W		12.53	0.45	0.45	4.22	
ALL		2795.62	100.00	100.00	63.45	44.06

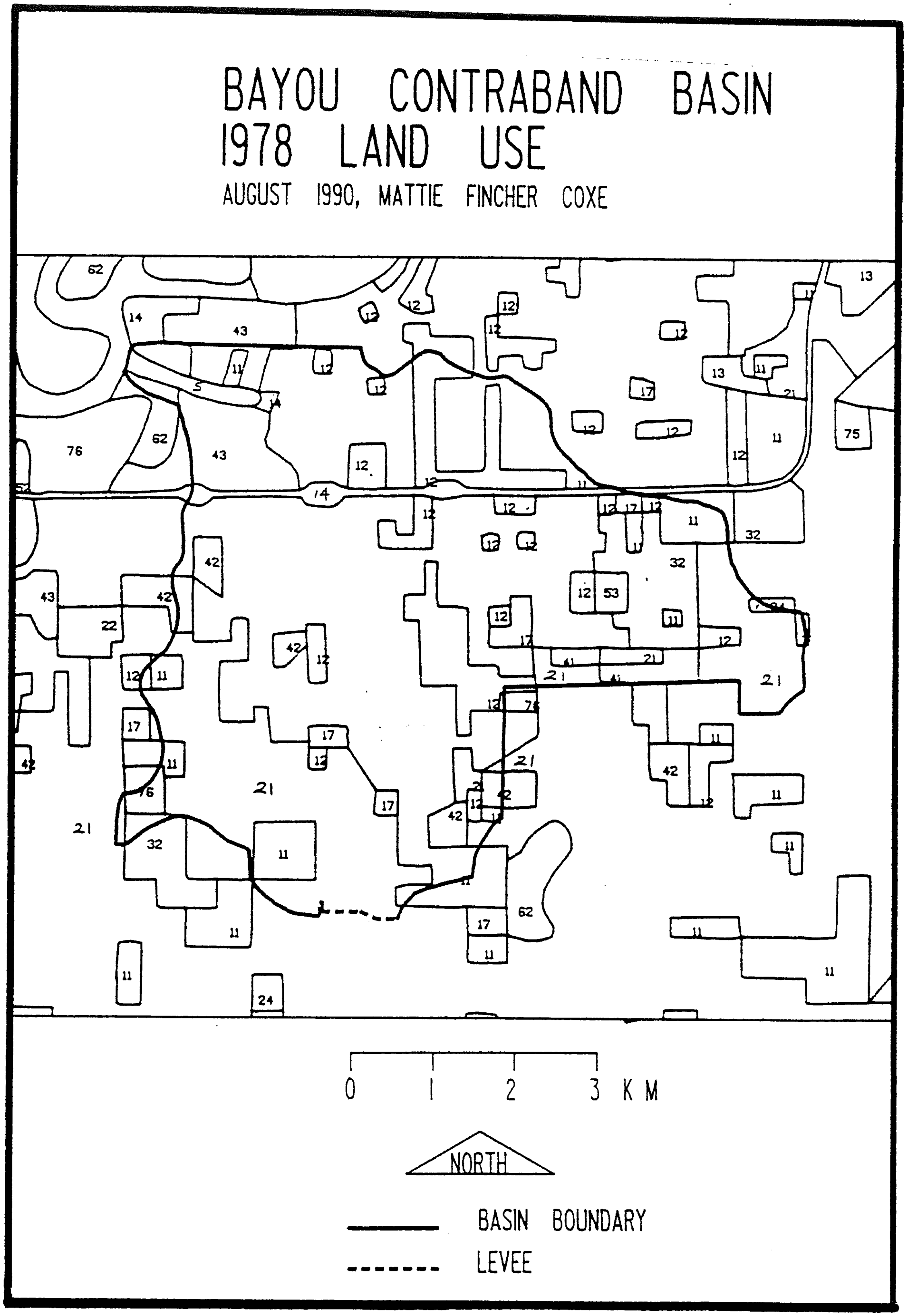


Percent of Basin Area in Different Types of Land Use

BASIN / % USE	Urban Land (1)	Agricultural Land (2)	Rangeland (3)	Forest Land (4)	Water (5)	Wetland (6)	Barren Land (7)
Hynson Bayou	76.7	15.4	0.0	0.73	0.0	4.4	2.8

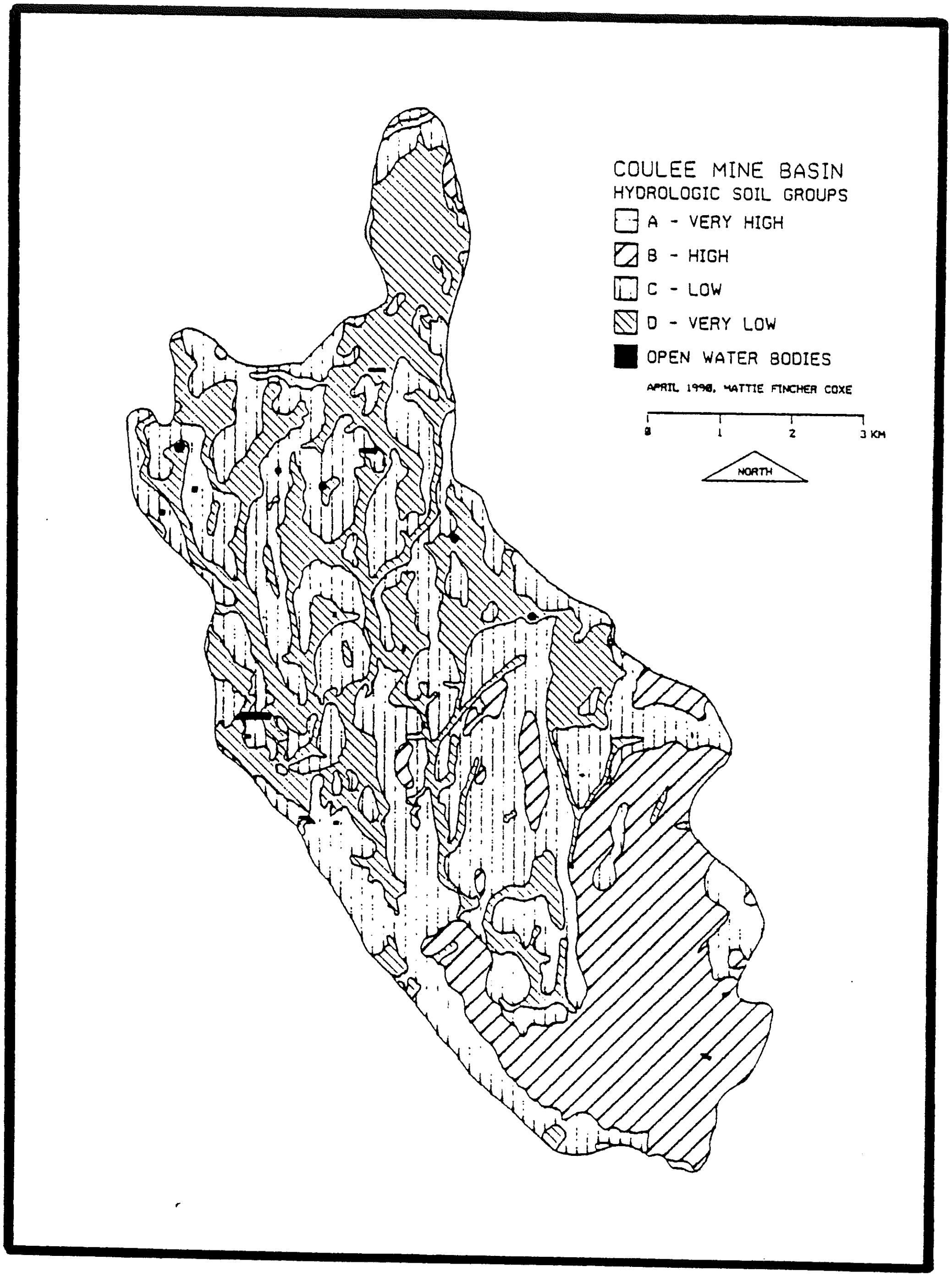


BAYOU CONTRABAND Lake Charles		AREA			PERI-METER	INDEX OF SIMPLICITY
		hectares	%	%	km	area/perimeter
HYDRO-LOGIC SOIL GROUP	B	12.90	0.36	94.94	2.01	
	D	3343.77	94.58		57.55	
OPEN WATER - W		48.07	1.36	5.06	16.50	
URBAN DISTURBED - U		130.49	3.69		16.07	
ALL		3535.23	100.00	100.00	92.13	38.37

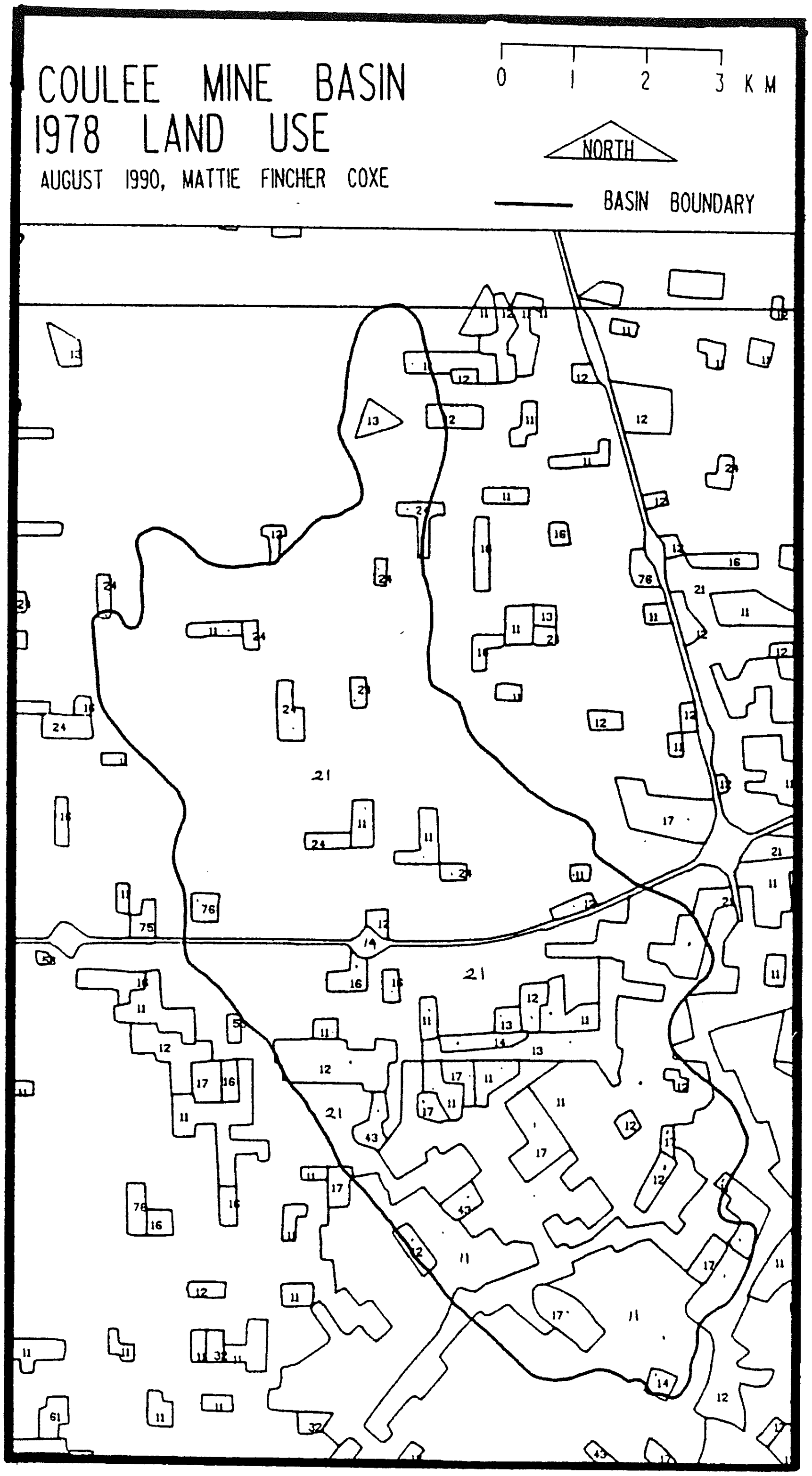


Percent of Basin Area in Different Types of Land Use

BASIN / % USE	Urban Land (1)	Agricultural Land (2)	Rangeland (3)	Forest Land (4)	Water (5)	Wetland (6)	Barren Land (7)
Contra-band B.	63.8	21.1	4.2	8.1	2.0	0.3	0.5

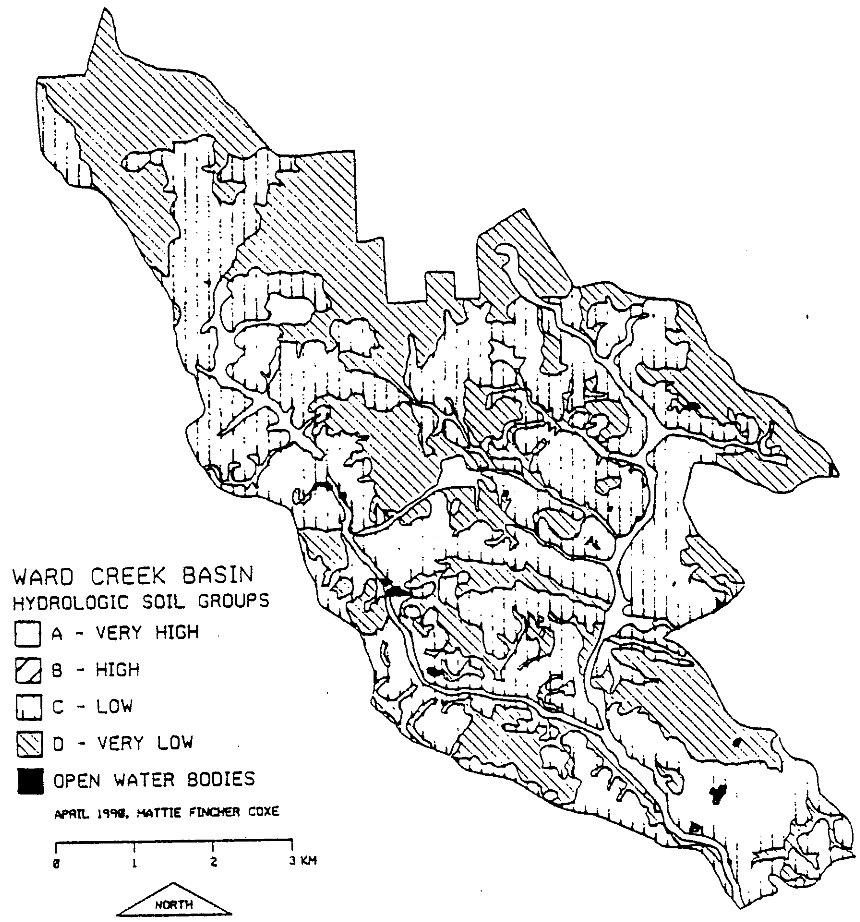


COULEE MINE Lafayette		AREA			PERI-METER	INDEX OF SIMPLICITY
		hectares	%	%	km	area/perimeter
HYDRO-LOGIC SOIL GROUP	B	1385.12	22.87	99.66	44.88	
	C	2876.01	47.48		234.39	
	D	1775.45	29.31		185.56	
UNKNOWN - ?		3.60	0.06	0.34	0.97	
SEWAGE LAGOON - S		1.30	0.02		0.81	
OPEN WATER - W		15.56	0.26		7.30	
ALL		6057.04	100.00	100.00	473.91	12.78

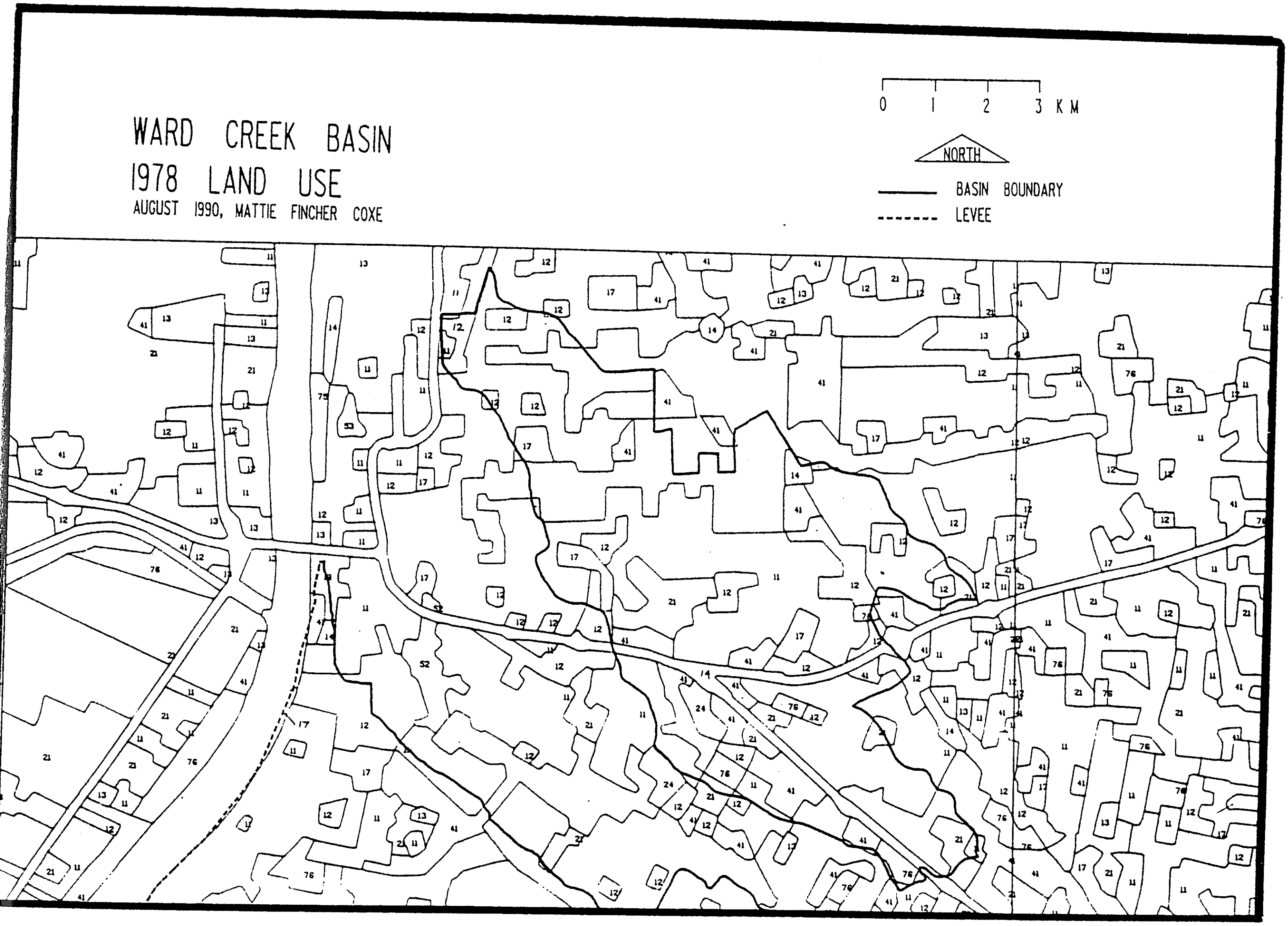


Percent of Basin Area in Different Types of Land Use

BASIN / % USE	Urban Land (1)	Agricultural Land (2)	Rangeland (3)	Forest Land (4)	Water (5)	Wetland (6)	Barren Land (7)
Coulee Mine	36.7	62.5	0.0	0.6	0.0	0.0	0.2

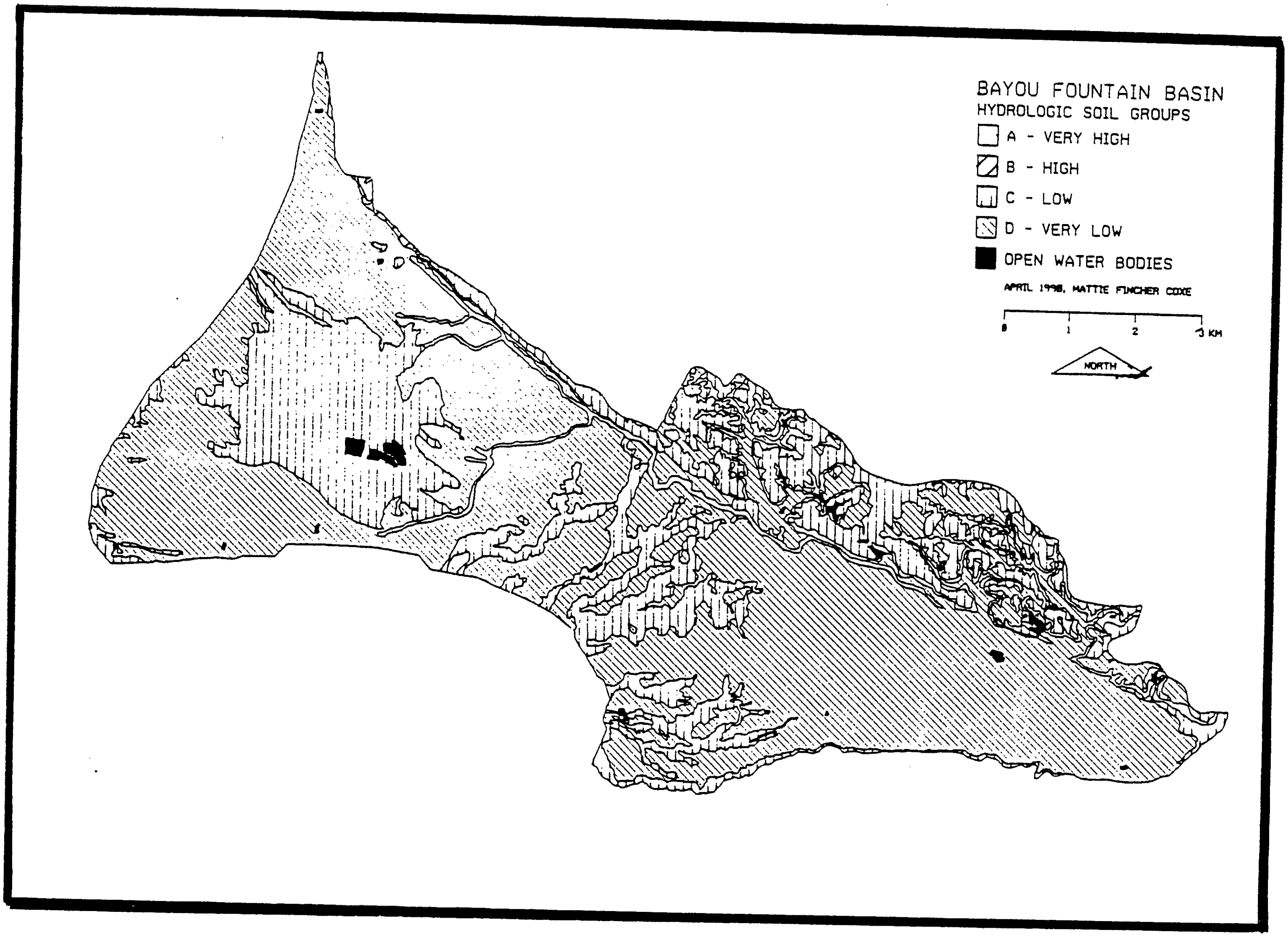


WARD CREEK Baton Rouge		AREA			PERI- METER	INDEX OF SIMPLICITY
		hectares	%	%	km	area/perimeter
HYDRO- LOGIC SOIL GROUP	C	2611.74	52.85	92.82	231.55	
	D	1975.09	39.97		191.17	
OPEN WATER - W		15.70	0.32	7.18	8.12	
FILL (Manmade) - M		339.15	6.86		69.32	
ALL		4941.68	100.00	100.00	500.16	9.88

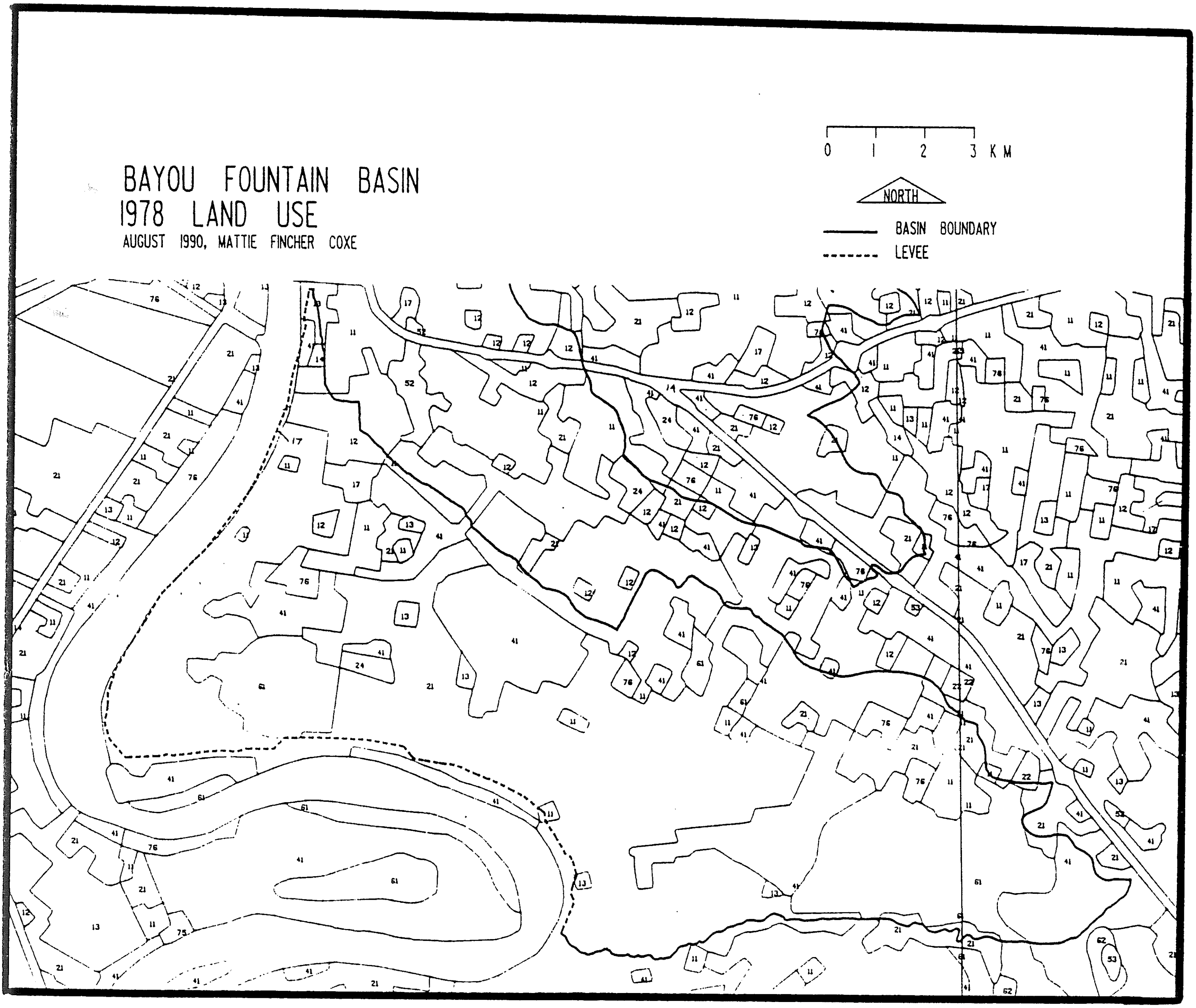


Percent of Basin Area in Different Types of Land Use

BASIN / % USE	Urban Land (1)	Agricultural Land (2)	Rangeland (3)	Forest Land (4)	Water (5)	Wetland (6)	Barren Land (7)
Ward Creek	77.4	8.3	0.0	12.4	0.0	0.0	1.8



BAYOU FOUNTAIN Baton Rouge		AREA			PERI-METER	INDEX OF SIMPLICITY
		hectares	%	%	km	area/perimeter
HYDRO-LOGIC SOIL GROUP	B	12.53	0.12	94.87	3.90	
	C	3070.17	29.26		319.75	
	D	6890.03	65.49		327.13	
FILL (Manmade Land) - M		157.85	1.50	5.13	48.02	
SEWAGE LAGOON - S		1.91	0.02		0.98	
OPEN WATER - W		57.58	0.55		18.91	
TERRACE SOILS - T		322.99	3.07		128.95	
ALL		10521.06	100.00	100.00	847.64	12.09



Percent of Basin Area in Different Types of Land Use

BASIN / % USE	Urban Land (1)	Agricultural Land (2)	Rangeland (3)	Forest Land (4)	Water (5)	Wetland (6)	Barren Land (7)
Bayou Fountain	14.5	49.3	0.0	18.8	0.0	15.6	1.7