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A Comparison of Three Flooding Regimes Atchafalaya Basin, Louisiana

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A COMPARISON OF THREE FLOODING REGIMES ATCHAFALAYA BASIN, LOUISIANA

by

Johannes L. van Beek
Karen Wicker
Benjamin Small

Coastal Environments, Inc.
Baton Rouge, La. 70802

Contract No. 68-01-2299

Project Officers

Harold V. Kibby
(Project Officer through August 1975)
Corvallis Environmental Research Laboratory
Corvallis, Oregon 97330

Victor W. Lambou
(Project Officer from September 1975 to Present)
Environmental Monitoring and Support Laboratory
Las Vegas, Nevada 89114

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ENVIRONMENTAL MONITORING AND SUPPORT LABORATORY
LAS VEGAS, NEVADA 89114

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FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report compares hydrologic regimes of three backwater areas in the Atchafalaya Basin, Louisiana. The purpose of these comparisons is to improve the understanding of process-environment relationships as a basis for evaluating management alternatives regarding protection and enhancement of the Basin's environmental quality and related resource values, including flood control. The U.S. Environmental Protection Agency, the U.S. Corps of Engineers, the U.S. Department of Interior, the State of Louisiana, special interest groups, and other interested individuals will use this information to assess the potential impact of the hydrological modifications proposed by the Corps. The information will also be useful to those who develop alternative land and water-quality management plans which will accommodate flood flows and maintain an acceptable level of environmental quality. Further information on this survey may be obtained from the Water and Land Quality Branch, Monitoring Operations Division.

George B. Morgan
Director
Environmental Monitoring and Support Laboratory
Las Vegas

ABSTRACT

Three backwater areas in the Atchafalaya Basin, Louisiana, are compared. The purpose of this comparison is to improve the understanding of process-environment relationships as a basis for evaluating management alternatives regarding protection and enhancement of the Basin's environmental quality and related resource values and the use of the Basin for flood control. The three areas studied are Fordoche and Buffalo Cove, within the Atchafalaya Basin Floodway and subject to annual flooding by the Atchafalaya River, and Pat Bay which is located outside the floodway and in which flooding is controlled by local rainfall. Hydrologic regimes are compared for relative contributions of river water and local drainage, amplitude of water level fluctuations, mode of water introduction and movement, and related introduction of sediments. From the comparison, the following were seen as the most urgent needs for management of Atchafalaya Basin Floodway units: 1) induction of low discharge throughflow in order to enhance water exchange in those areas presently subject to a backwater regime and insufficiently dewatered, 2) reduction of inflow associated with short term water level fluctuations during the annual rise of Atchafalaya River stages in order to reduce sediment introduction, 3) maximum utilization of the unit's precipitation surpluses as a source of floodwater to reduce inflow of Atchafalaya River water and sediments, 4) realization of 1), 2), and 3) through water introduction at the upper end of the unit and simultaneous control over outflow at the lower end of the unit.

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LIST OF SYMBOLS AND ABBREVIATIONS

EPA - U.S. Environmental Protection Agency

U.S.C.E. or USCE - U.S. Corps of Engineers

MSL or msl - mean sea level

m - meters

m/s- meters per second

kg/s - kilograms per second

lbs/s - pounds per second

g/l - grams per liter

km - kilometer

cfs or c.f.s - cubic feet per second

cms or c.m.s. - cubic meters per second

mos. - months

ACKNOWLEDGMENTS

We wish to acknowledge the assistance of the U.S. Army Corps of Engineers, New Orleans District, in making available to us unpublished water level data essential to the present study.

Equally important have been the guidance and critical review provided by the U.S. Environmental Protection Agency Project Officers. The project was initiated under the direction of Dr. Harold V. Kibby, U.S. Environmental Protection Agency, Corvallis, Oregon, and completed under the supervision of Mr. Victor W. Lambou, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Several members of the Coastal Environments, Inc., staff contributed to specific elements of this study. We wish to acknowledge in particular the contributions of Mr. Philip Light and Dr. Sherwood M. Gagliano, the cartographic work of Curtis Latiolais and editing of Peggy King and Ava L. Haymon.

SECTION I

INTRODUCTION

The Atchafalaya Basin in south-central Louisiana is a large [4,500 square kilometers (km^2)] alluvial basin that has national significance as a multiple resource. It derives this significance principally from high quality habitats for fish and wildlife, a semi-wilderness area of high recreational value, and its function as a floodway for the lower Mississippi River.

The quality and long-term use of these principal resources are increasingly endangered because present land and water uses are in conflict with hydrologic requirements of the natural environment as well as among themselves. These conflicts have dictated the need for development and implementation of an effective multi-use land and water management plan to sustain or enhance environmental quality and to achieve modes of use that recognize environmental constraints.

As part of an interagency study by the U.S. Corps of Engineers (U.S.C.E.), the U.S. Environmental Protection Agency (EPA), and the U.S. Fish and Wildlife Service, two successive studies focused on the need for the requirements of surface water management. The first Environmental Protection Agency study dealt with identification of the Basin's environments and the manner in which their aggregate characteristics are controlled and affected by natural processes and human use (Gagliano and van Beek, 1975). This work defined major problems and developed conceptual guidelines for surface water management. The second study report is a continuation of the first, with more detailed consideration of water needs of the natural environment and of the various land and water uses. On the basis of general water management requirements for the Atchafalaya Basin as a whole and specific requirements for its primary use as a floodway, a multi-use management plan was developed (van Beek *et al.*, 1976) and presented as an alternative to channelization as proposed by the U.S.C.E.

The previous studies showed clearly that acceptance of flood control as the primary management objective is not incompatible with the need to protect and enhance the natural environment. On the contrary, the two have a parallel major requirement in that both flood control and natural resource values of the Atchafalaya Basin need be managed so that neither is adversely affected. This holds not only for the present floodway, but also for areas outside the floodway which may be required when capacity of the present system is further reduced.

Within the present floodway, the essential management requirement for both flood control and environmental quality is to reduce sedimentation associated with annual introduction of Atchafalaya River water. At present, sedimentation in backwater areas is the main threat to an already reduced and insufficient floodway capacity and to the overflow areas as fish, wildlife, and swamp forest habitats. Management strategies should, therefore, be aimed at annual introduction of Atchafalaya River water into the swamp basins only to the extent necessary to meet hydroperiod, water level, and water quality requirements. Furthermore, introduction of water should occur in such a way that associated sediment influx is minimal and that unavoidable sedimentation is least detrimental to the natural environment and floodway capacity.

Development of detailed management strategies for the floodway swamp have become most urgent in view of pending plans for further channelization of the Atchafalaya River. As authorized, the channelization project is intended to reduce sediment influx into backwater areas through a reduction in normal-year river stages so that less water is diverted into overbank storage. First, this conflicts severely with water needs of the overflow swamps. Second, the authorized project does not alter the mode of water diversion, which is believed to be the main cause of the present excessive and detrimental sedimentation.

An alternative approach to water management for flood control, more compatible with environmental quality needs, was developed in the previous studies (Gagliano and van Beek, 1975; van Beek et al., 1976). That approach suggests: 1) confinement of Atchafalaya River flows to enhance enlargement of the Main Channel through natural processes, and 2) structural management of water diversion from the river into the backswamps so that control can be exerted over volume, quality, and inflow process.

General recommendations were made concerning control over diversion from the Main Channel and desirable stage variation. However, insufficient information was available to make recommendations concerning the various possible modes of water introduction into individual swamp sub-basins or management units. Therefore, the present study was undertaken to compare the hydrologic regime of three sub-basins that differ from each other with regard to mode of flooding, stage variation, relative contribution of Atchafalaya River water and local runoff, and type of environment. The sub-basins selected were Fordoche, Buffalo Cove, and Pat Bay (Figure 1-1). In addition to showing necessary hydrologic variation, those areas were chosen because they formed distinct hydrologic units with well-defined boundaries and points of water exchange. The above three areas were also chosen because baseline studies concerning biota and water quality (Lantz, 1974; Bryan et al., 1974) and management requirements (Gagliano and van Beek, 1975; van Beek et al., 1974; van Beek et al., 1976) are available. Baseline data were also available from the U.S. EPA and the U.S. Fish and Wildlife Service ongoing studies.

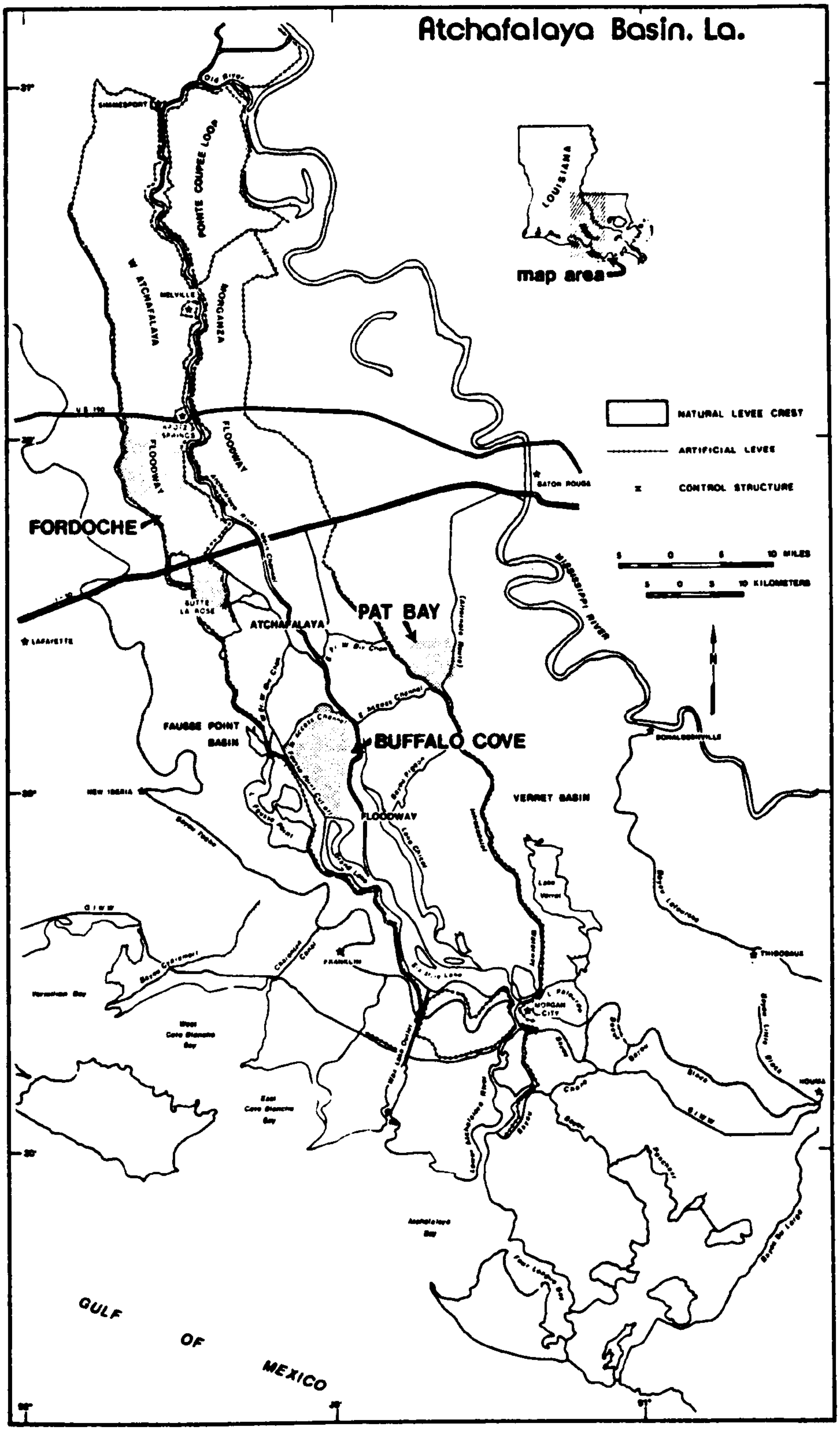

Figure 1-1. Location of three study areas within the Atchafalaya Basin.

SECTION II

CONCLUSIONS

1) Fordoche and Buffalo Cove differ from Pat Bay primarily because of greater amplitude of annual stage fluctuation and partly because of contribution of Atchafalaya River water to annual flooding.

2) Both Buffalo Cove and Pat Bay experience primarily a backwater flooding regime with throughflow limited mostly to the lower margin and involving the lake environment.

3) In Fordoche, introduction of external, local drainage produces a throughflow regime during most of the year throughout the unit, but backwater flooding does occur in the lower half of the unit during Atchafalaya River flood stages.

4) The relative contribution of Atchafalaya River water to annual flooding during the 1975-1976 study period was five times as great in Buffalo Cove as in Fordoche.

5) The relative contribution of precipitation surpluses to annual flooding was approximately three times as large in Pat Bay as it was in Fordoche and Buffalo Cove.

6) In Pat Bay short-term fluctuations of water level exceed average annual fluctuation in amplitude.

7) On a comparable basis, water replacement in Pat Bay about equaled that of Fordoche and was nearly one and a half times greater than in Buffalo Cove.

8) Short-term fluctuations during the annual rise of river stage increased sediment input into Buffalo Cove by a least 20 percent.

9) In Fordoche, short-term inflows were eliminated by the throughflow regime but related reduction in sediment input was more than offset by the sediment input associated with inflow of drainage through the Courtableau Drainage structure.

10) Buffalo Cove experiences high sedimentation rates because a single major channel introduces most of the water to a small portion of the area experiencing an unimpeded throughflow regime.

11) To minimize sediment introduction into floodway units requires reduction of short-term stage fluctuations and maximum use of precipitation surpluses. This can be obtained without adversely affecting water exchange only by management for a throughflow regime in which discharge rates are no higher than the minimum necessary to maintain required circulation.

12) With the constraints of the Atchafalaya Basin Floodway, a managed throughflow regime is more likely to enhance environmental quality than a backwater regime.

SECTION III

RECOMMENDATIONS

1) Water management should provide for maximum use of local precipitation surpluses to reduce the need for introduction of sediment-laden river water into floodway swamp environments.

2) Except when necessary to maintain environmental quality, short-term water level fluctuations in floodway swamp basins should be reduced in order to reduce river water introduction while maintaining desired extent, depth, and duration of annual flooding.

3) Data collection and analysis concerning the hydrologic regimes of at least Fordoche, Buffalo Cove, and Pat Bay should continue in order to include conditions other than the 1975-1976 water year, during which Atchafalaya River stages were below average.

4) Hydrologic regime characteristics should be related to biological parameters other than vegetation associations and to water quality parameters to provide a more complete basis for management decisions.

5) Pending verification of present findings through inclusion of normal-year hydrologic data, it is recommended that a water management plan for the floodway swamp provide for a throughflow regime in which, at least during flood stages, water is introduced at the upper end of each basin through over-bank flow when possible and in which outflow is controlled to maximize use of precipitation surpluses and to control the rates of inflow and throughflow.

SECTION IV

GENERAL CHARACTERISTICS OF STUDY AREA AND SCOPE OF STUDY

Historically, the Atchafalaya Basin contained a complex of lakes and backswamps which were interspersed with and surrounded by natural levee ridges of varying magnitude. Bald cypress and tupelo gum predominated in the swamps, while mesophytes grew on the higher ridges and natural levees. Early accounts of oak lumbering in the area (Comeaux, 1972) indicate that oak was probably an important component of these mesic associations. The swamps were subject to an annual flooding and dewatering regime of moderate amplitude that was governed by local rainfall and limited introduction of Mississippi River and Red River waters.

The above setting rapidly changed over the past 75 years. Lumbering, farming, increased Mississippi River diversion and an associated increase in sedimentation, floodway construction, and channelization drastically altered the hydrologic regime, topography, and natural vegetation patterns. New controls were instituted on hydrologic and sedimentary processes and on the distribution and predominance of particular vegetation associations (van Beek et al., 1976; O'Neil et al., 1975). As a result, the three areas selected for study differ significantly with regard to environmental composition. They reflect modification of the natural environment caused by a combination of human and natural processes.

The most obvious difference is between Pat Bay, on the one hand, and Fordoche and Buffalo Cove on the other. Construction of the Atchafalaya Basin Floodway separated the basin into a central area dominated by riverine processes and two marginal areas where in situ processes prevail (Gagliano and van Beek, 1975). The Pat Bay study area lies outside the floodway in the eastern marginal area, or the Verret Basin; the Fordoche and Buffalo Cove sub-basins are located within the floodway (Figure 1-1). The Buffalo Cove and Fordoche units show differentiation due to progressive southward building of the Atchafalaya River floodplain. The Fordoche area, located further north, has been subject to riverine processes for a longer period of time. Therefore, succession toward a terrestrial environment is more advanced. These differences will be expanded upon in the following chapters through analysis of the three sub-basin environments as they relate to present and past natural processes and human use.

Emphasis in the present study is on the analysis and comparison of hydrologic regimes of the three units with regard to annual introduction of river water, annual introduction of sediment, and habitat differentiation. Associated with each of the above aspects is a large number of pertinent questions that will require at least partial answers prior to implementation of an overall management plan. One of these questions concerns the mode and volume of water introduction into individual swamp basins, which determine the pattern and amount of backwater sedimentation.

Sediment is carried into backwater areas by Atchafalaya River water diverted from the Main Channel. Therefore, to reduce detrimental effects of sedimentation, there are three basic options. The first is to reduce the volume of water diverted into the backwater areas. The second is to reduce the concentration of sediments carried by the diverted water. The third is to manage the flooding processes in such a way that sediment is deposited where it least affects valuable aquatic habitats.

Reduction of water diversion into backwater areas can be accomplished in various ways. One is to alter the hydrologic regime by means of the proposed channelization of the Main Channel. Since this leads to substantial decreases in the duration and extent of annual flooding, this method is inconsistent with the need to maintain and enhance renewable resource value and environmental quality as part of improved floodway use.

Reduction of water diversion is also possible without decreasing the extent and depth of flooding. Two possibilities are to reduce the flux of river water and to capitalize on local runoff as a partial substitute for river water. In various areas, such as the southern part of the Buffalo Cove Management Unit, river water moves through the unit at nearly all times. Inflow and outflow occur simultaneously with only different proportions determining whether stages are rising or falling. This type of condition may be referred to as a throughflow regime and is illustrated in Figure 4-1C. In such a case, inflow exceeds the volume of water required to equalize stages on the inside and outside of the swamp basin.

A throughflow regime is conducive to excess sedimentation and rapid loss of aquatic habitat, particularly when water introduction through overbank flow is eliminated as a result of the artificially increased height of surrounding levee ridges (Figure 4-1D). In such a case, the entire inflow is confined to a usually small number of channels, with a resultant increase of inflow velocities. These high velocities allow, in turn, for high concentrations of sediment in the inflowing water; this concentration of sediment is sustained until inflowing waters enter a lake or swamp environment where the water is no longer confined. There, sediment is deposited and causes a rapid environmental transition, with loss of high-quality aquatic habitat. Furthermore, it is evident that introduction of sediment under the throughflow regime increases with the rate of flux.

Contrasting with the above flooding process is the backwater regime. As illustrated in Figure 4-1A, water other than precipitation is introduced into the swamp basin only across the lower boundary of the basin and only to the extent that such becomes necessary to equalize water levels on the inside and outside. Water thus moves in and out of the basin rather than through it. With regard to river water introduction, the Fordoche area may be considered a backwater area. However, the backwater regime is modified because of

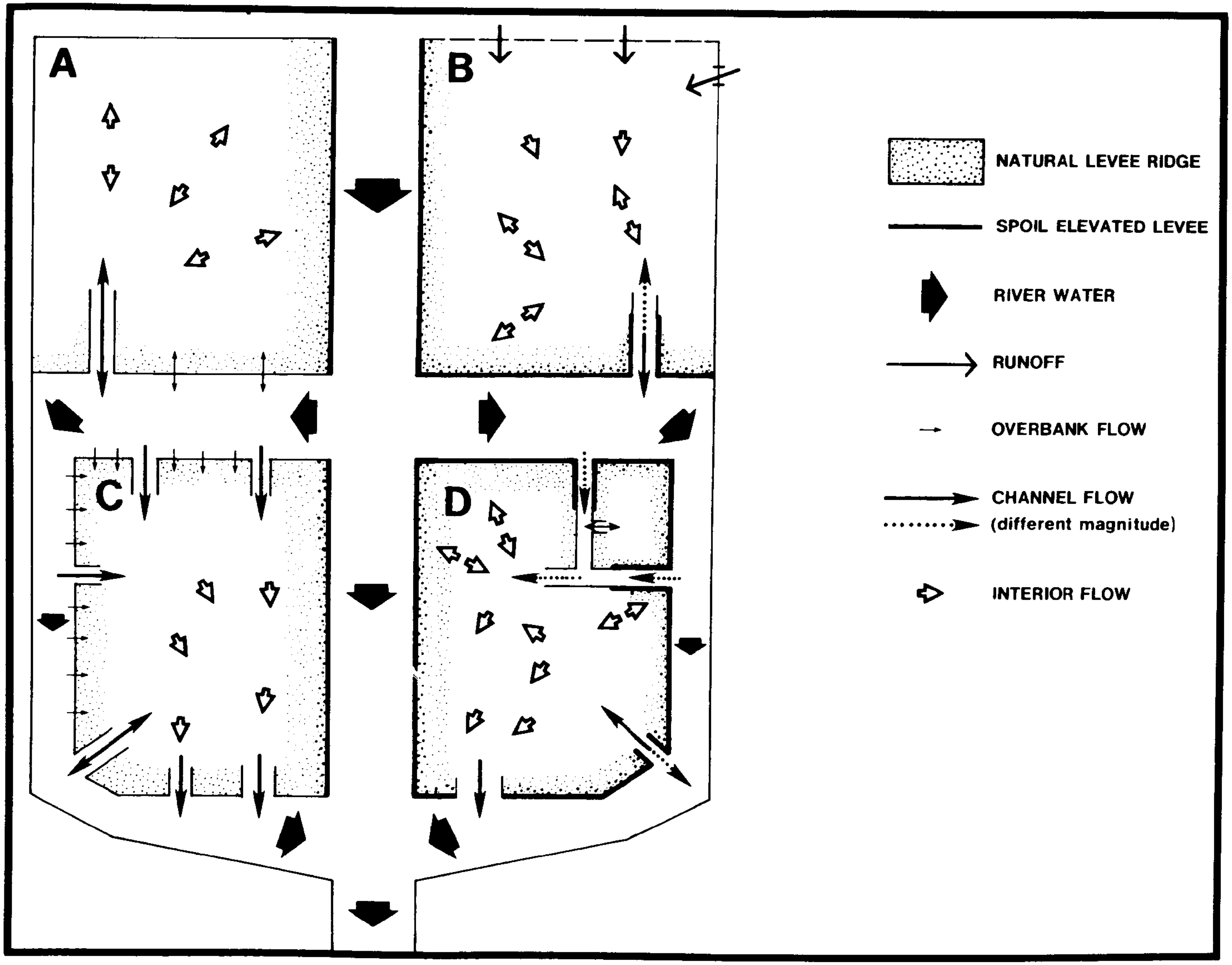

Figure 4-1. Various modes of water introduction into individual swamp basins. A. Backwater flow; B. Modified backwater flow; C. Throughflow; D. Modified throughflow.

introduction of runoff into the Fordoche basin from outside the floodway. Obviously, inflow of river water to only the extent necessary to equalize flow also reduces the introduction of excessive sediment.

Water needs and sedimentation can be further reduced when flooding and dewatering of the swamp basins are managed in such a way that a gradual rise and recession occurs without the many fluctuations. Every fluctuation means an inflow of water and sediment that contributes only partially or not at all to the necessary annual flooding and dewatering. In other words, reduction of inflow may be obtained by limiting it to those volumes necessary to produce a desired stage rise and to maintain circulation.

Necessary structural controls would also allow maximum use of precipitation surplus by holding such a surplus during times when a water level rise is desired, even though river levels may be temporarily falling. Runoff stored in this way would decrease the volume of river water needed to meet given water level requirements.

Whereas the previous discussions contrast backwater flow and throughflow, a second differentiation as to mode of flooding can be made; that is, between overbank flow and channel flow. It was pointed out already that elimination of overbank flow increases inflow velocities and thereby sediment concentrations of the inflowing water. Channelized inflow causes sediment to be carried toward the center of the swamp basin, where it eliminates aquatic habitat. In fact, continuation of such a sedimentation pattern will eliminate a swamp basin as a depression because elevations of the interior area will eventually equal that of the rim. In contrast, introduction of water into a swamp basin through overbank flooding should change the pattern of sedimentation and greatly minimize its detrimental effect. Most sediment would be deposited along the basin rim where inflow velocities are reduced as water moves through the vegetation that occupies the rim. This is the natural process by which the basin-levee complex developed in the first place and by which this type of environment is usually sustained.

Whether the above possibilities are acceptable alternatives depends on a number of factors related to environmental quality and biological productivity. At present, it is not yet possible to estimate, for example, the extent to which river water can be substituted for by local runoff or the number of stage fluctuations reduced without adversely affecting environmental quality and biological productivity. Yet, the necessity of acquiring that type of information is apparent and is, in part, why the present study was undertaken. By comparing the hydrologic regimes of three areas that differ with regard to contributions of river water to annual flooding, amplitude of stage fluctuations, mode of water introduction, apparent sedimentation, and other related aspects, at least a basis can be established for evaluating management alternatives.

An equally important complex of questions concerns the relationship between hydrologic regimes and habitat. Development of water management guidelines requires more than an understanding of hydrologic functioning of various swamp basins. Other hydrologic aspects that enter into the decision-making process concern the duration and depth of flooding and sediment introduction, as these determine the type and distribution of biological communities.

The present study, in comparing hydrologic regimes and environments of the aforementioned swamp basins, builds further on approaches and data developed during the previous water management studies of the Atchafalaya Basin. In addition, a field program was conducted over the period of September 1975 through June 1976. Discharges were measured monthly, on the average, at all inlet and outlet channels of each of the three swamp basins. Simultaneously, depth-integrated samples of suspended load were obtained. The samples were analyzed in the laboratory for concentrations of sand and silt plus clay fractions. Staff gages were placed in the center of each of the three study areas to augment daily stage observation at U.S.C.E water level gages. Measurements and sampling proceeded according to the guidelines established by the U.S. Geological Survey (Guy and Norman, 1970). With regard to habitat differentiation and interior circulation, field surveys included qualitative observations and incidental measurements during traverses through each of the swamp basins. Field surveys served furthermore to augment information derived from aerial photo interpretation.

The following three chapters will analyze separately the three study areas, Fordoche, Buffalo Cove, and Pat Bay.

SECTION V

BAYOU FORDOCHE

This section of the report will discuss the Bayou Fordoche study area, a distinctly bounded area between the outer floodway levees and the Atchafalaya River guide levees. The boundaries and setting will be discussed first. Then the hydrologic regime will be discussed, under "Annual flooding," followed by the vegetation and wildlife, under "Habitat." In "Water and Sediment Budget, 1975-1976," the rates of sedimentation in the Fordoche area are analyzed in terms of the sources and stages of water introduction there.

BOUNDARIES AND SETTING

The Bayou Fordoche area covers approximately 270 km^2 of the Atchafalaya Basin floodway immediately south of U.S. Highway 190 (Figure 1-1 and 5-1). Rigid boundaries delineate the area as a hydrologic unit. The western boundary is formed by the continuous artificial levee of the floodway; the eastern boundary by the continuous artificial levee of the Atchafalaya River. U.S. Highway 190 and railroad embankments form the northern boundary, and a natural levee ridge associated with an abandoned Teche distributary bounds the area to the south.

Topography reflects the area's geologic history as an inter-levee basin between the Teche and Atchafalaya River natural levees. A broad, natural levee ridge which extends along the eastern margin is related to former annual overflow of the Atchafalaya River. Similar natural levee ridges parallel Bayou Courtableau, extending northwestward into the northern half of the area. These are reminiscent of the time that Bayou Courtableau served both natural drainage into and diversion of water and sediment from the Atchafalaya River. The levee ridges form the highest ground and are occupied mainly by bottomland hardwoods.

The western half of the area is occupied by a depression extending north-south over the entire length of the area. The northern two-thirds of this depression is covered with swamp and bottomland hardwood forests, while the southern one-third contains Henderson Lake.

Related to the above setting, drainage is westward from the Atchafalaya natural levee ridge into the depression and southward through the depression into Henderson Lake. Bayou Fordoche serves as the primary drainage stream for the depression with numerous smaller bayous contributing.

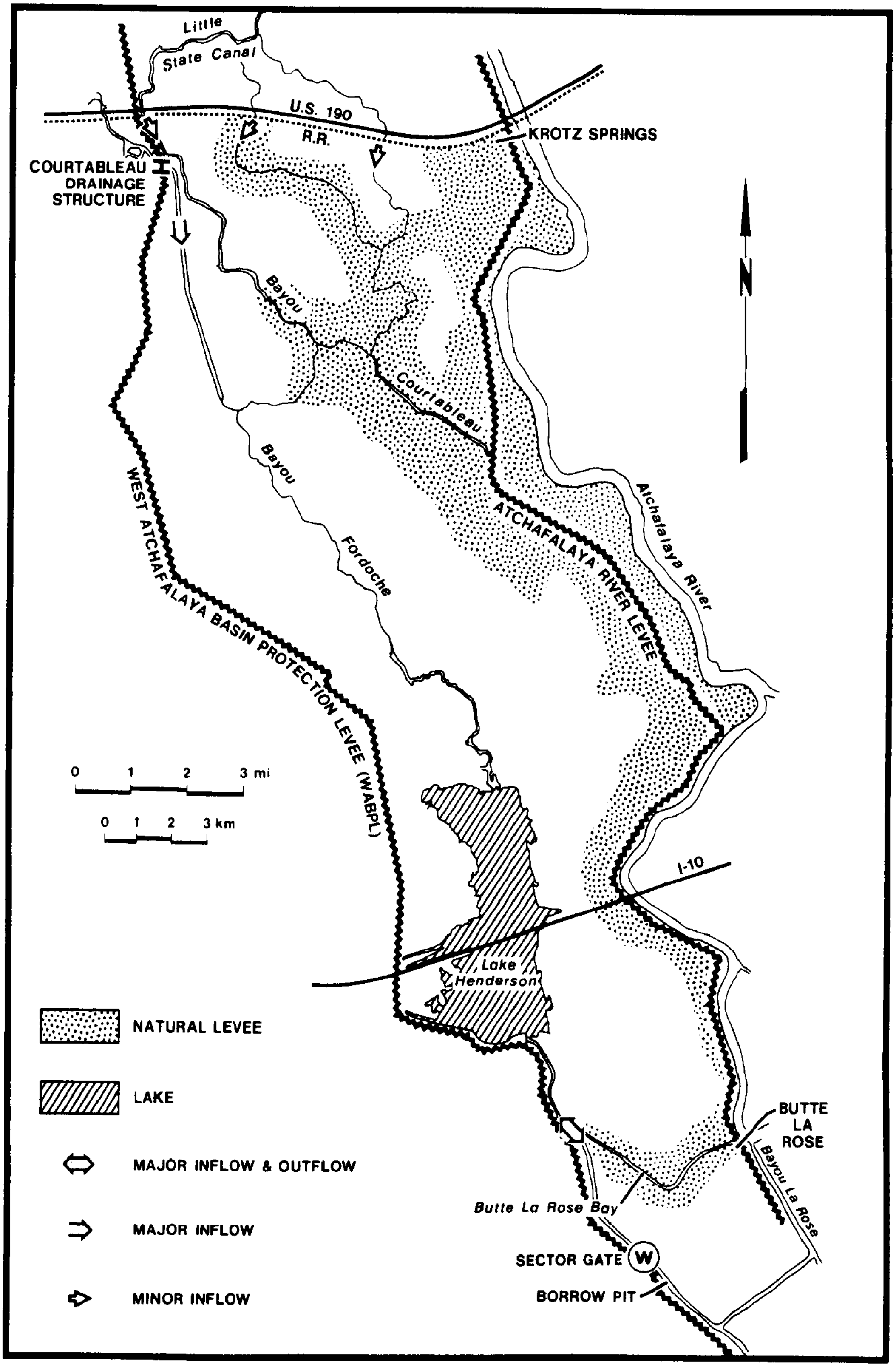

Figure 5-1. Geomorphic characteristics and inflow locations, Fordoche Management Unit.

ANNUAL FLOODING

Two sources of water, the Atchafalaya River and local runoff, contribute to annual flooding, but the rigid boundaries of the Fordoche unit place distinct constraints on routes of water introduction. Atchafalaya River water enters across only the southern boundary through the West Atchafalaya Basin Protection Levee borrow pit after diversion from the river into Bayou La Rose (Figure 5-1). Introduction of local runoff from outside the Fordoche unit can occur across the northern boundary and through the Bayou Courtableau Drainage Structure located in the West Atchafalaya Basin Protection Levee. Little State Canal and two smaller channels allow drainage water from the West Atchafalaya Floodway to the north to enter Fordoche.

Dewatering of the Fordoche area occurs almost entirely through the West Atchafalaya Basin Protection Levee borrow pit and is equally dependent on Atchafalaya River stages at Butte La Rose. However, dewatering can be controlled below 2.25 m above mean sea level (MSL) because of a sector gate built for that purpose in the borrow pit (Figure 5-1).

Average conditions for the annual flooding regime are depicted by Figure 5-2 in the form of two mean annual hydrographs and three elevation frequency or hypsometric curves. Hydrographs give average monthly stages as recorded over the period 1961 through 1970 in the northern half (Bayou Fordoche) and the southern part (Henderson Lake). Hypsometric curves give the percentage of area below a given elevation or water level along U.S. Corps of Engineers (USCE) survey ranges characteristic for the northern part (Range 1), central part (Range 6), and southern part (Range 8), of the Fordoche unit, respectively. Range locations and gage locations are shown later in Figure 5-5.

The northern part is defined as the area between U.S. Highway 90 and range line 5. The central part extends from range line 5 southward to range line 7, and the southern part occupies the remaining area south of range line 7. Elevation distributions along Ranges 1, 6, and 8 are taken as representative of the above three areas respectively.

Water levels are highest in April/May and lowest in September, October, and November. Maximum levels are about equal in the upper and lower parts of the unit, but levels differ by about 1.2 m during low stage. Thus, a southward gradient is present during most of the year which maintains water movement from north to south. Also, stage variation is twice as large in the southern part (Henderson Lake, 2.7 m) as in the northern part (Bayou Fordoche, 1.3 m).

Comparison of the hypsometric curves and hydrographs in Figure 5-2 reveals a gradient in depths and duration of annual flooding from north to south. The Bayou Fordoche hydrograph applies to northern Fordoche (Range 1), while the Henderson Lake hydrograph, because of the lesser open water gradient, approximates levels in both central (Range 6) and southern (Range 8) Fordoche. The graph, then, shows that during high stage, only 50 percent of the northern third of the unit is flooded while about 80 percent of the central and

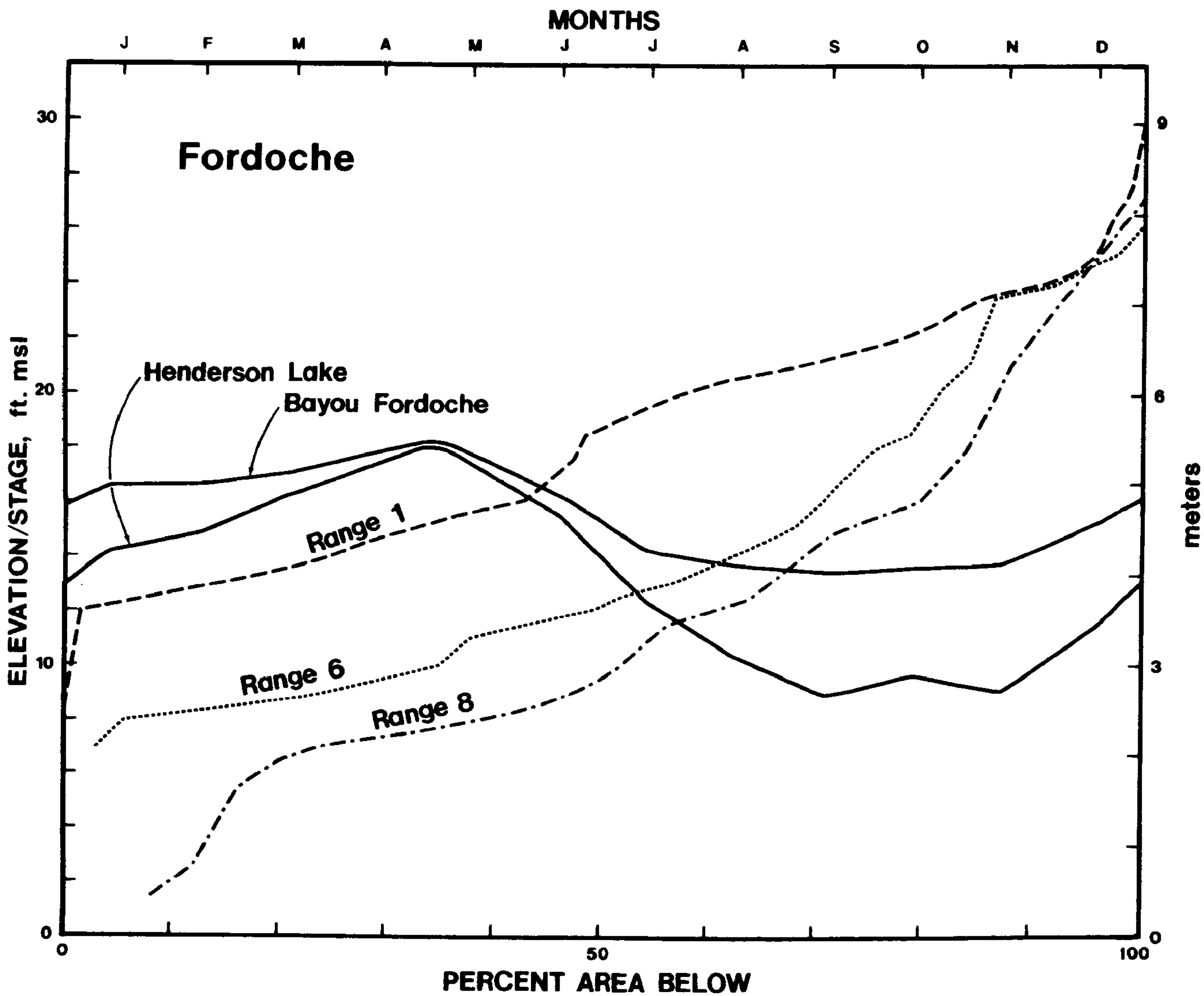

Figure 5-2. Average annual stage hydrographs for Henderson Lake and Bayou Fordoche, and elevation frequency curves for the upper (range 1), central (range 6), and lower (range 8) parts of the Fordoche Management Unit.

southern parts is submerged. Dewatering during low stages is nearly complete in northern Fordoche, while some 30 to 40 percent of the area, including the lake, remains submerged in the central and southern parts. Water depths in the northern swamp generally do not exceed 1 m, while southward they increase to as much as 2.5 m during spring flooding.

An additional aspect is revealed by the shape of the hydrograph. One notices that water levels rise relatively slowly from January to April so that about 50 percent of the northern swamp and 70 percent of the southern swamp are submerged over the first four or five months of the year. Subsequent dewatering is seen to be much more rapid.

The hydrologic regime is summarized with regard to hydroperiod in Table 5-1. Based on the hydrographs and hypsometric curves, the period and extent of flooding were calculated for the upper, middle, and lower parts of Fordoche. Selected hydroperiod lengths relate to biological habitat and management objectives as set forth in the previous report (van Beek et al., 1976) and Table 5-2.

HABITAT

Prior to construction of artificial levees in the early 1930's, the Fordoche unit contained well-drained lands along the natural levee ridges of the Atchafalaya River, Bayou Courtableau, and Butte La Rose Bay (Figure 5-1), with backswamp occupying most of the remaining area westward toward the Teche levee ridges. In the western part of the unit, north-south alignment of remnant river channels facilitated drainage of the backswamp into Butte La Rose Bay and the Atchafalaya River. On the east side, drainage was much less efficient and natural ponding had led to development of a lake that coincided approximately with the southern half of the present Henderson Lake. A mixed hardwoods vegetation covered portions of the Atchafalaya River and Bayou Courtableau natural levee which had not been cleared for agriculture. Cypress-tupelo associations occupied the lowlands subject to the longest period of flooding. Lands along the toe of the natural levee, representing a transitional zone, contained a swamp-mixed hardwood association. The hydrologic regime was probably the dominant factor governing the distribution of vegetation in this natural environment.

By the early twentieth century, this pattern had been significantly altered by lumbering and oil exploration, especially in the southern two-thirds of the unit. The cypress industry had removed all marketable logs, leaving only stumps and unsound cypress trees. The second-growth forests that emerged in the scarred backswamp contained some cypress, but were composed mainly of willow (Salix nigra) and cottonwood (Populus deltoides). Spoil banks resulting from pipeline canals and location dredging were also colonized by vegetation associations dominated by willows and cottonwood.

Completion of the West Atchafalaya Basin Protection Levee which further blocked natural southward drainage, and construction of the Atchafalaya River

TABLE 5-1. EXTENT AND DURATION OF FLOODING, FORDOCHE MANAGEMENT UNIT

	PERIOD FLOODED*** (Months)	AREA* %	AREA** (km^2)	ELEVATION* (m)
NORTHERN FORDOCHE (Range 1)	0 - 1	52	67	> 5.3
	1 - 4	5	7	4.9 - 5.3
	4 - 8	17	22	4.3 - 4.9
	8 - 11	5	7	4.1 - 4.3
	11 - 12	21	27	< 4.1
CENTRAL FORDOCHE (Range 6)	0 - 1	26	20	< 5.2
	1 - 4	7	6	4.5 - 5.2
	4 - 8	30	24	3.5 - 4.5
	8 - 11	11	9	2.8 - 3.5
	11 - 12	26	21	< 2.8
SOUTHERN FORDOCHE (Range 8)	0 - 1	17	10	> 5.2
	1 - 4	11	7	4.5 - 5.2
	4 - 8	18	10	3.5 - 4.5
	8 - 11	6	4	2.8 - 3.5
	11 - 12	49	29	< 2.8
TOTAL	0 - 1	36	97	
	1 - 4	7	20	
	4 - 8	21	56	
	8 - 11	7	20	
	11 - 12	29	77	

*Estimated from given range line

**Area for given subunit is estimated from area percent at a given range line

***Estimated from stage data

TABLE 5-2. RELATIONSHIP BETWEEN FLOODING CHARACTERISTICS AND BIOLOGICAL CONDITIONS AND VALUES

Hydroperiod Class Interval	Class V 11-12 mos.	Class IV 8-11 mos.	Class III 4-8 mos.	Class II 1-4 mos.	Class I 0-1 mos.
Flooding Characteristics	Permanent and subpermanent aquatic habitat; lakes, bayous, main river channels.	Swampland subject to extended flooding. Flooding may begin in November and last through July or later. Wholly or partly dewatered from late summer to early fall. Deep swamps.	Moderately flooded swampland. Flooding may begin in December and extend through July. Typically dry mid-summer to mid-fall. Intermediate swamps.	Swampland subject to a relatively short flood period. Land is usually flooded only during the spring months during highest river stages. Shallow swamps.	Land which is not flooded or only briefly flooded during the average water-year. Flood period, if any, usually in mid-spring, crests of natural levees and spoil banks.
Plant Communities	Epiphytes of tree covered areas: Spanish moss, lichens, mosses, resurrection fern. Overstory: water tupelo, baldcypress; willow along river channels. Understory trees and shrubs: buttonbush. Floating aquatic plants: water hyacinth, water lettuce, frogbit, duckweed, *Riccia*, *Azolla*. Submerged aquatic plants: coontail, water celery, *Egeria*, fanwort, *Hydrilla*, *Chara*.	Epiphytes: Spanish moss, ressurection fern, lichens, mosses. Overstory trees: water tupelo, baldcypress. Understory trees and shrubs: buttonbush, water elm. Herbaceous forms: Floating aquatics - water hyacinth, water lettuce, duckweed, frogbit, *Riccia*, *Azolla*. Submerged aquatic - coontail. Emergent aquatics - arrow-arum, pickerelweed.	Epiphytes: Spanish moss, lichens, mosses, resurrection fern. Overstory trees: baldcypress, water tupelo, pumpkin ash, green ash, bitter pecan, black willow and sandbar willow in areas where sedimentation is active. Understory trees and shrubs: buttonbush, Virginia willow, silver bells, water elm. Herbaceous forms: Floating aquatics - water hyacinth, water lettuce, frogbit, duckweed, *Riccia*, *Azolla*. Submerged aquatics - coontail. Emergent aquatics - lizard's tail, arrow-arum, spider lily, arrowhead.	Epiphytes: Spanish moss, lichens, mosses, ressurection fern. Overstory: baldcypress, green ash, red maple, bitter pecan; black willow, cottonwood, and sycamore may become established where sedimentation is strong. Understory trees and shrubs: wax myrtle, palmetto, *Crataegus* Spp., swamp privet, red bay. Vines: rattan, pepper vine, *Trachelospermum*. Herbaceous Forms: Floating aquatics - water hyacinth, water lettuce, frogbit, duckweed, *Riccia*, *Azolla*. Emergent aquatics - lizard's tail, *Polygonum* Spp., royal fern, false nettle.	Epiphytes: Spanish moss, lichens, mosses, ressurection fern, mistletoe. Overstory trees: cottonwood, black willow and sycamore where sedimentation is active; water oak, overcup oak, American elm, hackberry, sweetgum, nuttall oak; live oak on some higher sites. Understory trees and shrubs: box elder, deciduous holly, wax myrtle, *Crataegus* Spp., Elderberry, pokeweed. Vines: poison ivy, rattan, muscadine, eardrop vine, *Smilax* Spp., dewberry, crossvine, trumpet creeper, Japanese honeysuckle. Herbaceous forms: false nettle, butterweed, *Spilanthes*, *Oplismenus*.
Importance to Fish and Wildlife	Permanent habitat for fishes and other aquatic fauna. Lakes and bayous are spawning areas for sport and commercial fishes. River channels provide habitat for fishes preferring a current (channel catfish, striped bass, paddlefish). Crawfish population small as compared to swamp areas. Habitat for minks, otters, nutria, raccoons, wading birds, waterfowl, snakes, alligators, frogs.	Alternately part of the aquatic and terrestrial environment. Feeding area for adult and juvenile fishes. Long hydroperiod assures time for growth of juvenile fishes. Crawfish are exposed to prolonged predation. Habitat for furbearers, wading birds, some waterfowl. May serve as habitat for terrestrial species (deer, rabbits) when dry.	Intermediate hydroperiod swamps are utilized as feeding areas by adult fishes and are important as nursery areas for young of year fishes. Hydroperiod is long enough to allow for growth and sexual maturity of crawfish and short enough to prevent over-predation by aquatic predators: crawfish burrow into bottom muds during dry periods. Intermediate hydroperiod swamps serve as habitat for aquatic mammals, birds, reptiles and amphibians when flooded and for terrestrial species when drained.	Swamps serve as a nursery area for juvenile fishes and as a feeding area for adult fishes when flooded. Shallow swamps may also serve as a spawning area for certain fishes (e.g., gars, carp). Crawfish utilize short hydroperiod swamps as feeding and growing areas. Utilized by aquatic species of wildlife when flooded and by terrestrial species when dry.	Essentially dry land environments, these areas may be utilized by aquatic fauna, including fishes and waterfowl, during the brief flood period. Much of the northern end of the basin consists of this habitat type in the early stages of succession. Wildlife present includes deer, bear, rabbits, squirrels, bobcats, skunks, armadillos, turkey, woodcocks and many non-game species. Certain of the higher ridges and islands in the lower end of the basin support this type of habitat.
Management Objectives	1. Maintenance of aquatic area. 2. Water quality protection and enhancement. 3. Reduction of sedimentation rate. 4. Control of aquatic weeds. 5. Reduction of extreme flood volume.	1. Maintenance of a water depth of at least 4 ft. during months of crawfish trapping. 2. Improvement of oxygen content of waters to reduce trap mortalities to crawfish. 3. Improvement of extent of dewatering in late summer and early fall. 4. Reduction of sedimentation rate. 5. Reduction of extreme flood volume. 6. Control of aquatic weeds.	1. Regulation of hydroperiod to assure adequate conditions for crawfish and fish reproduction. 2. Reduction of sedimentation rate. 3. Control of aquatic weeds. 4. Reduction of extreme flood volume.	1. Reduction of extreme flood volume. 2. Reduction of sedimentation rate.	1. Reduction of extreme flood volume. 2. Reduction of sedimentation rate.

levees, which blocked Bayou Courtableau and Butte La Rose Bay, further impounded the Fordoche unit. As a result, a larger portion of the unit became permanently flooded, especially after installation for fisheries purposes of a 2.25-m MSL sector gate in the West Atchafalaya Basin Protection Levee borrow pit. Henderson Lake increased to a minimum area of 20 km^2, and an area ranging from 120 to 200 km^2 experienced a longer hydroperiod than had previously existed (Lantz, 1974). As suggested by the following map comparison, the new hydrologic regime is largely responsible for maintaining the type of second-growth forest that emerged after the area was lumbered. Characteristics of this regime were already summarized in the previous section and Table 5-1.

On the basis of topographic and hydrologic data, extent and duration of flooding could be mapped. Figure 5-3 shows the hydroperiods as experienced by various parts of the Fordoche unit. The area of shortest hydroperiod is found along the Atchafalaya River natural levee and abandoned distributary and crevasse deposits. Hydroperiods increase in duration westward, away from the levee flank, and southward, in response to general surface gradient and the increased ponding effect.

A comparison of the spatial distribution of areas subject to a given hydroperiod with that of vegetation (Figures 5-3, 5-4) generally supports a correlation that has been observed by others in similar wetland environments (Penfound, 1952; U.S. Department of Agriculture, 1973). The correlation applicable in the Fordoche unit is summarized in Table 5-3.

TABLE 5-3. RELATIONSHIP BETWEEN DURATION, AVERAGE DEPTH OF FLOODING, AND VEGETATION ASSOCIATIONS IN FORDOCHE MANAGEMENT UNIT

Duration of Flooding (months)	Average Depth of Flooding (m)	Vegetation Associations (EROS, 1975)
0 - 1	0.1	mixed hardwoods
1 - 4	0.4	swamp/mixed hardwoods
4 - 8	0.8	swamp/mixed hardwoods willow/cottonwood
8 - 11	1.0	willow/cottonwood
11 - 12	>1.0	cypress/tupelo

Many of the natural levee lands experiencing a hydroperiod of 0-1 month are well above 5.4 m MSL and are no longer subject to annual flooding. Consequently, a large portion of this rich alluvial soil has been cleared for agriculture, as shown in Figure 5-4. The remaining area supports mixed hardwood forests. The areas with hydroperiods of 1-8 months represent transitional zones as evidenced by the swamp/mixed hardwood forests. Hydroperiods of 8-12 months are tolerated only by cypress/tupelo gum and willow/cottonwood associations.

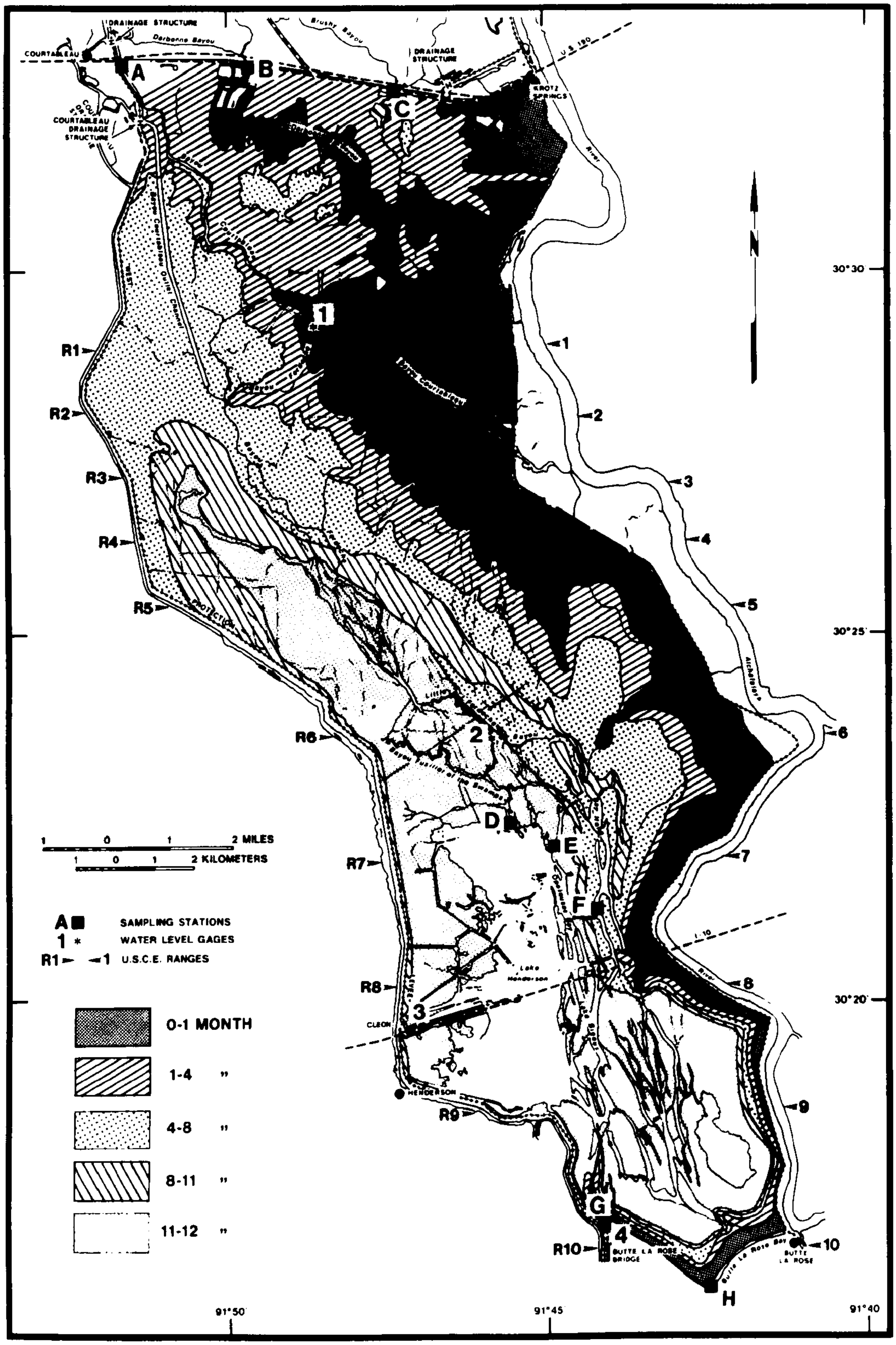

Figure 5-3. Extent and duration of flooding, Fordoche Management Unit.

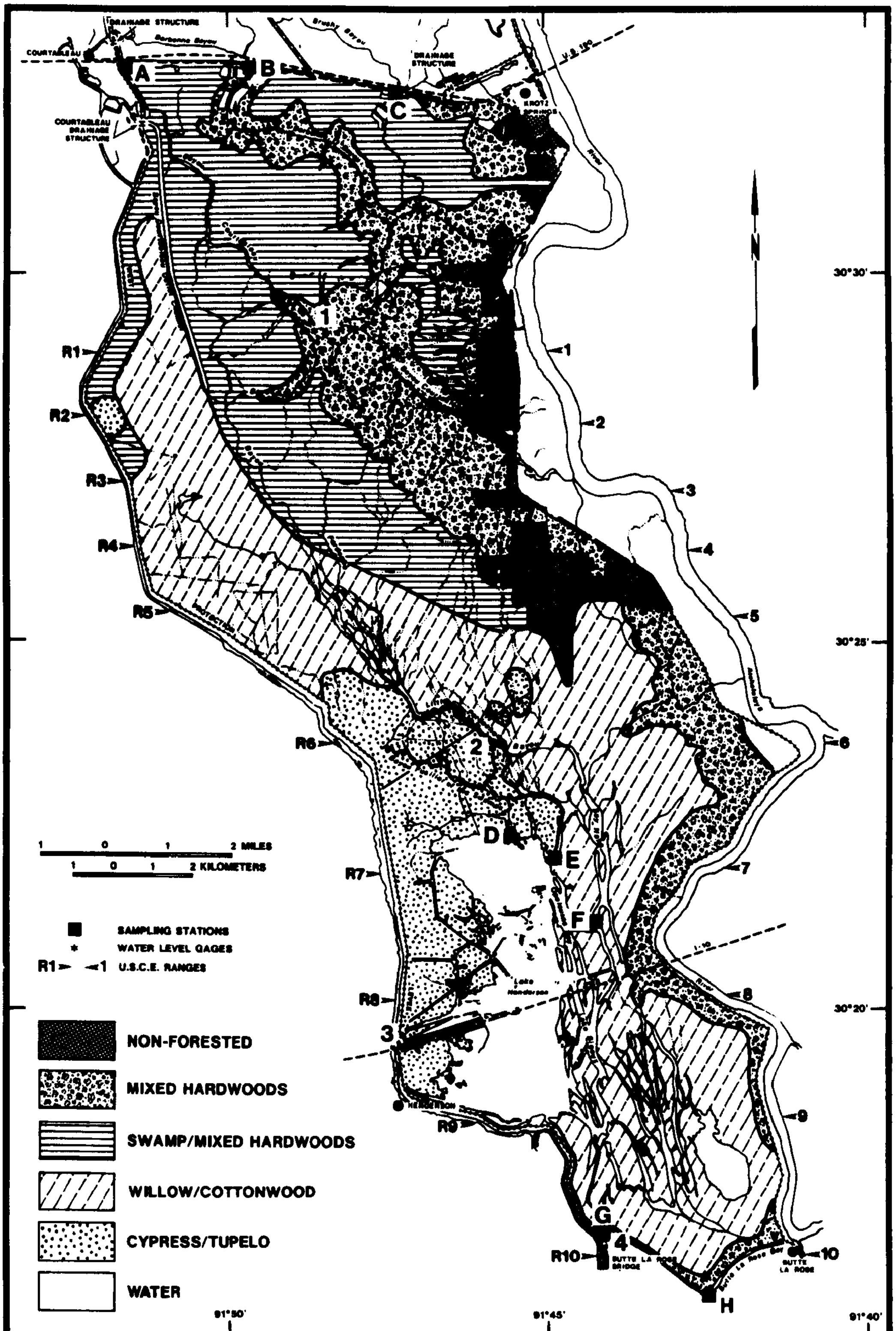

Figure 5-4. Distribution of vegetation associations, Fordoche Management Unit (after EROS, 1975).

Lumbering in the early twenties is believed to have been partly responsible for the invasion of the willow/cottonwood association, which presently predominates. Lumbering techniques, especially clear-cutting, provided both open conditions and exposed mineral soils favorable for willow germination and growth. On the other hand, it is generally believed that tupelo/gum and cypress are the climax species in deep swamp environments and "will regenerate usually to what they were before cutting, although willow may temporarily dominate cut-over areas" (U.S. Department of Agriculture, 1973). It should be added, however, that the greater stage fluctuations that came with increased diversion of Mississippi River water and floodway construction and impoundment of the Fordoche unit placed additional constraints on the lumbered area with regard to cypress regeneration.

The only portion of the Fordoche area which contains dense stands of cypress and scattered tupelo gum is the southwestern perimeter of Henderson Lake. Since these trees are secondary growth and the area is generally submerged throughout the year with stage variations up to 4 m, these stands of cypress/tupelo gum must be attributed to regeneration during pre-floodway conditions or regeneration from stumps. Possibly this was one of the earlier areas lumbered.

WATER AND SEDIMENT BUDGET, 1975-1976

Much insight into the hydrologic processes that govern the Fordoche regime can be obtained from inspection and comparison of detailed stage hydrographs for the area. For this purpose, 1975-1976 stage data were obtained for the following U.S. Army Corps of Engineers gaging stations (Figure 5-5): Bayou Fordoche (1) in the upper part of the unit, Cleon (3) and West Atchafalaya Basin Protection Levee borrow pit at Butte La Rose Bridge (4) in the lower part of the unit, and Atchafalaya River at Butte La Rose. Plotted in the form of stage hydrographs (Figure 5-6), these data immediately suggest the nature of relationships between water levels in the Fordoche unit, river stages, and inflow of drainage water.

The Atchafalaya River shows a low-stage period from September through November, an accelerating rise from November through March, and a decelerating recession from April through July. For further discussion and comparison, the hydrograph is divided into five intervals according to direction and rates of Atchafalaya River stage changes. Intervals are marked I through V (Figure 5-6). River levels during most of Period I were below crest level of the borrow pit sector gate. Therefore, inflow of river water was largely prevented, as were river-caused stage fluctuations.

For the upper and lower parts of the Fordoche unit, behavior of water levels differs in several respects, both when compared to each other and when compared with river stages. The most striking aspect of the hydrograph for the Upper Fordoche area (Bayou Fordoche, Figure 5-6) is a large number of peaks, each showing a rapid rise and gradual recession. The reason for these peaks becomes obvious when comparing the hydrograph with the precipitation data and with inflow from the Courtableau Drainage Structure. Both

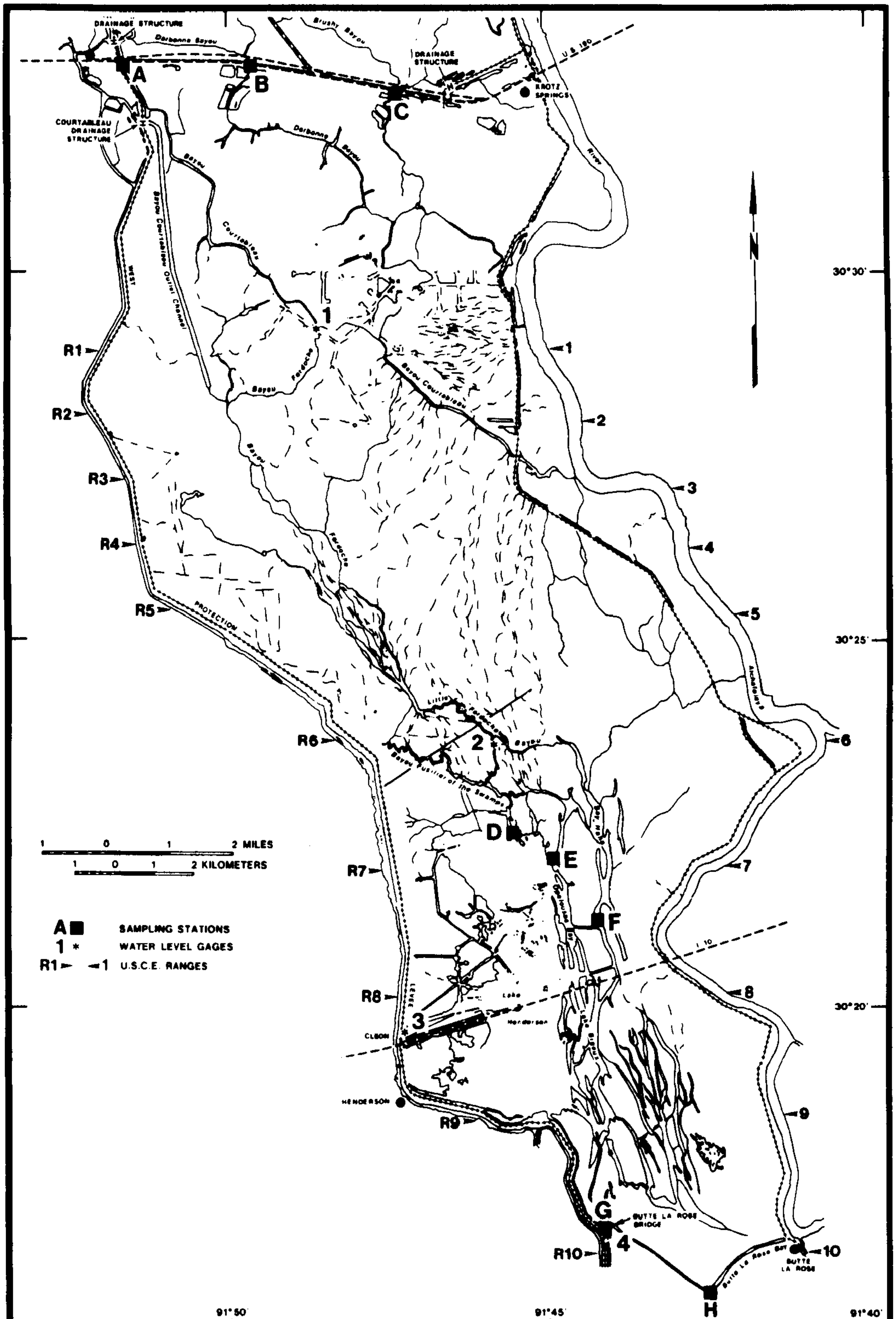

Figure 5-5. Location of water level gages, topographic survey ranges, and discharge-sediment measurement stations in Fordoche Management Unit.

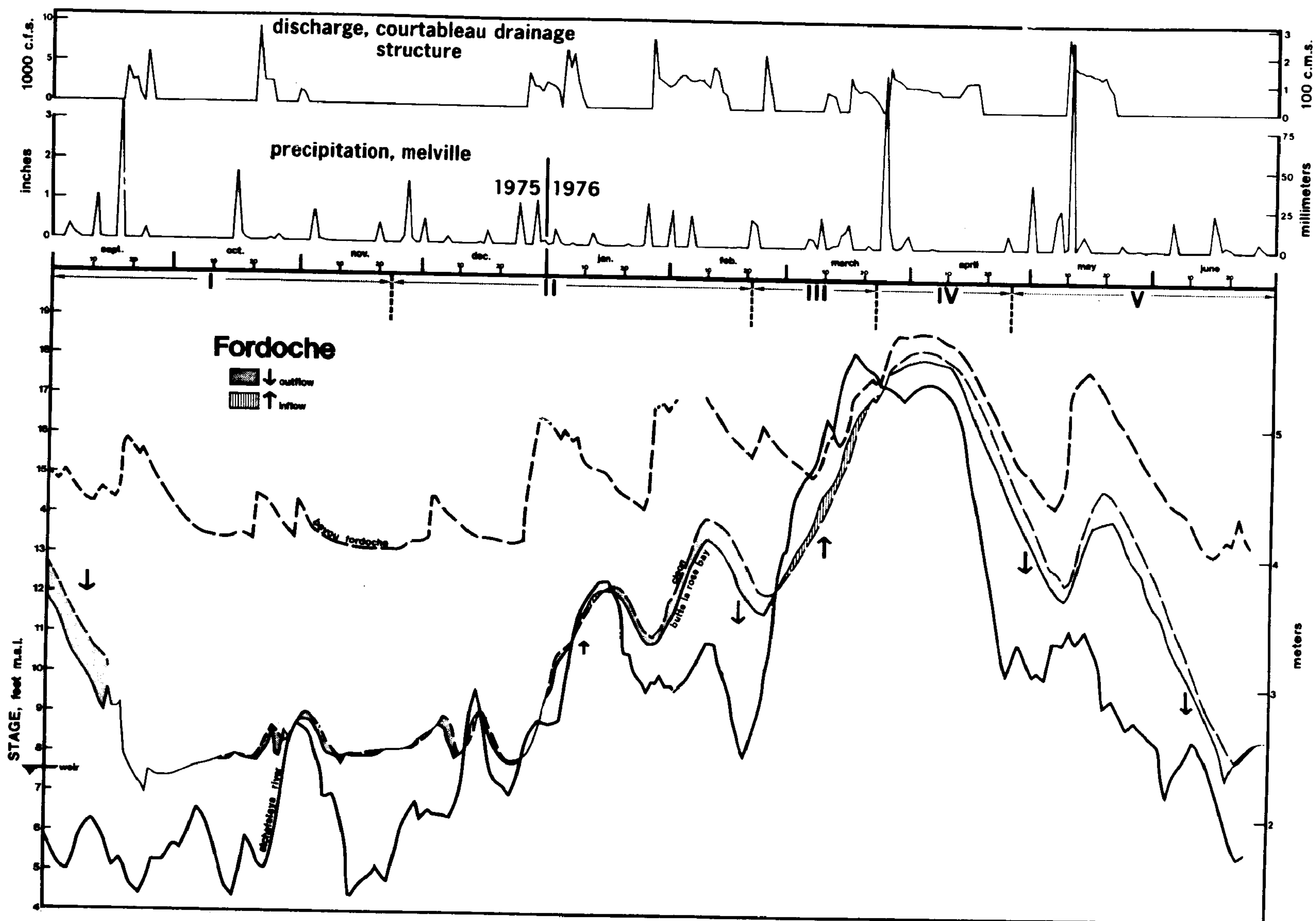

Figure 5-6. Stage hydrographs for Upper Fordoche (Bayou Fordoche) and Lower Fordoche (Butte La Rose bridge and Cleon) and the Atchafalaya River, discharge hydrograph for Courtableau Drainage Structure, and precipitation at Melville, Louisiana.

are plotted as a time series above the hydrograph in Figure 5-6. One notices that at the onset or immediately following major precipitation, the drainage structure is opened, providing a much larger inflow into the sub-unit than would result from local runoff. Consequently, a rapid rise in swamp water levels is produced, in particular because transfer of water from the upper to the lower part of Fordoche is slow due to hydraulic constraints.

The slow rate at which the Upper Fordoche swamps drain into Henderson Lake relative to the rapid rate at which water levels fall in Lower Fordoche results in a considerable southward gradient. In Figure 5-6, one notices that as the Henderson Lake area is draining rapidly through the borrow pit, water levels in the Upper Fordoche area recede much slower, resulting in a 1.5-m difference in water level between the Bayou Fordoche and Henderson gages. The resultant gradient is sustained throughout Period I, as is the associated southward movement of water. Invariably, flow measured at the mouth of Bayou Fordoche was into Henderson Lake, while at the borrow pit outlet (Butte La Rose Bridge), flow was outward almost continuously.

The effect of the Courtableau structure becomes more pronounced during the winter (Period II) when frontal rainfall intensifies. Introduction of runoff water into Upper Fordoche produces rapid rises in January and February. As water moves toward the lower part of the area, an additional aspect of water introduction through the Courtableau structure becomes apparent. This concerns the interaction with rising Atchafalaya River waters. The introduced runoff tends to amplify rises produced by the Atchafalaya River, and interaction is such that rising river stages prevent outflow of much or all of the drainage water. At the same time, accumulated runoff prevents river waters from flowing into the Fordoche area. Thus, during January and February, a 1.2-m net rise occurred, which was almost entirely attributed to inflow from the Courtableau Drainage Structure and local runoff. During those months, water stages were maintained above those of the Atchafalaya River so that the outflow that occurred during the previous four months was sustained despite rising river stages (Figure 5-6).

During Period III, introduction of drainage water was insufficient to offset the accelerated rise of Atchafalaya River stages. In March, a net rise of 1.5 m occurred in Lower Fordoche, part of which was contributed by river waters entering Henderson Lake. On the basis of flow direction and gradient observations, river water is believed not to have moved northward beyond Henderson Lake. Since stages increased more rapidly in the Henderson area than in northern Fordoche, the gradient between the two areas was all but eliminated at the time of flood stage (Figure 5-6).

Water levels remained at peak stage for about two weeks in April. During that time, introduction of drainage water and runoff was sufficient to establish a southward gradient and produce outflow from the unit. As recession of stages began, outflow was accelerated and continued even during a temporary May rise. The above pattern was sustained through the month of June

In summary, the hydrographs show that during the 11-month study period, a net rise and fall of 3 m occurred. Water requirements for this phenomenon were met largely by local runoff and inflow from the Courtableau Drainage Structure, while additional amounts were provided when Atchafalaya River stages also forced river water into the Fordoche basin. During the 11 months considered here, the regime was such that outflow from the system predominated for 6 months, flow was variable for 4 months, and inflow from the river occurred for 1 month. Of particular importance is that interaction between rising river stages and rising stages in Henderson Lake due to drainage water arrival was such that outflow continued even during significant rises in Atchafalaya River stages.

To further characterize water movement with regard to the Fordoche area, a number of flow conditions considered typical are given in Table 5-4. The data pertain to the borrow pit where it enters the Fordoche unit, to Bayou Fordoche where it enters Henderson Lake, and to Little State Canal where it crosses the northern boundary of the Fordoche unit (Stations G, D, A: Figure 5-5). A notable occurrence at Station G is the difference between suspended load concentrations for Period III, when Atchafalaya River water is entering the unit, and the remaining time, when outflow dominates. Bayou Fordoche is seen to have a rather steady southward flow except during Period III, when rising stages due to river water inflow eliminate the gradient. Inflows at Little State Canal appear to be very small, especially since these represent the total of measured inflow across the northern boundary. Not included in the tabulation are the inflows from the Courtableau Drainage Structure since these will be discussed in subsequent paragraphs.

Combining all available hydrologic data for the 1975-1976 period allows estimation of respective contributions to the flooding process by local precipitation, introduced drainage, and the Atchafalaya River. For this purpose and in recognition of a surface-water gradient, the Fordoche area is divided into two nearly equal-sized areas: Upper, or northern, and Lower, or southern Fordoche. U.S. Army Corps of Engineers survey range 5 (Figure 5-5) was selected as the dividing line; water levels throughout Upper Fordoche were assumed to equal those recorded at the central Bayou Fordoche gage (1) and water levels in the area below range 5 were assumed to equal the average of the Opelousas Bay (4) and Cleon (3) gages. Only precipitation and monthly evapotranspiration rates were applied equally to each area. Precipitation data used were those at Melville, Louisiana, immediately to the north of the Fordoche area. Evapotranspiration rates were those determined for Melville through water-balance calculation in a previous study (van Beek et al., 1976).

Using topographic data from the U.S. Army Corps of Engineers survey Ranges 1 through 8, storage curves were developed for both Upper and Lower Fordoche (Figure 5-7). Time periods within which water-level changes were of a nearly constant rate and single direction were then used as intervals over which storage changes were determined. Generally, these intervals extended from one to four days. For each of those intervals, precipitation rates and the inflow of water through the Courtableau Drainage Structure were calculated. For the latter, U.S. Army Corps of Engineers discharge rating curves (Communication with U.S. Army Corps of Engineers, 1976) were used in

TABLE 5-4. CHARACTERISTIC FLOWS IN THE FORDOCHE MANAGEMENT UNIT

STATION	PERIOD	DISCHARGE m^3/s	DIRECTION	AVERAGE VELOCITY	SUSPENDED SEDIMENT SAND g/l	SUSPENDED SEDIMENT SILT & CLAY g/l
G	I	38	out	0.35	0	0.019
	II	102	out	0.62	0.006	0.076
	III	81	in	0.38	0.003	0.273
	IV, V	110	out	0.59	0.005	0.043
D	I, II, IV, V	12	south	0.06	0	0.075
	III	3	south	0.02	0	0.043
A	I, II, III, IV, V	5	south	0.31	0	0.156

G = Borrow Pit where it enters the Fordoche Unit
D = Bayou Fordoche where it enters Henderson Lake
A = Little State Canal where it crosses the northern boundary in the Fordoche Unit

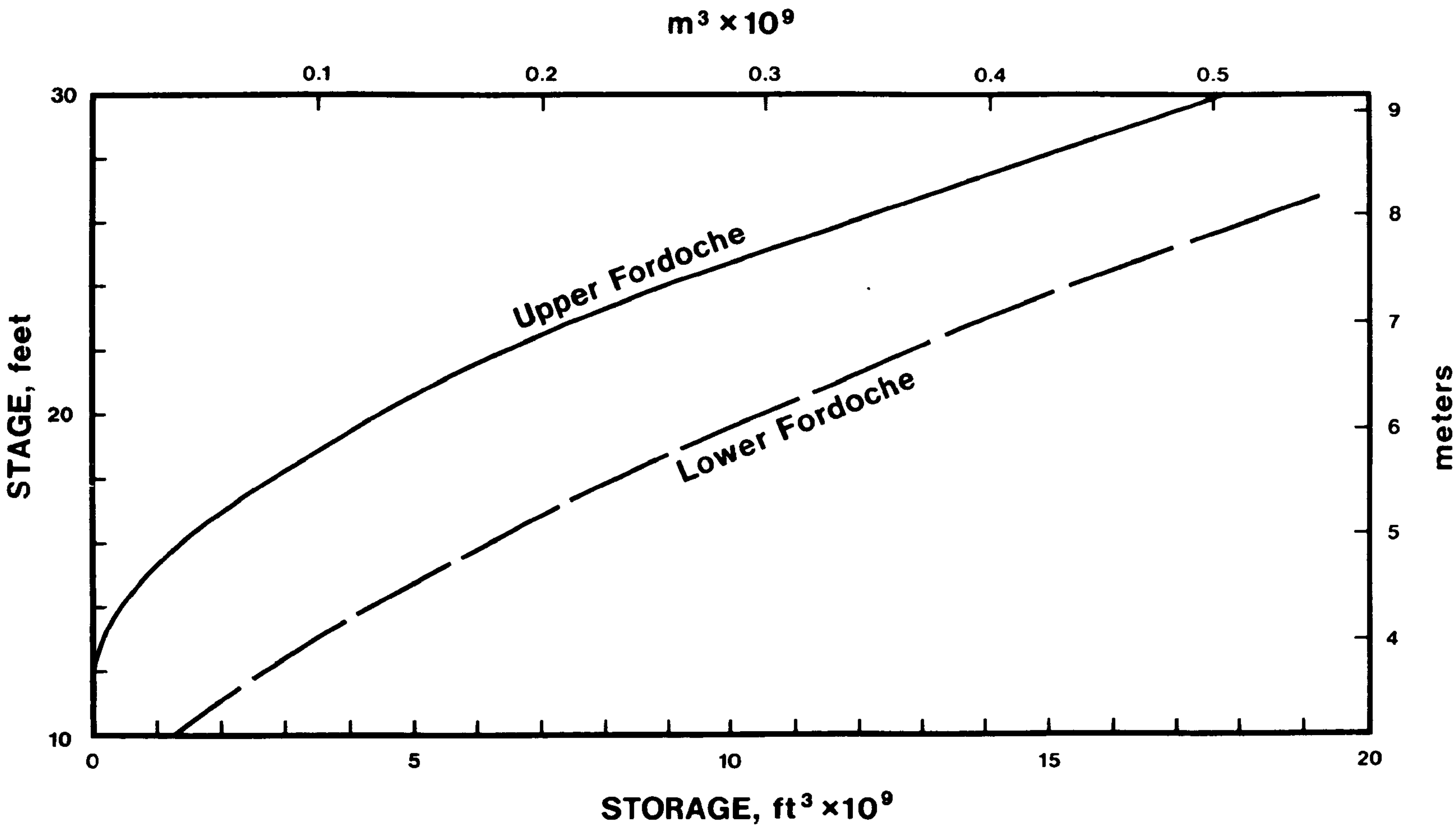

Figure 5-7. Storage curves for Upper and Lower Fordoche.

combination with stage data from the following two gages: Bayou Courtableau above Drainage Structure and Bayou Courtableau Outlet Channel near Southeast Wing Wall. Through stepwise calculation, storage changes in Upper Fordoche (ΔS_{UF}) and Lower Fordoche (ΔS_{LF}) as obtained from stage changes were then defined in terms of the following variables:

x_1 = precipitation excess in Upper Fordoche;
x_2 = inflow from Courtableau Drainage Structure into Upper Fordoche;
x_3 = flow into or from Lower Fordoche ($x_3 = \Delta S_{UF}-x_1-x_2$);
x_4 = precipitation excess in Lower Fordoche;
x_5 = flow into or from Upper Fordoche ($x_5 = -x_3$); and
x_6 = flow from or into Atchafalaya River via borrow pit ($x_6 = \Delta S_{LF}-x_4-x_5$).

Results of the above calculations are summarized in Table 5-5 according to the time periods I-V. It should be stressed beforehand that the obtained volumetric values can be only first approximations because of the assumed conditions and the limited data control. Comparisons of instantaneous discharges calculated from flow measurements and average discharges calculated from storage change show a general agreement (±30 percent). Also, the direction of flow at the borrow pit outlet as calculated is in agreement with that recorded daily by the surface-water gradient between the two southernmost gages.

Assuming that the obtained values are an accurate reflection of at least relative magnitude and direction of water movement, a number of conclusions may be derived from Table 5-5 for the 1975-1976 study period. First, the data suggest that river water contributed very little to flooding of Upper Fordoche. Of the total water input into that area, 83 percent was introduced through the Courtableau structure, and 11 percent was derived from local rainfall. Thus, only 6 percent of the water introduced into Upper Fordoche came from the Atchafalaya River and then only after having been mixed with waters of Lower Fordoche. Flooding of Upper Fordoche thus is accomplished primarily by ponding of water introduced through the Courtableau structure and, to some extent, local rainfall. Ponding occurs as a result of rising river stages.

With regard to the Lower Fordoche area, the data corroborate the earlier conclusions concerning interaction between rising Atchafalaya River stages and water released from Upper Fordoche. The Atchafalaya River contributed only sixteen percent of the total water input into the Lower Fordoche subunit. Local precipitation accounted for 9 percent, and water released from Upper Fordoche supplied the remaining 75 percent. Inflow of river water was at a maximum during the stage rise that occurred in Period III. However, even then river water accounted for only about half (53 percent) of the inflow that produced the rise. The other half was provided by water released from the Upper Fordoche area and by local precipitation. When considered along with the information concerning the limited northward flow into Upper Henderson, this suggests that river water remained largely confined to Henderson Lake.

TABLE 5-5. WATER INPUT, FORDOCHE UNIT, 1975-1976 (in $m^3 \times 10^6$)

PERIOD		UPPER FORDOCHE			LOWER FORDOCHE			FORDOCHE TOTAL		
		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
I	in	24.3	97.8	23.0	22.4	106.1	34.8	46.7	97.8	34.8
	out	-22.9		-106.1	-21.2	-23.0	-185.9	-44.1		-185.9
II	in	28.3	303.4	21.1	26.1	321.6	42.1	54.4	303.4	42.1
	out	-3.4		-321.6	-3.2	-21.1	-304.2	-6.4		-304.2
III	in	8.9	90.0	13.2	8.2	72.2	90.7	17.1	90.0	90.7
	out	-1.8		-72.2	-1.6	-13.2	-24.6	-3.4		0.0
IV	in	17.2	185.9	0.2	15.9	190.4	0.0	33.1	185.9	0.0
	out	-4.5		-190.4	-4.2	-0.2	-213.0	-8.7		-213.0
V	in	27.9	157.0	8.9	25.8	157.0	13.6	53.8	157.0	13.6
	out	-25.8		-157.0	-23.8	-8.9	-414.7	-49.6		-414.7
TOTAL	in	106.6	834.1	66.4	98.4	847.3	182.2	205.1	834.1	181.2
	in %	11	83	6	9	75	16	17	68	15

x_1 = precipitation excess in Upper Fordoche
x_2 = inflow from Courtableau Drainage Structure into Upper Fordoche
x_3 = flow into or from Lower Fordoche ($x_3 = \Delta S_{UF} - x_1 - x_2$)
x_4 = precipitation excess in Lower Fordoche
x_5 = flow into or from Upper Fordoche ($x_5 = -x_3$)
x_6 = flow from or into Atchafalaya River via borrow pit ($x_6 = \Delta S_{LF} - x_4 - x_5$)
x_7 = total precipitation excess in Fordoche Management Unit ($x_7 = x_1 + x_4$)
x_8 = inflow from Courtableau Drainage Structure ($x_8 = x_2$)
x_9 = water exchange with Atchafalaya River via borrow pit ($x_9 = x_6$)

Another matter of interest related to the water balance is the extent to which inflow of water exceeded the volume required to produce a gradual rise and fall between the same maximum and minimum. Also important is the amount of flushing, an estimate of which can be obtained by comparing the above excess with the volume of water present in the swamp basin. Table 5-6 allows the above comparisons. It shows that a gradual rise and fall of equal amplitude, but without fluctuations, could have been obtained with approximately one-fourth of the flow that entered the Fordoche Unit. Most of the excess flow was introduced during the large amplitude fluctuations of Period II.

Flow introduced in excess of volumes needed to produce observed net water-level changes is seen to largely exceed the volume of water already in storage. Though much of this excess water resulted in superimposed, individual rises, mixing and subsequent release must have produced considerable turnover of swamp waters since the largest part of introduced water enters in the upper area and moves through the Fordoche Unit.

Having obtained an estimate of river water inflow into the Fordoche Unit, an approximate value can also be derived for associated sediment introduction. In order to make such an approximation, a sediment-load discharge relationship was used that is based on the combined data for Fordoche and Buffalo Cove. Due to dominance of outflow and limited sampling frequency, sediment-load data for Fordoche alone were insufficient. However, the available data were found to follow the discharge-sediment load relationship determined for Buffalo Cove. Introduced sediment load was estimated on the basis of average inflow over the same short time intervals used in the water balance calculation. The obtained values are summarized in Table 5-7 by the stage-related time intervals. However, this calculated sediment input does not represent total input.

Sediment is also introduced through the Courtableau Drainage Structure. Water entering through that structure constitutes primarily runoff from agricultural areas. Twice during a 1977 follow-up study, discharge measurements were made and integrated water samples obtained in the Courtableau Drainage Channel about 300 m below the structure while it was in operation. Sediment concentrations followed the load-discharge relationship referred to above and shown later in Figure 6-10. This allowed an estimate of sediment introduction through the Courtableau Structure. The obtained values are summarized in Table 5-8.

Comparison with Table 5-7 shows that, of the total water introduction into Fordoche during the study period, 32 percent was derived from the Atchafalaya River and 68 percent from outside agricultural drainage. However, as much as 91 percent of the estimated sediment introduction was through the Courtableau Structure. Since load-discharge relationships were found to be similar for both reports, this indicates that the higher sediment input through the Courtableau Structure is caused by higher average discharge rates resulting in higher concentrations of suspended sediment.

TABLE 5-6. COMPARISON BETWEEN ACTUAL FLOW AND MINIMUM FLOW NECESSARY TO PRODUCE OBSERVED NET STAGE VARIATION

PERIOD	STAGE VARIATION m		NEEDED WATER $m^3 \times 10^6$		PRECIPITATION SURPLUS $m^3 \times 10^6$	NEEDED INFLOW $m^3 \times 10^6$	ACTUAL INFLOW $m^3 \times 10^6$			EXCESS FLOW $m^3 \times 10^6$	VOLUME STORED $m^3 \times 10^6$
	Upper Fordoche	Lower Fordoche	Upper Fordoche	Lower Fordoche			Courtableau	Atchafalaya River	TOTAL		
	4.5	3.6									94.8
I			-18.4	-58.9	2.7	0.0	97.8	34.8	132.6	132.6	
	4.8	2.3									17.5
II			-1.4	67.4	47.8	19.6	303.4	42.1	345.5	325.9	
	3.9	2.8									33.5
III			79.3	164.2	13.8	229.7	138.9	90.8	229.7	0.0	
	5.5	5.5									320.0
IV			-58.0	-172.7	24.5	0.0	137.0	0.0	185.9	185.9	
	4.5	3.6									96.3
V			-21.2	-56.1	3.9	0.0	157.0	13.6	170.6	170.6	
	3.9	2.4									14.0
TOTAL						249.3			1064.3	815.0	

TABLE 5-7. SUSPENDED SEDIMENT INTRODUCED WITH RIVER WATER INTO THE FORDOCHE UNIT

Period	Suspended Sediment kg x 10^6	Water m^3 x 10^6	Average Concentration kg/m^3
I	7.0	34.8	0.20
II	4.7	42.1	0.11
III	15.3	90.7	0.17
IV	0.0	0.0	-
V	2.0	13.6	0.15
Total	30.5	181.2	0.17

TABLE 5-8. SUSPENDED SEDIMENT INTRODUCED WITH AGRICULTURAL RUNOFF THROUGH COURTABLEAU DRAINAGE STRUCTURE

Period	Suspended Sediment kg x 10^6	Water m^3 x 10^6	Average Concentration kg/m^3
I	49.0	97.9	0.5
II	115.0	293.8	0.4
III	20.0	90.0	0.2
IV	56.0	180.6	0.3
V	81.0	147.8	0.5
Total	321.0	810.1	0.4

SECTION VI

BUFFALO COVE

In this section, the Buffalo Cove study area will be analyzed. As in the preceeding chapter, the topics discussed will be "Boundaries and Setting," "Annual Flooding," "Habitat," and "Water and Sediment Budget, 1975-1976."

BOUNDARIES AND SETTING

Like the Fordoche area considered in the preceding section, the Buffalo Cove area is located in the western half of the Atchafalaya Floodway some 50 km south of the Fordoche Unit. Although the entire management unit covers an area of 230 km^2, in the present study emphasis was placed on the northern half, which forms a well-defined sub-basin and hydrologic unit (Figure 1-1, 6-1). Boundaries are partially natural, partially man-made. To the east, the Buffalo Cove area is bounded by the spoil-elevated natural levee of the Atchafalaya Basin Main Channel and the natural levee ridge of West Fork Chicot Pass, an abandoned distributary of the Atchafalaya River. The northern boundary is formed by spoil-elevated, natural levee ridges of a number of old distributary channels that were linked through channelization to form the West Access Channel. The elevated left bank of Fausse Point Cut, an artificial channel, forms the western rim of the swamp basin, which converges farther south, in the vicinity of Buffalo Cove, with the West Fork Chicot Pass levee ridge. Surrounding the southern tip of Buffalo Cove is a developing natural levee ridge along a distributary channel referred to hereafter as Mud Lake Pass.

The Buffalo Cove swamp is part of an inter-levee basin that, prior to floodway construction, extended southeastward between natural levees of Chicot Pass (Main Channel) and its West Fork on the east side and the Bayou Chene (Access Channel) distributary network on the north side. With construction of the West Atchafalaya Basin Protection Levee and Fausse Point Cut, this basin was truncated, and development of a fully enclosed depression was initiated. At present, spoil-elevated levee ridges surround the Buffalo Cove sub-basin along most of its perimeter (Figure 6-2). The ridges along the West Access Channel and the Main Channel are the widest and highest and are no longer overtopped during normal flood stages. Spoil-elevated banks of Fausse Point Cut are somewhat narrower and lower, but still attain an elevation equal to or slightly above normal high-water level and also form a barrier to water exchange.

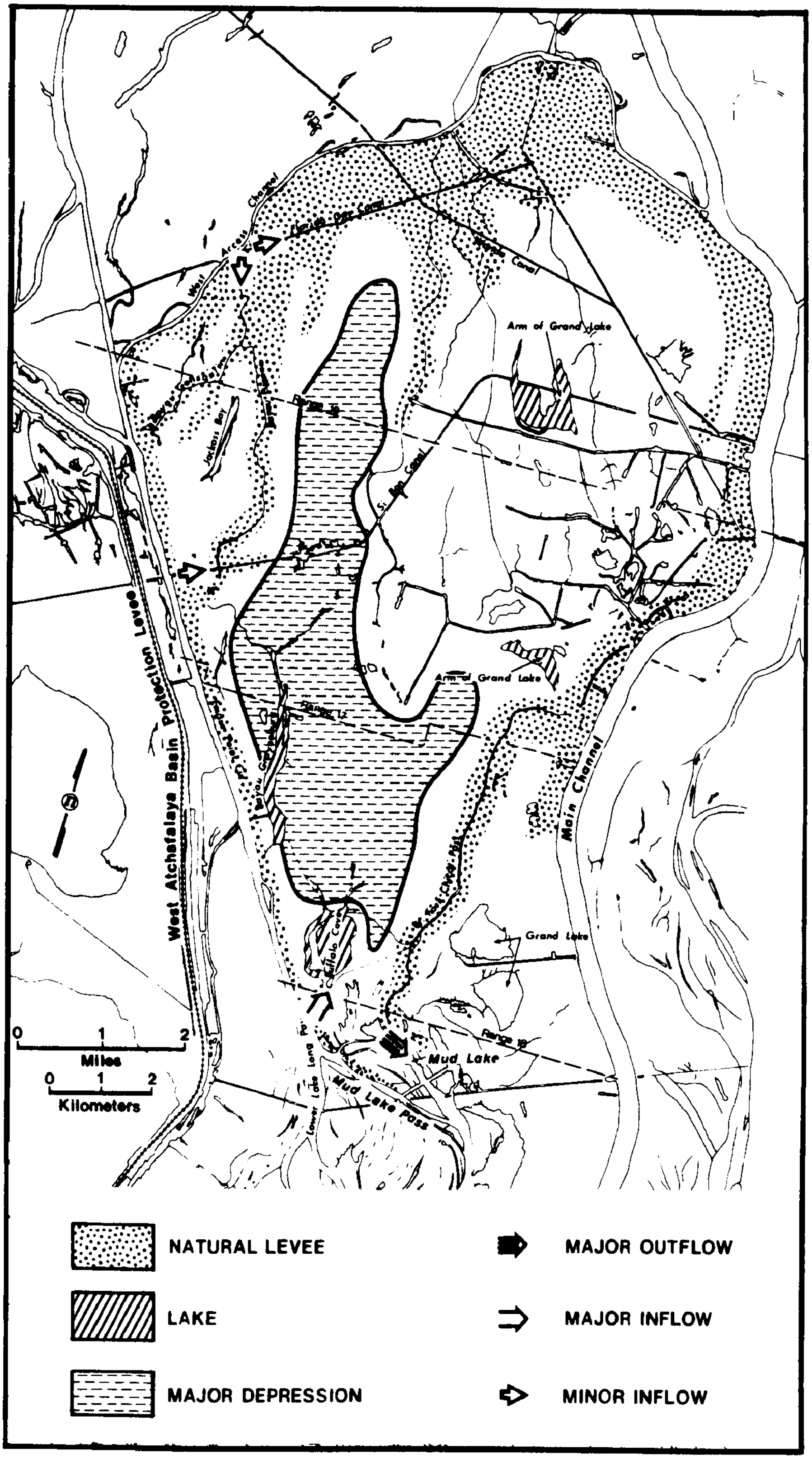

Figure 6-1. Geomorphic characteristics and inflow locations, Buffalo Cove Management Unit.

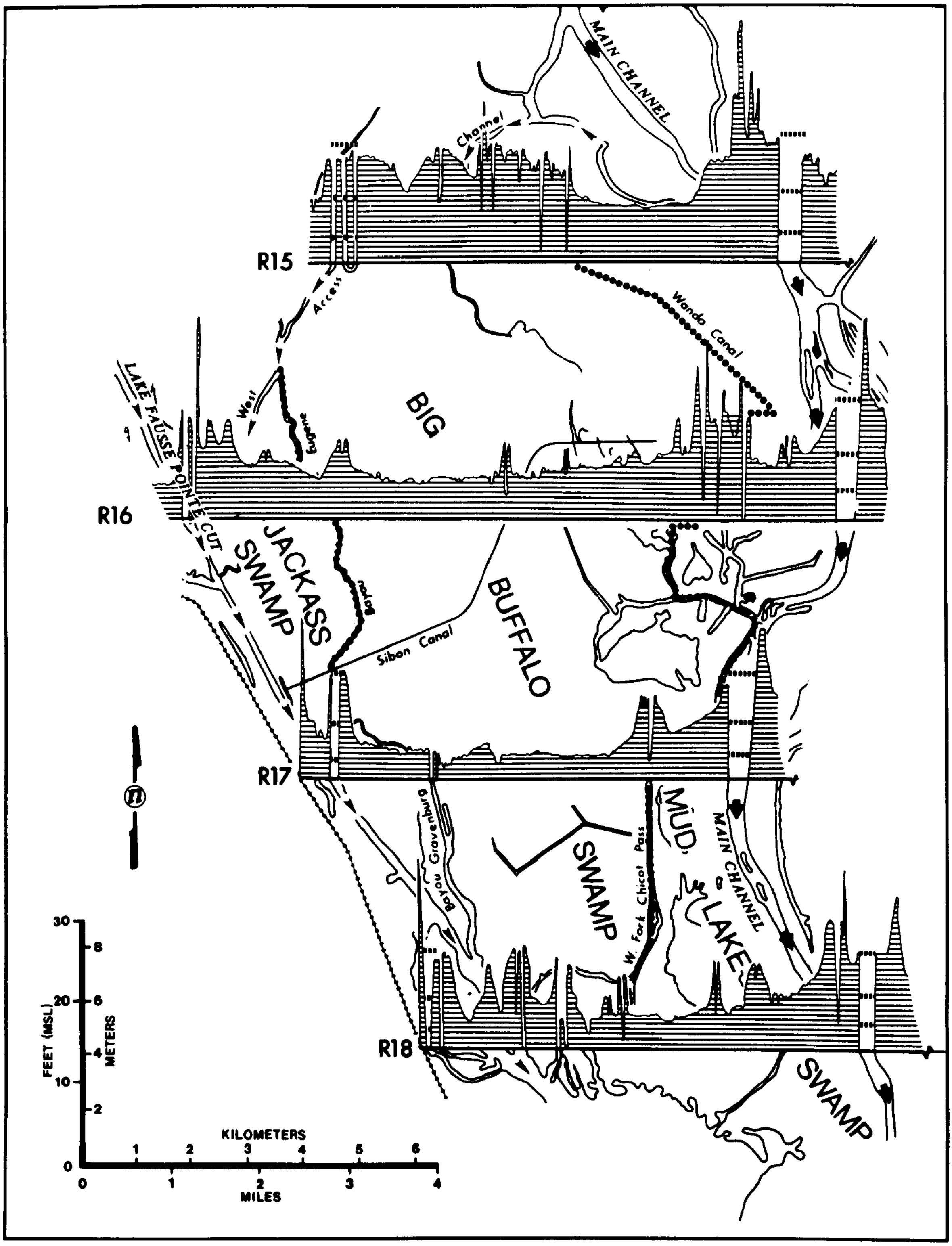

Figure 6-2. Topography of Buffalo Cove sub-basin showing elevated rim.

Except for the northeastern one-third of the sub-unit, most of the area confined by the levee-spoil ridges is occupied by deep swamp. A continuous depression approximately 5 to 7 km wide extends parallel to the Fausse Point Cut levee (Figure 6-1). Reflecting pre-floodway conditions, this depression slopes westward and southward and contains a number of small lakes that became isolated with truncation of the basin. Recent sedimentation has enclosed and rimmed this depression at its southern end so that the lowest elevations now occur north of Buffalo Cove Lake.

In the northeastern one-third, the swamp basin and associated lakes were largely filled as a result of sediment influx associated with early oil field development. In many respects, that area's habitats are transitional between the swamp basin and levee ridges.

ANNUAL FLOODING

Annual flooding of the Buffalo Cove basin during normal water years is almost totally dependent on three openings connecting the basin with the West Access Channel and Fausse Point Cut. These are Bayou Eugene, the Sibon pipeline canal, and the entrance channel to Buffalo Cove Lake (Figure 6-1). Dewatering occurs to some extent through the latter two, but mainly through Mud Lake into Mud Lake Pass. The entrances to both Buffalo Cove Lake and Mud Lake function at all times, while flow in Sibon Canal and Bayou Eugene only occurs during medium and high river stages.

Large volumes of sediment are deposited in the lower part of the Buffalo Cove basin as a result of the inflow being accommodated mainly through the entrance to Buffalo Cove Lake and the Sibon Canal. Both of these channels divert water from the Fausse Point Cut, in which flow velocities and suspended sediment concentration are usually high. By way of the West Freshwater Distribution Channel and the West Access Channel, Fausse Point Cut receives approximately 10 percent of the Atchafalaya River flow. As water flows in, high velocities and suspended load concentrations are maintained because of the large water demand that is to be met through the two small channels. However, where inflowing water is discharged into the open swamp from Sibon Canal and into Buffalo Cove Lake, velocities decrease abruptly and most sediment is deposited. Consequently, rapid loss of aquatic habitat is occurring and is apparent particularly in Buffalo Cove Lake, where extensive willow thickets have been established on newly formed shoals. Detrimental sedimentation is further stimulated by the simultaneous occurrence of outflow at Mud Lake and inflow at the entrance channels. This means additional inflow of sediment-laden water to accommodate losses through Mud Lake.

The overall flooding regime of the Buffalo Cove basin can be described as varying from throughflow to backwater flooding, depending on location in the basin and river stage. During flood stages, with water entering through Bayou Eugene, throughflow is maintained from north to south in the deep swamp which occupies the western half of Buffalo Cove. When stages are such that overbank flow of Bayou Eugene is eliminated, throughflow only pertains to the western area south of Sibon Canal. With further reduction in water level, when both Bayou Eugene and Sibon Canal cease to function, the entire area north of Buffalo Cove Lake reverts to a backwater regime.

The northeastern part of the Buffalo Cove basin experiences a backwater regime at all times. Major connections with the West Access Channel or Main' Channel are absent so that flooding of the northeastern part of the basin occurs from within following inflow through the three aforementioned entrance channels.

The contribution of local rainfall to annual flooding is limited to precipitation surplus. This runoff drains into the western half of the Buffalo Cove basin, where it collects in the depression paralleling Fausse Point Cut. Since most of the basin is flooded during times that surpluses occur, runoff patterns are of little or no consequence.

The annual flooding and dewatering regime is very similar to that of the Fordoche area and is illustrated in Figure 6-3. The survey ranges used correspond to those shown in Figure 6-2. In the absence of long-term water level records within the Buffalo Cove area, stages were determined on the basis of adjacent gaging records (Lower Grand Bayou) and short-term records at the entrance to Buffalo Cove Lake. A single hydrograph sufficiently represents conditions in both the northern and southern parts of the area, since southernmost channels predominate the flooding and dewatering processes. Neither the influx of water through Bayou Eugene and Sibon Canal nor the rate of outflow at the southern end appear sufficient to maintain a gradient similar to the one observed in the Fordoche basin.

Annual flooding and dewatering of Buffalo Cove follow the same temporal variation as in the Fordoche area, but the amplitude is about 0.5 m less since the area is located farther downstream. The composite elevation frequency curve (R 16,17,18) and the hydrograph in Figure 6-3 show that nearly the entire basin is submerged during spring flood stages. Water depths reach 1.5 m in the swamp and exceed 3 m in some lakes and streams. Only the basin rim remains above water, as indicated by the elevations of levee crests given in the margin of Figure 6-3. Submergence is deepest in the central area, represented by Range 17. Location of the latter on the graph relative to Ranges 16 and 18 clearly reveals the gradual increase in elevation northward and the presence of a higher rim along the southern margin.

Dewatering during late summer and fall exposes approximately 70 percent of the swamp floor, predominantly in the northeastern part of the Buffalo Cove sub-basin. The west-central part of the swamp remains flooded to depths of 0.5 m, with larger water depths occurring in the isolated lakes and drainage streams. It should also be noted that most of the southern rim is exposed during low stages.

Using the composite hypsometric curve and the stage hydrograph, the hydrologic regime can be summarized with regard to hydroperiod (Table 6-1).

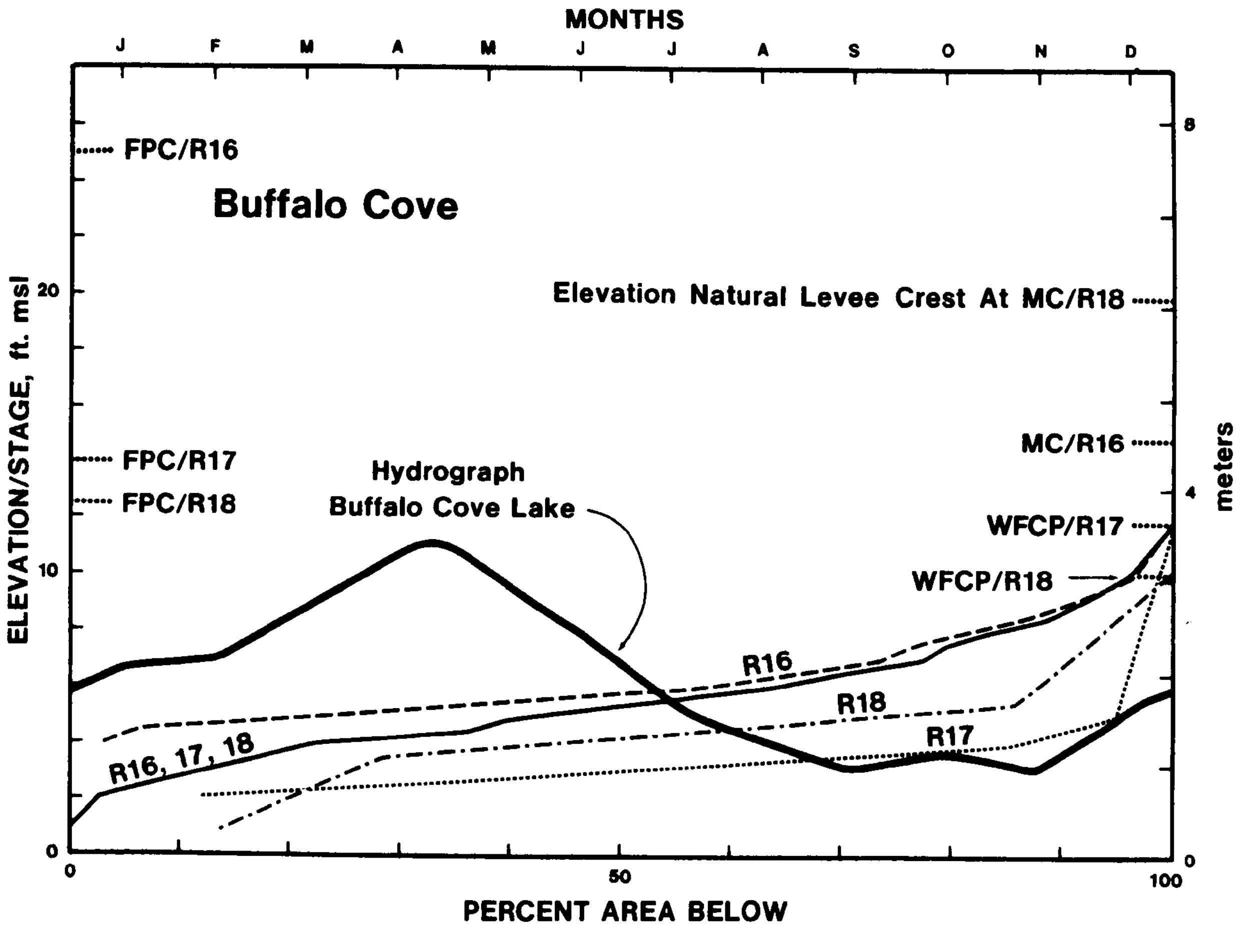

Figure 6-3. Average annual stage hydrograph for Buffalo Cove Lake, elevation frequency curves for USCE range lines (R16, R17, R18) combined and separately, and crest elevations for natural levee ridges bounding the Buffalo Cove Management Unit (FPC/R16 is Fausse Point Cut at Range 16; MC = Main Channel, WFCP is West Fork Chicot Pass).

TABLE 6-1. EXTENT AND DURATION OF FLOODING, BUFFALO COVE

Elevation (m)	Area (%)	Area (km^2)	Period Flooded (months)
>3.2	3	3	0 - 1
2.2 - 3.2	10	9	1 - 4
1.3 - 2.2	52	47	4 - 8
1.0 - 1.3	19	17	8 - 11
< 1.0	16	15	11 - 12

HABITAT

At the turn of the century, Buffalo Cove was largely a backswamp/lake environment covered with cypress-tupelo gum forests that were in the process of being harvested. Mixed hardwoods occurred along the natural levee ridges of the Bayou Chene distributary system. Portions of these ridges had been cleared for agriculture and the small farming community of Bayou Chene. Since that time, considerable changes have occurred as a result of changes in hydrologic regime and sedimentation. Presently, much of the vegetation within the unit represents a transitional stage from backswamp to either natural levee associations (Wicker, 1975) or back to open lake.

Areal extent and duration of flooding were also mapped for the Buffalo Cove area (Figure 6-4) for the purpose of comparing them with distribution of vegetation associations (Figure 6-5,6-6). Freedom from flooding or hydroperiods of less than one month are found along the spoil-elevated levee ridges that surround the basin. These areas correspond to a narrow bank of mixed bottomland hardwoods, in many cases including substantial stands of willow.

The areas experiencing hydroperiods of one to four months are seen to be largely occupied by a mixture of cypress and willow, similar to the areas being flooded from four to eight months. In both cases, willows have invaded a second-growth cypress swamp as a result of continuous, massive sedimentation. In the northeastern part, sedimentation resulted partly from development of the Chicot Oil Field and canalization linking the Main Channel with the swamp basins. Sediment introduction also occurred through several distributaries of the Bayou Chene complex, which entered the northern half of Buffalo Cove prior to about 1950, when most were closed artificially or naturally.

A cypress-tupelo-willow association dominates the deepest area of the basin, with hydroperiods from eight to twelve months. Also in this case, willow has invaded the second-growth cypress-tupelo swamp as a result of clearcutting and sedimentation, even though sedimentation rates in this area, with the exception of the southern margin, have been much less because of hydrologic constraints.

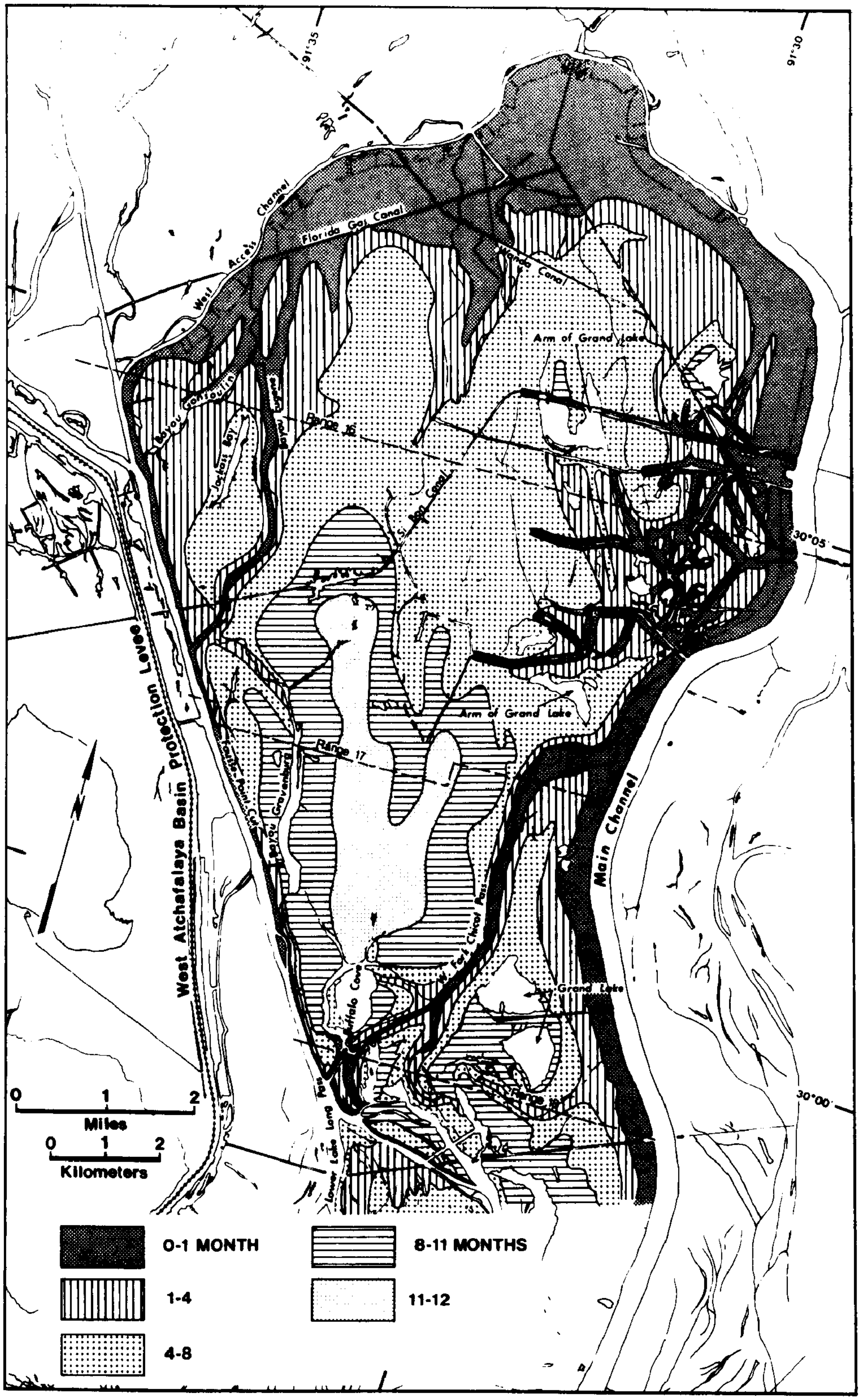

Figure 6-4. Extent and duration of flooding, Buffalo Cove Management Unit.

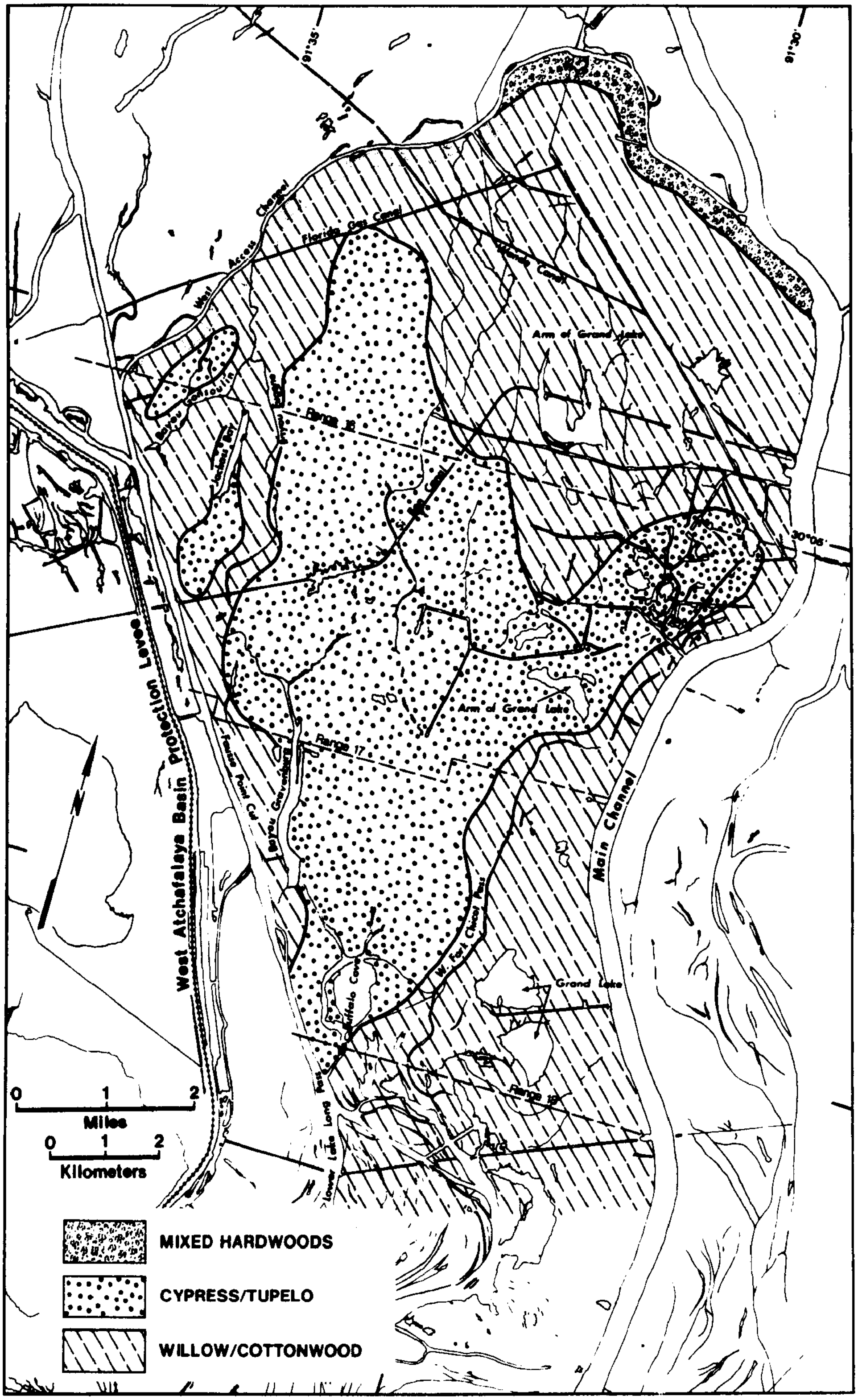

Figure 6-5. Distribution of vegetation associations, Buffalo Cove Management Unit (after EROS, 1975).

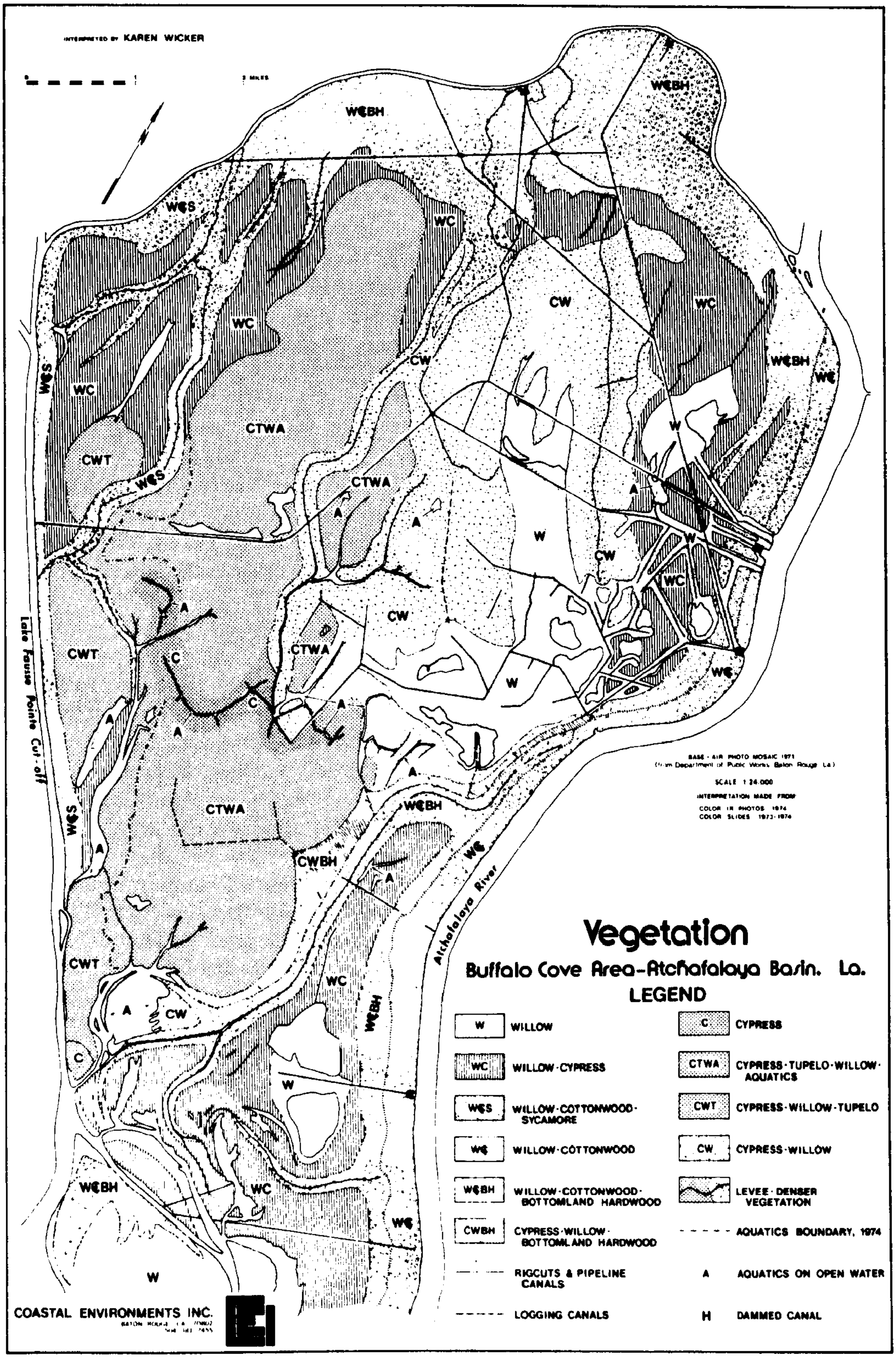

Figure 6-6. Distribution of vegetation associations from 1974 photography, Buffalo Cove Management Unit (after van Beek et al., 1976).

Ponding of water in the central depression between Fausse Point Cut and West Fork Chicot Pass, together with the large stage variation, has totally impeded regeneration of cypress or, for that matter, further expansion of willow stands. Additionally, forest regeneration is constrained by a nearly continuous and often mobile mat of water hyacinths which prohibits rooting of tree species on the swamp floor. As a result, much of the area is presently opening up and transgressing to a hyacinth-covered lake.

The relationship between hydroperiod and vegetation association is summarized in Table 6-2. However, it should be stressed again that, through the hydrologic regime, sedimentation has a significant bearing on the distribution of vegetation. The invasion of willows throughout Buffalo Cove clearly illustrates this additional factor in habitat control.

WATER AND SEDIMENT BUDGET, 1975-1976

Water-level data for the Buffalo Cove area are limited. A single gage at the entrance to Buffalo Cove Lake has been in operation only since March 1976; therefore, the stage hydrograph was obtained partially through hindcasting on the basis of stage data from the nearby gage at Lower Grand Bayou (Figure 6-7) and statistical correlation.

Despite the marginal location of the Buffalo Cove gage, the associated hydrograph is felt to be fairly representative of water levels throughout the Buffalo Cove sub-basin. Field observations showed that much of the time, inflow and outflow occurred only at the lower end of the unit and that stages between the upper and lower end differed by no more than 0.2 m. A lack of gradient was furthermore indicated by additional level data obtained from a staff gage at the southern end of Gravenburg (Figure 6-7).

Since most river water entering Buffalo Cove is diverted from the Atchafalaya River through the Old Atchafalaya River, West Freshwater Distribution Channel and Fausse Point Cut, the Butte La Rose gage was selected again as a reference gage. Stages for the Atchafalaya River and Buffalo Cove are plotted in Figure 6-8. In addition, the diagram shows the precipitation record for Jeanerette, Louisiana, located 20 km southwest of the center of Buffalo Cove.

From the graph, it is immediately apparent that there is a direct relationship between the river stages and water levels in Buffalo Cove. Even minor fluctuations in Atchafalaya River stage are recorded within the study area. Precipitation, on the other hand, does not appear to visibly affect stages in the Buffalo Cove basin. This may be because of the wetland character of the area with associated storage characteristics, or because of the masking of rainfall effects by simultaneous changes in river stage. Thus, from the graph we must conclude that essentially all stage fluctuations in the Buffalo Cove swamp are controlled by the Atchafalaya River.

Riverine control means that each rise in river stage produces inflow into Buffalo Cove. Because of the rather symmetrical shape of individual hydrograph peaks, inflow must have occurred about fifty percent of the time for

TABLE 6-2. HYDROPERIOD AND VEGETATION ASSOCIATIONS, BUFFALO COVE MANAGEMENT UNIT

DURATION OF FLOODING (MONTH)	AVERAGE DEPTH OF FLOODING (m)	VEGETATION ASSOCIATION WICKER (1975)	VEGETATION ASSOCIATION EROS (1975)
0 - 1	< 0.1	willow cottonwood bottomland hardwood willow willow cottonwood willow cottonwood sycamore	mixed hardwoods willow cottonwood
1 - 4	0.4	willow cottonwood bottomland hardwood cypress willow bottomland hardwood willow willow cottonwood sycamore willow cypress	cottonwood willow
4 - 8	0.8	cypress tupelo willow aquatics cypress willow cypress willow tupelo willow	cypress tupelo cottonwood willow
8 - 11	1.1	willow cypress cypress tupelo willow aquatics willow cypress	cypress tupelo cottonwood tupelo
11 - 12	> 1.1	cypress tupelo willow aquatics	cypress tupelo

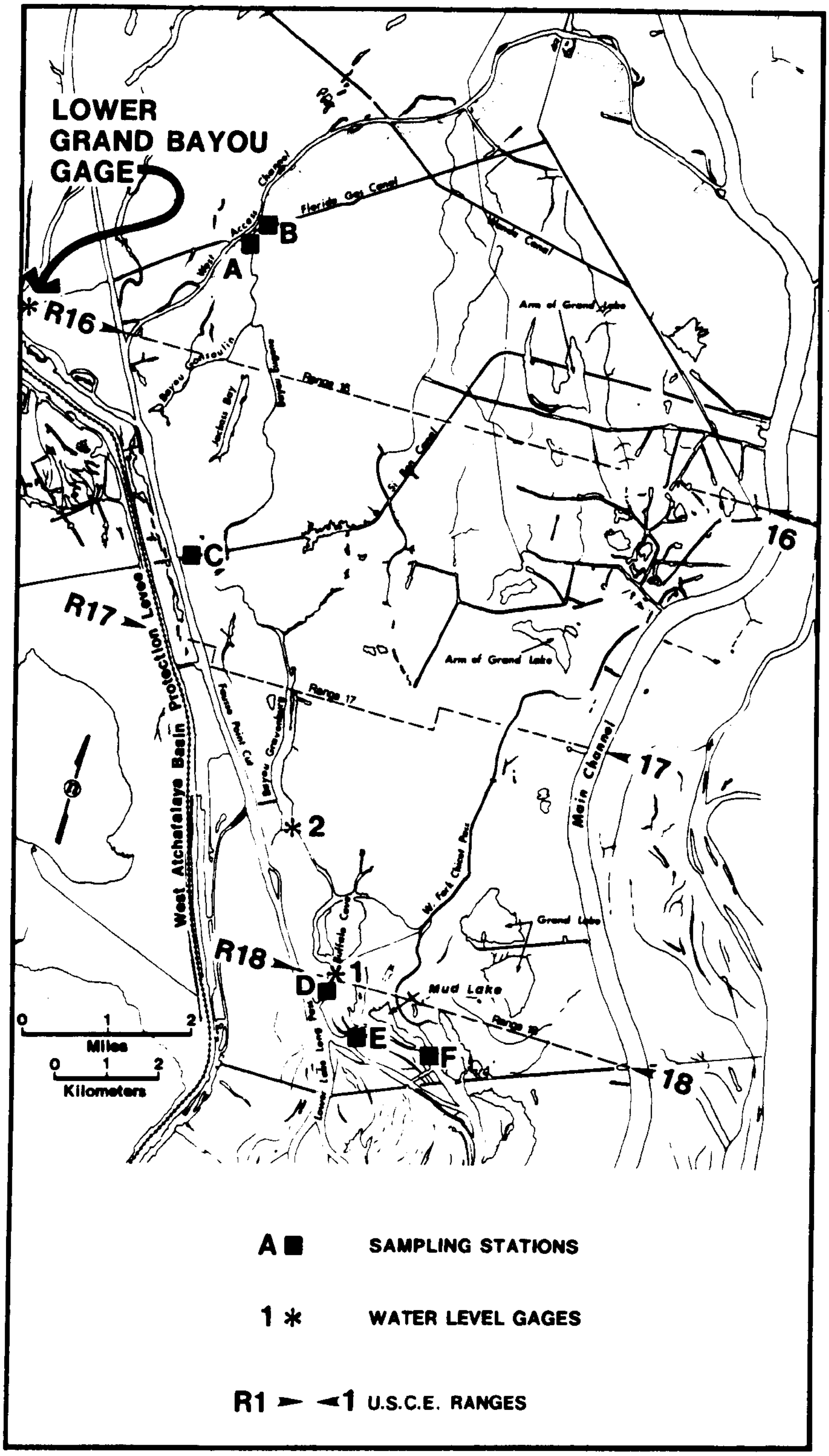

Figure 6-7. Location of water level gages, discharge/sediment sampling stations, and topographic survey ranges in Buffalo Cove.

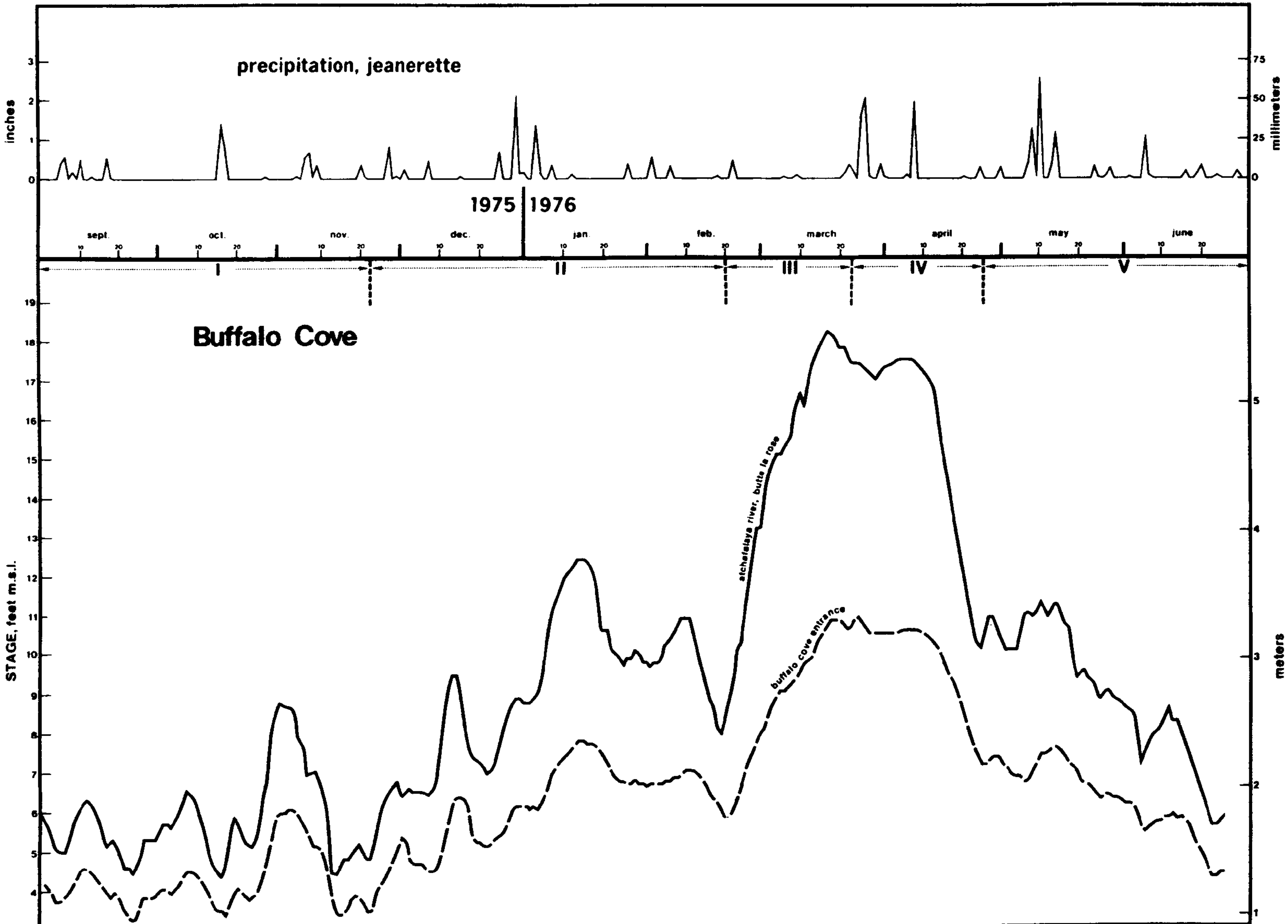

Figure 6-8. Stage hydrographs for Buffalo Cove and Atchafalaya River, and precipitation at Jeanerette, Louisiana.

175 days. During 67 of those inflow days, introduction of water was entirely confined to the Buffalo Cove Lake entrance since low water levels and sediment buildup prevented inflow through either Bayou Eugene or Sibon Canal.

The above information allows estimation of the minimum inflow of river water for the period of study. As was done for Fordoche, segmenting the hydrograph according to short-term rises and recessions allows stage changes to be expressed as changes in storage. The relationship between storage and stage is given in Figure 6-9. The graph was based on U.S. Army Corps of Engineers survey data along Ranges 15 through 18. To allow storage changes to be expressed in terms of inflow or outflow of river water, changes resulting from precipitation surplus or from water loss due to evapotranspiration were separated. The necessary water balance information was developed on the basis of synoptic precipitation data from Jeanerette, Louisiana, and the average monthly evapotranspiration values were derived for that station during the previous study (van Beek et al., 1976).

Flow data obtained through the calculation referred to above are summarized in Table 6-3. The record is divided into five periods according to rate and direction of stage changes (Figure 6-8). During Period I, no net change of water level occurred, but inflow resulted from stage fluctuations. A slow, net rise occurred during Period II, followed by a rapid rise in Period III. Comparison of inflows of stage changes for Periods II and III indicates that stage fluctuation in Period II was responsible for most inflow of river water; a net stage change of +0.5 m in Period II was associated with about the same inflow as the +1.6 m rise during Period III. Absence of inflow during Period IV resulted from a rapid and continuous recession. Fluctuation during the subsequently slow recession in Period V again produced inflow of river water.

Since reduction of sediment requires reduction of water introduction, it is of interest to estimate the extent to which river water inflow exceeded the volume required to produce a hydrograph similar to the one observed with regard to minimum and maximum stage, but with omission of fluctuation. Such estimates are given in the last column of Table 6-3. The rise from +1.2 m to +3.3 m MSL would have required 128.2 x 10^6 m^3 of river water, or only 37 percent of that calculated to have entered the Buffalo Cove swamp under the present, unmanaged conditions.

This estimate of the amount of river water introduced into the Buffalo Cove swamp during the 1975-1976 study period also facilitates an estimation of suspended sediment introduction. Suspended load concentrations from samples taken during inflow together with flow discharge measurements gave suspended sediment discharge. In this manner, the relationship between flow and sediment discharge could be defined as in Figure 6-10. Sediment introduction was then calculated on the basis of the same short-term discharges used in estimating total inflow. The data are summarized in Table 6-4 according to the earlier-used time intervals I-V.

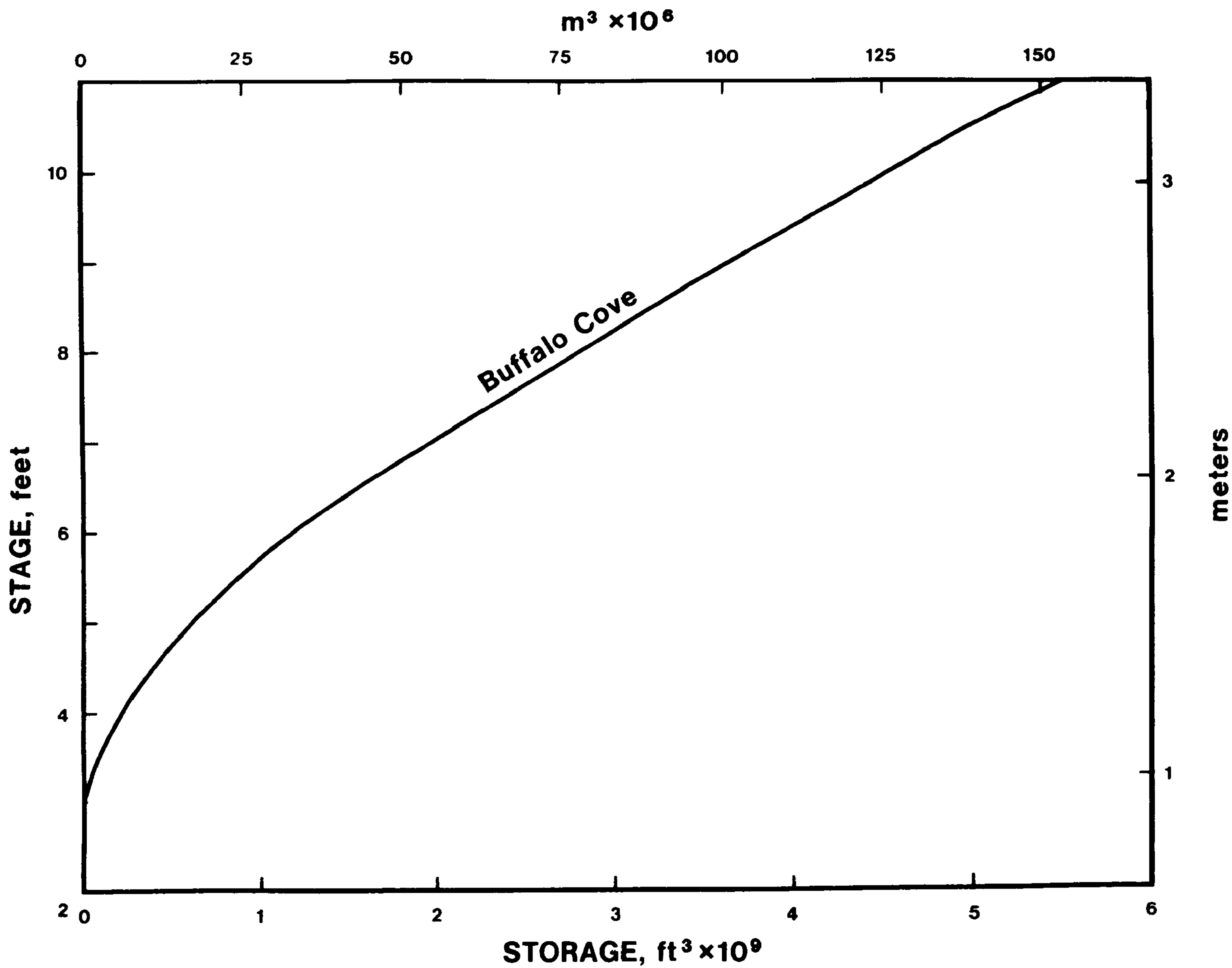

Figure 6-9. Storage curve, Buffalo Cove Management Unit.

TABLE 6-3. COMPARISON BETWEEN ACTUAL INFLOW AND MINIMAL INFLOW REQUIRED TO PRODUCE OBSERVED NET STAGE VARIATION

PERIOD	ACTUAL INFLOW 10^6 m^3	STAGE CHANGE (m) MSL	MINIMAL WATER NEED 10^6 m^3	PRECIPITATION SURPLUS 10^6 m^3	MINIMAL INFLOW 10^6 m^3
I	64.6	1.2			
II	129.5	1.2 - 1.7			
III	122.7	1.7 - 3.3			
I, II, III	316.8	1.2 - 3.3	152.9	24.7	128.2
IV	0.0	3.3 - 2.1	0.0		
V	29.1	2.1 - 1.2	0.0		
TOTAL	345.9				128.2

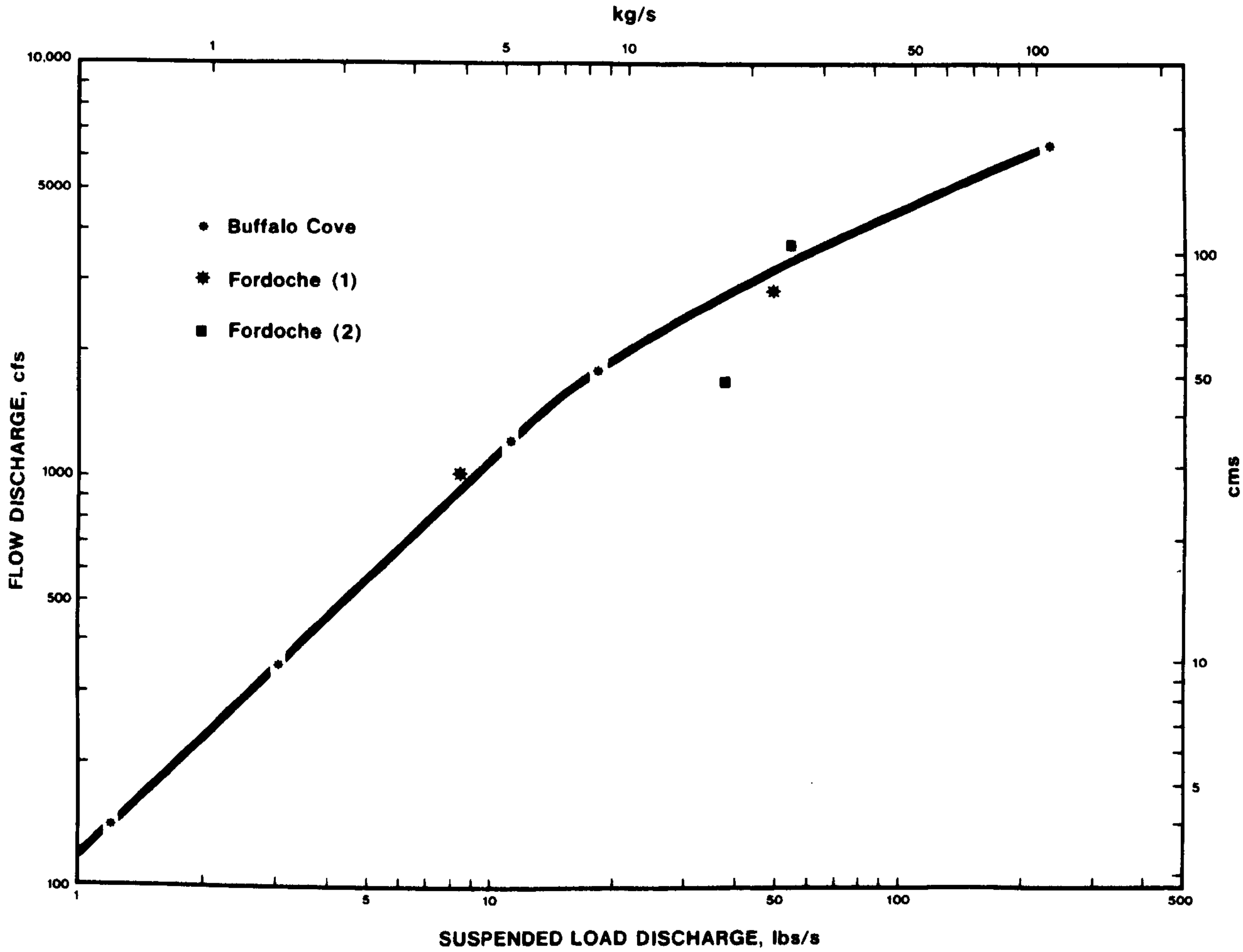

Figure 6-10. Relationship between inflow and introduction of suspended sediment load for Buffalo Cove and Fordoche. Fordoche (1) is Butte La Rose Bridge, Fordoche (2) is Courtableau Drainage Structure.

TABLE 6-4. ESTIMATE OF SEDIMENT INTRODUCTION, 1975-1976

Period	With Actual Flow 10^6 kg	With Minimal Inflow 10^6 kg
I	10.4	0
II	22.7	10.2
III	22.5	14.4
I, II, & III	55.6	24.6
IV	0	0
V	4.2	0
TOTAL	59.8	24.6

The first column gives the sediment introduction as associated with the unrestrained stage fluctuations. Corresponding inflow data are those in the first column of Table 6-3. Total estimated sediment introduction was 59,800 metric tons. In view of the relative magnitude of the measured discharges at all the channels through which inflow occurred, it is obvious that most of this sediment reached the unit via Buffalo Cove Lake.

The above estimates of water and sediment introduction are necessarily conservative. Data are insufficient to account in detail for additional inflow that must have been required to offset water losses through Mud Lake during rising and stationary water levels. A general idea of the extent to which introduction of water and sediment may be underestimated can be obtained from incidental discharge measurements.

Table 6-5 presents examples of measured flows at the various channels connecting Buffalo Cove swamp with the surrounding river water source. The data show that during the gradual rise of Period II, on January 15, 1976, water loss through Mud Lake amounted to 48 percent of the measured total inflow. Similarly, losses were 22 and 70 percent, respectively, during the rapid rise of Period III and during a small rise superimposed on the gradual recession of Period V. Incidental measurements thus suggest that inflow into Buffalo Cove as obtained from water level changes underestimates actual inflow by 18 to 40 percent, depending on the rate at which water levels are rising. Assuming underestimation to have averaged 30 percent, actual inflow and sediment introduction for the 10-month study period thus were probably on the order of 450×10^6 m^3 of water and 77.74×10^6 kg of sediment.

An estimate of sediment introduction in case of minimum flow required to produce only the net changes in water level, as given in the second column of Table 6-4, was more difficult to obtain since use of a gradually rising water level from the low stage to the high stage, as was used for estimating water input, cannot be applied in that case. Individual rises must be used with associated discharge to account for change in sediment concentration with change in discharge rate. The procedure used, therefore, was to incorporate only those individual rises or parts thereof that produced a net stage increase. For the remaining times, water levels were assumed controlled by rainfall excesses and shortages.

TABLE 6-5. FLOWS MEASURED AT ENTRANCE CHANNELS, BUFFALO COVE, 1975-1976

Period/Date	I/29-10-75		II/85-1-76		III/19-3-76		V/29-4-76	
	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%
Bayou Eugene	0.0		2.4	5	36.7	20	2.5	7
Florida Gas	0.0		0.0		21.7	12	2.2	6
Sibon Canal	0.0		10.6	20	51.2	28	4.0	11
Buffalo Cove	9.8	100	38.9	75	74.4	40	26.3	75
Total Inflow	9.8	100	51.9	100	184.0	100	35.0	100
Mud Lake Outflow	0.0	0	-24.8	48	-41.5	22	-24.7	70

During Period I, water levels were above desired management levels (van Beek et al., 1976), and no inflow was required. With a controlled system, water level could have dropped by 0.3 m, due to evapotranspiration, to 0.9 m at the end of Period I (Figure 6-3). In the absence of inflow, no sediment would have been introduced. During Period II, elimination of the many fluctuations and those inflows that only bring water levels back to where they were before recession will also limit sediment introduction and reduce it to nearly one-half. Elimination of the first half of the Period III rise equally reduced calculated sediment influx for that time interval. Total reduction of sediment influx would have been 35.2 metric tons, or 56 percent.

There are two additional reasons why the earlier estimation of water and sediment influx is conservative. In many years, a second flood crest appears in June; such a rise was absent in 1976. The magnitude of this crest may be only slightly less than the March/April peak. Since it is often preceded by a month-long recession, inflows during this second major rise could be assumed similar to those of Period III. Since management objectives do not require such a major second rise in water levels, controlled inflow would necessarily reduce sedimentation well beyond that indicated above.

The second reason concerns bed load transport. In the case of Buffalo Cove, where water introduction is confined to a few, relatively small channels, current velocities become high, particularly during flood season. Not only does this produce an even greater increase in suspended load concentrations, but it also allows substantial sediment movement along the bed by tractive forces. Table 6-6 presents a number of typical values for flow velocities and suspended load concentrations. Velocities can reach 0.75 m/s and are sufficient to move a considerable quantity of fine sand as bed load. The ample availability of such material is indicated by the high, suspended-sand load values and by the sediments exposed during low stage in Buffalo Cove Lake and Sibon Canal.

TABLE 6-6. FLOWS INTO BUFFALO COVE

STATION	PERIOD	DISCHARGE m^3/s	DIRECTION	AVERAGE VELOCITY m/s	SUSPENDED SEDIMENT SAND g/l	SUSPENDED SEDIMENT SILT & CLAY g/l
Buffalo Cove Entrance	I	10	in	0.23	0.004	0.136
	II	40	in	0.57	0.020	0.302
	III	75	in	0.75	0.056	0.521
Sibon Canal	II	10	in	0.25	0.047	0.432
	III	48	in	0.75	0.025	0.401
Bayou Eugene	II	2	in	0.06		0.354
	III	37	in	0.58	0.037	0.661

An additional aspect of the hydrologic regime is the rate at which water is replaced. While full treatment of this aspect goes beyond the scope of this report, some idea can be obtained from a short-term analysis. Figure 6-11 shows the result of stage fluctuations during the months of September and October. This is during Period I when water levels fluctuated but no net rise occurred. The upper graph represents water levels; the lower graph, changes in make-up of swamp waters. Numbers (1) through (6) relate to individual water-level rises. Assuming total mixing of inflowing river water with the ambient swamp waters, composition of the swamp water was calculated following each period of inflow and outflow. Thus, on September 20, 1976, water flowing out of the swamp was calculated to have had the following composition; 32 percent of the water had been in the swamp since September 1; 54 percent had been introduced during the first rise (1) from September 1 through 11; 14 percent had been introduced during the second rise (2). It is therefore evident that water flowing from Buffalo Cove becomes highly complex within a short period of time due to the large number of fluctuations. Though small, stage fluctuations occurred frequently enough and ambient volumes of water were small enough for 90 percent of the swamp water to be replaced in one month if there had been total mixing (Figure 6-11). Field observations during this study and by others (Bryan et al., 1974) indicate, however, that mixing is incomplete, especially during low stages, due to lack of circulation. The above conclusions, therefore, are estimates only and are subject to modification when more is known about the extent to which mixing occurs in certain parts of the swamp basin.

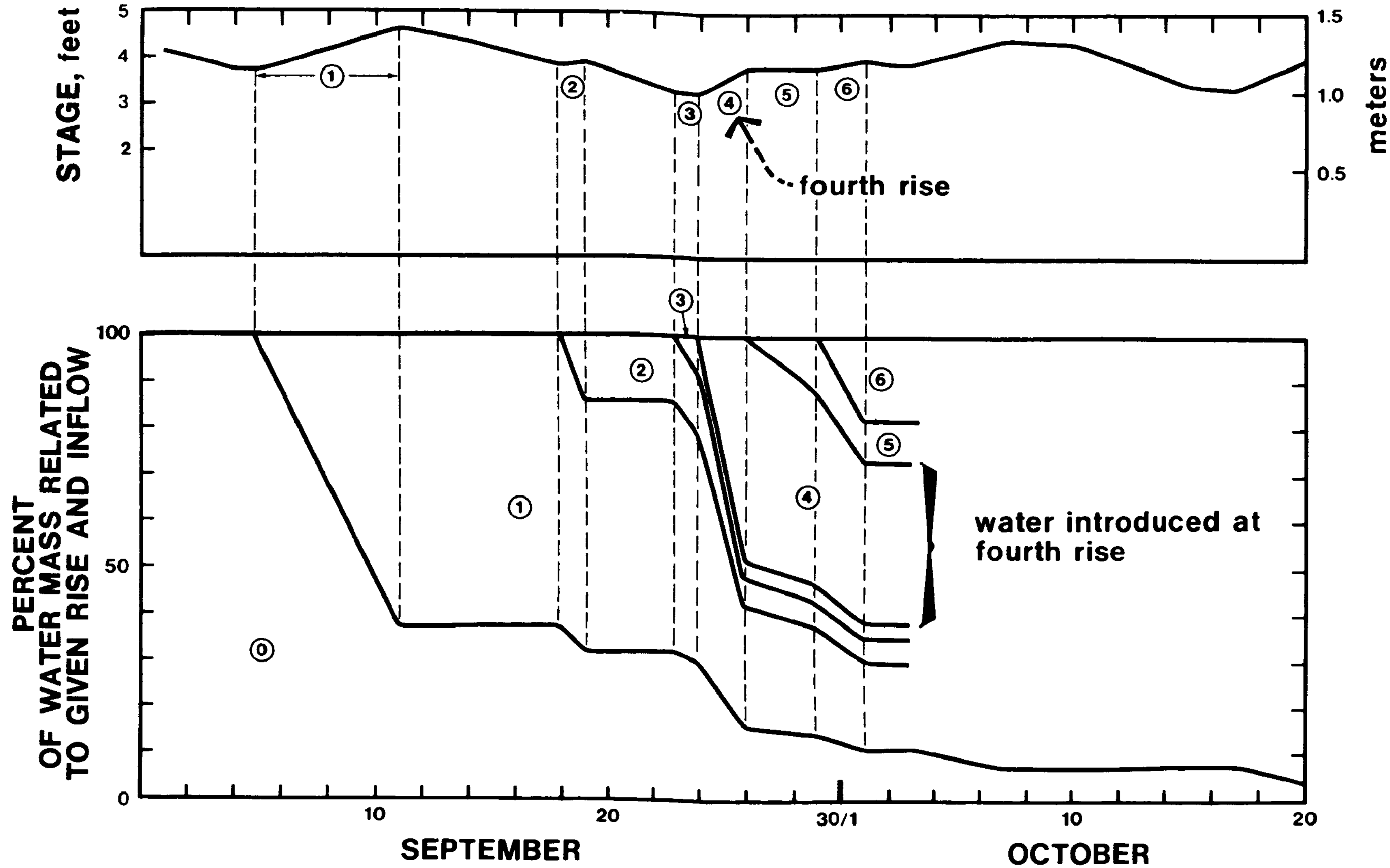

Figure 6-11. Changes in composition of swamp water as related to water-level fluctuations in Buffalo Cove under the assumption of total mixing.

SECTION VII

PAT BAY

In this section the Pat Bay study area is analyzed. This unit is on the eastern side of the Atchafalaya Basin, but outside the artificial floodway levees. The topics are the same as in the two preceeding chapters, "Boundaries and Setting," "Annual Flooding," "Habitat," and "Water and Sediment Budget, 1975-1976."

BOUNDARIES AND SETTING

Located outside the Atchafalaya Basin Floodway, the Pat Bay area (Figure 7-1) is a 45-km^2 hydrologic unit that is as well defined as the Fordoche and Buffalo Cove basins. Boundaries are partly natural, partly man-made. Along the north side, a boundary is formed by the natural levee ridge of Upper Grand River. Most of the eastern boundary is a southward continuation of the above levee ridge along Lower Grand River, except for a short segment of spoil banks of the Intracoastal Waterway Alternate Route. An artificial western boundary is formed by the low banks of the East Atchafalaya Basin Protection Levee borrow pit.

Land forms of the Pat Bay area relate mostly to pre-floodway conditions. The levee ridges along Upper and Lower Grand River were formed when these streams were part of an incipient Atchafalaya River. Having a width of about 2 km and a crest elevation of 3 m above MSL, the levee ridges are out of proportion to present stream size, stages, and discharges, and are clearly relict features. So are the much lower ridges that parallel the abandoned distributaries, Pat Bayou, Sullivan Bayou, and Cross Bayou, and segment the western part of the Pat Bay unit (Figure 7-1). The southward decrease in width and elevation of these distributary levee ridges signifies a previous diversion of water and sediment into Pat Bay from Upper Grand River. The two elongated lakes within the area, Pat Bay and Sullivan Lake, appear to have been integrated into this distributary system and to have functioned as wide channels. In contrast to the floodway swamp basins, the lakes do not occupy the lowest part of individual sub-basins, but are surrounded by higher rims that function as a sub-basin boundary.

Since the Pat Bay basin lies outside the floodway, elevation data for the area are limited to the 1.5- and 3.0-m MSL contours and to some isolated data points. These data show crest elevations for the Upper and Lower Grand River levees of 2.5 to 3 m MSL and from 1.5 to 2.5 m for the natural levee of

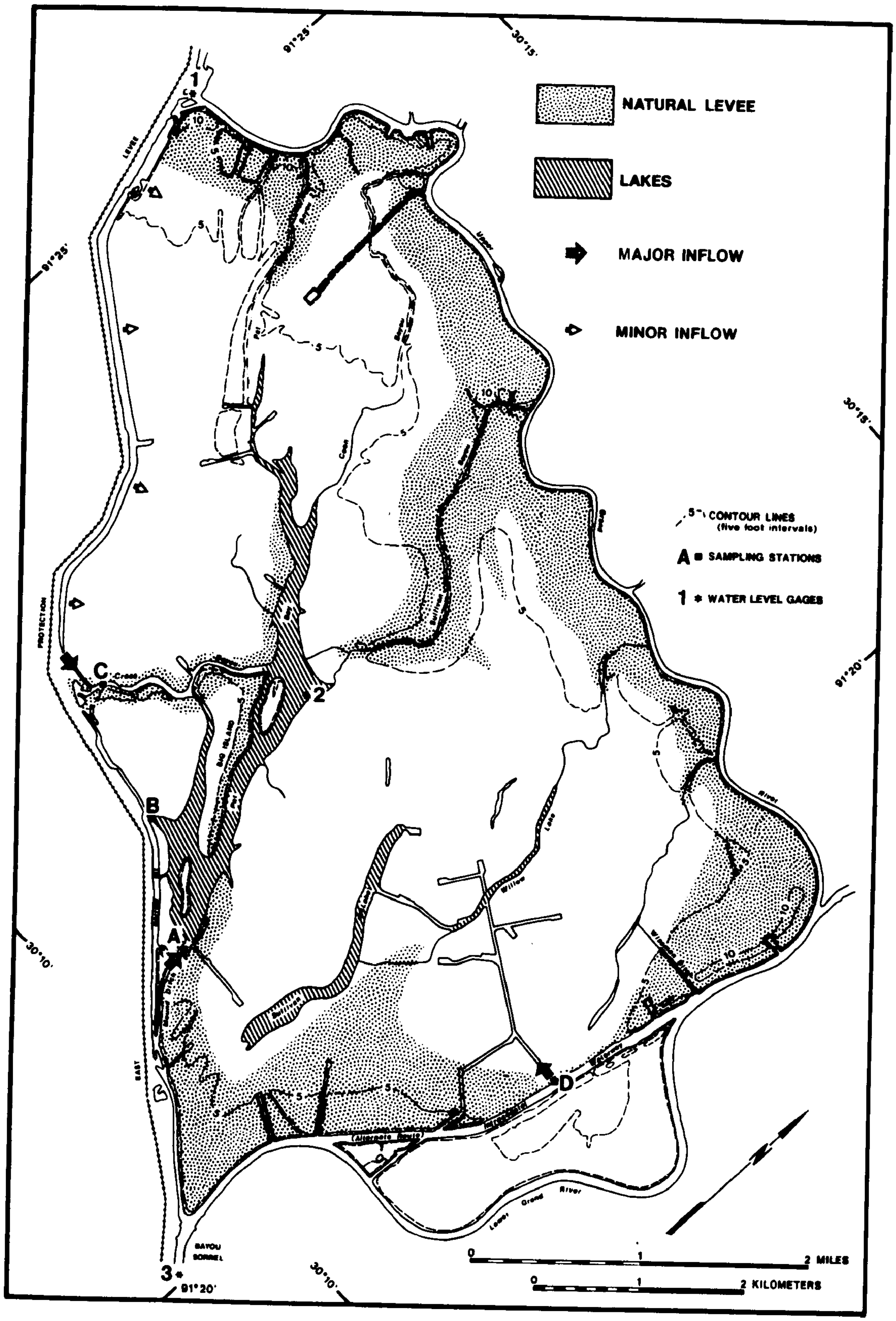

Figure 7-1. Geomorphic characteristics and flow locations, Pat Bay.

Sullivan Bayou. The remainder of the area lies below 1.5 m MSL. On the basis of 1930 surveys of the floodway area adjacent to Pat Bay, it may be assumed that the swamp floor elevation lies between one-half and one meter MSL.

ANNUAL FLOODING

Hydrologically, the Pat Bay area is part of the Verret Basin contained between the East Atchafalaya Basin Protection Levee and the natural levees of the Mississippi River, Bayou Lafourche, and Bayou Black (Figure 1-1). Drainage from the northern half of this watershed is intercepted by the Gulf Intracoastal Waterway Alternate Route, and to some extent by Upper Grand River and the East Atchafalaya Basin Protection Levee borrow pit (Figure 7-1). As a result, the channels from which water is diverted into the Pat Bay area carry water derived from a drainage basin that consists partly of agricultural lands. Most of the remaining area contains bottomland hardwood swamp forests. Accelerated runoff associated with the agricultural development and the location of Pat Bay at the outlet of the Upper Verret watershed causes rapid rises of water level after a major rainfall. Also, since most of the initial runoff will be from agricultural fields rather than from the swamp areas, water introduced into Pat Bay is likely to be composed mostly of agricultural runoff.

Modes of water inflow into Pat Bay from surrounding channels vary with stage. Most of the inflow occurs through three channels (A,B, and C) connecting the East Atchafalaya Basin Protection Levee borrow pit with Pat Bay proper and through the Sullivan Oil Field access canal (D) connecting Willow Lake and the Gulf Intracoastal Waterway Alternate Route (Figure 7-1). Mound Ditch (A) and the Sullivan access canal (D) are also the main outlets during dewatering. During the high stages of winter and spring, which are caused by local rainfall, water may enter the area from the East Atchafalaya Basin Protection Levee borrow pit through overbank flow. However, along the Gulf Intracoastal Waterway Alternate Route, Upper Grand River, and the Lower Grand River, this flooding process is prevented by high bank elevations. Limited inflow from Upper Grand River may occur during the spring flooding through Bayou Sullivan.

Water-level fluctuations are controlled primarily by the local water balance, except during the fall when water levels are low in both the Atchafalaya Basin Floodway and the Verret Basin. Under those conditions, the Intracoastal Waterway Locks remain open to facilitate navigation, and fluctuations of the Atchafalaya River are thus transferred to the Verret Basin.

Average annual variation of water levels is presented in Figure 7-2 and is based on gages along the Gulf Intracoastal Waterway Alternate Route at Upper Grand River and Bayou Sorrel. The small amplitude of the hydrograph is in striking contrast with those described earlier. The difference between the high average stage in March and low stages from July through October is only 0.4 m. It may also be noted that flood stage in the Pat Bay area is attained one month earlier than inside the floodway. Figure 7-2 also presents

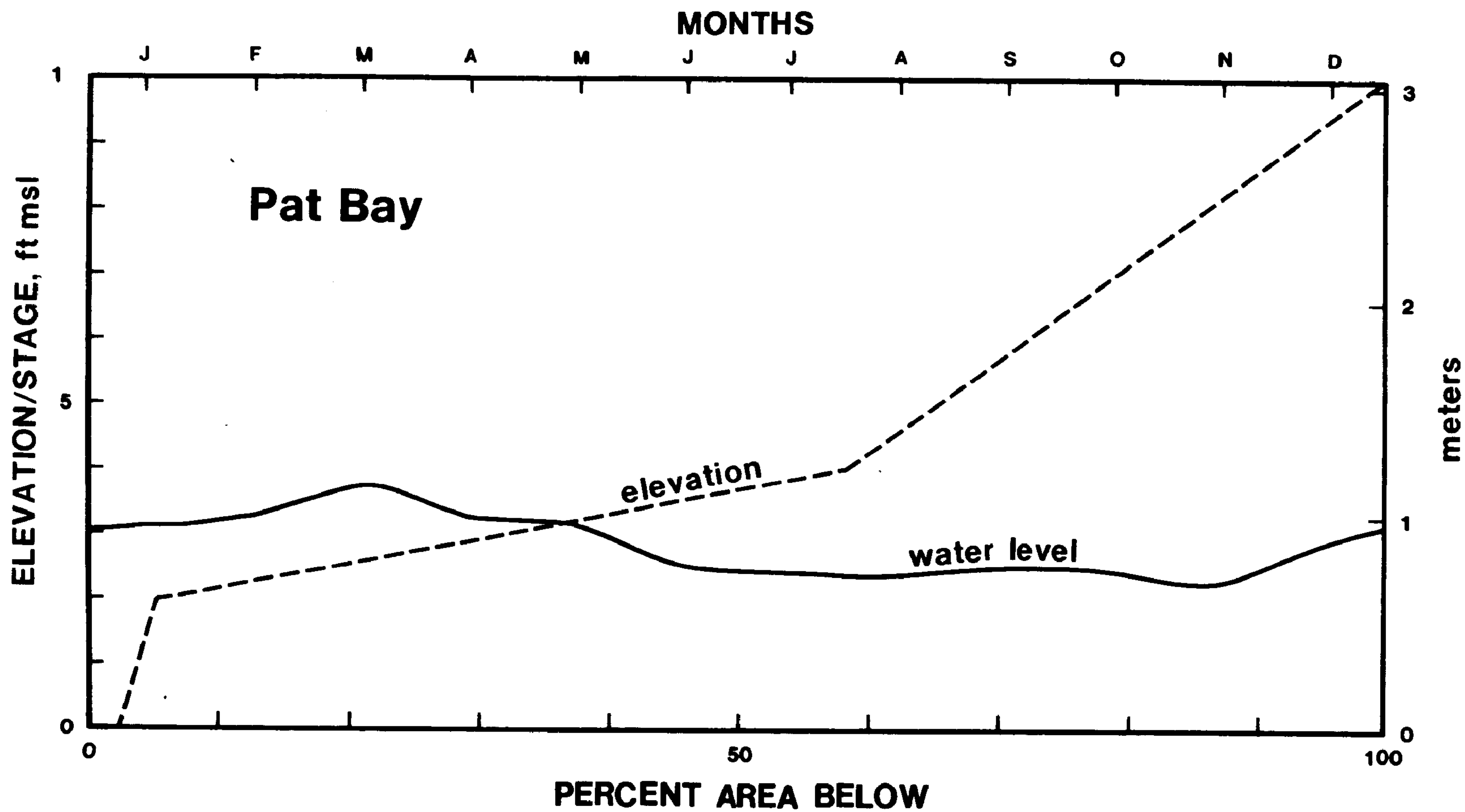

Figure 7-2. Average annual stage hydrograph and approximate elevation distribution, Pat Bay Management Unit.

a provisional hypsometric curve. Using the percent area above the 1.5 MSL contour, the percent area of permanent water bodies, and the elevation of the swamp floor in the adjacent Atchafalaya Basin Floodway as surveyed in the 1930's, an approximate elevation frequency distribution could be obtained. On the basis of the obtained hypsometric curve, an estimate can be made of extent and duration of flooding. These estimates are presented in Table 7-1.

TABLE 7-1. AREAL EXTENT AND DURATION OF FLOODING AND ASSOCIATED VEGETATION IN PAT BAY MANAGEMENT UNIT

Period Flooded (months)	Area (km^2)	Area (%)	Vegetation Association	Area (km^2)	Area (%)
0-1	24	54	mixed hardwoods	9	21
			bottomland hardwoods/ cypress	11	25
1-4	5	12			
4-8	9	19	cypress/tupelo gum	21	46
8-11	4	8			
11-12	3	7	water	3	6
			other	1	2

HABITAT

Vegetation was mapped on the basis of 1974 color-infrared imagery flown in May and by field inspection. The distribution of vegetation associations is shown in Figure 7-3. Mixed hardwoods with shrubs and herbaceous-vine understory occupy the natural levee ridges of Upper and Lower Grand River and Sullivan Bayou down to about 1.5 m MSL. During normal years, this area does not experience flooding. A transitional zone of mixed bottomland hardwoods and cypress occupies the toe of the above levee ridges and extends along the distributary levee ridges of Pat Bay, Cross Bayou, and the banks along Pat Bay. Based on natural levee gradients, elevations of these areas are estimated to range between 1.2 and 0.9 m, which would result in an annual flooding period of one to four months. The remainder of the area is occupied by cypress-tupelo gum forests. The areal extent of the vegetation associations is summarized in Table 7-1 together with related hydroperiods.

Compared to the relationships between hydroperiod and vegetation association that were presented for the Buffalo Cove and Fordoche units, the Pat Bay area shows some major discrepancies. As seen in Table 7-1, cypress-tupelo communities extend upward into the area experiencing flooding only one to four months of the year. This condition is believed to represent a relict relationship that dates back to the pre-floodway environment when the area was subject to annual overflow from the Atchafalaya River. Since floodway construction and the related reduction in annual flooding, some invasion of the cypress-tupelo forest by bottomland hardwoods has occurred, but it

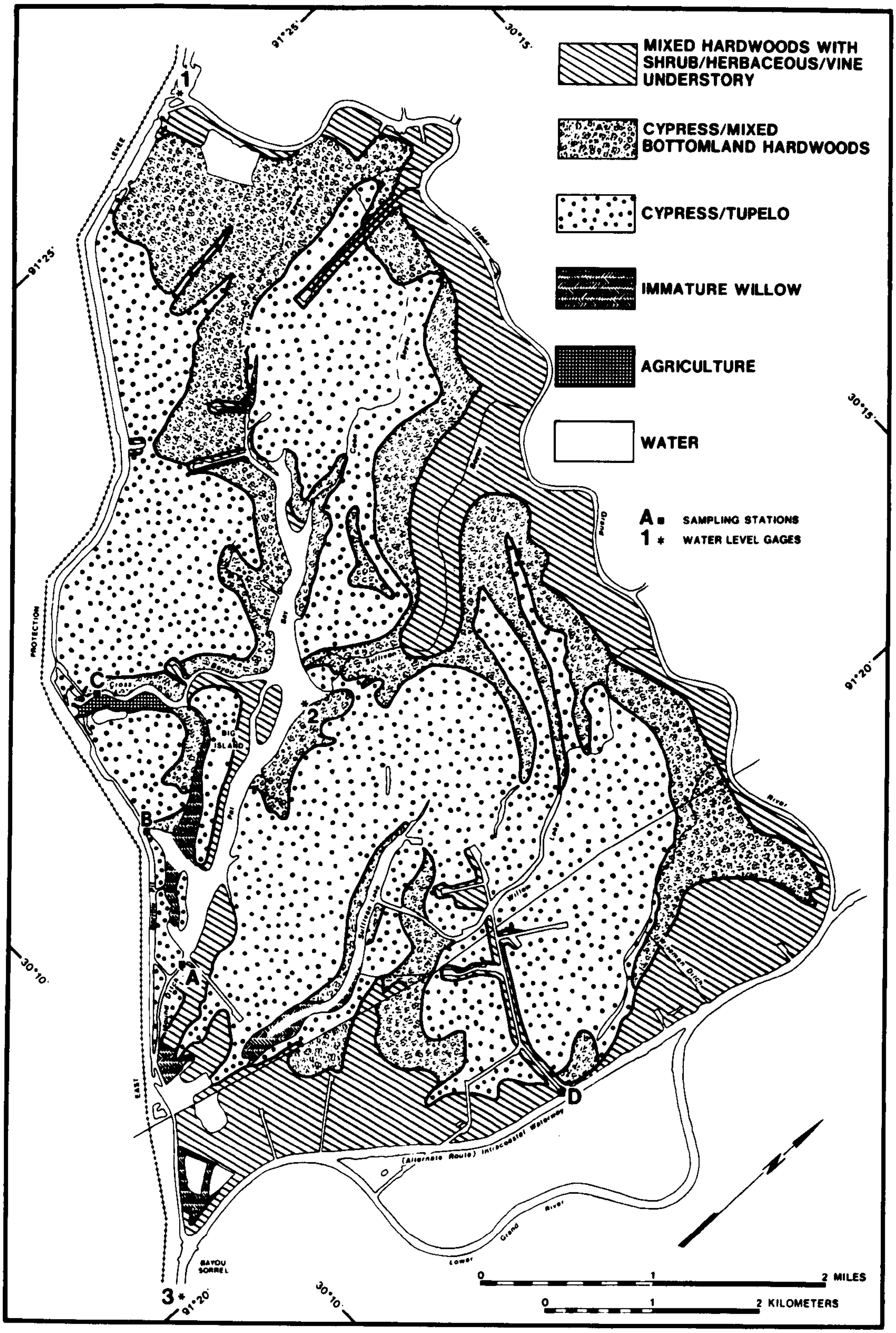

Figure 7-3. Vegetation associations in Pat Bay.

appears that competition from the established cypress-tupelo forest has prevented adjustment to the present regime.

Willows and cottonwood are present in the Pat Bay unit, but never reach the extent or dominance so prevalent inside the floodway. This may be attributed partly to limited sedimentation and partly to stage variations being less extreme. The first restricts availability of bare mineral soil necessary for willow invasion. The second reduces the frequency with which shallow lake and channel bottoms are exposed to allow germination of tree seeds, followed by long hydroperiods which allow only willows to survive. The presence of willows and cottonwood is confined mainly to spoil sites associated with mineral-industry canals and waterways and to limited areas of lake bottoms.

The vegetation distribution shown in Figure 7-3 further illustrates the topographic characteristics outlined earlier. Patterns reveal the individual sub-basins and the extent to which these are connected with channels surrounding the Pat Bay area. The map supports the earlier observation that most of the area is subject to backwater flooding from the Gulf Intracoastal Waterway and Pat Bay proper.

WATER AND SEDIMENT BUDGET, 1975-1976

Stage data for the Pat Bay area for the period of study are presented in Figure 7-4 together with the precipitation data as recorded at the Gulf Intracoastal Waterway Alternate Route navigation lock at Bayou Sorrel. The two time series clearly show the response of water levels to local rainfall during the period of January through June, 1976. Stage fluctuations during the fall of 1975, on the other hand, are not as closely related to precipitation. They are caused mainly by fluctuations in the Atchafalaya River which are transferred to the Verret Basin through the navigation lock. The lock remains open when stages in both the Atchafalaya Basin Floodway and the Verret Basin are low. Water levels may have been affected additionally by water introduction into the Verret Basin from the Mississippi River through the Port Allen lock.

The different controls over water-level fluctuation produce an apparent difference in the two parts of the hydrograph (Figure 7-4). Rises and recessions associated with Atchafalaya River stage are both gradual and of limited elevation. In contrast, rises produced by local runoff are steep and of greater magnitude. Subsequent recessions, however, are gradual again.

Related to characteristics of the stage fluctuations, flow measurements for the Pat Bay area are very limited despite repeated surveys of the area. Flow could be identified in only two cases during any of the surveys in any of the channels connecting the swamp with surrounding waterways. This is believed to relate to the small water-level changes and resultant limited volume of water exchange. Also, the cross-sectional area of the total channels is probably large relative to the volume of water exchanged and to the rate at which exchange takes place. Consequently, flow rates may often be below the level of detection. Inflow was measured only once during a major

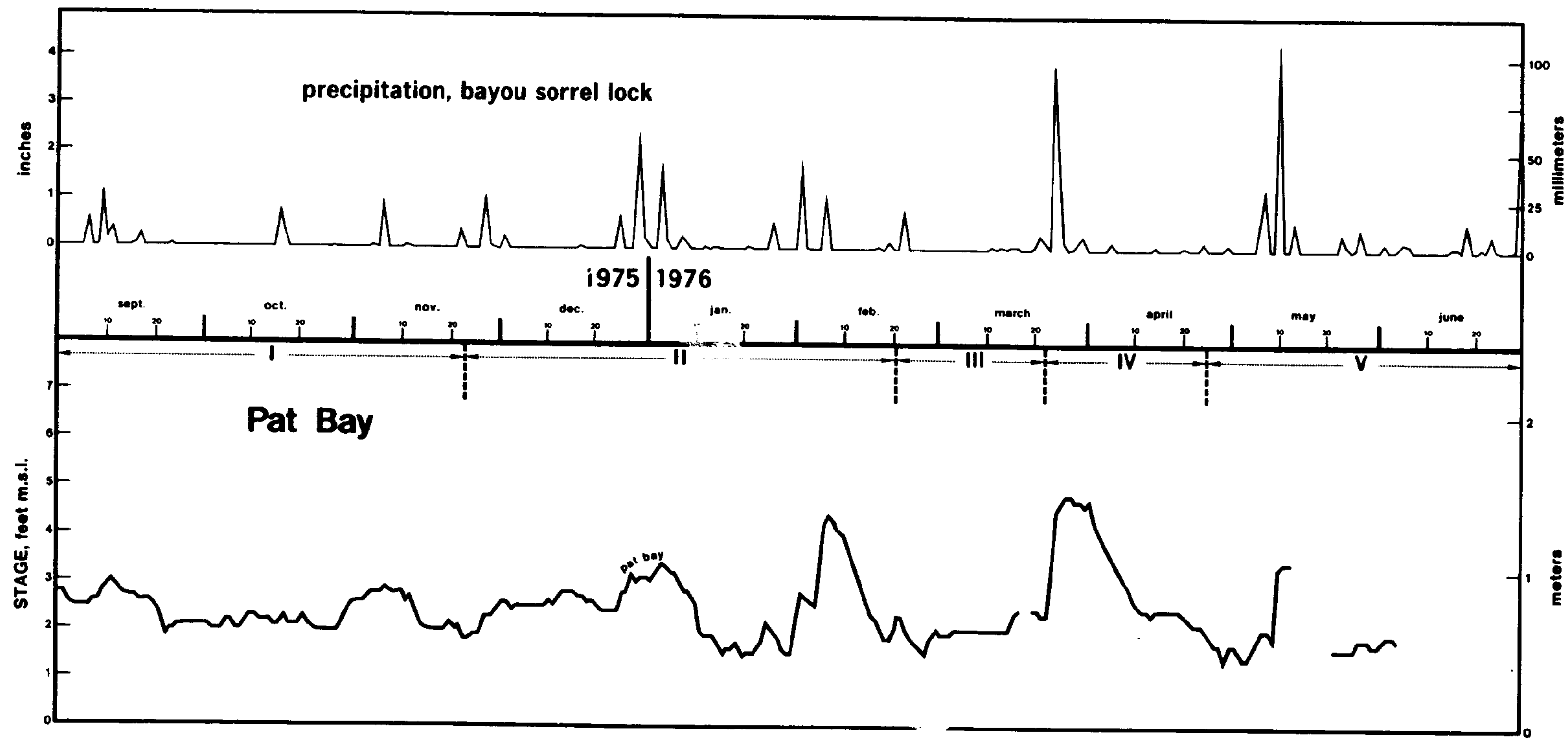

Figure 7-4. Stage hydrograph, Pat Bay, 1975-1976.

rainfall, 10 cm in 24 hours, when water levels rose about 0.5 m. Even then, velocities remained below 0.15 m/s. Inflow at that time occurred mainly through Mound Ditch.

Despite the near absence of discharge data, an attempt was made to evaluate water exchange with surrounding channels on the basis of stage and precipitation data. The same procedure was followed as in the case of Fordoche and Buffalo Cove. Table 7-2 presents the data in terms of contributions by surrounding channels and in situ rainfall to flooding of Pat Bay during the study period. The breakdown by period is for comparison with Fordoche and Buffalo Cove only; it is not stage-related in the present case.

TABLE 7-2. WATER INTRODUCTION, PAT BAY

Period	Pat Bay Inflow $m^3 \times 10^6$	Rainfall $m^3 \times 10^6$	Total $m^3 \times 10^6$
I	8.4	2.4	10.8
II	14.4	10.4	24.8
III	2.2	0.9	3.1
IV	12.5	6.8	19.3
V	4.5	5.6	10.1
TOTAL	42.0	26.1	68.1

The data in Table 7-2 suggest that of the total volume of water that entered Pat Bay, about 60 percent entered from the surrounding channels. Insofar as this water entered at relatively high velocities during rapid, rainfall-caused rises, sediment must have been introduced at the same time into Pat Bay and Willow Lake. During the single measurable inflow condition, suspended sediment concentration averaged 0.075 g/l.

On the basis of field observations, it may be assumed that nearly all sediment introduction occurs during the type of rise referred to above. A total of three such rises occurred during the study period, with a total inflow of 20.9×10^6 m^3. At the above-mentioned concentration of suspended sediment, a total load of 1,567 metric tons of sediment would have been introduced into the Pat Bay area during the study period.

SECTION VIII

COMPARISON

In comparing the three swamp basins, the topical sequence followed for the individual areas can largely be used again. Differences in the setting, annual flooding regime, and introduction of water thus can be discussed in terms of consequence with regard to habitats and the direction in which the unit's environments are moving.

SETTING

The settings of Fordoche, Buffalo Cove, and Pat Bay are very much alike in general topography. Each of the three areas extends from a major natural levee complex into a swamp basin that has been truncated by a floodway levee. Related to this topography, three environments are recognized: the high, natural levee rim, a transitional zone along the levee flank, and the swamp depression. Except for its natural levee ridges, each unit is annually flooded, with depth and duration of flooding increasing away from the natural levee. Mixed hardwoods occupy the highest areas where the duration of flooding is less than one month per year. Swamp/mixed hardwoods appear in the transitional zone subject to annual flooding for periods of from one to four months. Swamp forests and lakes cover the area where hydroperiods are greater than four months.

The setting of the three areas becomes very different when considering their relationship to the Atchafalaya River. Buffalo Cove, Fordoche, and Pat Bay, in that order, are increasingly divorced from riverine processes. A floodway levee totally separates Pat Bay from Atchafalaya River water and sediment. The only riverine effects felt are minor water-level fluctuations that are transmitted through the navigation lock in the levee during the dry, low-stage, fall months when the lock remains open.

In Fordoche, partial elimination of riverine processes has occurred as a result of construction of the Atchafalaya River levee and operation of the Courtableau Drainage Structure. If observed conditions are indicative of general processes, then direct influence of the Atchafalaya River is limited to only the lower half of Fordoche through introduction of water and sediment. Indirect effects still extend over the entire unit since outflow of water is controlled by Atchafalaya River stages, as is the annual flood stage.

In Buffalo Cove, though substantial, interference with riverine influences has been the least. Water-level variation, inflow and outflow, and introduction of sediment all relate directly to Atchafalaya River discharges and stages. Only the mode of annual flooding and the distribution patterns of sedimentation have been modified.

Closer analysis of topography reveals another difference among the three units that relates to setting and becomes apparent when elevation frequency curves are compared (Figures 5-2, 6-3, and 7-2). Fordoche is located in the upper part of the Atchafalaya Basin, where floodplain development had advanced considerably prior to confinement of the Atchafalaya River. As a result, there exists a difference of about 3 m between median elevations in Upper and Lower Fordoche, or a north-south surface gradient of 0.0001. As a result of human controls over river development, Buffalo Cove and Pat Bay never experienced such floodplain development and lack such a gradient. Consequently, movement of water through the swamp is facilitated to a greater degree in the Fordoche unit.

ANNUAL FLOODING

Annual flooding contrasts exist in the first place between the floodway units and Pat Bay. In Fordoche and Buffalo Cove, annual flooding shows an accelerating rise from November to April/May, a recession from April/May to August/September, and a low stage during September, October, and November. The principal water-level control is the Atchafalaya River, which results in an amplitude of the average annual hydrograph on the order of 2 to 3 m.

Pat Bay also experiences an accelerating rise beginning in November, but since it is controlled by local precipitation surpluses, the hydrograph peaks in March, one month earlier. The return to low water levels also occurs earlier, beginning in June. The low water period thus lasts five months as compared to three inside the floodway. Amplitude of the average annual stage variation is only about 0.5 m as compared to 3 m in Fordoche and 2.4 m in Buffalo Cove.

A second contrast concerns the source of water for annual flooding. Pat Bay relies entirely on local runoff, at least half of which is derived from areas in agricultural use. Buffalo Cove receives nearly all its water from the Atchafalaya River; local precipitation forms a relatively minor contribution. The Fordoche Unit takes an intermediate position in that it has two major sources. Local drainage, mainly from agricultural areas, is introduced through the Courtableau Drainage Structure. During the 1975-1976 period, it formed the primary source of water. Atchafalaya River water enters mainly during the rapid rise preceding the spring flood peak and represents the second source.

Modes of water introduction and the control of stages over water movement show both differences and similarities among the three areas. In none of the cases is a true throughflow regime experienced throughout the unit. Regimes range from backwater flooding to a mixture of throughflow and backwater flooding.

Regime similarity is greatest among the Pat Bay and Buffalo Cove units. In each, throughflow is limited to one margin of the unit, the southwestern margin in both cases. The limited area of throughflow includes the major lakes, Pat Bay proper in Pat Bay, and Buffalo Cove Lake and Bayou Gravenburg in Buffalo Cove. The remainder of the area subject to annual flooding experiences a backwater regime.

There exists, however, an important difference in the backwater regime between Pat Bay and Buffalo Cove that is not brought out by the average annual hydrographs. In Pat Bay, major individual fluctuations in water level are associated with heavy rainfall as was illustrated in Figure 7-4. These individual fluctuations often exceed the mean annual fluctuation in amplitude. Consequently most of the swamps in Pat Bay experience alternate flooding and dewatering rather than continuous flooding for extended periods.

In Buffalo Cove, individual fluctuations of water level have a much lesser amplitude relative to the amplitude of annual water level fluctuations. Fluctuations are caused by the Atchafalaya River and superimposed on the gradual rise and fall cycle of river stages. This insufficient dewatering allows water masses to remain in the swamp for extended periods in areas farthest away from inflow and outflow points. These water masses remain stagnant except for areal compression and expansion during inflow and outflow respectively. Stagnation is further contributed to by extensive water hyacinth mats which impede circulation and mixing with incoming waters. These relatively stagnant water masses become of low quality in terms of dissolved oxygen concentrations and affect much of the basin when they expand during falling stages. Even during the annual low water period, the Buffalo Cove swamp forests are not fully dewatered (including the extremely low summer stages of 1976 when standing water was observed in the swamp depressions as far north as above the Sibon Canal). All swamp waters thus are not replaced on an annual basis.

The common characteristics of a backwater regime contrast Buffalo Cove and Pat Bay with the Fordoche Basin. The Fordoche regime is largely dominated by throughflow, even though induced by introduction of external drainage rather than river water. Together with the larger surface gradient in Fordoche, the introduction of water at the upper end maintains water movement through the basin during much of the year. Water moves through the swamp into the lake located at the lower end, where it produces a water level rise. Except during rapid rise of the Atchafalaya River to flood levels, the discharge of drainage into Lake Henderson is sufficient to prevent inflow of river water. In many cases, continuous water movement through Fordoche and outflow at the lower end are maintained even when Atchafalaya River levels are rising.

Even though considerable introduction of sediment occurs with the inflow at the upper end, very little of this sediment reaches Lake Henderson. As indicated by very low sediment concentration (0.10-0.15 mg/l) in Bayou Fordoche, where it enters Lake Henderson, most sediment is filtered out in the swamps of Upper Fordoche.

When spring flooding in Fordoche accelerates and approaches flood stages, the regime is partially converted to a backwater condition. Atchafalaya River stages exceed those in Henderson Lake, and inflow of river water commences. Drainage then becomes ponded in the upper part of the unit, and circulation through the swamp diminishes.

The difference in the annual flooding and dewatering regime between Fordoche and Buffalo Cove has important ramifications when considering only sediment introduced by river water. The fact that every stage fluctuation causes river water to enter Buffalo Cove means also a high frequency of sediment introduction. Even when ignoring sediment introduced as a result of throughflow in the lower end, riverine sediment introduction into Buffalo Cove appears to have exceeded that into Fordoche by a factor of two during the study period. This happened despite the fact that most sediment was introduced during flood stages when river water inflow occurred in both Fordoche and Buffalo Cove. However this difference in sediment input is entirely offset by the additional introduction of sediment into Fordoche through the Courtableau Drainage Structure.

On the basis of 1975-1976 measurements and related calculations, some of the differences outlined in the above paragraphs may be summarized in tabular form. It should be realized, however, that differences in size and topography of the Fordoche, Buffalo Cove, and Pat Bay basins are additional factors. To take this into account, two additional parameters are used: the volume of water stored during the highest stage of the study period (S_{max}) and the area flooded at that stage (A_{max}).

Table 8-1 presents a comparison for a number of regime parameters. These include total water input (Q_{tot}) broken down by source (Atchafalaya River, External Drainage, and Precipitation Surplus), a relative measure of water renewal using the ratio of total water input and total water volume stored at the maximum stage, a relative measure of energy flux using the ratio of total water input and the area flooded at maximum stage, total sediment input (L_{tot}) and a measure of sedimentation per unit area.

From the table, a number of aspects are apparent. The relative contribution of drainage and river water to Fordoche and Buffalo Cove are seen to be nearly reversed. Atchafalaya River water is five times as important to flooding Buffalo Cove as it is to Fordoche.

Per unit area, Fordoche receives the largest volume of water because limited river-water input is more than offset by drainage entering through the Courtableau Drainage Structure from outside the unit. Fordoche is followed by Buffalo Cove and Pat Bay in that order. The decrease reflects largely the decrease in amplitude of water level fluctuation and depth of flooding, and in part differences in the rate of water movement through the units.

Of interest also is the ratio of total water input to total volume of water stored at maximum stage. This value may be seen as a relative measure of water renewal. Again Fordoche has the highest value, but is followed by Pat Bay rather than Buffalo Cove. The value indicates that water in Buffalo Cove

TABLE 8-1. COMPARISON OF HYDROLOGIC REGIME PARAMETERS

Regime Parameter \ Water Source	FORDOCHE External Drainage	FORDOCHE Atchaf. River	FORDOCHE Precip. Surplus	BUFFALO COVE Atchaf. River	BUFFALO COVE Precip. Surplus	PAT BAY Ext. Drng.	PAT BAY Precip. Surplus
Total water input (Q_{tot}, $m^3 x 10^6$) (Q_{tot}, %)	834 68	181 17	205 15	346(450)* 88(91)*	47 12(9)*	42 62	26 38
Area flooded at maximum stage (A_{max}, km^2)	177			88		28	
Water input/unit area (Q_{tot}, A_{max}, m)	6.9			4.5(5.6)		2.4	
Total Sedim. load fluct.(m)	3.0			2.2		1.0	
Storage max. stage (S_{max}, $m^3 x 10^6$)	327			154		20	
Measure water renewal (Q_{tot}/S_{max})	3.7			2.5(3.2)*		3.4	
Imp. Atch. Riv. (Q_{tot},Atch/S_{max})	0.5			2.2(2.9)*		0	
Total Sedim. input (L_{tot}, kg x 10^6)	321	30	0	60(78)*	0	2.4	0
Measure of Sedim. (0.084 L_{tot}/A_{max}, mm/m^2)	1.6			0.6(0.8)*		0.08	

* Value in parenthesis accounts for simultaneous outflow and inflow.

is the most stagnant and is most likely to have the lowest dissolved oxygen values. It should also be kept in mind that the values do not take into account the effects of the circulation on replacement of waters as discussed earlier in the report. Thus, while throughflow makes the values fairly representative for most of Fordoche, the backwater regime in Buffalo Cove will tend to reduce the value for most of that unit while increasing it in the small part of Buffalo Cove experiencing throughflow. To a lesser extent such differences would also be found in Pat Bay.

Sediment input is seen to be negligible in Pat Bay, and greatest in Fordoche as related to the Courtableau Drainage Structure. This becomes especially evident when comparing sedimentation per unit area. However, while the estimated value for Fordoche is nearly three times as high as that for Buffalo Cove, this does not indicate the relative proportion of adverse affects. In Fordoche most sediment is distributed through overflow of the swamp/mixed hardwoods and willow/cottonwood in the upper part of the unit. In Buffalo Cove, most sediment enters at the lower end into Buffalo Cove lake and rapidly decreases the remaining lake habitat below the level of hydrologic utility as a habitat during low water seasons.

HABITAT

When taking into account setting and flooding characteristics together as two major factors with regard to habitat, significant differences become apparent among the three units. First, there is the extent of area flooded during average maximum stage relative to the total area. Secondly, there is the area of permanent or nearly permanent water bodies relative to the area flooded annually. The latter aspect is important in particular when considering that the flooded area can be used as part of the aquatic ecosystem by fishes only to the extent that non-migratory fishes can be accommodated by the permanent water bodies during low stage. The above two comparisons are made in Table 8-2. In Table 8-3 a comparison is made between duration and depth of flooding.

TABLE 8-2. COMPARISON OF HABITAT PARAMETERS

	Fordoche		Buffalo Cove		Pat Bay	
	km^2	%	km^2	%	km^2	%
Part of unit flooded at aver. max. stage	175	65	87	96	25	55
Permanent water relative to area flooded	49	28	11	13	3	12

TABLE 8-3. COMPARISON OF DURATION AND DEPTH OF FLOODING

	Percent Area Flooded and Average Maximum Depth of Flooding					
	Fordoche		Buffalo Cove		Pat Bay	
Hydroperiod	%	m	%	m	%	m
0 - 1	36	<0.1	3	<0.1	54	<0.1
1 - 4	7	0.4	10	0.4	12	0.1
4 - 8	21	0.8	52	0.8	19	0.2
8 - 11	7	1.0	10	1.1	8	0.4
11-12	29	>1.0	16	>1.1	7	>0.4

Table 8-2 shows that in both Fordoche and Pat Bay, permanent water bodies occupy nearly one-third of the total aquatic environment. Most of this area is open lake, where oxygen values remain high as a result of circulation and wind stress. In contrast, the permanently flooded area in Buffalo Cove occupies only 13 percent of the annually flooded area, and at least half of this is comprised of permanently flooded swamp associated with the central depression in which dissolved oxygen concentration often falls below levels necessary for most aquatic forms and desirable for tree growth. Usefulness of some of the permanent water-bodies is further reduced as a result of sedimentation and commensurate decrease in depth to less than 0.3 m during low stages.

Table 8-3 furthermore shows that both Fordoche and Pat Bay have a much larger area than Buffalo Cove in which flooding does not occur, or occurs only for a brief period, and which favors mixed hardwoods. The Fordoche area especially is one of strong contrasts when comparing its large mixed hardwood habitat and large lake area.

It should also be noted that when comparing both Table 8-2 and 8-3 data for Fordoche and Pat Bay, the two areas appear to have much similarity in habitat distribution with respect to hydroperiod. The major difference then appears to be the amplitude of stage fluctuation and related depth of flooding and the difference in mode of annual flooding.

The most salient feature of Buffalo Cove is the large area subject to four to eight months of flooding. This is the area where the hydroperiod is long enough to allow for growth and sexual maturity of crawfish and short enough to prevent over-predation by aquatic predators. In this regard, it may also be important that water levels in both Fordoche and Pat Bay are high earlier than in Buffalo Cove. This relates to the contribution of water by local rains as opposed to Atchafalaya River control. Early conditions of deep water in the swamps provide a greater amount of predation for the young crawfish.

With regard to the cypress-tupelo swamp forests, the three longer hydroperiod classes may be grouped since they tend to exclude other tree species except willow. Areas subject to flooding for periods of four to twelve months take up about half of both Fordoche and Pat Bay, but extend over nearly 90 percent of Buffalo Cove. With regard to duration of flooding, Buffalo Cove thus favors maintenance and establishment of cypress-tupelo forest. However, sedimentation, depth of flooding, and dewatering characteristics offset that hydroperiod aspect.

Ponding of water and hyacinth mats in the central depression of Buffalo Cove during low stages are prohibitive to the rejuvenation of cypress and tupelo. As a result, present tree losses due to insufficient soil aeration, sedimentation, and low dissolved oxygen levels result in a thinning out of the cypress-tupelo forest. In the absence of forest renewal, the central area advances toward an open lake. Ponding similarly affected Lower Fordoche beginning prior to floodway construction. This transgression toward open lake in the center of Buffalo Cove must be considered a desirable change. It will again provide the necessary aquatic habitat to sustain fish populations during dewatering of the swamp or during periods when dissolved oxygen levels in the stagnant swamp waters become too low. The process replaces the lakes that have been lost to sedimentation.

Sedimentation still prevents reestablishment of cypress in the southern part of Buffalo Cove at least for the moment. Areas exposed during low stages are open and covered by bare mineral soil, which favors willow over other vegetation. Continuing sedimentation will most likely lead to a mixed hardwood succession in the area now occupied. An additional factor prohibitive to reestablishment of cypress-tupelo forest in many areas inside the floodway units is the depth of annual flooding, even where hydroperiods are from four to eight months. This prevents the survival of first-year seedlings. Average depth of flooding is compared also in Table 8-2, which shows that the areas in Fordoche and Buffalo Cove favoring cypress-tupelo forest in terms of hydroperiods are flooded to average depths of about one meter. In contrast, flooding of that environment in Pat Bay is only in the order of 0.2 m.

DISCUSSION

The comparison between hydrologic units suggests that it is feasible to achieve a reduction of sedimentation and improvement of environmental quality through surface water management. The main strategy for such management should be: 1) maximum use of precipitation surpluses to reduce the need for river water introduction, 2) reduction of at least the short-term water level fluctuations superimposed on the annual spring rise, 3) assurance of sufficient dewatering of those basins that experience a backwater flooding regime, 4) introduction of limited throughflow in those areas subject to a backwater regime and insufficiently dewatered, 5) provision for overbank flow where possible and multiple location of water introduction in order to reduce the sediment introduction into swamp basins through single high velocity channels, 6) management of water levels to limit willow invasion and to permit reestablishment of cypress-tupelo communities, 7) provide for succession to sufficient areas of lake environment to sustain fish populations of a size that allows full utilization of the periodically flooded area, and 8) keep lakes free from emergent vegetation and water hyacinths to provide for maximum uptake of oxygen by the water.

The Fordoche Basin illustrates that overflow swamps of the Atchafalaya Basin Floodway can be maintained as highly productive environments with a more limited inflow of Atchafalaya River water provided that the large amplitude of annual water level fluctuations is maintained. Although it is recognized that the Fordoche Basin has an additional source of water not readily available to other swamp basins, internal precipitation surpluses are available during winter and spring in all areas. Through storage of these surpluses, the need for Atchafalaya River water introduction to achieve necessary flooding can be reduced. This reduction would occur during those months that sediment concentrations of introduced river water are highest. A reduction in excess of 15 percent would therefore be attainable in sediment introduction.

Management for a gradual rise and fall of water levels without the many fluctuations would greatly reduce inflow of river water. In the summer and fall, these fluctuations may be advisable to sustain dissolved oxygen levels. However, during the general rise of the Atchafalaya River stages and associated inflow in late winter and early spring, such fluctuations may not be essential to water quality. Reduction of these fluctuations could reduce sedimentation by as much as 20 percent, as illustrated by the Buffalo Cove sediment budget.

Comparison of the three regimes of Buffalo Cove, Pat Bay, and Fordoche suggests that low dissolved oxygen levels in Buffalo Cove are largely the result of insufficient water replacement. During the low water phase in early summer of 1976, field observations by the U.S. Environmental Protection Agency showed anoxic conditions in Buffalo Cove, while oxygen levels in Pat Bay did not fall below critical levels. It is believed that the recurring water quality problems in Buffalo Cove result from incomplete replacement of water in Buffalo Cove on an annual basis due to insufficient removal of water from the swamp during low stages. Low-quality water remaining in the basin should, in turn, adversely affect the quality of water following additional influx. A strategy for water management should therefore be to provide for annual dewatering of areas subject to a backwater regime to the extent that water is held only in lakes and channels where meteorologic processes enhance direct oxygen input. Where outside water levels and basin topography do not permit such dewatering, throughflow should be induced by water introduction in the upper basin to annually purge the swamp system.

When combining the principal requirements to reduce sedimentation and enhance environmental quality, the present study points to the throughflow regime as the most desirable, provided that control is exerted over the outflow of water. Meeting the paramount need to limit short-term water level fluctuations in order to reduce inflow of river water and sediment would interfere with the environmental quality of basins now subject to a backwater regime. Two major reasons for this can be identified. One is that limited fluctuation would further reduce water replacement in basins that already experience anoxic conditions due to insufficient dewatering; the natural trend for the latter is to increase due to increases in Atchafalaya River stage (van Beek et al., 1976) and ponding caused by sedimentation. Secondly, reduced fluctuation would reduce the frequency at which water from the swamps discharges into lakes and streams. Such a reduction would greatly affect the flow of organic matter and nutrients into the aquatic environments.

Both of the above impacts would be avoided in case of throughflow, such as in Fordoche, where water movement through the swamps into Henderson Lake is nearly continuous. Although it is recognized that a second external source of water is available in Fordoche, this does not prevent establishment of a throughflow regime in those basins flooded by river water only, since water level differences at the upper and lower boundaries of the unit provide the necessary force to induce flow. Paramount to provision for throughflow would be, however, control over the rate and mode of introduction of such flow so as to minimize sediment introduction. A condition such as exists at the lower end of Buffalo Cove should be avoided.

Water outflow at the lower end of a basin should be limited to the minimum amount necessary for maintaining water movement through the basin so as to ensure sufficient water replacement. In turn, this would reduce volumes and rates of inflow and associated sediment introduction. Water introduction should occur, to the extent possible, through overbank flow. This is essential, particularly during annual flood stages when suspended sediment concentrations in source channels are highest.

The Atchafalaya Basin Floodway environment is highly conducive to willow growth. Although under controlled conditions willow forests may represent a major fiber resource, their present invasion of shallow water bodies and swamp forests constitutes a deterioration of the basin's environmental quality. This invasion is enhanced by massive sedimentation and early summer low-water levels. Where the organic clays of lake bottoms or the swamp floor become covered and built-up through deposition of fine sand and silt introduced through channel flow, willows establish themselves immediately upon emergence of the wet bare mineral soil needed for seed germination. Since seed fall generally extends from April to July and willow seeds, unless floating, remain viable only from 12 to 24 hours, water level control could possibly be used to limit willow growth. Postponement of natural dewatering until August of those aquatic environments that favor willow growth could greatly ameliorate present lake habitat losses.

In the floodway, partial reversion of cypress-tupelo swamps to open water is considered desirable in those areas where the ratio of open lake area to annually flooded area has greatly decreased through loss of lakes by sedimentation. In other areas, however, loss of these forests represents an environmental degradation. Water management may be necessary to reverse the present trend of disappearing cypress forests by reducing sedimentation and allowing reestablishment of cypress seedlings through maintaining flooding and dewatering schedules for a number of years in areas where seed-bearing trees still remain. To provide a seed bed, exposure of the organic clays of the swamp floor is required in the normal low-water period of late fall, when cypress seeds have ripened. Flooding levels in subsequent years must be limited so as not to exceed height of the seedlings, but could increase annually according to the rate of tree growth. Rates during the first and second year may be as much as 0.3 and 0.6 m, respectively (Mattoon, 1915). The need for such management should be assessed through analysis of expected frequencies of consecutive low discharge years such as occurred in 1976 and 1977.

APPENDIX A

SUMMARY OF FLOWS DURING STUDY 1975-1976 ($m^3 x10^6$)

	FORDOCHE				BUFFALO COVE			PAT BAY		
	Inflow external drainage Courtableau Structure	Net input precipitation	Inflow Atch. Rvr. Water [1]	Outflow	Inflow Atch. Rvr. Water [1,3]	Net input precipitation	Outflow [3]	Inflow from external channels	Net input precipitation	Outflow
I 9 Sept-23 Nov	97.8	2.6	34.8	185.9	64.6	8.6	64.2	8.4	2.4	5.3
II 24 Nov-21 Feb	303.4	48.0	42.1	304.2	129.5	14.8	70.7	14.4	10.4	13.7
III 22 Feb-20 Mar	90.0	13.7	90.7	0.0	122.7	2.2	0.0	2.2	0.9	0.9
IV 21 Mar-26 Apr	185.9	24.4	0.0	213.0	0.0	11.9	102.0	12.5	6.8	17.9
V 27 Apr-23 June	157.0	4.2	13.6	414.7	29.1	11.2	75.7	4.5	5.6	5.8
TOTAL	834.1	92.9	181.2	117.8	345.9	48.7	312.6	42.0	26.1	43.6

1) Water is derived from Atchafalaya River through distributary channels.

2) Pat Bay flows extend only through May 30.

3) Inflow and Outflow volumes are estimated to have been an average of 30 percent greater than those shown due to simultaneous inflow and outflow through the southern segment of the Buffalo Cove unit (inflow through Buffalo Cove Lake, outflow through Mud Lake).

LIST OF REFERENCES CITED

Bryan, C. F., F. M. Truesdale, D. S. Sabins, and C. R. Dumas. 1974. Annual Report, A Limnological Survey of the Atchafalaya Basin, Louisiana. Cooperative Fishing Unit, Louisiana State University, Baton Rouge, Louisiana.

Comeaux, Malcolm. 1972. Atchafalaya Swamp Life: Settlement and Folk Occupations. Louisiana State University, Geoscience, Baton Rouge, Louisiana. 111 pp.

EROS. 1975. Vegetation map of Atchafalaya Basin Floodway prepared by EROS Applications Assistance Facility. U.S. Department of the Interior, Bay St. Louis, Mississippi.

Gagliano, S. M., and J. L. van Beek. 1975. Environmental Base and Management Study, Atchafalaya Basin, Louisiana. U.S. Environmental Protection Agency, Socio-Economic Environmental Studies Series, Report EPA 600/5-75-006. Washington, D.C.

Guy, H. P., and V. W. Norman. 1970. Field Methods for Measurement of Fluvial Sediment. Techniques of Water Resources Investigation of the U.S. Geological Survey. Book 3, Applications of Hydraulics, U.S. Geological Survey.

Lantz, K. E. 1974. Natural and Controlled Water Level Fluctuations in a Backwater Lake and Three Lóuisiana Impoundments. Louisiana Wild Life and Fisheries Commission, Fisheries Bulletin Number 11, Baton Rouge, Louisiana.

Mattoon, Wilbur R. 1915. The Southern Cypress. Department of Agriculture Bulletin No. 272. 74 pp.

O'Neil, C. P., J. E. de Steiguer, and G. W. North. 1975. Trend Analysis of Vegetation in Louisiana's Atchafalaya River Basin. EROS Applications Assistance Facility, National Space Testing Laboratory, Bay St. Louis, Mississippi.

Penfound, W. T. 1952. Southern Swamps and Marshes. Botanical Review, No. 18, pp. 413-446.

U.S. Department of Agriculture, Forest Service. 1973. Silvicultural Systems for the Major Forest Types of the United States. Agricultural Handbook No. 445. Washington D.C. 114 pp.

Wicker, K. M. 1975. Recent Changes in Physiography of Buffalo Cove, Atchafalaya Basin, Louisiana. M.S. Thesis, Louisiana State University, Baton Rouge, Louisiana.

van Beek, J. L., P. Light, and W. G. Smith. 1974. Water Management Plan, Buffalo Cove Swamp. Atchafalaya Basin Division, Louisiana Department of Public Works, Baton Rouge, Louisiana. 55 p.

van Beek, J. L. , W. G. Smith, J. W. Smith, and P. Light. 1976. Plan and Concepts for Multi-Use Management of the Atchafalaya Basin, Louisiana. U.S. Environmental Protection Agency, Socio-Economic Environmental Studies Series, EPA-600/3-77-062, Washington, D.C.

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16. ABSTRACT

Three backwater areas in the Atchafalaya Basin, Louisiana, are compared. The three areas studied are Fordoche and Buffalo Cove, within the Atchafalaya Basin Floodway and subject to annual flooding by the Atchafalaya River, and Pat Bay which is located outside the floodway and in which flooding is controlled by local rainfall. Hydrologic regimes are compared for relative contributions of river water and local drainage, amplitude of water level fluctuations, mode of water introduction and movement, and related introduction of sediments. From this comparison, the following were seen as the most urgent considerations for management of Atchafalaya Basin Floodway units: 1) Induction of low discharge throughflow in order to enchance water exchange in those areas presently subject to a backwater regime and insufficiently dewatered, 2) reduction of inflow associated with short-term water level fluctuations during annual rise of Atchafalaya River stages in order to reduce sediment introduction, 3) maximum utilization of the unit's precipitation surpluses as a source of floodwater to reduce inflow of Atchafalaya River water and sediments, 4) realization of 1), 2), and 3) through water introduction at the upper end of the unit and simultaneous control over outflow at the lower end of the unit.

17. KEY WORDS AND DOCUMENT ANALYSIS

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